SOURCES OF HEAVY METALS IN VEGETABLES IN CAPE TOWN, AND POSSIBLE METHODS OF REMEDIATION

MARŸKE MEERKOTTER

A thesis submitted in partial fulfilment of the requirements for the degree of *Doctor Philosophiae* in the Department of Biodiversity and Conservation Biology, University of the Western Cape

Supervisor: Prof LM Raitt (University of the Western Cape)

Co-supervisor: Prof L Brendonck (Katholieke Universiteit Leuven)

February 2012

SOURCES OF HEAVY METALS IN VEGETABLES IN CAPE TOWN, AND POSSIBLE METHODS OF REMEDIATION

MARŸKE MEERKOTTER

KEY WORDS

Cadmium

Lead

Zinc

Agricultural resources

Crop quality

Mitigation/remediation methods

Triple super phosphate fertilizer

EDTA

Vegetable farming practices

Pollution sources

ABSTRACT

SOURCES OF HEAVY METALS IN VEGETABLES IN CAPE TOWN, AND POSSIBLE METHODS OF REMEDIATION

M. Meerkotter

PhD thesis, Department of Biodiversity and Conservation Biology, University of the Western Cape

Cape Town includes two vegetable farming areas within the city limits, the Joostenbergvlakte/

Kraaifontein area and the Philippi area. Both areas supply produce to local markets and further afield. Sporadically, high levels of cadmium, copper, lead and zinc have been found to occur in some of the soils, irrigation water resources and crops. To find the sources of specifically Cd, Pb and Zn to these agricultural systems, extensive analysis of several heavy metals in inputs such as fertilizers, agrochemicals and supplementary water resources to these farming areas was undertaken. Heavy metal concentrations in soils, irrigation water resources and crops were also determined. Two mitigation techniques that could be used to remediate Cd, Pb and Zn contamination were investigated. The first mitigation method included immobilization of heavy metals as phosphate complexes by using a triple super phosphate fertilizer, while the second method involved mobilisation and thus leaching of heavy metals away from plant roots using EDTA. These mitigation methods were tested in a pot experiment using cabbage as the experimental crop and soil from these areas as growth medium. A survey of common farming practices in these two areas and farmers' willingness to use remediation methods was conducted. The results in general indicated that crops from

these two areas were fit for human consumption and that raw (unprocessed) cattle manure and chicken manure were the greatest sources of heavy metals in both farming areas. It was found that the use of EDTA led to elevated levels of Cd, Pb and Zn in cabbage, while the use of triple super phosphate at a low concentration contributed to limiting the uptake of Cd, Pb and Zn, but only minimally. Most farmers are willing to apply remediation methods but only when they have been proven necessary. In general, the same farming practices occurred in both areas. Farmers from the Philippi area tended to rely more heavily on subterranean water resources. It became clear that unprocessed manures should be used with caution and that more appropriate heavy metal remediation methods should be sought.

February 2012

DECLARATION

I declare that: "Sources of heavy metals in vegetables in Cape Town, and possible methods of remediation" is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Marÿke Meerkotter

February 2012

Signed: M. Meerkotter ………………………….

ACKNOWLEDGEMENTS

Allow me to thank the following people for their continuous support and encouragement, as well as technical support and advice as I worked on this thesis:

From the Biodiversity and Conservation Biology Department:

Prof. L Raitt, Prof. L Brendonck, Mr. L Cyster and Mrs. L van Heerden

Friends and family:

Miss. C Biggs, Mr. M Malan, Mrs. M Augustus, my parents and family

I give God the glory for enabling me to complete this thesis in Jesus Christ, my Lord and strength.

CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 1

INTRODUCTION TO THE STUDY 'SOURCES OF HEAVY METALS IN VEGETABLES IN CAPE TOWN, AND POSSIBLE METHODS OF REMEDIATION' AND A LITERATURE REVIEW

1.1. Aims of the research

Research done during the past ten years in both the Philippi, Joostenbergvlakte and Kraaifontein agricultural areas of Cape Town revealed that the concentrations of heavy metals, cadmium, copper, lead and zinc in respectively, soil, water and vegetables exceeded the limits set by South African regulations and guidelines (Aza-Gnandji, 2011; Meerkotter, 2003; Qoko, 2003; Sogayise, 2003). Guidelines used for evaluating the irrigation water were from the reference: Department of Water Affairs and Forestry (1996) South African Water Quality Guidelines (Second edition), Volume 4: Agricultural Use, Irrigation. Guidelines for concentrations of elements in the soils were adopted from: Water Research Commission (1997) Permissible Utilization and Disposal of Sewage Sludge. Regulations proclaimed under the Foodstuffs, Cosmetics and Disinfectants Act (Department of Health, 2003; Government Gazette, 1994;) were used to test vegetables against.

This research therefore aimed firstly, to determine, the sources of the specific heavy metals cadmium, lead and zinc (amongst other elements such as calcium, cobalt, chromium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, phosphorous, selenium, tin and vanadium) in various inputs to both the Philippi, Joostenbergvlakte and Kraaifontein farming areas. In the event of heavy metal contamination of agricultural resources in these areas becoming a health hazard, this research secondly investigated, two mitigation treatments in a pot experiment using soils from these farming areas as growth medium. The one mitigation method involved the application of EDTA and the other the application of triple super phosphate fertilizer. Thirdly through this research, awareness was to be raised amongst the farmers of these farming areas, with regard to heavy metal pollution in the agricultural system and its various implications. Gathering information about general farm practices in these farming areas was to be attempted.

This study mainly focused on the scientific issues involved. Socially, however, there rested an obligation on the researcher to inform farmers of the Philippi, Joostenbergvlakte and Kraaifontein agricultural areas of the heavy metal contamination problem that could be looming. Although it was important to raise this potential problem that could develop in the near future, it had to be done in a manner that would not cause harm to these farming communities, through loss of agricultural activity due to unnecessary exaggeration of the issue (Furness, 1996; The Constitution of the Republic of South Africa, 1996). Conducting a brief survey to gather some farming practice information from the farmers, as well as their thoughts on mitigation, was aimed at addressing this looming problem more effectively.

Scientifically, determination of the source(s) of the problem heavy metals would be a "reactionary response" to lessen the scale of heavy metal contamination bound to occur in the future if intervention is not made, while investigating different methods of mitigation would be a "proactive response" to determine useful heavy metal mitigation/remedial methods if needed in the future in these agricultural areas. Important issues relating to these agricultural areas are discussed in the following section of this chapter, after which this research is related to global studies of similar nature in the Literature Review section of this chapter.

1.2. Background to the vegetable farming areas of Cape Town

This research contributes towards the 'Sustainable utilization of subterranean water resources for the improvement of the quality of life' project, which falls under the broader; 'Dynamics of Building a Better Society Programme (DBBS)'. The DBBS programme combined the expertise and knowledge base of the University of the Western Cape with that of the Flemish Universities through the Flemish Interuniversity Council (Vlaamse Interuniversitaire Raad).

The quality of subterranean water resources is often affected by agricultural activities above ground. Heavy metals and other pollutants in agricultural soils and surface irrigation waters could enter subterranean water resources through runoff and leaching thus affecting the sustainable utilization of subterranean water resources (Li and Shuman, 1997 a; Li and Shuman, 1997 b; Tijani, 2009). Once subterranean water resources have been contaminated they are not easily decontaminated. Use of contaminated subterranean water, above ground, may lead to further pollution of surface water resources and agricultural soil as pollutants cycle from below ground to above ground and *vice versa* (Alam *et al.*, 2003). Addition of pollutants to the agricultural environment could intensify the existing problem and thus, monitoring of surface and subterranean water resources and agricultural soil is of importance to ultimately ensure, good quality potable and irrigation water and production of consumer safe crops (Arora *et al.*, 2008).

The Cape Metropolitan Area contains both primary and secondary aquifers, some of which have been studied since 1966. Of these, the primary aquifer, the Cape Flats aquifer, has been explored since 1980 as possible supplementary resource to the current domestic water supply of Cape Town. All subsequent investigations of this aquifer indicated that it would be a significant resource to supplement the current municipal water supply and that abstraction could begin immediately. To date abstraction from this aquifer, to supplement municipal water resources of the Cape Metropole, aimed for domestic use, has not happened, yet, conservation of the quality of this water resource is necessary as the demand for potable water increases, with increase in Cape Town's population size (Fraser and Weaver, 2000; Rose, 1996, Vandoolaeghe, 1990; Wright and Conrad, 1995).

It was reported in June 2005 that the Western Cape's water resources were almost fully utilized and that there was already a deficit in some areas, hence the need for effective use of subterranean water resources to supplement surface water resources has become more urgent (Yeld, 2005). These subterranean water resources and the proper management thereof have, in view of the above, become increasingly important. Presently, Cape Town's farming communities use water from both primary and secondary aquifers for irrigation purposes and some private landowners have boreholes and well points fed by these aquifers. Proposals were placed on the table in 2002 to encourage the installation of more private boreholes and well points in the Cape Metropole, to help minimize the amount of treated municipal water currently used for irrigation of gardens, sports fields and recreational areas. Abstraction of water from the Cape Flats aquifer and secondary aquifers for domestic use has been accomplished successfully in the Atlantis area and Cape Flats aquifer water is used for irrigation in the Mitchell's Plain area (Harris *et al.*, 1999, Rose, 1996; Saayman and Adams, 2002; Vandoolaeghe, 1990).

Saayman and Adams (2002) reported that the water of both the primary and secondary aquifers of the Cape Flats is generally of good quality. However, in light of the abovementioned, it should be clear that the demand for water in the Western Cape, necessitates that the quality of not only surface water resources, but indeed also subterranean water resources, be protected, and that proper management of use of these water resources is of extreme importance.

Intrusion of seawater into the Cape Flats aquifer has been suspected in isolated areas in Cape Town. Fortunately, a recent study by Aza-Gnandji (2011) reported it not so in the Philippi farming area, which is near the False Bay coast line. The research did, however, indicating that over-abstraction was taking place in some areas (Aza-Gnandji, 2011). Phosphate contamination of the Cape Flats aquifer has been detected especially in the Philippi agricultural area and this has been correlated positively with agricultural practices such as fertilizer use (Bertram, 1989). Mineralisation of subterranean water in the Philippi farming area, as well as leaching of wastewater, into subterranean water resources, from treatment plants in the adjacent Mitchell's Plain area has also been indicated (Chittenden Nicks Partnership, 1997; Fraser and Weaver, 2000; Harris *et al.*, 1999; Rose, 1996; Wright and Conrad, 1995). Focussed attention has not been paid to the level of pollution of these aquifers. This study indirectly addresses this issue with regard to heavy metal contamination of Cape Town's agricultural areas (Fraser and Weaver, 2000; Vandoolaeghe, 1990; Wright and Conrad, 1995,).

Cape Town's two agricultural areas, the Joostenbergvlakte/Kraaifontein and Philippi areas' soils are of the Cenozoic Sandveld group deposit, which lies on top of the meta-sedimentary Malmesbury Shales and Cape Granite bedrock. The Cape Flats aquifer, a primary aquifer, lies in the Sandveld group deposit. Many farmers abstract water from this primary aquifer for irrigational purposes. Some farmers also abstract water from the secondary aquifer in the Malmesbury shales meta-sediment (Cole and Roberts, 1996; Fraser and Weaver, 2000; Harris *et al.*, 1999; Rose, 1996; Saayman and Adams, 2002; Wright and Conrad, 1995).

The Cape Flats aquifer is a regionally unconfined aquifer and hence subject to pollution from various activities and sources aboveground, i.e. air pollution, surface water pollution and soil pollution amongst other (Itoh *et al.*, 2006; Tijani, 2009; Wei and Yang, 2010). The secondary Malmesbury shale aquifer, is less influenced by aboveground activities, however, there may be areas of linkage between the primary and secondary aquifers, which means that the primary aquifer could contaminate the secondary aquifer or *vice versa*, depending on either aquifer's water quality (Fraser and Weaver, 2000; Harris *et al.*, 1999; Rose, 1996; Saayman and Adams, 2002; Wright and Conrad, 1995).

At several sites in the Philippi farming area, the water table is approximately 1,5m below the surface most of the year and hence the transfer of surface pollutants, and specifically heavy metals, to the subterranean water resources is a pressing issue that needs to be addressed. Furthermore, the common practice of using a combination of both surface and subterranean water for irrigation of many of Cape Town's agricultural areas perpetuates the cycling of pollutants and heavy metals in these agricultural environments, and may be directly or indirectly linked to the contamination of subterranean water resources and hence influence the sustainability of these resources (Alam *et al.*, 2003).

To determine the extent of heavy metal contamination, agricultural soils, irrigation water and vegetables were sampled intermittently between 2000 and 2004 from Cape Town's two major agricultural areas, Philippi and the Joostenbergvlakte/Kraaifontein area. Samples collected from the Joostenbergvlakte, in 2003, indicated that lead was the most abundant heavy metal, specifically in vegetables and some soils collected from the area. Cadmium was also present in excess in most vegetable samples from the Joostenbergvlakte/Kraaifontein area. Samples collected from the Philippi area, in 2000, revealed contamination of soils and vegetables with cadmium, lead and excess levels of zinc. Excessive levels of copper were also found in some soils of the Philippi area in 2000 (Meerkotter, 2003; Sogayise, 2003). These recorded incidences of heavy metal contamination called for further investigation into the sources of these heavy metals to these agricultural areas. Once the sources have been identified, control over the extent of heavy metal contamination might be achieved. This should enable the development of activities that will make sustainable utilization of all agricultural resources (soil, irrigation water and subterranean water resources) possible.

Both the Philippi and Joostenbergvlakte/Kraaifontein farmers contribute significantly as suppliers to Cape Town's fresh produce market; therefore addressing the issue of heavy metal contamination in these areas' crops is of great importance. The Cape Town fresh produce market in turn, is the third largest contributor to South Africa's fresh produce among 16 of South Africa's major fresh produce markets (Directorate Agricultural Statistics, 2000). In the light of South Africa's growing population it is imperative that as the demand for vegetables grows, the importance of ensuring sustainable utilization of agricultural land is ensured (Meerkotter, 2003).

In light of the above findings from previous studies, this research entitled "Heavy Metals, and Vegetable Farming in Cape Town: Sources and Remediation", was to investigate means of dealing with the existing heavy metal contamination problems in both the Joostenbergvlakte, Kraaifontein and Philippi farming areas. Finding the sources of the heavy metals that are problematic in these areas would be a stepping-stone towards finding means of remediation or at least mitigation, which might lead to enabling action in alleviating heavy metal contamination problems on these farms, should they arise in the near future. Globally, a heavy metal contamination of agricultural systems has been investigated and is highlighted in the following section of this chapter.

1.3. Literature review on global examples of heavy metal contamination on vegetable farms and methods of remediation

A survey, in the summer and winter of 2000, to determine the extent of heavy metal contamination in the Philippi agricultural area indicated that lead, zinc and cadmium concentrations in vegetables exceeded the concentrations allowed under regulations formulated in the South African Foodstuffs, Cosmetics and Disinfectants Act of 1972. Although the concentrations of cadmium, lead and zinc exceeded the levels set by these regulations, based on Dietary Reference Intake values the vegetables were still fit for human consumption as the measured metals concentrations contributed minimally towards the diet (Meerkotter, 2003). Studies done in Bangladesh and Beijing and New Zealand also found that, although their respective maximum permissible concentrations for foodstuffs may be exceeded in the edible parts of some crops, these crops were still not a health risk and thus safe for consumption, indicating that set maximum permissible concentrations for foodstuffs in various countries are often almost too stringent (Alam *et al.*, 2003; Furness, 1996; Khan *et al.*, 2008 a; Song *et al.*, 2009).

Although excess levels of essential elements, such as zinc, in vegetables, could be advantageous and boost the consumer's immune system, excess levels of cadmium and lead may adversely affect the consumer in the long run, as these elements bio-accumulate in the consumer's body. Studies in northern Pakistan for example, declared vegetables that did not exceed health risk values for a host of heavy metals as unsafe for consumption even though only Pb was present in excess, since Pb posed a health risk to consumers (Khan *et al.*, 2010).

A study in Nanning, China found that the consumption of vegetables that contained Cd and Pb were particularly hazardous to consumers' health and that the selection of vegetable crops that accumulated less Cd and Pb was necessary in areas where Cd and Pb contamination was prominent in agricultural systems (Cui *et al.*, 2004). The intake of heavy metals through consumption of contaminated vegetables is thus a real health risk. The effects of cadmium, lead and zinc, in the human body were discussed by Meerkotter (2003) in the thesis "Heavy Metals, and Vegetable Farming in Cape Town". Table 1 summarises the human body's systems affected by these elements.

Table 1: Human body systems affected adversely by excess amounts of cadmium, copper, lead and/or zinc intake (Meerkotter, 2003)

Human body systems	Cadmium	Copper	Lead	Zinc
Integumentary system			X	X
Muscular system				X
Skeletal system	X	X	X	
Nervous system			X	
Endocrine system			X	X
Circulatory system		X	X	X
Lymphatic system				X
Respiratory system			X	
Digestive system	X	X	X	X
Urinary system	X	X	X	X
Reproductive system			X	

Ingestion of heavy metal contaminated vegetables is a main source of heavy metals to the human body. Vegetables may become contaminated through irrigation with heavy metal contaminated water (Nayek *et al.*, 2010). It is thus desirable to keep irrigation water resources relatively free from heavy metals, but in many counties such as Jordan, Serbia and parts of India, fresh water resources are limited and the use of wastewater has become necessary (Al-Zu'bi, 2007; Singh *et al.*, 2010 b; Surdyk *et al.*, 2010). Though Surdyk *et al.* (2010) and a study done in Beijing by Khan *et al.* (2008 b) found that wastewater treated vegetable crops they studied were not a health risk in terms of heavy metal content, this was not the case in studies elsewhere. Contrary to the studies of Surdyk *et al.* (2010) and Khan *et al.* (2008 b), the studies of Singh *et al.* (2010 b) in India, Mapanda *et al.* (2007) in Zimbabwe, Zeng *et al.* (2008) on a vegetable land in eastern China and pot experiments by Akbar *et al.* (2010) and Khan *et al.* (2008 b) indicated that irrigating crops with wastewater elevated the health risk of these crops in terms of heavy metal content.

A study done in urban areas of Uganda found however that crops could be safely grown on contaminated soils and treated with wastewater as long as these vegetables were washed properly before cooking (Nabulo *et al.*, 2010). Kiziloglu *et al.* (2008) pointed out that the level of treatment of wastewater greatly determined its usefulness for vegetable irrigation. It was found that untreated wastewater could only be used for a short period of time before posing a threat to crops in terms of heavy metal contamination. The use of primary treated wastewater could, however, be used over a much longer period of time on agricultural land (Kiziloglu *et al.*, 2008). It has also been found in some studies that the organic content of soils may be increased through irrigation with wastewater, which could be a benefit by leading to increased crop yields as found in a study by Wang *et al.* (2007). A study in the Shandong Province of China found that Pb was often added to agricultural soils by wastewater irrigation, as well as, through vehicle and industrial fumes, while Cd, Cu and Zn were mainly added to agricultural systems through the use of agrochemicals (Liu *et al.*, 2011).

As important as quality irrigation water resources are to ensure the production of quality crops, so important is the quality of the soil in which they are grown. Several studies worldwide indicated that agricultural soil may become contaminated with heavy metals through irrigation with wastewater as mentioned, loading with sewerage sludge, dust from metal processing industries, electronic waste recycling and atmospheric deposition (Itoh *et al.*, 2006; Larcher, 2003; Luo *et al.*, 2011, Nicholson *et al.*, 2003; Sharma *et al.*, 2008). Run-off from urban areas and atmospheric depositions are a great source of heavy metals to soils, but it needs to be noted that the sources of heavy metals to respectively urban soils and agricultural soils are not necessarily the same (Shirasuna *et al.*, 2006; Wei and Yang, 2010). Agricultural soils, like those of the Philippi, Joostenbergvlakte and Kraaifontein areas of Cape Town are, however, most likely to be contaminated with heavy metals through addition of inorganic fertilizers, manures; agrochemicals and sewage sludge (Al-Zu'bi, 2007, Heijerick *et al.*, 2006; Jinadasa *et al.*, 1997; Muchuweti *et al.*, 2006; Nicholson *et al.*, 2003). It is important to note that each possible source of heavy metals should be monitored specifically rather than be subject to a general observation, in some cases for example the addition of manures increase the levels of Cd measured in lettuce while in other studies the addition of manures reduced the uptake of Cd by *Beta vulgaris* (Jinadasa *et al.*, 1997; Singh *et al.*, 2010 a). None the less, some general observations pertaining to the cycling of nutrients and heavy metals in an agricultural ecosystem should be considered to find a remedy in cases where heavy metal pollution exists.

In general, heavy metals can cycle through water, soils and the biosphere much like phosphorus cycles through an ecosystem, since most heavy metals do not exist in a gaseous state. Heavy metals may occur naturally in the soil or rocks of an area, or could be introduced to the soil in many ways, for example, through application of fertilizers that contain traces of heavy metals, deposition from polluted air or dumping of heavy metal containing substances in an area. Heavy metals may exist in the soil as ionic species that can be taken up by plants and could then be passed on to various consumers in the food-chain. The heavy metals can then return to soils through defecation, excretion or decay that follows the death of consumers of heavy metal contaminated foods. The cycle may then repeat itself and heavy metals may even reach water resources through runoff from various contaminated sites. Groundwater resources may also be contaminated as heavy metals percolate through the soil with water that would naturally recharge aquifers. Use of contaminated groundwater for irrigation, in turn, may re-contaminate, heavy metal polluted soil and thus accumulation of heavy metals could occur in an ecosystem and the crops grown in contaminated agricultural fields (McLaughlin *et al*, 1997; *Miller*, 1996; Sauvé *et al*, 1996).

Although vegetables most likely take heavy metals up from the soil in which they are grown, the fact that soils may be heavily contaminated with heavy metals may not necessarily mean that the vegetables grown in such soils would be a risk to consumers' health. Khan *et al.*'s study (2008 b) focussing on heavy metal contaminated soils in Beijing found that although the soils exceeded the permissible limits set for heavy metals therein, the crops grown on these soils did not pose a threat to consumers' health. On the contrary, studies by Jinadasa *et al.* (1997) in Sydney, Australia, Sharma *et al.* (2007) in Varanasi, India and Hao *et al.* (2009) in Southern Jiangsu Province, China showed that though agricultural soils contained relatively low concentrations of selected heavy metals, these metals were in concentrations greater than these countries' respective permissible levels in foodstuffs in the vegetables grown on these soils.

In a study by Azimi *et al.* (2006), it was found that the concentration of Cd in soil did not affect the concentration of Cd in the organs of pumpkins grown on these soils compared to pumpkins grown on uncontaminated soils. Similar results were obtained by Nabulo *et al.* (2010) who found that *Cucurbita maxima* and *Vigna unguiculata* were more able to restrict Cd uptake from contaminated soils. In the study by Azimi *et al.* (2006) the roots of radish were shown to accumulate less Cd than the stems and leaves. A study done by Queirolo *et al.* (2007), it was found that potatoes skins accumulated more Cd and Pb than the other part of the potato. Cao *et al.* (2010) found that leafy vegetables were more likely to accumulate heavy metals than Solanaceae vegetables. A study done by Nabulo *et al.* (2011) showed that though grown on the same soil medium, leafy vegetables from tropical areas accumulated more Cd than temperate types. Furthermore, in a study where soil was saline and heavy metal contamination a problem, the growth of several vegetable crops was tested and most successful was the salt tolerant tomato plant, which was also able to accumulate less heavy metals than other crops (Li *et al.*, 2010). These studies indicated that different crops respond differently to similar heavy metal concentrations (Yusuf *et al.*, 2003). When faced with heavy metal contamination of agricultural soils farmers may be wise to plant crops that would be less likely to accumulate great amounts of heavy metals.

Though the washing of crops prior to cooking can reduce the presence of heavy metals thereon, it is important to reduce the uptake of heavy metals by crops (Sharma *et al.*, 2008; Sharma *et al.*, 2009). This may be achieved though various remediation techniques, some of which are mentioned in the following sections of this chapter. An obvious way of reducing heavy metals in the agricultural system would be to simply reduce the use of fertilizers and chemicals that contain heavy metals. Elevation of soil's organic matter content to bind metals to the soil and render them unavailable to plants can also be achieved rather easily (Paradelo *et al.*, 2011). Soil pH can also be elevated to immobilize heavy metals (Marschner, 1995).

Other methods involve the removal of polluted topsoil and its replacement with unpolluted topsoil or simply covering the polluted soil layer with a layer of unpolluted topsoil. These methods are, however, not very practical. The removal of polluted topsoil may cause pollution in the area where it is dumped and obtaining unpolluted topsoil from elsewhere to substitute the removed soil would damage the source area's ecosystems by causing erosion (Miller, 1996). Polluted topsoil could, instead of removal, be stabilized through addition of additives that can immobilize metals in the soil (Boisson *et al.*, 1999). Other remedies might include the *in situ* or *ex situ* "washing" of soil with chelating agents or acids to remove heavy metals. The "washing" of soil could also be combined with phyto-remediation (Sun *et al.*, 2001). Phyto-remediation with economically viable crops is an additional option farmers might have (Zheljazkov and Nielsen 1996).

The use of plants species to remove or extract heavy metals from the soil and in so doing clean the soil for planting of less tolerant crops could be considered (Qoko, 2003). Phyto-remediation though having benefits may however take years to clean soils sufficiently and thus might make this method less plausible to commercial farmers. Getting rid of the polluted plant material after remediation is also problematic. Phyto-remediation may, however, be useful when applied to contaminated sites where human contact is not frequent (Salido *et al.*, 2003). If an economically viable crop could be used for phyto-remediation, farmers may choose this form of remediation above the addition of amendments or, removal of topsoil or, the "washing" of soil which may in cases be unpractical and also more costly. Growth of essential oil crops on contaminated agricultural fields, in Bulgaria, for the purpose of phyto-remediation, proved not only viable but also a profitable way of ridding soil of unwanted heavy metals (Zheljazkov and Nielsen, 1996). *Helianthus annuus* (sunflower), has also been shown useful in the removal of Pb and Zn from contaminated soils (Solhi *et al.*, 2005). Farmers of the Joostenbergvlakte/Kraaifontein and Philippi areas might be more inclined to use methods of mitigation that are profitable, such as phyto-remediation with economically valuable/viable crops. The question of farmers' willingness to use a remediation method such as phyto-remediation was addressed in this research and is discussed in Chapter four of this thesis.

Extraction of Cd, Cu, Pb and Zn by *Brassica juncea* (Indian mustard) has also been tested in the presence of nitrilotriacetate (NTA) and citric acid to help mobilize these heavy metals for uptake by plant roots. The ability of Indian mustard plants to take up heavy metals was significantly enhanced in the presence of NTA (Quartacci *et al.*, 2006). The use of EDTA and EDDS was also tested as amendments that can be used to facilitate phyto-remediation with, amongst other species, *Brassica rapa*, *Cannabis sativa*, *Helianthus annuus* and *Zea mays* (Meers *et al.*, 2005). These tests showed that neither EDTA nor EDDS were more useful to assist extraction of heavy metals by *Brassica rapa*, *Cannabis sativa*, *Helianthus annuus* and *Zea mays*, it was however clear that EDDS was more biodegradable than EDTA and this emphasized that caution needs to be taken when applying amendments to soils (Meers *et al.*, 2005).

Various chelates such as EDTA, EDDS, NTA and citric acid can be used to mobilize heavy metals in soils and leaching the metals from the reach of plant roots, reducing phytotoxicity of heavy metals in the rhizosphere (Meers *et al.*, 2005; Quartacci *et al.*, 2006). *In situ* mobilization of heavy metals may, however, be detrimental to the environment as heavy metals may be leached vertically and horizontally from one soil layer to the next as well as into surface and subterranean water resources. *Ex situ* washing of soil with chelating agents or acids to remove heavy metals would be possible, but is an unlikely solution when dealing with large areas of contamination. In combination with phyto-remediation, chelates may be used to solubilize heavy metals, making uptake of these heavy metals, by the remedial plant more effective. However, a combination of *in situ* application of chelating agents with phyto-remediation, though more effective, still leaves the possibility of contamination of subterranean water resources with heavy metals (Sun *et al.*, 2001). Therefore, *in situ* immobilization of heavy metals is considered a safer option in dealing with heavy metal contaminated soils.

Immobilization involves application of amendments to the soil that renders the heavy metals unavailable to plants. Applications of amendments that immobilize heavy metals in agricultural soils are viewed as the most cost effective and environmentally safe way to reduce the phyto-toxicity of contaminated soils. Application of vermiculite as an immobilizer to contaminated soils from Piedmont, Italy in a pot experiment, showed that the availability of heavy metals to *Spinach oleracea* were significantly reduced (Malandrino *et al.*, 2011). Various phosphate sources have also been used to immobilize heavy metals in soils and render them unavailable to plant roots. The use of a combination of phosphates, for example, biogenic apatite and mined phosphate proved to be better than using just mineral rock phosphates, since mineral rock phosphates often contained more heavy metals and thus nullified the effect of immobilizing heavy metals in the soil (Knox *et al.*, 2006).

Much attention has been given to the use of phosphate containing substances as amendments, examples are bentonite, zeolite, cyconic ash, compost, lime, steelshot-dolomite and hydroxyapatite among others. A study done by Zhu *et al.* (2004) on the effects of various phosphate containing amendments on lead uptake by two vegetable crops in an alkaline soil, indicated that hydroxyapatite was one of the most effective amendments for remediation of lead contaminated soils. Phosphogypsum, red gypsum and dolomite were also shown to be effective in reducing the mobility and bioavailability of lead, copper and cadmium in heavy metal contaminated soil (Illera *et al.*, 2004).

The substance Palygorskite was pointed out as contributing towards zinc deficiency in plants grown in Egyptian soils. Based on this, the use of Palygorskite to reduce the mobility of Cd, Cu, Pb and Zn in polluted soils was investigated by Alvarez-Ayuso and Garcia-Sanchez (2003). Low-grade MgO was found a suitable and economically feasible stabilizing agent prior to landfill, and hence it has been suggested that it might also be useful for *in situ* remediation of less polluted soils (Garcia *et al.*, 2004). Stirk and Van Staden (2001) investigated the use of organic soil amendments such as kelp to immobilize heavy metals in agricultural resources (water and soil).

The use of dried kelp to alleviate heavy metal contamination in water resources was proved viable (Stirk and Van Staden, 2001). Remediation of contaminated irrigation water might be done in a cost effective way through application of dried kelp (*Ecklonia maxima* and *Laminaria pallida*) and Kelpak waste, which can easily be obtained by farmers in the Western Cape. The addition of powdered kelp to polluted irrigation water caused sorption of metals to the kelp particles, which was filtered off from the remainder of water used for irrigation (Stirk and Van Staden, 2001). The use of dried, powdered kelp might also be useful in immobilization of heavy metals from polluted soils. However, use of organic material such as kelp and other chemical sorbants, poses a problem when looking at disposal of the contaminants after removal from irrigation water and/or soils.

From the above it is clear that various methods of remediation/mitigation exist, and in this research the use of EDTA and triple super phosphate was compared with regard to their ability to reduce uptake of specifically Cd, Pb and Zn by cabbage grown on a growth medium prepared from soils of the Philippi, Joostenbergvlakte and Kraaifontein areas. Before implementing remediation or mitigation techniques as means of reducing the uptake of heavy metals by crops from the local Joostenbergvlakte, Kraaifontein and Philippi farming areas, it is necessary to establish the sources of the problem heavy metals, Cd, Cu, Pb and Zn, to these farming communities. If these heavy metals could be traced to point sources, it may be relatively simple to remedy the situation by simply eliminating or reducing the use of the particular sources, or products. However, it is likely that several heavy metals may be sourced from inputs to these farmlands that are not necessarily under the farmers' control.

Finding the sources and inputs of heavy metals to these farmlands which included sampling of various fertilizers, manures, pesticides and crop sprays from these areas formed a central part of this research and is discussed in Chapter three of this thesis. Farmers of these farming communities were informed of the existing contamination problem in their areas and a survey was conducted amongst farmers to obtain their opinions about threats to their agricultural resources and their willingness to apply remediation methods if needed in the future.

1.4. The research problem and hypotheses for the study 'Sources of heavy metals in vegetables in Cape Town and possible methods of remediation'

Determining Cd, Cu, Pb and Zn sources to the Joostenbergvlakte/Kraaifontein and Philippi farming areas was a main focus of this research. Equally, this research aimed to find ways of reducing the uptake of these heavy metals by cabbage, a common crop produced in these two major farming areas, through mitigation with respectively EDTA and triple super phosphate as soil amendments. The research problem was therefore summarized as the "Identification of Cd, Pb and Zn inputs to the Joostenbergvlakte, Kraaifontein and Philippi farming areas and, suitable methods of mitigation, to reduce, the uptake of these metals by crops."

Heavy metals such as Cd, Pb and Zn are often byproducts in the production of phosphate fertilizers. It has also been indicated that poultry manure, sewerage sludge as well as fungicides, pesticides and herbicides, often contain heavy metals, such as copper and zinc (Heijerick *et al.*, 2006; Jinadasa *et al.*, 1997; Larcher, 2003; Meerkotter, 2003; Nicholson *et al.*; 2003). Based on these and similar findings in other studies it was hypothesised that significant concentrations of Cd, Pb and Zn would be measured in phosphate fertilizer samples, poultry manure samples, fungicides, pesticides and herbicide samples.

The attenuation capacity of the Joostenbergvlakte, Kraaifontein and Philippi's agricultural soils, being sandy soils, is not very high. These soils may hold heavy metals for a time, but eventually these metals may become available to crops or subterranean water resources, from where or through which it may be passed to the consumer. Possible leaching of elements such as, cadmium, copper, iron, manganese, potassium and zinc from surface soil layers to subterranean waters, during the rainy winter season, is suspected in the Philippi soils, as a lower concentration of these elements was measured in the winter of 2000, compared to the summer of 2000 (Meerkotter, 2003). This information led to the hypothesis that the concentrations of Cd, Cu, Pb and Zn in surface and subterranean water samples would be greater than seen in studies of previous years. Use of polluted water by Kraaifontein farmers from river systems such as the Kuilsriver system and storm water canals may also contribute to the presence of heavy metals in the agricultural field (Personal communication with farmers; Qoko, 2003). Various irrigation water sources were therefore to be examined and it was hypothesised that significant amounts of cadmium, copper, lead and zinc would be present in surface water resources, used to supplement irrigation water resources.

Irrigation water and cropped soils are intimately connected and contamination of the one will either directly or indirectly lead to further contamination of the other. The status of both thus needs to be monitored with consideration of the interchange of elements that happen between these two kinds of resources. It was hoped that a cost-effective amendment, to help immobilized heavy metals from polluted agricultural soils would be identified through this research. Based on literature, phosphate-containing amendments are effective immobilisers of heavy metals such as cadmium, lead and zinc; therefore it was hypothesised that application of appropriate amounts of triple super phosphate fertilizer would help immobilize heavy metals from a growth medium prepared from soils of the Joostenbergvlakte, Kraaifontein and Philippi farming areas, and render Cd, Pb and Zn unavailable to cabbage, thus being a better remedial amendment to immobilize metals in the soul than EDTA (Knox *et al.*, 2006).

1.5. Delimitation of the research

This research only reported on the different sources of heavy metals to the Joostenbergvlakte, Kraaifontein and Philippi farming communities, the better mitigation treatment between addition of EDTA and triple super phosphate to soil from these farming areas contaminated with Cd, Pb and Zn at maximum permissible soil concentrations set in South African guidelines and double these concentrations for each metal independently. A brief survey on farming practices in these areas also served to pin down information given by farmers from these areas through personal communication over the past decade.

This study did not seek to implement means of mitigation, but only to inform farmers of the sources of heavy metals to their farmlands and also the possibilities around reducing the ill-effects of heavy metals on their crops, in the soil and irrigation water, as well as subterranean water resources, through various mitigation treatments. This study is to be concluded not only with this thesis, but also by the compilation of a brochure to be made available to farmers highlighting legal limits for heavy metals in the agricultural system, disclosure of sources of problematic heavy metals such as Cd and Pb and options in terms of mitigation treatments that could be used if in the future it should be needed. An outline for a brochure that could impart the results gathered through this research to farmers as explained here can be found on the last page of the Appendix to this thesis. Prior to this study and as part of the survey to gather farming practice information from farmers, a brochure was handed out to farmers to inform them of the results around heavy metal contamination in their farming areas in previous studies. An Afrikaans and English copy of this brochure are to be found in the first pages of the Appendix to this thesis.

Due to the sensitivity of this type of contamination problem i.e. possible legal and health implications, the results of this study are to be disclosed to academic and scientific communities rather than published in popular journals and magazines accessed by the broader group of vegetable consumers (Furness, 1996).

1.6. Overview of the research methodology

The research of this thesis was divided into three main studies namely; a study focused on heavy metal analysis of various inputs to farms as possible sources of heavy metals, a study focused on assessment of EDTA and triple super phosphate as possible mitigation/remedial treatments to decrease the uptake of Cd, Pb and Zn by cabbage grown on contaminated soil from the study areas and lastly, a study was conducted to gather information about farming practices from the study areas and to ascertain farmers' willingness to apply remediation methods if it was ever proven necessary. A brief summary of the methodologies of each of these studies is given in sections 1.6.1, 1.6.2 and 1.6.3 of this chapter.

1.6.1. Analysis of various inputs to farms as possible sources of heavy metals

Vegetables and soil from fields in the Joostenbergvlakte, Kraaifontein and Philippi areas were to be collected and tested for heavy metals. Various irrigation water resources from these areas were also sampled and tested for heavy metals. Livestock manures and crop sprays were also collected and tested for heavy metals. The chemical analysis of the collected samples was done by a local testing laboratory and statistical processing of the data was done with the help of a bio-statistician.

1.6.2. Assessment of mitigation techniques (Pot experiment)

A multifactor experiment was designed, with the help of a bio-statistician, to evaluate the effectiveness of EDTA and triple super phosphate amendments respectively in reducing the uptake of Cd, Pb and Zn by cabbage. Materials and methods used by Geebelen *et al.* (2002), Wu *et al.* (2004) and Zhu *et al.* (2004), amongst others, were used to plan this experiment. A randomised block design with three replicates, in othe words, three plants for each treatment was constructed. The growth medium for this pot experiment was prepared from topsoil collected from the Philippi and Joostenbergvlakte/Kraaifontein areas. The growth medium was altered with respectively Cd, Pb and Zn at three different concentrations; *In situ* concentration of the respective metals in the growth medium, the maximum permissible concentrations for these heavy metals in soil (South African guidelines) and double the maximum permissible concentrations for these heavy metals (South African guidelines).

Three different EDTA concentrations were tested to mobilise heavy metals in the soil, away from plant roots, to deeper soil levels and three different concentrations of triple super phosphate fertilizer was applied to immobilise heavy metals in the soil, rendering them unavailable to plant roots for uptake. The control treatment entailed the growth of cabbage at the different concentrations of the different heavy metals without any added amendment. Chemical analysis of the cabbage and soil samples from this pot experiment was also conducted by a local testing laboratory while the results of this study were also processed with the help of a biostatistician.

Neither of the mitigation treatments were successful enough to justify testing them in the field, as discussed in Chapter three of this thesis. A field trial would typically have involved the selection of an agricultural site that showed significant heavy metal pollution. The field trial would involve, applying a range of amendment concentrations to the site's soil and selection of a relevant crop species to test the mitigation treatments on (Brown, *et al.*, 2004; Melamed *et al.*, 2003).

1.6.3. Farming practice survey

A survey was to be conducted among farmers of the Joostenbergvlakte, Kraaifontein and Philippi farming areas to find out what the common farming practices were in these areas. Survey methods as suggested by Serumaga-Zake *et al.* (2004) were followed. Information of the two main farming communities (the Philippi area and the Joostnebergvlakte/Kraaifontein area) was to be compiled separately to allow for comparison between these two farming communities as they may be influenced by different factors. The questionnaire was compiled according to principles and guidelines provided by Serumaga-Zake *et al.* (2004) and skills obtained during a workshop organized by the Postgraduate Education and Throughput programme of the University of the Western Cape in August 2005. The questionnaire was constructed to gather information that attempted to provide answers to the following questions:

1. How long farming has taken place in these farming areas?
2. Which crops were planted most frequently?
3. How much and what kinds of fertilizers, manures and agrochemicals were used?
4. What were the sources of irrigation water?
5. Are there any specific pollution threats in these areas?
6. Is there a problem with irrigation water becoming saline?
7. What mitigation techniques would farmers prefer to use?
8. Are farmers aware of the legal implications regarding pollution of their agricultural resources?

The researcher adhered to the ethics guidelines for performing a survey as described by the South African Medical Research Council to avoid infringing on the rights of farmers through this research (Labuschagne, 2005; The Constitution of the Republic of South Africa, 1996). The results for this study were processed with the help of a biostatistician.

1.7. Outline of chapters in this thesis

This first chapter focuses on introducing the thesis topic and in the context of related studies in the literature. Chapter two describes the results gathered about the heavy metal content of various inputs to the Joostenbergvlakte, Kraaifontein and Philippi vegetable farming areas of Cape Town. The study investigating the use of EDTA and triple super phosphate respectively as remediation methods on soils from these areas, with cabbage as test crop, is described in detail in Chapter three of this thesis. Chapter four records the most significant data gathered about farming practices in these farming areas and discusses farmers' willingness to employ remedial treatments, while Chapter five highlights the main results and conclusions that were made during the course of this research project as a whole.

1.8. References

Alam MGM, Snow ET, Tanaka A (2003) Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. The Science of the Total Environment 308: 83-96

Alvarez-Ayuso E, Garcia-Sanchez A (2003) Palygorskite as a feasible amendment to stabilize heavy metal polluted soils. Environmental Pollution 125: 337-344

Al-Zu'bi Y (2007) Effect of irrigation water on agricultural soil in Jordan valley: An example from arid area conditions. Journal of Arid Environments 70: 63-79

Akbar Jan F, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M (2010) A comparative study of human risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). Journal of Hazardous Materials 179: 612-621

Arora M, Kiran B, Rani S, Rani A, Kaur B, Mittal N (2008) Heavy metal accumulation in vegetables irrigated with water from different sources. Food Chemistry 111: 811-815

Aza-Gnandji CDR (2011) Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa. Unpublished Masters thesis. Department of Earth Sciences. University of the Western Cape, Cape Town

Azimi AA, Navab Daneshmand T, Pardakhti A (2006) Cadmium absorption and accumulation in different parts of kidney beans, radishes and pumpkins. Journal of Environmental Science and Technology 3: 177-184

Bertram WE (1989) Geohidrologiese opname in die Philippi-landbougebied, Kaapse Vlakte. Tegniese verslag Gh 3595. Direktoraat Geohidrologie, Departement van Waterwese (DWAF), Pretoria

Boisson J, Ruttens A, Mench M, Vangronsveld J (1999) Evaluation of hydroxyapatite as metal immobilizing soil additive for remediation of polluted soils. Part 1. Influence of hydroxyapatite on metal exchangeability in the soil, plant growth and plant material accumulation. Environmental pollution 104: 225-233

Brown S, Chaney R, Hallfrisch J, Ryan JA, Berti WR (2004) *In situ* soil treatments to reduce the Phyto- and bioavailability of lead, zinc and cadmium. Journal of Environmental Quality 33: 522-531

Cao H, Chen J, Zhang J, Zhang H, Qiao L, Men Y (2010) Heavy metals in rice and garden vegetables and their potential health risks to inhabitants in the vicinity of an industrial zone in Jiangsu, China. Journal of Environmental Sciences 22: 1792-1799

Chittenden Nicks Partnership (1997) The future of the Philippi horticultural area. Chittenden Nicks partnership, Cape Town

Cole DI, Roberts DL (1996) Lignite from the western coastal plain of South Africa. Journal of African Earth Sciences 23: 95-117

Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ, Qiu Y, Liang JZ (2004) Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environmental International 30: 785-791

Department of Health (2003) Legislation – regulations: Regulations relating to maximum levels of metals in foodstuffs: Amendment. http://www.doh.gov.za/docs/index.html Downloaded on 15/12/2003

Department of Water Affairs and Forestry (1996) South African water quality guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation, DWAF, Pretoria

Directorate Agricultural Statistics (2000) Statistics on fresh produce markets. Department of Agriculture, Pretoria, Report 38

Fraser L, Weaver J (2000) Cape Flats Aquifer: Bulk Water for Cape Town Now. Contract Report submitted to Ninham Shand Consulting Engineers, Stellenbosch

Furness H (1996) New Zealand in danger of over-reacting to cadmium issue. http://webnz.com/fertresearch/cadmium/cadmium_danger.htm Downloaded on 01/08/2001

Garcia MA, Chimenos JM, Fernandez AI, Miralles L, Segarra M, Espiell F (2004) Low-grade MgO used to stabilize heavy metals in highly contaminated soils. Chemosphere 56: 481-491

Geebelen W, Vangronsveld J, Adriano DC, Carleer R, Clijsters H (2002) Amendment-induced immobilization of lead in a lead-spiked soil: Evidence from phytotoxicity studies. Water, Air, and Soil Pollution 140: 261-277

Government Gazette (1994) Foodstuffs, cosmetics and disinfectants Act 1972: Act no. 54 of 1972. Government Gazette no 15954: 12-13

Hao XZ, Zhou DM, Huang DQ, Cang L, Zhang HL, Wang H (2009) Heavy metal transfer from soil to vegetable in Southern Jiangsu Province, China. Pedosphere 19: 305-311

Harris C, Oom BM, Diamond RE (1999) A preliminary investigation of the oxygen and hydrogen isotope hydrology of the greater Cape Town area and an assessment of the potential for using stable isotopes as tracers. Water SA 25: 15-24

Heijerick DG, Van Sprang PA, Van Hyfte AD (2006) Ambient copper concentrations in agricultural and natural European soils: an overview. Environmental Toxicology and Chemistry 25: 858-864

Illera V, Garrido F, Serrano S, Garcia-Gonzales MT (2004) Immobilization of the heavy metal Cd, Cu and Pb in an acid soil amended with gypsum- and lime-rich industrial byproducts. European Journal of Soil Science 55: 135-145

Itoh Y, Yoshinga S, Miura S (2006) Atmospheric lead and cadmium deposition within forests in the Kanto district, Japan. Journal of Forest Research 11: 137-142

Jinadasa KBPN, Milham PJ, Hawkins CA, Cornish PS, Williams PA, Kaldor CJ, Conroy JP (1997) Survey of cadmium levels in vegetables and soils of greater Sydney, Australia. Journal of Environmental Quality 26: 924-933

Khan S, Rehman S, Khan AZ, Khan MA, Shah MT (2010) Soil and vegetables enrichment with heavy metals from geological sources in Gilgit, northern Pakistan. Ecotoxicology and Environmental Saftey 73: 1820-1827

Khan S, Aijun L, Zhang S, Qinhong H, Zhu YG (2008 a) Accumulation of polycyclic aromatic hydrocarbons and heavy metals in lettuce grown in the soils contaminated with long-term wastewater irrigation. Journal of Hazardous materials 152: 506-515

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008 b) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution 152: 686-692

Kiziloglu FM, Turan M, Sahin U, Kuslu Y, Dursun A (2008) Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica olerecea* L. var botrytis) and red cabbage (*Brassica olerecea* L. var. rubra) grown on calcareous soils in Turkey. Agricultural Water Management 95: 716-724

Knox AS, Kaplan DI, Paller MH (2006) Phosphate sources and their suitability for remediation of contaminated soils. Science of the Total Environment 357: 271-279

Labuschagne, A (2005) South African Medical Research Council: Ethics and Human Rights. http://www.mrc.ac.za/ethics/ethicshuman.htm Downloaded on 26/10/2005

Larcher W (2003) Physiological plant ecology. 4th Edition. Springer-Verlag, Berlin

Li Q, Cai S, Mo C, Chu B, Peng L, Yang F (2010) Toxic effects of heavy metals and their accumulation in vegetables grown in a saline soil. Ecotoxicology and Environmental Safety 73: 84-88

Li Z, Shuman LM (1997 a) Mobility of Zn, Cd and Pb in soils as affected by poultry litter extract – I. Leaching in soil columns. Environmental Pollution 95: 219-226

Li Z, Shuman LM (1997 b) Mobility of Zn, Cd and Pb in soils as affected by poultry litter extract – II. Redistribution among soil fractions. Environmental Pollution 95: 227-234

Liu P, Zhao H, Wang L, Liu Z, Wei J, Wang Y, Jiang L, Dong L, Zhang Y (2011) Analysis of heavy metal source for vegetable soils from Shandong Province, China. Agricultural Sciences in China 10: 109-119

Luo C, Liu C, Wang Y, Xiang L, Fangbai L, Zhang G, Li X (2011) Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. Journal of Hazardous Materials 186: 481-490

Malandrino M, Abollino O, Buoso S, Giacomino A, La Gioia C, Mentasti E (2011) Accumulation of heavy metals from contaminated soil to plants and evaluation of soil remediation by vermiculite. Chemosphere 82: 169-178

Mapanda F, Mangwayana EN, Nyamangara J, Giller KE (2007) Uptake of heavy metals by vegetables irrigated using wastewater and the subsequent risks in Harare, Zimbabwe. Physics and Chemistry of the Earth 32: 1399-1405

Marschner H (1995) Mineral Nutrition of Higher Plants. 2nd Edition. Academic Press, London

McLaughlin M, Maier N, Rayment G, Sparrow L, Berg G, McKay A, Milham P, Merry R, Smart M (1997) Cadmium in Australian potato tubers and soils. Journal od Environmental Quality 26: 1644-1649

Meerkotter M (2003) Heavy metals, and vegetable farming in Cape Town. Unpublished Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Meers E, Ruttens A, Hopgood M, Lesage E, Tack FMG (2005) Potential of *Brassic rapa*, *Cannabis sativa*, *Helianthus annuus* and *Zea mays* for phytoextraction of heavy metals from calcareous dredged sediment derived soils. Chemosphere 61: 561-572

Melamed R, Cao X, Chen M, Ma LQ (2003) Field assessment of lead immobilization in a contaminated soil after phosphate application. The Science of the Total Environment 305: 117-127

Miller G (1996) Living in the Environment. 9th Edition. Wadsworth Publishing Company, Belmont

Muchuweti M, Birkett JW, Chinyanga E, Zvauya R, Scrimshaw MD, Lester JN (2006) Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: implications for human health. Agriculture, Ecosystems and Environment 112: 41-48

Nabulo G, Black CR, Young SD (2011) Trace metal uptake by tropical vegetables grown on soil amended with urban sewage sludge. Environmental Pollution 159: 368-376

Nabulo G, Young SD, Black CR (2010) Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. Science of the Total Environment 408: 5338-5351

Nayek S, Gupta S, Saha RN (2010) Metal accumulation and its effects in relation to biochemical response of vegetables irrigated with metal contaminated water and wastewater. Journal of Hazardous Materials 178: 588-595

Nicholson FA, Smith SR, Alloway BJ, Carlton-Smith C, Chambers BJ (2003) An inventory of heavy metals inputs to agricultural soils in England and Wales. The Science of the Total Environment 311: 205-219

Paradelo R, Villada A, Barral MT (2011) Reduction of the short-term availability of copper, lead and zinc in a contaminated soil amended with municipal solid waste compost. Journal of Hazardous Materials 188: 98-104

Qoko, M (2003) Monitoring of heavy metals in the Kuilsriver and potential use of macrophytes in heavy metal remediation. Unpublished, Masters thesis. Department of Biodoversity and Conservation Biology. University of the Western Cape, Bellville

Quartacci MF, Argilla A, Baker AJM, Navari-Izzo F (2006) Phytoextraction of metals from a multiple contaminated soil by Indian mustard. Chemosphere 63: 918-925

Queirolo F, Stegen S, Restovic M, Paz M, Ostapczuk P, Schwuger MJ, Muñoz L (2007) Total arsenic, lead, and cadmium levels in vegetables cultivated at the Andean villages of northern Chile. The Science of the Total Environment 255: 75-84

Rose R (1996) An assessment of the groundwater quality of the area southwest of Philipi, Cape Town. Unpublished, Honours thesis. Department of Geology. University of the Western Cape, Bellville

Saayman IC, Adams S (2002) The use of garden boreholes in Cape Town, South Africa: lessons learnt from Perth, Western Australia. Physics and Chemistry of the Earth 27: 961 - 967

Salido AL, Hasty KL, Jae-Min L, Butcher DJ (2003) Phytoremediation of arsenic and lead in contaminated soil using Chinese brale ferns (*Pteris vittata*) and Indian Mustard (*Brassica juncea*). International Journal of Phytoremediation 5: 89-103

Sauvé S, Cook N, Hendershot W, McBride M (1996) Linking plant tissue concentrations and soil copper pools in urban contaminated soils. Environmental Pollution 94: 153-157

Serumaga-Zake PAE, Arnab R, Kotze D, Stiegler N (2004) An introduction to statistical survey methods. Unpublished book. University of North West, Mafikeng

Sharma RK, Agrawal M, Marshall FM (2009) Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. Food and Chemical Toxicology 47: 583-591

Sharma RK, Agrawal M, Marshall FM (2008) Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: a case study in Varanasi. Environmental Pollution 154: 254-263

Sharma RK, Agrawal M, Marshall FM (2007) Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicology and Environmental Safety 66: 258-266

Shirasuna H, Fukushima T, Matsushige K, Imai A, Ozaki N (2006) Runoff and loads of nutrients and heavy metals from an urbanized area. Water Science and Technology 53: 203-213

Singh A, Agrawal M, Marshall FM (2010 a) The role of organic vs. inorganic fertilizers in reducing phytoavailability of heavy metals in a wastewater-irrigated area. Ecological Engineering 36: 1733-1740

Singh A, Sharma RK, Agrawal M, Marshall FM (2010 b) Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food and Chemical Toxicology 48: 611-619

Sogayise, M (2003) Contamination of vegetables with heavy metals. Unpublished, Honours thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Solhi M, Shareatmadari H, Hajabbasi MA (2005) Lead and zinc extraction potential of two common crops, *Helianthis annuus* and *Brassica napus*. Water, Air and Soil Pollution 167: 59-71

Song B, Lei M, Chen T, Zheng Y, Xie Y, Li X, Gao D (2009) Assessing the health risk of heavy metals in vegetables to the general population in Beijing, China. Journal of Environmental Sciences 21: 1702-1709

Stirk WA, Van Staden J (2001) Some physical factors affecting adsorption of heavy metals from solution by dried brown seaweed material. South African Journal of Botany 67: 615-619

Sun B, Zhao FJ, Lombi E, McGrath SP (2001) Leaching of heavy metals from contaminated soils using EDTA. Environmental Pollution 113: 111-120

Surdyk N, Cary L, Blagojevic S, Jovanovic Z, Stikic R, Vucelic-Radovic B, Zarkovic B, Sandrei L, Pettenati M, Kloppmann W (2010) Impact of irrigation with treated low quality water on the heavy metal contents of a soil-crop system in Serbia. Agricultural Water Management 98: 451-457

The Constitution of the Republic of South Africa (1996) Act 108, Chapter 2: Bill of rights, Section 24: Environment. One law for one nation

Tijani MN (2009) Contamination of shallow groundwater system and soil-plant transfer of trace metals under amended irrigated fields. Agricultural Water Management 96: 437-444

Vandoolaeghe MAC (1990) The Cape Flats aquifer. Director-General for Water Affairs, Pretoria. Technical report no. Gh3687

Wang J, Wang G, Wanyan H (2007) Treated wastewater irrigation effect on soil, crop and environment: wastewater recycling in the Loess area of China. Journal of Environmental Sciences 19: 1093-1099

Water Research Commision (1997) Permissible utilization and disposal of sewage sludge. WRC, Pretoria

Wei B, Yang L (2010) A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal 94: 99-107

Wright A, Conrad J (1995) The Cape Flats aquifer current status. Council for Scientific Research, Stellenbosch

Wu LH, Luo YM, Xing XR, Christie P (2004) EDTA-enhanced phytoremediation of heavy metal contaminated soil with Indian mustard and associated potential leaching risk. Agriculture, Ecosystems and Environment 102: 307-318

Yeld J (2005) The future rests on a change of season. Cape Argus, 29 June, p. 14

Yusuf AA, Arowolo TA, Bamgbose O (2003) Cadmium, copper and nickel levels in vegetables from industrial and residential areas of Lagos City, Nigeria. Food and Chemical Toxicology 41: 375-378

Zeng Z, Li L, Mei X (2008) Heavy metal content in Chinese vegetable plantation land soils and related source analysis. Agricultural Sciences in China 7: 1115-1126

Zheljazkov VD, Nielsen NE (1996) Effect of heavy metal on peppermint and cornmint. Plant and Soil 178: 59-66

Zhu YG, Chen SB, Yang JC (2004) Effects of soil amendments on lead uptake by two vegetable crops from lead-contaminated soil from Anhui, China. Environmental International 30: 351-356

CHAPTER 2

A SURVEY OF HEAVY METAL CONTENT IN WATER, SOIL AND VEGETABLES PRODUCED IN THE AGRICULTURAL AREAS OF PHILIPPI, KRAAIFONTEIN AND JOOSTENBERGVLAKTE AND POSSIBLE SOURCES OF HEAVY METALS

2.1. Introduction

The Philippi, Joostenbergvlakte and Kraaifontein agricultural areas in the Western Cape supply local and national markets with vegetables and as such it is important that quality vegetable produce is ensured through compliance with regulatory standards. The demand for vegetables from these two Cape Town agricultural areas is also increased as stress is experienced in agricultural areas elsewhere in South Africa. Decreased production of potatoes in the Sandveld area of the Western Cape for example, due to increased infection with plant viruses and water shortages led to a greater demand for potatoes from the local Cape Town vegetable farmers in Philippi and the Joostenbergvlakte/Kraaifontein area during 2005, while heavy metal pollution of crops in the Wonderfonteinspruit area in Gauteng placed Cape Town farmers on alert in terms of supplying crops to markets beyond Cape Town in 2007 (Bonthuys, 2005; Tempelhoff, 2007).

In the Wonderfonteinspruit area, heavy metals and radioactive elements leaching from goldmine sludge dams posed a threat to agricultural areas and though cabbage sampled in the area did not contain radioactive elements, it did contain elevated levels of iron (136 mg/kg), manganese (59 mg/kg), vanadium (98 mg/kg) and zinc (112 mg/kg), which exceeded limits set for these element in vegetables, emphasizing how vulnerable agricultural lands are to surrounding mining and industrial areas (Tempelhoff, 2007). Locally, the Philippi farming area and Joostenbergvlakte/Kraaifontein farming areas are threatened by urban expansion of both residential and industrial nature and thus careful monitoring of the health of these agricultural areas is needed (Cao *et al.*, 2010; Hao *et al.*, 2009; Map Studio, 2007; Rule *et al.*, 2005). Research done during the past ten years in both the agricultural areas of Philippi, Kraaifontein and the Joostenbergvlakte revealed that the concentrations of heavy metals, cadmium, copper, lead and zinc in respectively, soil, water and vegetables exceeded on occasion the limits set by South African regulations and guidelines (Meerkotter, 2003; Sogayise, 2003).

It is useful to note that in relation to guidelines set in other countries, South African guidelines are very stringent and though some agricultural resources may exceed South African guidelines they may still be considered fit for agricultural use and human consumption (Commissie van de Europese Gemeenschappen, 2001; Commission of the European Community, 2006; Murphy, 1997). Nonetheless, this research aimed at verifying again the status of heavy metal contamination in water, soil and vegetables produced in these areas and to find possible sources of heavy metal inputs to these areas. This study focused specifically on the amounts of cadmium, copper, lead and zinc, which were found to be problematic elements in various kinds of samples from these farmland systems during surveys conducted between 2000 and 2003 (Meerkotter, 2003; Sogayise, 2003). Guidelines most relevant to the time of sampling were used to evaluate samples against and are mentioned in the Materials and Methods section of this chapter.

Irrigation water resources, cropped soils, and soils prepared for cropping as well as the edible portions of crops were to be tested for heavy metals during this part of the research. It was hypothesised that the status of heavy metal contamination of irrigation water resources, soil and vegetables would be the same or only marginally greater than measured in previous years' tests. The reason for this hypothesis was that not much time had passed since previous surveys, the maximum time gap being five years (Meerkotter, 2003; Sogayise, 2003). Times of summer drought may have shown increased concentrations of heavy metals in soils, crops and water but these situations could easily have be altered as winter rains could have played a role in diluting heavy metal contents of soils. Balance may thus have been maintained in terms of heavy metal concentrations in these agricultural systems as seasonal rainfalls fluctuated. This may have been achieved as rainfall may have lead to the leaching of heavy metals to deeper soil layers thus possibly resulting in lower heavy metal concentrations in crops harvested in the winter rainfall season compared to crops harvested in the previous summer season (Li *et al.*, 2008; Miller, 1996; Summerfield, 1994).

The two farming areas are not located in close proximity to each other, their virtual centres being about 25 km apart (Map Studio, 2007; Figure 2.1). The two areas differ slightly in lithology making direct comparisons somewhat difficult, however, similar patterns may be expected, though for different physical reasons. Since these two farming areas, though separate in many ways, are major suppliers of vegetables to communities in specifically Cape Town and they were expected to bear more similarities than differences to one another, compared to vegetable farming communities elsewhere in South Africa. These farming areas are often spoken of as 'one' representing Cape Town's vegetable produce as a whole (Personal communication with farmers, 2007).

Philippi's soils are sandy and rich in silica which leads to easy leaching of nutrients to deeper soil layers beyond the roots of crops and subsurface water resources. The accompanying high water table in the Philippi area can however in turn lead to the cycling of heavy metals from deeper soil layers back to surface soils and also into irrigation water resources (Brown, 1996; Chittenden Nicks Partnership, 1997; Rice and Rice, 1997). The application of fertilizers, crop sprays etc which may be loaded with contaminants such as heavy metals can thus be diluted and flushed away from the top soil layers, from where crops will extract it, through irrigation, rain or the rising and lowering water table. The sandy soils of the Philippi area give relief in that contaminants can easily be leached away from crop roots, however; the presence of a high water table in this area is a concern as underground water resources can easily be polluted since the soil has a low attenuation capacity (Brown, 1996; Eigenhuis, 1997; Rice and Rice, 1997).

Soils from the Joostenbergvlakte and Kraaifontein area is slightly different in that they are sandy, but deeper layers are rich in clay which in winter often leads to much water logging (Brown, 1996; Cole and Roberts, 1996; Rice and Rice, 1997). In the Joostenbergvlakte/ Kraaifontein area, nutrients and contaminants such as heavy metals may be leached from surface waters to soils and *vice versa* but, contaminants may remain in top soil layers longer since it can not easily be leached past deeper clay rich soil layers (Brown, 1996; Eigenhuis, 1997; Rice and Rice, 1997). Due to the fact that the Joostenbergvlakte is topographically slightly lower than the Kraaifontein area and has deeper sandy soils, it is slightly more comparable to the Philippi area in terms of lithology (Personal communication with consultants from Agri Mark, Durbanville and Kraaifontein, 2011). Based on lithology and the possible cycling of elements through the agricultural system during different seasons of the year, it seems that Philippi's groundwater is a target for accumulation of heavy metal and other contaminants, while in the Kraaifontein area, the groundwater resources seem to be protected by clay layers leaving the topsoil a target for accumulation of heavy metal and other contaminants. The mere presence of contaminants in soils do not necessarily imply that crops will be contaminated.

Though contaminants may be present in topsoil layers they will not necessarily be available to plants. In winter, for example, water logging and/or flooding, as seen in both study areas, often leads to damage of crop roots to the extent that crops will not readily take up nutrients and contaminants from the soil, though they may be present in high concentrations. In both areas, in summer, though concentrations of nutrients and contaminants may be high in soils, the absence of rain and thus often lower soil water content can prevent crop roots from readily taking up nutrients and contaminants and much irrigation is needed to keep soil moisture at levels enabling crops to take up nutrients effectively. (Brown, 1996; Eigenhuis, 1997; Li *et al.*, 2008; Rice and Rice, 1997).

In the two farming areas concerned, sprinkler irrigation is most often used during summer while especially in the Philippi area, during the rainy winter season, little sprinkler irrigation is needed as land is often waterlogged due to a high water table. In these two areas the flow of water is often regulated where run-off from land is collected in canals and in the case of winter drained away or, as in the case of dry summers, recycled. In the Philippi area, where farmers often face a lack of water in summers due to water leaching speedily into the deeper levels of very sandy soils, many farmers have lined their irrigation water holding dams with water impermeable layers and have even done so under some cropped fields so that water may not be lost to readily during dry summer months (Kane, 2002; Kinchen and King, 2003; Personal communication with farmers, 2007; Rice and Rice, 1997; Summerfield, 1994).

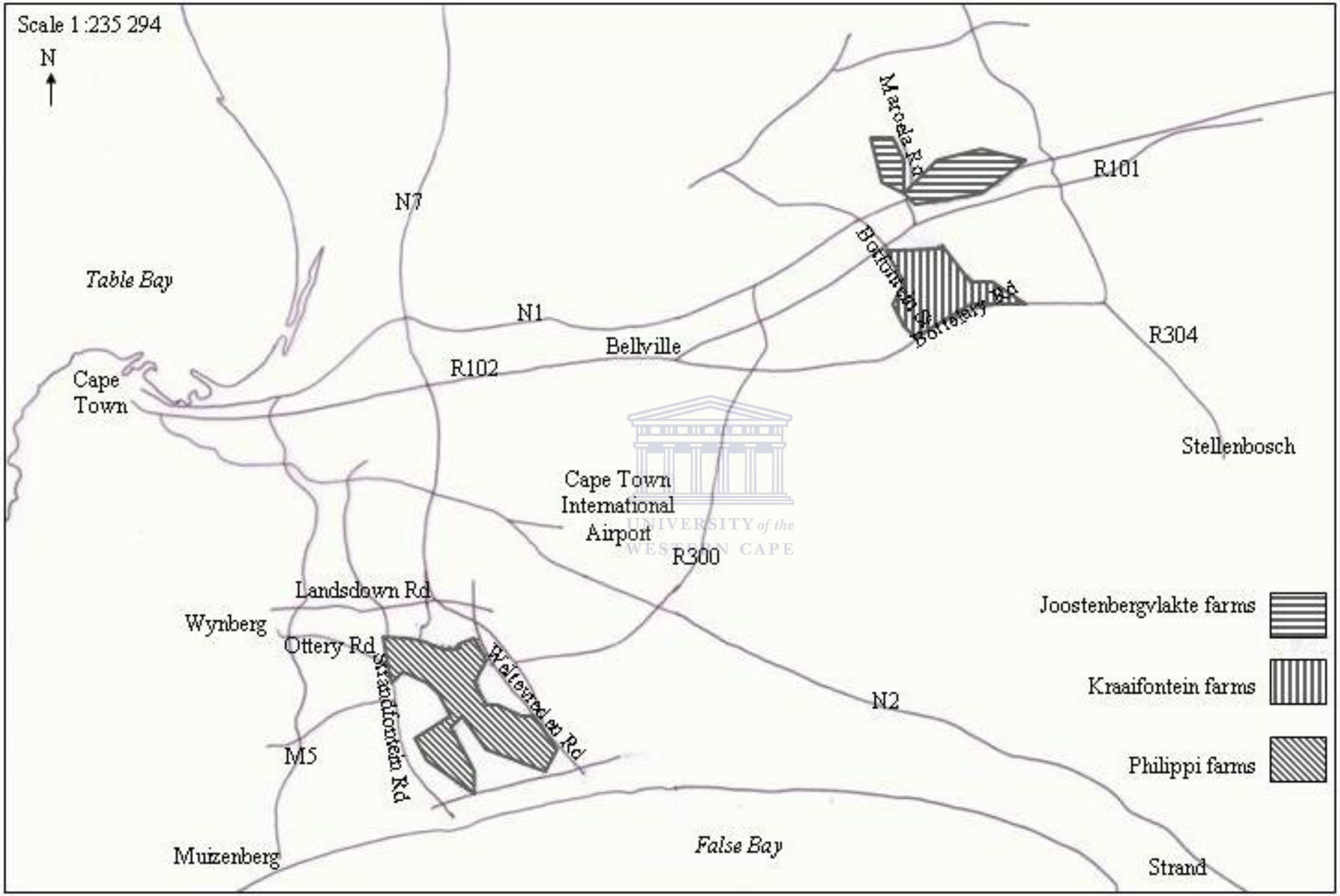


Figure 2.1: Location of the Joostenbergvlakte, Kraaifontein and Philippi farming areas (Adapted from Map Studio 2007)

Though lining of dams and soils is beneficial in summer, this kind of intervention holds a possible problem as pollutants may become more concentrated in cropped soils and irrigation water holding dams lined with impermeable layers to keep water from leaching to deeper soil levels. Such interventions of this kind could see waters not necessarily being diluted in terms of heavy metals during rainy seasons, but rather becoming more contaminated with rain not diluting as much as needed (Kane, 2002; Kinchen and King, 2003).

Research done in Philippi, during 2000, showed seasonal variations in heavy metal concentrations in soils and in water resources but not in vegetables (Meerkotter, 2003). Seasonality could however play a role in keeping heavy metal concentrations though fluctuating still balanced in the agricultural system. In dry summer seasons, heavy metal accumulation in soils is a greater likelihood in the face of continued addition of fertilizers compared to the accumulation of heavy metals in soils during the rainy winter seasons, when heavy metals may be leached to deeper soil layers through percolation and top soil thus become slightly diluted in terms of heavy metals. Though one would expect a greater accumulation of heavy metals in vegetables in the dry summer seasons, this does not happen, as balance is maintained in that low soil water content during dry summers renders much of the heavy metals unavailable to crop roots and prevents excessive uptake of heavy metals from the soil despite continued addition of fertilizers (Li *et al.*, 2008; Marschner, 1995; Rice and Rice, 1997).

Where winter rains may dilute the concentrations of heavy metals, the simultaneous addition of fertilizers can cause negation of this natural form of dilution. In a system where natural dilution is negated and dry summers coincide with further application of fertilizers, the problem of heavy metal contamination is only expected to increase and as little addition of fertilizers, pesticides and fungicides as possible is recommended (Kane, 2002; Webber and Singh, 2003).

Whilst addition of fertilizers may lead to increased heavy metal concentrations in soils, crops and irrigation water resources, the concentration of heavy metals may overall remain fairly constant in agricultural soils as crops may extract significant amounts of heavy metals from these soils each growing season leaving soils relatively depleted of heavy metals, a principle used in bioremediation. Cabbage produced in the extremely contaminated Wonderfonteinspruit area accumulated heavy metals and spinach accumulated even more heavy metals. A study in Aznalcóllar in Spain showed that *Brassica juncea* was able to extract copper, lead and zinc from heavy metal contaminated soils, though not as successfully as other crops often used in bioremediation (Clemente *et al*, 2005; Kothe *et al.*, 2005; Li *et al.*, 2010; Tempelhoff, 2007; Wang *et al.*, 2006). While the concentration of heavy metals in agricultural soils may be lowered through harvesting, this is most likely negated by speedy addition of fertilizers for the planting of new crops. Though planting and harvesting of crops could potentially keep the amount of heavy metals fairly constant in agricultural soils, the total removal of heavy metals in such a way may take years, if ever accomplished, as often seen in bioremediation trials. Beets, mustard and sunflowers have been used in bioremediation trials such as these, but problematic is the fact that heavy metals accumulate in the roots and thus often remain in soils post harvesting (Clemente *et al*, 2005; Kothe *et al.*, 2005; Marschner, 1995). Total removal of heavy metals or decrease in its present levels in agricultural soils is however highly unlikely as continued input of fertilizers and the use of agrochemicals is the *status quo*.

This study glanced over the concentrations of cadmium, copper, lead and zinc in fertilizers, manures and crop sprays (which is often a mixture of various agrochemicals) used on the selected farms. It was expected that manures would contain significant amounts of certain heavy metals, which may explain the elevated levels thereof seen in soils and vegetables. Manures have been shown by various researchers to contribute significant amounts of cadmium, lead, and more specifically zinc to agricultural soils and therefore possibly the concentrations of these in vegetables as well as related water resources (Kane, 2002; Webber and Singh, 2003). It was hypothesized that significant levels of cadmium and lead were to be measured in various fertilizer samples and that significant levels of zinc were to be measured in poultry manure. It was also hypothesized that significant copper concentrations were to be measured in crop sprays often containing a mixture of fungicides, insecticides, herbicides and nutrients, since copper has historically been used in various pesticides.

While the addition of fertilizers and use of crop sprays that contain elevated levels of problematic heavy metals can be controlled, there are several factors that are almost out of a farmer's control in terms of preventing pollution on his lands. As stated in chapter one, heavy metals can enter agricultural fields in various ways and finding point sources of pollution into these agricultural areas is fairly difficult. Those sources that can be identified as problematic should best be monitored in terms of its influx to the agricultural field and eliminated or be reduced in terms of its use as far as possible. Water flowing into an agricultural area is an example of a source of possible pollutants, not necessarily under the control of the farmer while pesticides, fungicides and various fertilizers could be sources of pollutants and their use is more directly under the control of the farmer (Kane, 2002, Khan *et al.*, 2008). It is important to note that a deduction about the safety of a soil amendment such as a fertiliser or manure can not simply be made based on its heavy metal content since, for example, the presence of high zinc concentrations in a fertilizer, may inhibit a crop from taking up excessive amounts of cadmium which may be present in the same fertiliser or soil, since these metals are similar and not distinguished among by certain crop's roots (Kirkham, 2006; Marschner, 1995).

In terms of fertilizers such as sewage sludge and manures, several researchers evaluating the contaminant limits of South Africa against those used in other countries, commented that the limits set in South Africa for several heavy metals and other contaminants in sludge and manures used in agricultural were unnecessarily restrictive. Based on several studies, they found that the application of sludge and manures to agricultural land, at agronomic rates, should not significantly contaminate associated groundwater or surface water resources. Application of sludge and manures are accordingly only a concern in areas with an important and vulnerable aquifer. These researchers however warned that bulk storage of sludge or manures near irrigation water resources are a great source of concern as they are most likely to form point sources of pollution (Murphy, 1997; Webber and Singh, 2003). Relating this again to what is under a farmers' control in terms of preventing pollution, it is obvious that some farming practices in the Philippi and Joostenbergvlakte/Kraaifontein farming areas need to be changed, as heaps of manure are often situated next to irrigation water holding dams and they pose a clear threat as possible point sources of pollution if not covered properly especially during the rainy season (Murphy, 1997, Webber and Singh, 2003). The Philippi area is also situated on the Cape Flats Aquifer and this is an important and vulnerable aquifer in Cape Town, thus use of manures and sludge must be monitored carefully, especially the Philippi area (Bertram, 1989; Chittenden Nicks Partnership, 1997, Eigenhuis, 1997).

The Kraaifontein farmers often use water from the Theewaterskloof dam and the local Scottsdene Waste Water Treatment Plant next to the Botfontein Road along which many Kraaifontein farms lie (Figure 2.1). In Philippi especially in times of drought, some farmers make use of water from storm water canals that flow through industrial areas, residential areas and informal settlements before it reaches the farm lands to supplement irrigation water resources (Cao *et al.*, 2010; Meerkotter, 2003; Map Studio, 2007; Personal communication with farmers, 2007; Qoko, 2003). Pollutants can enter the agricultural land via these additional water resources that are not directly situated on the farms and the amount of contaminants gathered from these resources my further be concentrated as fertilizers, agrochemicals and run-off from nearby roads flow into the agricultural system's soils or irrigation water resources (Owens and Niemeyer, 2005; Rule *et al.*, 2005; Webber and Singh, 2003).

Major roads and Cape Town's International Airport also lie between these two farming areas and thus deposits from air pollution can also contribute to contamination of irrigation water resources and soils (Kane, 2002; Figure 2.1). In this study various water resources, on the farms, that contribute to irrigation waters were tested for heavy metals. Significant amounts of cadmium, copper, lead and zinc were expected to be seen in various water resources, used to supplement irrigation water resources. Following is a discussion of the collection and analysis of the various samples that were collected from the Philippi, Joostenbergvlakte and Kraaifontein farming areas.

2.2. Materials and Methods

The methods for sample collection are reported on in this section while the specific kinds of samples collected are summarised in Table 2.1. Sampling took place in the summer of 2006 and specifically in the month of February. Sampling sites were from the two major vegetable production agricultural areas in Cape Town, namely, the Joostenbergvlakte/Kraaifontein and Philippi agricultural areas (Figure 2.1). The Philippi farming area is situated about 16 km southwest of the Cape Town City Centre. Philippi's farming areas can easily be accessed via Strandfontein Road which forms its eastern border as well as Weltevreden Road which forms its western border. The Joostenbergvlakte/Kraaifontein area is divided into two areas, the Joostenbergvlakte farmlands and the Kraaifontein farmlands. These two areas are divided by the N1 national road. From the Cape Town City Centre, the Joostenbergvlakte lies about 36 km in a north-western direction and north of the N1 national road while the Kraaifontein area is about 34 km northwest of the City Centre and south of the N1 national road. The Joostenbergvlakte can be accessed via Maroela Road which is a main road off the N1 and the Kraaifontein area can more easily be accessed via Van Riebeeck Street, a main road off the N1, which becomes Botfontein Street and ends in a T-junction with Bottelary Road which forms the southern border for the vegetable farming area of Kraaifontein (Map Studio, 2007, Figure 2.1).

In both the Philippi and Joostenbergvlakte/Kraaifontein agricultural farming areas, a total of five farmers agreed to partake in the sample collecting survey. It is important to note that many farmers rent land for cropping, especially in the Philippi farming area and it was observed that the same land may be used for cropping by several different farmers over a relatively short period of time. The number of farmers that participated in the survey is thus not to be used as indicative of statistical relevance but rather the number of samples that could be collected from each area as well as the spread of the collected samples over each farming area as a whole.

Obtaining samples of livestock manures (poultry and cattle manures), irrigation waters (from canals, dams, borehole inlet pipes and sprinkler systems), soils from cropped lands, crop sprays and crops were dependent on each farmers' co-operation and permission to access various parts of their agricultural lands. Sample numbers were not only subject to a farmer's extent of co-operation, but also the availability of a particular sample type upon sampling. In the case of collecting vegetable samples, for example, the number of samples that could be collected of a specific crop species could not be regulated and neither could the same developmental stage between cropped sites of the same species be guaranteed.

Table 2.1: Comparison of samples and the sample quantities collected from the Joostenbergvlakte/Kraaifontein agricultural area and the Philippi agricultural area

Sample Type	Joostenbergvlakte/Kraaifontein area	Philippi area
Water from dams	23	37
Tributaries/canals	3	3
Dam piped water inputs	17	26
Sprinkler water	9	8
Crop spray	3	5
Cattle manure	8	8
Chicken manure	3	10
Soil planted with beetroot	2	0
Soil planted with cabbage	6	8
Soil prepared for cabbage	4	9
Soil planted with carrots	4	8
Soil prepared for carrots	3	5
Soil prepared for cauliflower	0	3
Soil planted with lettuce	1	2
Soil prepared for lettuce	3	5
Methylbrominde treated soil	2	1
Beetroot	2	0
Cabbage	6	8
Carrots	4	8
Lettuce	1	2

Collection of crop sprays was also problematic as sprays were collected from actual crop spray vehicles while in the process of spraying crops. Crop spray vehicles were not present on all farms upon sampling and the labourers were not always able to indicate the content of the sprays they were applying to crops. Borehole water inlet pipes were not always accessible for sampling neither was the collection of water from sprinkler systems always possible.

In the case of collecting soil samples, soils at times already lay bare after harvesting or soils were freshly prepared and fertilized for the next crop planting season, making the collection of soils in the same state difficult. Overall collecting samples that were statistically comparable was problematic. Nonetheless average concentrations of heavy metals could be calculated for the various sample types that gave sufficient representation of the agricultural areas concerned (Cao *et al.*, 2010; Khan *et al.*, 2008; Wang *et al.*, 2006).

The heavy metals that were tested for specifically, but not exclusively, included cadmium, chromium, copper, mercury, lead, nickel and zinc, which have clear regulatory standards and were tested for in previous studies in these two areas (Meerkotter, 2003; Qoko, 2003; Sogayise, 2003). Heavy metal analysis of soils, waters, vegetables, manures, crop sprays and other samples was done by BemLab, an independent research and test laboratory, based in the Strand (Figure 2.1). The collection of samples in this study and its preparation for analysis by BemLab is discussed here below.

Water was collected from irrigation water holding dams, borehole water inlet pipes, sprinkler water systems, canals and tributaries that entered the irrigation water holding dams at several points on several farm lands. The pH of each water sample was determined upon return to the lab. Water was then filtered and concentrated Nitric acid added to reduce the pH of the water to pH 2 as means of preservation. The water was kept at 4 °C until the samples could be taken to BemLab for analysis (Meerkotter, 2003). The total concentrations of elements, in each sample, were measured with a Varian Vista MegaPixel Detecor Inductively Coupled Plasma - Optical Emission Spectrometer (MPX ICP-OES) at BemLab's laboratories.

Soil samples were collected from cropping sites as near as possible if not adjacent to each dam from which water was collected. Each site was represented by one composite soil sample. Each composite soil sample consisted of ten subsamples that were collected randomly across a particular cropped field selected for sampling. The collected soil only consisted of topsoil to the approximate average depth of 15 cm in which crop roots grew. The soil samples were air-dried in a laboratory for approximately three weeks. Once soils were dry, they were sieved in a 2 mm particle size sieve and this soil was then taken to BemLab for chemical analysis (Meerkotter, 2003; Wang *et al.*, 2006).

BemLab's procedures for determining total concentrations of Cd, Cu, Fe, Hg, Mn, Pb, Sn and Zn from each soil sample included its extraction from the soils with a 0.1M hydrochloric acid solution (normally 5.0 g of soil:20 ml of a 0.1M hydrochloric acid) by shaking the mixture in an extraction bottle for 15 min on a reciprocal shaker. Determination of Ca, K, Mg and Na concentrations included the extraction thereof with an ammonium acetate solution (normally 5.0 g of soil extracted with 50 ml ammonium acetate solution) through shaking the solution in an extraction bottle on a reciprocal shaker for 30 min. All extractions were then filtered and the concentration of each sample's Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Pb, Sn, V and Zn, amongst other elements, were determined by a MPX ICP-OES (Personal communication Dr. W.A.G. Kotzé and A. Van Deventer, BemLab, 2006). Soil pH was determined by mixing 20 cm^3 deionized water with 20 g soil (a 1:1 weight/volume ratio) then stirring it occasionally and measuring its pH after one hour (Meerkotter, 2003, Wang *et al.*, 2006).

Crop collection involved collection of available crops on the same site from which soil was collected. A composite sample of a particular crop was collected for each site. Each composite sample was made up of ten subsamples. In the laboratory, the crops were washed with tap water and the edible portions separated for use in further analysis. The composite sample (edible parts only) for each site was oven-dried at 80 °C for four days, ground and then sent for analysis at BemLab. At BemLab, standard procedure was followed which would normally be 1.00 g of each sample placed in a crucible and muffle furnace for eight hours at 480° C. After ashing in the muffle furnace the crucibles were allowed to cool and be wet with deionised water followed by addition of 5 ml of hydrochloric acid which was then warmed to cause total dissolution of the material. The residue was transferred to a volumetric flask and made up to 50 ml with distilled water. The solutions were then submitted to the MPX ICP-OES for measurement of total Ca, Cd, Cr, Cu, Hg, K, Mg, Mn, Na, Ni, Pb, Sn, V, Zn and other elements. In the case of measuring Cd and Pb, a 10 – 20% loss of the element was estimated using this procedure (Personal communication with Dr. W.A.G. Kotzé, BemLab, 2006).

A list of the most commonly used agrochemicals was compiled as access to chemical storage facilities on farms was allowed. One farmer kindly gave access to the official agrochemical product description documents of several commonly used agrochemicals in the studied areas. The amount of heavy metals in each agrochemical was gleaned from the product description documents and is summarized in Table 2.8 in the Results section of this chapter.

Guidelines for maximum permissible heavy metal concentrations in various agricultural resources were obtained from the following documents and are used in the results tables of this chapter: Guidelines for irrigation water resources: Department of Water Affairs and

Forestry (1996) South African Water Quality Guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation. DWAF, Pretoria.

Guidelines for agricultural soils: Water Research Commission (1997) Permissible Utilisation and Disposal of Sewage Sludge. 1st Edition. WRC, Pretoria.

Guidelines for vegetable crops: Department of Health (2004) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 26279,

Department of Health (2003) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 25015 and

Commission of the European Communities (2006) Setting maximum levels for certain contaminants in foodstuffs: Commission regulation 1881.

Guidelines for sludge used agriculturally: Water Research Commission (1997) Permissible Utilisation and Disposal of Sewage Sludge. 1st Edition. WRC, Pretoria.

Statistical processing of the data gathered in the lab about the collected samples was done by Mr. F. Calitz from the Biometry Unit of the Agricultural Research Counsel, Infruitec, Stellenbosch. The most useful statistical information was found to be in the simple statistics (means, standard deviations, minimums and maximums) which was supported by T-tests that showed significant differences and is reported on in Table 2.12 in the Results section of this chapter. Pearson Correlations were also done but these were not as useful and are reported on in Table 2.13 in the Results section.

2.3. Results

The results for this research are indicated in several tables at the end of this section of this chapter. In the results tables the Philippi area will be abbreviated as 'Plp' while the Joostenbergvlakte/Kraaifontein area will be abbreviated as 'J/K'. Table 2.2 and Table 2.3 display the main results that were found for various surface irrigation water resources. Tables 2.4, 2.5 and 2.6 display the main results for the various cropped soils in the studied areas. Fertilizers', manures' and crop sprays' heavy metal concentrations are indicated in Tables 2.7. Table 2.8 indicate the heavy metal contents of several agrochemicals used in the studied areas and Tables 2.9, 2.10 and 2.11 summarize the concentrations of heavy metals in cabbage, carrots and lettuce. T-tests were performed on all data and those reflecting significant differences are indicated in Table 2.12. The most useful Pearson Correlations are reported on in Table 2.13. A brief summary of each table's apparent main trends is given in this section and discussed in details in the Discussion section which follows hereafter. Reference is made mainly to Cd, Cr, Cu, Hg, Pd, Ni and Zn concentrations in collected samples, as these have clear regulatory guidelines in South Africa and in the European Community. Though other heavy metals were tested for (Co, Fe, Mn, Mo, Sn and V), they were found either in such low quantities that it was not deemed necessary to indicate them in the results or their maximum permissible concentrations were not indicated in South African regulations nor in European regulations.

With regards to samples collected from irrigation water holding dams, a comparable number of samples were collected from each farming area and were in numbers also comparable to samples collected in 2000 from the Philippi farming area. It was expected for both study areas that significant amounts of Cd, Cu, Pb and Zn would be seen in various surface irrigation water resources based on previous research in these areas as mentioned in the

Introduction and these metals are specifically reported on here. Considering the averages and standard deviations in Table 2.2 it would seem that the concentrations of most heavy metals, in irrigation water from holding dams, were not obviously different between the Joostenbergvlakte/Kraaifontein areas and the Philippi area during 2006. Still only referring to averages and standard deviations, comparing the concentrations of heavy metals measured in Philippi in 2000 to those measured in Philippi in 2006, it would appear that almost all heavy metal concentrations (except for Fe) were slightly lower in irrigation water from holding dams in 2006, the significance of these differences were however not confirmed by further statistical tests. Though in Philippi in 2000 differences were seen between samples collected in winter compared to those collected in summer, they were not significantly different except for total Cu. Neither in 2006 nor in 2000 did any of the above mentioned heavy metals exceed permissible total concentrations set therefore in agricultural irrigation waters according to South African guidelines.

Various water inputs to irrigation water holding dams were measured and are indicated in Table 2.3. Comparisons between the various water inputs showed that none of the heavy metals exceeded the maximum set for agricultural irrigation water by South African regulations. Looking only at averages and standard deviations it would seem that in the case of Cd, no concentration differences between the different types of supplementary water resources and water issuing from sprinkler systems during irrigation occurred. It was interesting to note that piped water inputs, except for Cr and Pb concentrations, did not seem to differ between the two main study areas though they may have had very different origins. In the case of Cd, Co, Cr, Fe and Ni there seemed to be differences between sprinkler water from Philippi compared to sprinkler water from the Kraaifontein area but this could not be confirmed by further statistical analysis (Table 2.12). From the results it could not be stated conclusively whether tributaries and or canals or piped inlet waters were the greater in terms of total heavy metal content overall.

Table 2.2: Mean heavy metal concentrations in samples collected from irrigation water holding dams measured in mg.l^{-1}, from the farming areas of Joostenbergvlakte, Kraaifontein (J/K) and Philippi (Plp)

Heavy Metal	Plp 2000 Summer (n=35)	Plp 2000 Winter (n=46)	Plp 2006 Sumer (n=37)	J/K 2006 Summer (n=27)	SA's Maximum Permissible Concentration
Cd	**0.010**	**0.020**	**0.001**	**0.000**	**0.050**
Std dev	0.007	0.006	0.001	0.000	
Maximum	0.050	0.060	0.006	0.001	
Cr	**0.050**	**0.040**	**0.001**	**0.002**	**1.000**
Std dev	0.011	0.010	0.004	0.002	
Maximum	0.230	0.150	0.020	0.008	
Cu	**0.010**	**0.020**	**0.004**	**0.005**	**5.000**
Std dev	0.009	0.000	0.002	0.005	
Maximum	0.300	0.070	0.009	0.020	
Fe	**0.240**	**0.250**	**0.196**	**0.103**	**20.000**
Std dev	0.107	0.051	0.220	0.093	
Maximum	0.680	0.870	1.240	0.361	
Mn	**0.030**	**0.030**	**0.013**	**0.089**	**10.000**
Std dev	0.009	0.010	0.013	0.148	
Maximum	0.070	0.140	0.052	0.662	
Ni	**0.020**	**0.020**	**0.003**	**0.007**	**2.000**
Std dev	0.005	0.000	0.005	0.004	
Maximum	0.050	0.050	0.024	0.013	
Pb	**0.140**	**0.170**	**0.007**	**0.004**	**2.000**
Std dev	0.018	0.077	0.007	0.006	
Maximum	0.050	2.220	0.021	0.024	
Zn	**0.050**	**0.040**	**0.006**	**0.007**	**5.000**
Std dev	0.009	0.012	0.004	0.004	
Maximum	0.080	0.260	0.020	0.019	

The results gathered for soils are summarized in Tables 2.4, 2.5 and 2.6 and they indicate the concentrations of heavy metals in soils planted with specifically cabbage, carrots and lettuce, which are main crops in these farming areas. It is interesting to note that the results in general did not support the hypothesis, which expected greater heavy metal concentrations than seen before. Using the averages and standard deviations only, soils were in general not necessarily more contaminated than previously measured but rather appeared to be marginally less contaminated than measured in previous studies. Where the measured concentrations were lower they were however not significantly less than those measured in previous years (Table 2.5).

Table 2.4, 2.5 and 2.6 also indicate the average concentration of heavy metals in soils prior to planting of specifically cabbage, carrots and lettuce and it was noted that there was not a difference between the concentrations of heavy metals in the soils before planting and well into the growing season. In 2000, some seasonal variations in soil heavy metal concentrations were observed for selected heavy metals and this may also apply today. In Philippi in 2000, in soils planted with cabbage, a seasonal variation in Cu and Zn concentrations seemed evident (Table 2.4), in soils planted with carrots, Zn showed seasonal variation (Table 2.5) and in soils planted with lettuce Cr, Cu and Pb varied between the winter and summer season (Table 2.6). Considering averages and standard deviations only Tables 2.4, 2.5, 2.6 and 2.12 seemed to indicate that Philippi's soils had greater concentrations of Cd, Co, Cr, Ni, Pb and Zn during 2006 compared to the soils of the Joostenbergvlakte/Kraaifontein area, this could however not be verified by further statistical analysis.

With regard to the maximum permissible concentrations of heavy metals set for South African agricultural soils, in Philippi, Cu, Pb and Zn concentrations exceeded the limits set for soils planted with cabbage and carrots, while Cu and Zn was too high in soils planted with lettuce. In general soils from the Joostenbergvlakte/Kraaifontein area were below maximum limits set for heavy metals in South African soils. In the case of both areas, none of the soils exceeded limits set by the European Community as their limits are much more lenient than South African limits (Murphy, 1997).

Table 2.3: Mean heavy metal concentrations in supplementary water sesources measured in mg.l^{-1}, for samples collected in the summer of 2006 in the farming areas of Joostenbergvlakte, Kraaifontein (J/K) and Philippi (Plp)

Heavy Metal	Plp tributries & canals (n=3)	J/K tributries & canals (n=3)	Plp piped water inputs (n=26)	J/K piped water inputs (n=11)	Plp sprinkler water (n=8)	J/K sprinkler water (n=9)	SA's Maximum permissible concentration
Cd	**0.0002**	**0.0006**	**0.0007**	**0.0001**	**0.0007**	**0.0003**	**0.050**
Std dev	0.0002	0.0008	0.0005	0.0003	0.0004	0.0005	
Maximum	0.0003	0.0015	0.0022	0.0009	0.0014	0.0015	
Cr	**0.0000**	**0.0028**	**0.0005**	**0.0023**	**0.0001**	**0.0013**	**1.000**
Std dev	0.0000	0.0011	0.0008	0.0015	0.0003	0.0012	
Maximum	0.0000	0.0035	0.0029	0.0063	0.0008	0.0028	
Cu	**0.0106**	**0.0033**	**0.0039**	**0.0064**	**0.0039**	**0.0037**	**5.000**
Std dev	0.0044	0.0017	0.0033	0.0063	0.0032	0.0021	
Maximum	0.0155	0.0051	0.0117	0.0177	0.0091	0.0081	
Fe	**0.0507**	**0.1239**	**2.0791**	**1.0069**	**0.1330**	**0.0480**	**20.000**
Std dev	0.0162	0.0844	8.1320	2.8200	0.0295	0.0264	
Maximum	0.0672	0.2108	41.4979	9.5056	0.1754	0.0973	
Mn	**0.0038**	**0.0484**	**0.0311**	**0.1721**	**0.0153**	**0.0328**	**10.000**
Std dev	0.0018	0.0374	0.0275	0.3043	0.0116	0.0585	
Maximum	0.0048	0.0915	0.0897	1.0027	0.0308	0.1842	
Ni	**0.0067**	**0.0059**	**0.0040**	**0.0064**	**0.0025**	**0.0077**	**2.000**
Std dev	0.0038	0.0039	0.0041	0.0038	0.0021	0.0059	
Maximum	0.0102	0.0103	0.0143	0.0126	0.0063	0.0190	
Pb	**0.0171**	**0.0033**	**0.0068**	**0.0050**	**0.0029**	**0.0016**	**2.000**
Std dev	0.0067	0.0040	0.0095	0.0076	0.0066	0.0026	
Maximum	0.0243	0.0078	0.0319	0.0234	0.0188	0.0070	
Zn	**0.0072**	**0.0157**	**0.0066**	**0.0121**	**0.0577**	**0.0220**	**5.000**
Std dev	0.0041	0.0190	0.0052	0.0072	0.1258	0.0288	
Maximum	0.0118	0.0375	0.0215	0.0237	0.3685	0.0817	

Table 2.4: Mean heavy metal concentrations in mg.kg^{-1} for soils planted with cabbage, from Joostenbergvlakte/Kraaifontein and Philippi farms

Heavy Metals	**Summer 2000 Philippi (n = 4)**	**Winter 2000 Philippi (n = 11)**	**Summer 2006**				**SA's Maximum Permissible Soil Concentrations (mg.kg^{-1})**	**EC's Maximum Permissible Soil Concentrations (mg.kg^{-1})**
			Plp planted soils (n = 8)	**Plp unplanted soil (n = 9)**	**J/K planted soils (n = 7)**	**J/K unplanted soils (n = 4)**		
Cd	**0.57**	**0.71**	**0.41**	**0.42**	**0.25**	**0.43**	**2.00**	**1.00 - 3.00**
std dev	0.68	0.43	0.13	0.15	0.14	0.23		
Maximum	1.57	1.59	0.68	0.67	0.39	0.66		
Cr	**51.69**	**19.30**	**9.56**	**9.39**	**1.80**	**2.25**	**80.00**	**100.00 (Belgium)**
std dev	52.94	29.86	5.41	6.10	0.78	1.67		
Maximum	130.00	107.70	19.88	18.41	2.92	4.63		
Cu	**37.34**	**7.85**	**11.97**	**11.46**	**6.85**	**4.67**	**6.60**	**.**
std dev	24.84	3.69	5.09	6.18	2.59	3.44		
Maximum	72.95	13.74	21.51	22.48	11.97	9.21		
Hg	**.**	**.**	**0.04**	**0.01**	**0.01**	**0.01**	**0.50**	**1.00 - 1.50**
std dev	.	.	0.04	0.02	0.01	0.01		
Maximum	.	.	0.13	0.04	0.03	0.03		
Ni	**3.60**	**2.94**	**1.77**	**2.09**	**0.97**	**1.26**	**50.00**	**30.00 - 75.00**
std dev	4.37	2.04	0.68	0.97	0.39	0.60		
Maximum	9.91	5.89	3.16	3.49	1.57	2.10		
Pb	**29.84**	**18.20**	**7.58**	**7.06**	**1.49**	**1.57**	**6.60**	**50.00 - 300.00**
std dev	22.29	9.62	5.08	5.26	0.71	1.11		
Maximum	60.79	38.47	16.57	14.61	2.46	2.41		
Zn	**148.15**	**36.90**	**64.59**	**62.49**	**42.74**	**32.81**	**46.50**	**150.00 - 300.00**
std dev	138.81	22.61	22.00	27.14	14.58	24.30		
Maximum	352.29	87.03	103.24	106.59	67.16	67.91		

Table 2.5: Mean heavy metal concentrations in mg.kg^{-1} for soils planted with carrots, from Joostenbergvlakte/Kraaifontein and Philippi farms

Heavy Metals	Summer 2000 Philippi (n = 10)	Winter 2000 Philippi (n = 22)	Summer 2006				SA's Maximum Permissible Soil Concentrations (mg.kg^{-1})	EC's Maximum Permissible Soil Concentrations (mg.kg^{-1})
			Plp planted soils (n = 8)	Plp unplanted soil (n = 5)	J/K planted soils (n = 4)	J/K unplanted soils (n = 3)		
Cd	**0.59**	**0.93**	**0.47**	**0.48**	**0.20**	**0.26**	**2.00**	**1.00 - 3.00**
std dev	0.51	0.53	0.16	0.21	0.12	0.11		
Maximum	1.77	1.63	0.72	0.82	0.36	0.37		
Cr	**36.04**	**18.51**	**6.88**	**6.69**	**1.76**	**1.15**	**80.00**	**100.00 (Belgium)**
std dev	17.76	12.28	3.12	3.40	1.11	0.73		
Maximum	62.48	47.51	13.42	12.13	2.86	1.68		
Cu	**25.02**	**13.42**	**8.69**	**12.31**	**4.94**	**2.33**	**6.60**	**.**
std dev	10.92	9.50	4.40	5.23	2.62	2.15		
Maximum	45.21	36.28	16.31	19.86	7.87	4.77		
Hg	**.**	**.**	**0.02**	**0.02**	**0.01**	**0.01**	**0.50**	**1.00 - 1.50**
std dev	.	.	0.02	0.02	0.01	0.01		
Maximum	.	.	0.04	0.04	0.03	0.01		
Ni	**2.70**	**3.58**	**1.94**	**1.95**	**1.12**	**0.48**	**50.00**	**30.00 - 75.00**
std dev	2.86	2.39	0.94	0.91	0.75	0.45		
Maximum	7.30	6.91	3.36	3.48	1.76	0.88		
Pb	**27.72**	**22.84**	**4.93**	**6.26**	**1.58**	**1.40**	**6.60**	**50.00 - 300.00**
std dev	6.23	8.48	2.79	4.14	0.64	0.86		
Maximum	60.04	35.31	8.87	10.68	2.53	2.15		
Zn	**113.10**	**52.24**	**47.53**	**69.60**	**25.55**	**12.57**	**46.50**	**150.00 - 300.00**
std dev	61.15	36.74	19.91	33.45	10.63	4.09		
Maximum	246.53	137.51	76.00	121.00	41.08	16.92		

Table 2.6: Mean heavy metal concentrations in mg.kg^{-1} for soils planted with lettuce, from the Joostenbergvlakte/Kraaifontein and Philippi farms

Heavy Metal	Summer 2000 Philippi (n = 6)	Winter 2000 Philippi (n = 3)	Summer 2006				SA's Maximum Permissible Soil Concentrations (mg.kg^{-1})	EC's Maximum Permissible Soil Concentrations (mg.kg^{-1})
			Plp planted soils (n = 2)	Plp unplanted soil (n = 5)	J/K planted soils (n = 1)	J/K unplanted soils (n = 3)		
Cd	**0.31**	**0.31**	**0.39**	**0.41**	**0.15**	**0.23**	**2.00**	**1.00 - 3.00**
std dev	0.21	0.17	0.15	0.18	.	0.23		
Maximum	0.53	0.49	.	0.68	.	0.48		
Cr	**31.92**	**3.23**	**4.06**	**6.63**	**1.56**	**0.98**	**80.00**	**100.00 (Belgium)**
std dev	10.16	1.56	0.84	4.56	.	0.15		
Maximum	43.51	4.65	.	13.59	.	1.11		
Cu	**19.84**	**4.52**	**5.23**	**8.81**	**3.11**	**3.65**	**6.60**	**.**
std dev	10.45	1.31	0.65	7.44	.	1.10		
Maximum	32.11	5.69	.	17.74	.	4.78		
Hg	**.**	**0.04**	**0.05**	**0.01**	**0.01**	**0.06**	**0.50**	**1.00 - 1.50**
std dev	.	0.04	0.04	0.01	.	0.01		
Maximum	.	0.08	.	0.02	.	0.01		
Ni	**3.07**	**1.17**	**1.32**	**1.57**	**0.89**	**1.31**	**50.00**	**30.00 - 75.00**
std dev	1.18	0.37	0.38	0.87	.	0.23		
Maximum	4.56	1.59	.	2.66	.	1.54		
Pb	**16.93**	**1.47**	**1.44**	**5.05**	**1.54**	**1.76**	**6.60**	**50.00 - 300.00**
std dev	10.26	0.64	0.90	4.04	.	1.82		
Maximum	27.45	2.08	.	10.70	.	3.64		
Zn	**78.39**	**29.14**	**34.42**	**54.96**	**18.58**	**27.95**	**46.50**	**150.00 - 300.00**
std dev	31.14	9.84	5.15	39.33	.	6.72		
Maximum	108.88	38.06	.	100.03	.	35.25		

Table 2.7 summarizes the concentrations of heavy metals in all agricultural soil samples, manures and crop sprays from both the Philippi and Joostenbergvlakte/Kraaifontein farming areas to represent Cape Town's agricultural areas as a whole. The mean concentrations of Cd and Pb in a phosphate fertilizer were found to be relatively high compared to the permissible concentration of these allowed in soils, but it was far below that permissible for sludge that can be applied to agricultural land. The levels of Cd and Pb measured in cattle manure was greater than that measured in chicken manure, the specific significance of this difference could however not be verified by further statistical analysis (Table 2.7). It was expected that Zn concentrations would be great in poultry manures and indeed it was found to be very rich therein compared to maximum limits set for dry sludge used in agriculture. Cattle manure also contained very high concentrations of Zn which exceeded limits set for Zn concentrations in dry sludge applied agriculturally (Dach and Starmans, 2005). Phosphate fertilizer in comparison to chicken manure and cattle manure contained more Hg even though it was not as great a source of any of the heavy metals concerned in relation to regulatory guidelines (Table 2.7). In comparison to maximum limits set for sludge used in agriculture, cattle manure and chicken manure exceeded the limits set for Cu. Cattle and chicken manure are thus sure sources of Cu and Zn to the studied agricultural areas' soils.

It was expected that significant Cu concentrations were to be measured in crop sprays since they often contain a mixture of fungicides, insecticides, herbicides and nutrients. Table 2.7 however shows that crop sprays contained very little heavy metals compared to other agricultural chemical additives such as manures and fertilizers (Table 2.8). Several farmers apply lime to their soils and samples taken on farms in the Joostenbergvlakte area showed lime to contain relatively high concentrations of Cu, Hg and Pb compared to other additives summarized in Table 2.7.

Table 2.7: Mean heavy metal concentrations in mg.kg^{-1} in crop sprayes, manures and soils from Joostenbergvlakte/Kraaifontein and Philippi farms

Heavy Metal	Crop Sprayes (n = 9)	Chicken Manure (n = 16)	Cattle Manure (n = 20)	Phosphate Fertilizer (n = 1)	Lime (n = 4)	*Cultivated Plp & J/K soils (n = 68)	South African Maximum Permissible Heavy Metal Concentrations for soils and in sludge used unrestrictedly in agricultural soils (mg.kg^{-1})
Cd	**0.00**	**0.12**	**0.49**	**0.49**	**0.06**	**0.37**	**2.00 (soil) 15.70 (dry sludge)**
std dev	0.00	0.03	0.82		0.09	0.17	
Maximum	0.00	0.16	3.82		0.19	0.82	
Cr	**0.01**	**10.55**	**36.59**	**18.22**	**7.53**	**5.35**	**80.00 (soil) 1750.00 (dry sludge)**
std dev	0.01	7.21	35.85		1.99	4.70	
Maximum	0.04	27.24	160.00		10.05	19.88	
Cu	**0.18**	**52.16**	**63.66**	**0.75**	**6.52**	**8.31**	**6.60 (soil) 50.50 (dry sludge)**
std dev	0.20	10.12	42.88		4.69	5.31	
Maximum	0.56	75.22	227.51		10.86	22.48	
Hg	**0.00**	**0.02**	**0.01**	**4.58**	**2.11**	**0.02**	**0.50 (soil) 10.00 (dry sludge)**
std dev	0.00	0.02	0.01		2.00	0.02	
Maximum	0.00	0.09	0.02		4.77	0.13	
Ni	**0.12**	**12.07**	**29.69**	**5.23**	**4.27**	**1.53**	**50.00 (soil) 200.00 (dry sludge)**
std dev	0.32	5.41	26.61		0.78	0.82	
Maximum	0.97	23.40	123.44		4.93	4.00	
Pb	**0.01**	**0.58**	**4.04**	**2.99**	**8.61**	**4.27**	**6.60 (soil) 50.50 (dry sludge)**
std dev	0.01	0.37	9.47		6.44	4.00	
Maximum	0.02	1.50	39.75		14.17	16.57	
Zn	**1.32**	**444.97**	**453.70**	**7.60**	**23.36**	**47.14**	**46.50 (soil) 353.30 (dry sludge)**
std dev	2.51	78.94	213.24		28.79	26.10	
Maximum	7.22	525.47	970.65		65.35	121.00	

* The combined averages for Philippi and Joostenbergvlakte/Kraaifontein soil samples represent not only soils planted with- or prepared for- cabbage, carrots and lettuce but, also include, soils planted with beetroot, cauliflower, spinach and soils undergoing methylbromide treatment.

To ascertain more regarding the contribution crop sprays make in terms of heavy metal contamination, several agrochemicals used in the farming areas concerned were evaluated by obtaining their official patent content and usage descriptions documents, as summarized in Table 2.8. The evaluated agrochemicals included fertilizers, fungicides, herbicides and insecticides commonly applied to crops in the studied areas. From Table 2.8 it could be deduced that in general most agrochemicals did not contain amounts of heavy metals that necessitated it being indicated as ingredients of note. Only two fungicides out of thirteen contained a heavy metal, respectively Cu in Coprox Super and Zn in Trimangol SC, as active ingredients while all other fungicides, herbicides and insecticides proclaimed the virtual absence of heavy metals in their constituency. All agrochemical fertilizers mentioned in Table 2.8 were loaded with heavy metals. The heavy metals indicated as present in the mentioned chemical fertilizers were however only those needed by plants such as Cu, Fe, Mn, Mo and Zn, while the presence or absence of heavy metals such as Pb and Cd were not stated.

Despite continued application of fertilizers and other agrochemicals, it was hypothesized that the status of heavy metal contamination of vegetables would be marginally greater than seen in previous years. In the case of Pb concentrations in cabbage and carrots, differences were seen between Philippi 2000 and Philippi 2006 samples but, unlike hypothesized, there seemed to be a reduced concentration observed rather than an increased concentration in these vegetables' Pb contents (Table 2.9 and Table 2.10). No significant differences were however seen between cabbage, carrots and lettuce produced in the Philippi area in 2006 compared to vegetables produced in the Joostenbergvlakte/ Kraaifontein area in 2006. The concentration of Hg was relatively high in carrots produced in the Joostenbergvlakte/ Kraaifontein area in 2006 in terms of the maximum permissible concentration allowed by

South African regulations. This concentration of Hg in carrots produced in the Joostenbergvlakte/Kraaifontein areas was relatively higher than that seen in carrots produced in the Philippi area in 2006 (Table 2.9 and 2.12). Carrots from the Philippi area, however, had a relatively greater concentration of Cu and seemingly greater concentration of Cd in their edible parts compared to those produced in the Joostenbergvlakte/ Kraaifontein area (Table 2.10 and 2.12). These noted differences where however not reflect as significant by other statistical tests.

In the case of Pb, a lower concentration was measured in cabbage and carrots produced in both farming areas compared to the concentration of Pb seen in these vegetables produced in Philippi in 2000 (Table 2.9 and Table 2.10). Though in the case of cabbage, carrots and lettuce; Pb and Zn exceeded South African limits set for vegetables, these concentrations did not exceed the European Community's limits (Tables 2.9, 2.10 and 2.11). Cd concentrations exceeded South African limits in carrots produced in Philippi in 2006 and lettuce produced in both areas in 2006 (Tables 2.10 and 2.11), but again one needs to note that South African limits are very restrictive (Murphy, 1997). The accumulation of Cd in carrots, related to soil Cd concentrations, is supported by Pearson Correlations seen in Tables 2.13. Other correlations were not conclusive as they did not support findings seen in other research. Soil pH also affects the uptake of metals and was supported by Correlations summarized in Table 2.13 (Kirkham, 2006, Marschner, 1995).

Table 2.8: List of common agrochemicals used on Cape Town's agricultural soils and their heavy metal content

Agrochemical	Producer	Use	Main Vegetable crop(s)*	Active ingredient(s)	Heavy metals in mg/kg
Amistar	Syngenta	Fungicide	Potatoes, Cruciferae, cucurbits, onions	Strobilurien	None indicated
Aphox	Syngenta	Insecticide	Potatoes, Cruciferae	Piricarbamate	None indicated
Ballona	Terona Plant Nutrition	Fertilizer	All crops	N, P, K, Mg, S and B, Cu, Fe, Mn, Mo and Zn	Cu 90mg/kg, Fe 1440mg/kg, Mn 1300mg/kg, Mo 120mg/kg and Zn 1500mg/kg
Bladbuff 5	Gouws and Scheepers	Water improver	All crops	Wetting-, spreading-, penetrating agents, acidifier, and pH indicator not named	None indicated
Bravo 270	Syngenta	Fungicide	Potatoes, Cruciferae, cucurbits, beans, peas	Chlorophthalimide	None indicated
Break-Thru	Degussa Africa	Wetting-, spreading-, penetrate surfactant	All crops	Polyether- polymethylsiloxane-copolymer	None indicated
Cabrio Top	BASF Chemical Company	Fungicide	Wine- and table grapes	Metiram dithiocarbamate, pyraclostrobin strobilurine	None indicated
CalMag Nitrate Plus B	Agrizone	Water soluble fertilizer	Potatoes, onions, beans	N, Ca, Mg, B	None indicated
Coprox Super	Tsunami Plant Protection	Fungicide	Potatoes, celery, Cruciferae, cucurbits, beans	Copper oxychloride	Copper oxychloride 8500mg/kg which is equivalent to 50% metallic copper
Crop Guard	Illovo Sugar	Nematicide	Potatoes, onions, carrots, lettuce	Furfural aldehyde	None indicated
Delta-Thrin 25 EC	Villa Crop Protection	Insecticide	Potatoes, Peas, Onions, lettuce, Cruciferae, beans	Deltamethrin pyrethoid	None indicated
Dithane M45 800 WP	Dow Agro Sciences	Fungicide	All crops	Mancozeb dithiocarbamate	None indicated
Dursban 2E	Dow Agro Sciences	Insecticide	Only deciduous fruit, citrus, cabbage, Brussels' sprouts	Chlorpyrifos	None indicated
Eco Pellets	Organic Choice	Composted	All crops	N, P, K, Mg, Ca, B, S, Mn, Cu,	Mn 5700mg/kg, Fe

		poultry manure		Fe, Zn	35770mg/kg, Cu 750mg/kg, Zn 6850mg/kg
Agrochemical	**Producer**	**Use**	**Main Vegetable crop(s)***	**Active ingredient(s)**	**Heavy metals in mg/kg**
Enhance Pellets	Avison	Composted chicken manure	All crops	N, P, K, Mg, Ca, B, S, Mn, Cu, Fe, Zn	Mn 676mg/kg, Fe 1919mg/kg, Cu 91mg/kg, Zn 562mg/kg
Fusilade Forte	Syngenta	Herbicide	All crops	Aryloxyphenoxyproprionate	None indicated
Gallant Super	Dow Agro Sciences	Herbicide	All crops	Haloxyfop-R methyl ester	None indicated
Goal 2XL 240 EC	Dow Agro Sciences	Herbicide	All crops	Oxyfluorfen diphenyl ether	None indicated
Goëmar BM 86 E	Terason	Fertilizer	Potatoes, peas, spinach, lettuce, carrots, cucurbits, celery, brassicas, beans	Seaweed cream GA14, B, Mg, Mo, S, Auxins, and Citokinins	Molybdenum 0.02%
Grab 500 EC	Gouws and Scheepers	Insecticide	Cucurbits	Fenthion organophosphate	None indicated
Herbi-Thal 480 SC	Ag-Chem Africa	Herbicide	Onions, lettuce, cauliflower, cabbage	Chlorthal-dimethyl phthalic acid compound	None indicated
Hunter 5C	BASF Chemical Company	Insecticide	Potatoes, Cruciferae	Chlorefenapir	None indicated
Judo 50 EC	Villa Crop Protection	Insecticide	Potatoes, Crufiferae, beans	Lambda-cyhalothrin pyrethroid	None indicated
Karate EC	Syngenta	Insecticide	Potatoes, peas, onions, Cruciferae, beans	Lambda-cyhalthrin pyrethroid	None indicated
Kelpak	Kelp Products	Fertilizer	Potatoes, peas, onions, lettuce, carrots, Cruciferae, beans	Auxins, Cytokinins	None indicated
Linagan SC	Makhteshim Agan	Herbicide	Potatoes, carrots	Linuron (Urea)	None indicated
Methamidofos 585 SL	Dow Agro Sciences	Insecticide	Potatoes, Cruciferae	Methamidophos (organophosphate)	None indicated
Methomex 200 SL	Makhteshim Agan	Insecticide	Potatoes, Cruciferae, beans	Methomyl carbamate	None indicated
Methomyl 200 SL	Dow Agro Sciences	Insecticide	Potatoes, Cruciferae, beans	Methomyl carbamate	None indicated
Nu-Film P	Miller Chemical and Fertilizer	Non-ionic sticker/spreader	All crops	Poly-1-p-Menthene	None indicated
Orius 2 WS	Makhteshim Agan	Fungicide	All crop seeds	Tebuconazole (triazole)	None indicated

Agrochemical	Producer	Use	Main Vegetable crop(s)*	Active ingredient(s)	Heavy metals in mg/kg
Phosdrin SL	Villa Crop Protection	Insecticide	Peas, Cruciferae, beans	Mevinphos (organophosphate)	None indicated
Proclaim	Syngenta	Insecticide	Tomatoes	Emamectin benzoate	None indicated
Quatro Induce	Terason	Fertilizer	All crops	N, P, Zn, Fe, Mn, Cu, B, Mo, Auxins and Cytokinins	Cu 504mg/kg, Fe 1001mg/kg, Zn 510mg/kg, Mn 507mg/kg and Mo 76mg/kg
Ridomil Gold Flo	Syngenta	Fungicide	Potatoes, Cruciferae	Mefenoxam phenylamide, chlorothalonil (chloronitrate)	None indicated
Sanamectin 18 EC	Dow Agro Sciences	Insecticide	Potatoes	Abamectin	None indicated
Sanlaxyl 700 WP	Dow Agro Sciences	Fungicide	Potatoes	Metalaxyl phenylamide, Mancozeb dithiocarbamate	None indicated
Score	Syngenta	Fungicide	Potatoes, beans	Difenoconazole triazole	None toxic
Selecron 500 EC	Syngenta	Insecticide	Potatoes, onions, cauliflower, cabbage	Profenofos premium grade organophosphate	None indicated
Sorba	Syngenta	Insecticide	Cabbage	Iufenuron benzamide	None indicated
Sovin Flo	Meridian Agritech	Fungicide	Potatoes	Dimethomorph cinnamic acid derivative	None indicated
Steward	Du Pont	Insecticide	Peas, Cruciferae, beans	Indoxacarb (Oxadiazine)	None indicated
Sumisclex	Philagro	Fungicide	Table grapes	Procymidone, Sulphur	None indicated
Suntap 500 SP	Gouws and Scheepers	Insecticide	Potatoes, peas, onions, cabbage, beans	Cartap hydrochloride	None indicated
Telone II	Dow Agro Sciences	Insecticide	Potatoes and all seeds	1,3 dichloropropene	None indicated
Topaz 200 EW	Syngenta	Fungicide	Peas, cucurbits	Penconazole triazole	None indicated
Totril	Bayer Crop Science	Herbicide	Onions, garlic	Loxynil (nitrile) (octanoate ester)	None indicated
Tracer 120 SC	Dow Agro Sciences	Insecticide	Peas, beans	Spinosad	None indicated
Tracer 480 SC	Dow Agro Sciences	Insecticide	Potatoes, peas, onions, spinach, lettuce, leeks, cucurbits, cabbage	Spinosad (naturalyte)	None indicated
Trimangol SC	Tsunami Plant Protection	Fungicide	Potatoes, beans	Maneb (dithiocarbamate), Zinc Oxide	Zinc oxide 4.7g/L

*The above agrochemicals are specifically effective for use on the indicated crop(s), but it does not exclude their use on other crops unless stated so.

Table 2.9: Mean heavy metal concentrations for cabbage produced in the Joostenbergvlakte/Kraaifontein and Philippi farming areas in mg.kg^{-1}

Heavy Metal	**Summer 2000**	**Winter 2000**	**Summer 2006**		**SA's Maximum Permissible**	**EC's Maximum Permissible**
	Plp (n = 4)	**Plp (n = 13)**	**Plp (n = 8)**	**J/K (n = 6)**	**Concentrations (mg.kg^{-1})**	**Concentrations (mg.kg^{-1})**
Cd	**0.38**	**0.37**	**0.04**	**0.04**	**0.05**	**0.20 wet weight**
std dev	0.28	0.21	0.02	0.01		
Maximum	0.72	0.60	0.06	0.06		
Cu	**4.25**	**5.23**	**4.02**	**4.19**	**30.00**	**.**
std dev	1.17	1.09	0.58	1.46		
Maximum	5.35	7.83	5.05	7.07		
Hg	**.**	**.**	**0.01**	**0.01**	**0.03**	**.**
std dev	.	.	0.01	0.01		
Maximum	.	.	0.02	0.03		
Pb	**3.03**	**4.76**	**0.25**	**0.21**	**0.10**	**0.30 wet weight**
std dev	2.15	2.84	0.08	0.08		
Maximum	6.18	8.58	0.41	0.31		
Zn	**60.03**	**48.00**	**45.59**	**50.07**	**40.00**	**.**
std dev	6.99	21.31	10.34	17.09		
Maximum	66.10	82.02	60.38	71.17		

Table 2.10: Mean heavy metal concentrations for carrots produced in the Joostenbergvlakte/Kraaifontein and Philippi farming areas in mg.kg^{-1}

Heavy Metal	**Summer 2000**	**Winter 2000**	**Summer 2006**		**SA's Maximum Permissible Concentrations (mg.kg^{-1})**	**EC's Maximum Permissible Concentrations (mg.kg^{-1})**
	Plp (n = 10)	**Plp (n = 24)**	**Plp (n = 8)**	**J/K (n = 4)**		
Cd	**0.46**	**0.31**	**0.18**	**0.09**	**0.05**	**0.10 wet weight**
std dev	0.43	0.33	0.08	0.03		
Maximum	1.51	1.54	0.30	0.11		
Cu	**10.77**	**5.28**	**7.76**	**5.97**	**30.00**	**.**
std dev	5.58	4.63	1.65	1.45		
Maximum	24.00	26.50	10.51	7.91		
Hg	**.**	**.**	**0.01**	**0.06**	**0.03**	**.**
std dev	.	.	0.01	0.10		
Maximum	.	.	0.03	0.21		
Pb	**2.86**	**3.64**	**0.29**	**0.33**	**0.10**	**0.10 wet weight**
std dev	2.01	2.29	0.14	0.09		
Maximum	6.33	9.96	0.55	0.41		
Zn	**58.30**	**25.74**	**64.33**	**61.80**	**40.00**	**.**
std dev	17.92	12.57	15.97	10.35		
Maximum	84.52	57.2	90.28	76.54		

Table 2.11: Mean heavy metal concentrations for lettuce produced in the Joostenbergvlakte/Kraaifontein and Philippi farming areas in $mg.kg^{-1}$

Heavy Metal	**Summer 2000**	**Summer 2006**		**SA's Maximum Permissible Concentrations ($mg.kg^{-1}$)**	**EC's Maximum Permissible Concentrations ($mg.kg^{-1}$)**
	Plp (n = 6)	**Plp (n = 2)**	**J/K (n = 1)**		
Cd	**0.33**	**0.25**	**0.1**	**0.05**	**0.20 wet weight**
std dev	0.41	0.15	.		
Maximum	0.98	0.36	.		
Cu	**12.17**	**11.86**	**9.28**	**30.00**	**.**
std dev	4.02	0.48			
Maximum	16.91	12.20			
Hg	**.**	**0.01**	**0.01**	**0.03**	**.**
std dev	.	0.00	.		
Maximum	.	0.01	.		
Pb	**4.11**	**0.19**	**0.46**	**0.10**	**0.30 wet weight**
std dev	1.69	0.21	.		
Maximum	5.41	0.34	.		
Zn	**93.27**	**205.69**	**301.23**	**40.00**	**.**
std dev	23.65	47.53	.		
Maximum	117.24	239.30	.		

Table 2.12: T-tests that showed significant differences between samples collected in 2006 from Joostenbergvlakte, Kraaifontein and Philippi farms

Heavy metals in sample	Joostenbergvlakte mean and sample number	Kraaifontein mean and sample number	Philippi mean and sample number	LSD (least significant difference)
Irrigation dam water Zn	0.0142 mg/l (n = 5)	0.0068 mg/l (n = 20)	0.0057 mg/l (n = 47)	0.0042
Water inlet pipe to dam Cr	0.0033 mg/l (n = 3)	0.0020 mg/l (n = 8)	0.0005 mg/l (n = 26)	0.0012
Water inlet pipe to dam Pb	0.0154 mg/l (n = 3)	0.0011 mg/l (n = 8)	0.0068 mg/l (n = 26)	0.0078
Sprinkler water Cd	0.0008 mg/l (n = 4)	0.0001 mg/l (n = 8)	0.0007 mg/l (n = 9)	0.0005
Sprinkler water Co	0.0009 mg/l (n = 4)	0.0016 mg/l (n = 8)	0.0008 mg/l (n = 9)	0.0006
Sprinkler water Cr	0.0025 mg/l (n = 4)	0.0012 mg/l (n = 8)	0.0001 mg/l (n = 9)	0.0005
Sprinkler water Fe	0.0605 mg/l (n = 4)	0.0444 mg/l (n = 8)	0.1299 mg/l (n = 9)	0.0235
Sprinkler water Ni	0.0033 mg/l (n = 4)	0.0083 mg/l (n = 8)	0.0027 mg/l (n = 9)	0.003
All soils Cd	0.2144 mg/kg (n = 9)	0.3041 mg/kg (n = 19)	0.3970 mg/kg (n = 85)	0.174
All soilsCr	1.3810 mg/kg (n = 9)	1.8120 mg/kg (n = 19)	6.1910 mg/kg (n = 85)	4.0215
All soils Pb	0.9690 mg/kg (n = 9)	1.1830 mg/kg (n = 19)	5.1230 mg/kg (n = 85)	3.641
All soil Zn	26.4900 mg/kg (n = 9)	35.6200 mg/kg (n = 19)	50.1100 mg/kg (n = 85)	22.219
Soil with cabbage Cd	.	0.2448 mg/kg (n = 10)	0.3833 mg/kg (n = 10)	0.0774
Soil with cabbage Co	.	0.3690 mg/kg (n = 10)	0.7001 mg/kg (n = 10)	0.2231
Soil with cabbage Cr	.	1.9310 mg/kg (n = 10)	8.7134 mg/kg (n = 10)	1.8178
Soil with cabbage Cu	.	7.4170 mg/kg (n = 10)	11.4610 mg/kg (n = 10)	2.2183
Soil with cabbage Hg	.	0.0111 mg/kg (n = 10)	0.0380 mg/kg (n = 10)	0.0103
Soil with cabbage Ni	.	1.0777 mg/kg (n = 10)	1.8387 mg/kg (n = 10)	0.4858
Soil with cabbage Pb	.	1.4212 mg/kg (n = 10)	7.1296 mg/kg (n = 10)	1.2458
Soil with cabbage Zn	.	43.1540 mg/kg (n = 10)	63.0160 mg/kg (n = 10)	15.1620
Soil with carrots Cr	.	1.7640 mg/kg (n = 4)	6.8840 mg/kg (n = 8)	2.9950
Soil with carrots Fe	.	1525.5000 mg/kg (n = 4)	941.6000 mg/kg (n = 8)	394.3100
Soil with carrots Ni	.	1.1168 mg/kg (n = 4)	1.9399 mg/kg (n = 8)	0.7002
Cu in carrots	7.9080 mg/kg (n = 1)	5.3530 mg/kg (n = 2)	7.9080 mg/kg (n = 8)	2.2476
Hg in carrots	0.0070 mg/kg (n = 1)	0.1135 mg/kg (n = 2)	0.0064 mg/kg (n = 8)	0.0345

Table 2.13: Pearson correlations between soil pH and heavy metals in soils and heavy metals in vegetables produced in February 2006 in Cape Town's agricultural areas

Metal in soil	Metal in vegetable and sample number (n)	Correlation Coefficient (P-value)
pH	Cr in cabbage (n = 14)	- 0.70014 (0.0053)
pH	Fe in cabbage (n = 14)	- 0.74212 (0.0024)
pH	Zn in cabbage (n = 14)	- 0.56783 (0.0342)
pH	Cr in lettuce (n = 3)	- 0.99996 (0.0055)
pH	Fe in lettuce (n = 3)	- 0.99993 (0 0073)
pH	Cd in carrots (n = 12)	+ 0.60552 (0.0369)
Cd	Cd in carrots (n = 12)	+ 0.70644 (0.0102)
Cr	Cd in carrots (n = 12)	+ 0.79123 (0.0022)
Cu	Cd in carrots (n = 12)	+ 0.60467 (0.0373)
Fe	Fe in lettuce (n = 3)	+ 0.99566 (0.0593)
Ni	Cd in carrots (n = 12)	+ 0.56634 (0.0549)
Ni	Pb in lettuce (n = 3)	- 0.99857 (0.0341)
Pb	Hg in lettuce (n = 3)	+ 0.99630 (0.0548)
Pb	Cd in carrots (n = 12)	+ 0.87129 (0.0002)
Pb	Cr in lettuce (n = 3)	- 0.99459 (0.0662)
Zn	Cd in carrots (n = 12)	+ 0.59038 (0.0433)

2.4. Discussion

The Joostenbergvlakte/Kraaifontein farming area and the Philippi farming area differ in terms of their irrigation water resources' origins. The Joostenbergvlakte/Kraaifontein area's farmers obtain water via boreholes from the Malmesbury shale meta-sediment aquifer, from the Teewaterskloofdam and the Scottsdene Waste Water Treatment Plant while the Philippi farmers extract water via boreholes from the Cape Flats aquifer in the Sandveld group deposit and obtain water from surrounding storm water canals (Cole and Roberts, 1996; Fraser and Weaver, 2000; Personal communication with farmers, 2007). Though the origins of irrigation water sources for these two farming areas' are different, overall, differences between the concentrations of heavy metals in irrigation waters from these two main areas were minimal and even insignificant (Table 2.2 and 2.3).

Significant amounts of Cd, Cu and Zn was expected in various types of irrigation water resources from the studied areas however, the South African maximum permissible concentrations for Cd, Cu and Zn were not exceeded in either study area. In neither study area did the other measured heavy metals (Cr, Co, Fe, Hg, Mn, Mo, Ni, Sn and V) exceeded set South African maximum permissible concentrations in piped water inputs to dams, irrigation dam water it self or sprinkler water. The concentrations of most heavy metals from Philippi's irrigation dam waters showed no significant differences to that measured in Philippi in 2000. Indicating that these systems have not necessarily become more contaminated, but that as in the case of Philippi, a balance is maintained by the present system's ecological functions. This is supported by the fact that little seasonal variations were seen in the case of most heavy metal concentrations in irrigation dam water resources in Philippi in 2000 (Li *et al.*, 2008; Meerkotter, 2003; Miller, 1996; Summerfield, 1994).

It was interesting to note that piped water inputs, except for Cr and Pb concentrations, did not seem to differ between the two main study areas though they may have had very different origins. All these inputs were subject to various factors and could not be expected as present on each farm in similar numbers as discussed to some extent in the Materials and Methods section of this chapter and summarized in Table 2.1. The number of canals and the presence of tributaries from rivers depended on the topographical position of each farm, whereas the collection of sprinkler water depended on the time of irrigation coinciding with sampling on a particular land. The amount of pipes that lead towards irrigation water holding dams also varied from farm to farm and not all pipes were permanent inlet structures at any particular dam. Some pipes were connected to boreholes while others directed flow of water from canals and tributaries or other dams to a specific dam at the time of sampling.

In the case of Cd, Co, Cr, Fe and Ni there seemed to be differences between sprinkler water from Philippi compared to sprinkler water from the Kraaifontein area (Table 2.12). The reasons for the differences in sprinkler waters were however not investigated and could be related to an array of factors, just one being for example, possible differences in materials used for the sprinkler system pipes itself, which was not investigated in this research (Department of Water Affairs and Forestry, 1996). From the results it can be seen that heavy metal contamination of irrigation water resources is not a major concern in either area at present. Irrigation water resources are currently not contaminated enough neither to jeopardize the production of quality vegetables in terms of heavy metal content, nor to pollute soils.

Water is cycled between irrigation water holding dams and various canals/tributaries and heavy metals from contaminated soils could easily be leached through percolation to these water resources and *vice versa* (Miller, 1996; Rice and Rice, 1997; Summerfield, 1994). Previous research showed that several soils from Philippi and Kraaifontein's farming areas contained heavy metals and this research aimed to determine whether the concentrations of heavy metal had increased in the soils since it was last tested (Meerkotter, 2003; Qoko, 2003; Sogayise, 2003). Taking into consideration that soils may have been flushed from heavy metals after each rainy season; that heavy metals could have been removed from soils by harvested crops and that addition of fertilizers, composts and pesticides may not have changed significantly, it was hypothesized that the concentrations of heavy metals would be marginally greater than measured in previous studies (Brown, 1996; Marschner, 1995; Miller, 1996; Rice and Rice, 1997; Summerfield, 1994). This hypothesis was however not supported by the results of this study.

A greater threat to irrigation water resources at present is salinization which is aggravated by bad farming practices, for example the storing of manure in heaps in close proximity to irrigation water holding dams, often seen on the studied farms (Murphy, 1997). Over-abstraction of underground water is also a great concern in that it can lead to salinization of irrigation waters and even intrusion of sea water into aquifers; fortunately this has not happened yet in the Philippi area and is a lesser threat in the Joostenbergvlakte/Kraaifontein area. Nonetheless, continued application of fertilizers especially in the form of manures in areas that have distinct dry seasons, such as seen in Cape Town, leave soils prone to salinization and this can also lead to salinization of water resources, especially underground water resources, which was confirmed in a recent study in the Philippi area (Aza-Gnandji, 2011; Brown, 1996; Li *et al.*, 2010; Rice and Rice, 1997).

Other threats to both agricultural areas are related to the expansion of residential and industrial areas that are encroaching farm land and in some cases has led to the loss of farm land since 2006 (Map Studio, 1999; Orthophoto Map Series A, 2001; Orthophoto Map Series A, 2007; Orthophoto Map Series A, 1992; Orthophoto Map Series B, 1992; Orthophoto Map Series B, 1999; Orthophoto Map Series B, 2001; Orthophoto Map Series C, 2001; Orthophoto Map Series D, 2001;). Apart from the great threat that urbanization has on these two farming areas, in terms of heavy metal contamination of these farm lands, increased air-pollution also poses a threat. Air-pollution is measured daily by several stations in and around Cape Town, however, the extent of contamination is described in terms of 'particulate concentration' where the identity of all the measured particles is unfortunately not given. In the absence of the revealed identity of air pollution particles, the actual contribution of air pollution in terms of Cd, Pb and other heavy metals to agricultural land is not clear, but well present (Webber and Singh, 2003). Though irrigation water resources are fairly uncontaminated in terms of heavy metals, agricultural soils are loaded with heavy metals and can pose a threat to irrigation water resources in the future (Miller, 1996).

Heavy metal contamination of agricultural soils of the Philippi and Joostenbergvlakte/ Kraaifontein farming areas was expected to be marginally greater than measured in studies prior to 2006. Concentrations of Cu, Pb and Zn were not significantly greater than measured prior to 2006. In Philippi's soils prepared for the planting of cabbage, carrots and lettuce the concentrations of Cu, Pb and Zn exceeded the maximum permissible concentrations set by South African guidelines, while soils form the Joostenbergvlakte/Kraaifontein area were below these maximum permissible concentrations. None of the heavy metals in soils of either area exceeded European maximum permissible concentrations. In the case of Cu the European limits were not clearly indicated but it is safely assumed that according to European standards our soils are overall fairly 'clean' in terms of their heavy metal content (Murphy, 1997). It is interesting to note that specifically Cu, Pb and Zn are also problematic metals elsewhere in the world in agricultural systems (Cao *et al.*, 2010; Hao *et al.*, 2009). Soil Cu, Pb and Zn content thus need more monitoring in future. The amount of cropped soils that could be sampled during the period of sample collecting, in for example the case of lettuce, was very low and a greater sample number might have been more conclusive and should be aimed for in future studies if practically possible.

Looking at averages and standard deviations the heavy metal concentrations of Philippi soils were greater than those of the Joostenbergvlakte/Kraaifontein area. This was an interesting observation since soils of the Philippi area have a lower attenuation capacity than soils form the Joostenbergvlakte/ Kraaifontein area (Eigenhuis, 1997). These higher concentrations seen in Philippi soils could be due to more intense farming as the Philippi farms often see as much as three crops per year per land and the Philippi farms have been farmed on for a greater number of years than the Joostenbergvlakte/Kraaifontein farms (Personal communication with farmers from Philippi and Joostenbergvlakte/Kraaifontein area, 2007).

It was interesting to note that in both areas, soils which were already carrying crops well into the growing season, were not significantly different in heavy metal concentrations than soils prepared for planting and not yet subjected to extraction of elements by vegetable crops. This may indicate that the soils are supplied with more than adequate amounts of fertilizer in comparison to what the crops actually need throughout the growing season thus soils are not significantly depleted of nutrients and heavy metals by crops upon harvesting. Furthermore, some agrochemical fertilizers are continually applied and thus as heavy metals and nutrients are extracted from soils during the growing season, these are replaced through application of agrochemical fertilizers and thus cropped soils do not appear significantly poorer in nutrients and heavy metals than soils prepared for cropping (Marschner, 1995; Rice and Rice, 1997; Webber and Singh, 2003). Continued application of fertilizers can however not be avoided as these areas have sandy soils that do not hold nutrients very well and thus soils need a fresh injection of nutrients after each harvest and in preparation for the next crop (Brown, 1996; Marschner, 1995; Rice and Rice, 1997).

Regulating the application rate of phosphate fertilizers should ensure that the final amounts of Cd and Pb added to soils are kept at a minimum, which is supported by the evidence of little increase in Cd and Pb concentrations in Philippi's agricultural soils since 2000 till 2006 as seen in Tables 2.4, 2.5 and 2.6. These results agree with those seen in studies by Brown, 1996; Marschner, 1995; Rice and Rice, 1997; Webber and Singh, 2003. It is important to note that the phosphate fertilizer sample measured represented but one general fertilizer brand while several other brands of phosphate fertilizers are also used by farmers but were not available for sampling. The use of chemical fertilizers seem to be a sure source of heavy metals to the agricultural field, however, use thereof according to the set application rates, under the supervision of an agronomist/agriculturalist, should help minimize the chances of produce, soils or water resources becoming contaminated to the point of exceeding permissible limits (Marschner, 1995; Webber and Singh, 2003).

Though soils may appear to contain high levels of heavy metals and other nutrients, these may not always be in a form that can by taken up by crops and thus the concentrations of heavy metals of concern often remain unchanged in soils throughout the growing season. Soil pH, P and Zn concentrations as well as organic matter content often reduce the uptake of heavy metals and thus alleviate stress caused by elevated heavy metal concentrations in agricultural soils (Brown, 1996; Kirkham, 2006; Rice and Rice, 1997). Some crops may have roots that are selective in terms of the heavy metals that they take-up and thus heavy metals may not necessarily be extracted by crops as in bioremediation processes (Clemente *et al.*, 2005; Kothe *et al.*, 2005; Marschner, 1995; Li *et al.*, 2008; Li *et al.*, 2010). It is important to note that bioremediation also requires the use of crops that are capable of effectively extracting the necessary heavy metals form soils. Though leafy vegetables do extract more heavy metals than non-leafy vegetables, they are not as effective as beets, mustard and sunflowers. Not all vegetable crops are good candidates for bioremediation as all crops do not necessarily extract significant amounts of heavy metals (Clemente *el al*, 2005; Kothe *et al.*, 2005; Li *et al.*, 2010; Wang *et al.*, 2006).

Soils planted with cabbage in Philippi in 2000 showed seasonal variation in Cu and Zn concentrations (Table 2.4), while soils planted with carrots, showed seasonal Zn variation (Table 2.5) and soils planted with lettuce showed seasonal variations in Cr, Cu and Pb concentrations (Table 2.6). These variations could be related to various possible factors such as the ability of these specific crops to extract the mentioned heavy metals more readily in favorable weather conditions or these variations could have coincided with application of agrochemicals that contained trace amounts of these metals and thus the observed seasonal variation may have been false or elevated. The presence of other elements in the soil may also have affected the uptake of these heavy metals by crops. Pearson Correlations showed that high soil pH, as seen in the study areas, can reduce the amount of Zn taken up by cabbage, while elevated levels of Cu in soils coincide with elevated levels of Cd in carrots (Marschner, 1995, Rice and Rice, 1997; Table 2.13).

It would be interesting to determine what the background soil heavy metal concentrations are in these two farming areas as one can then more closely evaluate the cycling of heavy metals in these agricultural systems (Cao *et al.*, 2010; Li *et al.*; 2008). It would seem that the applications of fertilizer are done in a very responsible manner as concentrations of heavy metals measured in Philippi soils in 2000, for example, are not significantly different from that measured in Philippi in 2006 (Table 2.4, 2.5 and 2.6). Each farmer makes use of an agronomist/agriculturalist to help calculate the amounts of fertilizers, manures and other agrochemicals that are needed per growing season. Since the application rates are very specific to particular cropping sites on each farms, crops intended for planting and seasonal vulnerability to pests, this study only briefly evaluated the contents of agrochemicals used in the studied areas and this was summarized in Table 2.8. For the purpose of this discussion it is assumed that these agrochemicals are applied as prescribed by their manufacturers, which should ensure that maximum permissible limits are not exceeded, if applied correctly (Brown, 1996; Marschner, 1995; Rice and Rice, 1997).

Farmers from the Joostenbergvlakte/Kraaifontein area and the Philippi area make use of similar agrochemicals and the same agronomists, agriculturalists and consultants are spoken of by farmers from both areas. Since agrochemicals used in these two areas are similar they were summarized in Table 2.8 as representative for the whole of vegetable farming in Cape Town. It was hypothesized that significant levels of Cd and Pb were to be measured in chemical fertilizers, and significant levels of Zn was expected to be seen in poultry manures (Dach and Starmans, 2005; Webber and Singh, 2003). Crop sprays were expected to contain significant Cu concentrations as they often contain mixtures of fungicides, pesticides, herbicides and nutrients.

The results indicated in Table 2.7 showed that indeed poultry manure, more specifically chicken manure, contained great amounts of Cd, Pb and Zn and that cattle manure was an even more substantial source of these heavy metals, this being a common finding in many agricultural areas worldwide (Dach and Starmans, 2005; Webber and Singh, 2003). Although phosphate fertilizer did contain Cb and Pb and as such would be a source thereof to the agricultural field, manures pose a greater threat in terms of elevation of heavy metal content of soils than phosphate fertilizers and agrochemical fertilizers such as Ballona, Goëmar BM 86 E, Quatro Induce, Eco pellets and Enhance pellets (Table 2.7 and 2.8).

The use of chicken manure is often replaced by or limited by additional use of chicken or poultry manures in the form of pellets such as the products Eco pellets and Enhance pellets. The Cu and Zn content of chicken manure was found to be very high compared to that permissible in dry sludge used agriculturally and as such use of chicken manure pellets which have altered or controlled concentrations of Cu and Zn would be preferable, especially since Cu and Zn concentrations in some farms' soils have been noted as problematic in the past and in this study (Meerkotter, 2003, Table 2.4, 2.5, 2.6, 2.7 and 2.8).

The use of chicken manure in the form of pellets is advantageous in that the storage of dry but raw chicken manure in heaps outside on agricultural land, where it is often drenched in rain or irrigation water and thus become possible point sources of contamination to water resources is avoided, since pellets are easily kept in store rooms as they are packed in convenient bags. Chicken/poultry manure pellets are also more advantageous in terms of the lesser amounts of bacteria that it exposes crops to in that these pellets are sterilized, unlike chicken manure and cattle manure. These pellets can also be enriched with other nutrients and a farmer can select the more appropriate pellets, where as chicken or cattle manure's quality and content is rarely guaranteed. The use of liquid chemical fertilizers such as Ballona, Goëmar BM 86 E and Quatro Induce is also common practice in these two agricultural areas (Brown, 1996; Rice and Rice, 1997, Table 2.8).

Ballona, Goëmar BM 86 E and Quatro Induce are examples of Group 2 fertilizers commonly used by the farmers from the studied areas. These fertilizers are applied to crops through out the growing season, commonly every 14 days, depending on the product and agronomist' or agriculturalist's advice. Though these fertilizers are placed in the same group they contain very different concentrations of various nutritional elements and heavy metals. Ballona for example contains 1440 mg/kg Fe, 1500 mg/kg Zn and only 90 mg/kg Cu, while Quatro Induce contains 1001 mg/kg Fe, 510 mg/kg Zn and 504 mg/kg Cu. These differences in concentrations do make better management practices possible as needs can be addressed more specifically and in the case of heavy metal contamination being a problem, fertilizers with lower concentrations of heavy metals can be selected for use (Brown, 1996; Rice and Rice, 1997).

For example, to avoid unnecessary increase in Cu concentrations in/on crops and in agricultural soils, a fertilizer such as Ballona which is low in Cu can be used during the period in which a crop spray such as Coprox Super that contains Cu as its active ingredient to prevent growth of fungi is used. So also, for example, to avoid excessive accumulation of Zn in the agricultural system a fertilizer such as Quatro Induce that is relatively low in Zn can be used during the period when a fungicide such as Trimangol SC which has Zn in its active ingredient is applied to crops. It was interesting to note that only Coprox Super and Trimangol SC each contained a heavy metal as part of its active ingredients while all other fungicides, herbicides and insecticides claimed the absence of heavy metals as part of their constituents (Product usage documentation; Tsunami Plant Protectoin Ltd. Terona Plant Nutrition Ltd. and Terason Ltd.; Table 2.8). From Table 2.8 it can be deduced that crop sprays, other than the indicated liquid fertilizers and manure pellets, do not pose a great threat in the agricultural environment in terms of heavy metal pollution, this is also the case in other countries as agrochemicals with less heavy metals and less harmful organic compounds are introduced to fight pests (Webber and Singh, 2003). The crop sprays collected on the studied farms, from spraying vehicles, did not contain significant amounts of heavy metals and probably did not contribute significant amounts of Cd, Cr, Cu, Hg, Ni or Pb to the studied agricultural lands (Table 2.7).

Of all the chemical input to these two agricultural areas, cattle manure and chicken manure are the most likely sources of heavy metals to these altered ecological systems, followed by chemical fertilizers of various kinds, this is also a common observation in other countries (Dach and Starmans; 2005; Webber and Singh, 2003). Lime also seemed a possible source of Cu, Hg and Pb and the use of it should be monitored carefully. Though no specific source could be pinpointed as greater heavy metal input to these agricultural areas it is recommended that soil Cu, Hg, Pb and Zn be monitored and application of fertilizers and manures adapted accordingly.

The application of fertilizers and various pesticides are crucial to the production of a successful crop for selling. Since fertilizers are continually applied to the agricultural lands of the two studied areas it was hypothesized that the status of heavy metal contamination of vegetables would be marginally greater than measured prior to this study. The results showed however that in the case of vegetables produced in Philippi in 2000 compared to those produced in Philippi in 2006, that heavy metal concentrations in vegetables were not significantly greater. In 2006 heavy metal concentrations in vegetables and specifically cabbage, carrots and lettuce were not significantly different between the two farming areas. This is good news since farmers from both agricultural areas often work together. Farmers supply one another with vegetables to help make-up vegetable orders; a farmer from Philippi may for example supply cabbage to a farmer in the Kraaifontein area who is short in terms of an order placed with him and this Kraaifontein farmer may at a later stage help a Philippi farmer to meet his order for carrots to a specific supplier for example (Personal communication with consultant from Agri Mark, Durbanville, 2011).

In this study it was observed that carrots produced in the Joostenbergvlakte/Kraaifontein area had a relatively great Hg content compared to carrots produced in the Philippi area, while carrots produced in the Philippi had a relatively greater Cu concentration compared to carrots produced in the Joostenbergvlakte/Kraaifontein area. In both cases South African regulations for Hg and Cu in carrots were exceeded (Table 2.9 and 2.10). It is important to note that the high concentration of Hg and Cu measured in carrots could have been induced by application of a fertilizer or other agrochemical just prior to sampling, and that one should not accept these measurements as the *status quo*. It is common practice to allow a period of rest, called a 'withholding period', between the last spraying of a crop with fertilizer or any other agrochemical and the date of harvesting. This withholding period helps to ensure that the active ingredients of agrochemicals will not exceed regulatory limits set therefore on crops. So for example a withholding period of 3 days is recommended by the producers of Coprox Super to ensure a significant decrease of Cu concentration on the leaves of cabbage prior to harvesting (Product usage documentation: Tsunami Plant Protection Ltd.). It is thus possible that the greater concentrations of Cu and Hg in carrots sampled in this survey could have coincided with a recent crop spraying event and the appropriate waiting period had not elapsed prior to sampling of carrots from the sampled fields. This is however not verifiable as the timing of crop spraying events and harvesting of samples for this study was not coordinated.

Nonetheless vegetables from the two farming areas are generally low in heavy metal contents and thus good for human consumption. South African regulatory concentrations set for vegetables are much more stringent than those of the European Community, even in the light of the fact that South African regulations refer to dry mass of samples while European regulations refer to wet mass of samples (Commission of the European Communities, 2006; Department of Health, 2003, Department of Health, 2004).

2.5. Conclusion

Though South African limits were exceeded in several agricultural resource samples, ranging from irrigation waters and soils to vegetables, there is no need for alarm, since South African regulations are very stringent compared to European regulations and thus our resources may be considered fairly 'clean' if measured against European standards. The greatest sources of contamination in terms of heavy metals were cattle and chicken manure samples collected on farms of both agricultural areas studied. The use of cattle and chicken manures should thus be monitored carefully and reduced where possible. Use of chemical fertilisers, should be kept at a minimum, but could help keep heavy metals at considerable low concentrations if used to supplement and/or reduce the use of cattle and chicken manures. Soils should be monitored in terms of their Cu, Pb and Zn concentrations according to South African regulations as these elements are present in high concentrations.

Future studies could focus on the cycling of nutrients from various fertilizers and manures as specified in regimes set by agronomists/agriculturalists in these two farming areas. Models for possible soil contamination from various heavy metal sources identified in this study could be focussed on in future research and even the fodder consumed by cattle and chicken from which manure is obtained could be investigated in terms of heavy metal content. Sampling methods can be improved by timing the sampling of crop sprays and sprinkler waters with actual application times thereof on farms. This can be done by contacting farmers prior to sample collecting to find out when sprinkler systems will be switched on and when crops will be sprayed with agrochemicals. Knowing when crops will be sprayed with agrochemicals will also help ensure that crops are collected after an appropriate withholding period has passed between the last crop spray date and the date of collecting crop samples. The dates of collecting vegetables samples should also be checked with farmers more closely to increase the amount of samples of the same age that can be collected during a specific time frame.

Coordinating the sampling of crops may be more difficult than coordinating the sampling of sprinkler water and crop sprays but farmers of these two study areas are not resistant to giving their cooperation to researchers. It is very important that farmers be kept in the loop of progress with research and be allowed access to the findings of research so that future studies may be received favourably in these farming areas. The findings of this study will be presented to farmers and indicate that there is not a cause for alarm but that the use of manures should be monitored carefully and where possibly be reduced, since it appears to be one of the main contributors of heavy metals to these agricultural soils. Chapter three will discuss methods of remediation in the event of soils and crops exceeding Cd, Cu, Pb and Zn concentration limits in the future.

2.6. References

Aza-Gnandji CDR (2011) Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa. Unpublished Masters thesis. Department of Earth Sciences. University of the Western Cape, Bellville

Bertram WE (1989) Geohidrologiese opname in die Philippi-landbougebied, Kaapse Vlakte. Tegniese verslag Gh 3595. Direktoraat Geohidrologie, Departement van Waterwese (DWAF), Pretoria, p. 1-23

Bonthuys J (2005) Weer en virusse kan boere in moerbedryf op die knieë bring, Groot kommer oor Sandveldt se habitat, Sandveldt stuur ‘n SOS. Die Burger, 14 Mei, p. 10, 17

Brown LV (1996) Applied Principles of Horticultural Science. Butterworth-Heinemann, Oxford

Cao H, Chen J, Zhang J, Zhang H, Qiao L, Men Y (2010) Heavy metals in rice and garden vegetables and their potential health risks to inhabitants in the vicinity of an industrial zone in Jiangsu, China. Journal of Environmental Sciences 22 (11): 1792-1799

Chittenden Nicks Partnership (1997) The future of the Philippi horticultural area. Chittenden Nicks Partnership, Cape Town

Clemente R, Walker DJ, Bernal MP (2005) Uptake of heavy metals and As by *Brassica junea* grown in a contaminated soil in Aznalcóllar (Spain): The effect of soil amendments. Environmental Pollution 138: 46-58

Cole DI, Roberts DL (1996) Lignite from the western coastal plain of South Afica. Journal of African Earth Sciences 23 (1): 65-117

Commission of the European Communities (2006) Setting maximum levels for certain contaminants in foodstuffs: Commission regulation 1881: 1-25

Commissie van de Europese Gemeenschappen (2001) Vastestelling van maximumgehalten aan bepaalde verontreinigingen in levensmiddelen: Commissie verordening 466/2001: 1-13

Dach J, Starmans D (2005) Heavy metals balance in Polish and Dutch agronomy: Actual state and provisions for the future. Agriculture, Ecosystems and Environment 107; 309-316

Department of Health (2004) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 26279

Department of Health (2003) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 25015

Department of Water Affairs and Forestry (1996) South African water quality guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation, DWAF, Pretoria

Eigenhuis B (1997) Modelling the contaminant attenuation capacity of sandy soils in the vadose zone. Unpublished Doctoral thesis. University of Stellenbosch

Fraser L, Weaver J (2000) Cape Flats Aquifer: Bulk Water for Cape Town Now. Contract Report submitted to Ninham shand Consulting Engineers, Stellenbosch

Hao XZ, Zhou DM, Huang DQ, Cang L, Zhang HL, Wang H (2009) Heavy metal transfer from soil to vegetable in Southern Jiangsu Province, China. Pedosphere 19: 305-311

Kane WM (2002) Health Matters! Volume 6, Environmental Poisoning. Grolier. Danbury, Connecticut

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution 152: 686-692

Kinchen J, King C (2003) Inventions and Inventors. Volume 4, farming, food and biotechnology. Grolier. Danbury, Connecticut

Kirkham MB (2006) cadmium in plants on polluted soils: effects of soil factors, hyperaccumulation, and amendments. Geoderma 137: 19-32

Kothe E, Bergmann H, Büchel G (2005) Molecular mechanisms in bio-geo-interactions: from a case study to general mechanisms. Chenie der Erde 65 (Article in press)

Kotzé WAG (2006) Personal Communication. BemLab Documents No. BWI/S15, BWI/S16, BWI/S12 and BWI/L03

Li QS, Cai SS, Mo CH, Chu B, Peng LH, Yang FB (2010) Toxic effects of heavy metals and their accumulation in vegetables grown in a saline soil. Ecotoxicology and Environmental Saftey 73: 84-88

Li Y, Gou X, Wang G, Zhang Q, Su Q, Xiao G (2008) Heavy metal contamination and source in arid agriculture soil in central Gansu Province, China. Journal of Environmental Sciences 20: 607-612

Marschner H (1995) Mineral Nutrition of Higher Plants. 2nd Edition. Academic Press, London

Map Studio (2007) Map Studio Street Guide: Cape Town. New Holland Publishing Ltd. South Africa

Meerkotter M (2003) Heavy metals, and vegetable farming in Cape Town. Unpublished Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Miller GT (1996) Ecosystems and how they work. In: Living in the Environment. Wadsworth Publishing Company, Belmont

Murphy K O'H (1997) Municipal sewage sludge disposal: development of guidelines and expert systems. Background information and literature survey. Water Research Council report 6056/1/97

Orthophoto Map Series A (2001) 3418 BA 1 Lotus River. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series A (1999) 3418 BA 2 Philipppi. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series A (1992) 3318 DD 6 De Novo. 3rd Edition. Chief Directorate Survey and Landformation, Mowbray

Orthophoto Map Series B (2001) 3418 BA 6 Zeekoevlei. 4^{th} Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series B (1999) 3418 BA 7 Strandfontein. 4^{th} Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series B (1992) 3318 DD 11 Hooggeleë. 3^{rd} Edition. Chief Directorate Survey and Landformation, Mowbray

Orthophoto Map Series C (2001) 3318 DC 10 Kraaifontein (north). 4^{th} Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series D (2001) 3318 DC 15 Kraaifontein. 4^{th} Edition. Chief Directorate Survey and Mapping, Mowbray

Owens JE, Niemeyer ED (2005) Analysis of chemical contamination within a canal in a Mexican border colonia. Environmental Pollution (Article in press)

Qoko M (2003) Monitoring of heavy metals in the Kuilsriver and potential use of macrophytes in heavy metal remediation. Unpublished, Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Rice LW, Rice RP (1997) Practical Horticulture. 3^{rd} Edition. Prentice Hall, New Jersey

Rule KL, Comber SDW, Ross D, Thornton A, Makropoulos CK, Rautiu R (2005) Diffuse sources of heavy metals entering an urban wastewater catchment. Chemosphere (Article in Press)

Sogayise M (2003) Contamination of vegetables with heavy metals. Unpublished, Honours thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Summerfield MA (1994) Fluvial processes. In: Global Geomorphology. Longman Scientific & Technical, New York

Tempelhoff E (2007) Besoedeling naby goudmyne bedreig duisende, besmet voedsel. Johannesburg Beeld, 31 Julie, p. 1

Wang G, Su MY, Chen YH, Lin FF, Luo D, Gao SF (2006) Transfer characteristics of cadmium and lead from soil to the edible parts of six vegetable species in southeastern China. Environmental Pollution 144: 127-135

Water Research Commission (1997) Permissable Utilisation and Disposal of Sewage Sludge. 1st Edition. WRC, Pretoria

Webber MD, Singh SS (2003) Contamination of Agricultural Soils. Agriculture and Agri-Food Canada http://www.agr.gc.ca/nlwis-snite/index_e.cfm?s1=pub&2=hs_ss&page=15 Downloaded 28/07/2005

CHAPTER 3

PHOSPHATE FERTILISER AND EDTA TREATMENTS AS MEANS OF MITIGATING THE UPTAKE OF CADMIUM, LEAD AND ZINC BY CABBAGE GROWN ON SOIL FROM CAPE TOWN'S AGRICULTURAL AREAS

3.1. Introduction

This study aimed to investigate the use of different concentrations of a triple super phosphate fertiliser and EDTA solutions to mitigating the uptake of cadmium, lead and zinc by cabbage plants. Investigating the application of EDTA and Phosphate fertiliser to mitigate the uptake of cadmium, lead and zinc by cabbage, is a preventative response in that the existing levels of cadmium, lead and zinc in soils of Cape Town's agricultural areas are sporadically and in few cases above the maximum permissible levels set for South African soils, but generally not in excess in cabbage and other crops. Cabbage is one of the main crop species produced in the Joostenbergvlakte, Kraaifontein and Philippi farming areas and ensuring quality production thereof is important (Meerkotter, 2003).

Various means of controlling excessive uptake of harmful heavy metals such as cadmium and lead as well as required heavy metals such as copper and zinc, by cabbage, have been studied and some are discussed in this chapter. In Chapter one, several other means of controlling the uptake of heavy metals, by various crops were discussed. It included the simple decrease in use of fertilizers and agrochemicals that contained heavy metals and also, more costly methods such as elevation of soil organic matter content, changing soil pH, adding stabilizing chemicals to the soil or making use of phyto-remediation and/or adding less costly amendments such as municipal solid waste compost to contaminated soils (Alvarez-Ayuso and Garcia, 2003; Bjelková *et al.*, 2011; Boisson *et al.*, 1999; Garcia *et al.*, 2004; Malandrino *et al.*, 2011; Paradelo *et al.*, 2011; Qoko, 2003; Salido *et al.*, 2003; Stirk and Van Staden, 2001; Sun *et al.*, 2000; Zeng *et al.*, 2011; Zheljazkov and Nielsen 1996). Many studies have also looked at the reduction of various microbial organisms (bacterial, archaeal and fungal communities) in soils contaminated with heavy metals and in future the introduction of specific microbial organisms to polluted soils might be useful in reducing the uptake of heavy metals by agricultural crops (Bhattacharyya *et al.*, 2008; Duan *et al.*, 2010; Macdonald *et al.*, 2011; Srivastava *et al.*, 2011).

Various chelates can be used to mobilize heavy metals in soils and to leach metals away from the reach of plant roots. EDTA is often used as a heavy metal mobilizing treatment and was therefore investigated in this study (Aldrich *et al*., 2004; Cui *et al.*, 2004; Lai and Chen, 2004; Lai and Chen 2005, Liphadzi and Kirkham, 2006, Lou *et al.*, 2005; Luo *et al.*, 2006; Palma and Mecozzi, 2007; Sun *et al.*, 2001; Thayalakumaran *et al.*, 2003; Turgut *et al.*, 2005; Wu *et al.*, 2004). In the light of the fact that leaching of heavy metals from soils could lead to contamination of subterranean water resources, immobilization treatments may be considered safer options (Wu *et al.*, 2004). Immobilization involves application of amendments to the soil which may bind the metals into soil organic complexes and so render them unavailable to plants. Phosphate-containing substances are often used as amendments for this purpose and some have been found very effective in alkaline soils, especially in reducing the uptake of lead (Brown *et al.*, 2005; Cao *et al.*, 2003; Huang *et al.*, 2003; Illera *et al.*, 2004; Jiao *et al.*, 2004; 2004; Melamed *et al.*, 2003; Owenby *et al.*, 2005; Pardo, 2004; Tan *et al.*, 2011; Tang *et al.*, 2004; Zhu *et al.*, 2004). The effectiveness of a triple super phosphate fertilizer was thus investigated in this study.

A study done on mine waste soils with a soil pH of 5.9 where cadmium was present at 92 $mg.kg^{-1}$, lead at 5022 $mg.kg^{-1}$ and Zn at 18532 $mg.kg^{-1}$ found that the application of phosphate in the form of a triple super phosphate amendment was most useful at reducing the phytotoxicity to plants grown on this soil (Brown *et al.*, 2005). Thus the ability to deal with possible future problems with excess levels of cadmium, lead and or zinc in Cape Town's agricultural soils by simple addition of more triple super phosphate fertilizer seems plausible. It is important to note that although this amendment improved the growth of the plants in this particular study by Brown *et al.* (2005) it did not fully reduce the bioavailability of cadmium, lead and zinc to the plants. Treatment of agricultural soils with inorganic fertilizers that contained phosphate as one of its main constituents have however been found to rather contribute to the increased bioavailability of cadmium, copper, lead and zinc to crops compared to the non application of a remedial treatment (Singh *et al.*, 2010). In comparison then an EDTA treatment at the right concentration level may be more useful to leach heavy metals away from crop roots.

A study done by Wu *et al.* (2003) found that the application of 3 $mmol.kg^{-1}$ EDTA to paddy soil contaminated with cadmium, copper, lead and zinc significantly increased the solution of these elements in the soil and thus its bioavailability to *Brassica juncea*, emphasizing the importance of using the correct amount of EDTA in a contaminated system. A phytoextraction study by Meer *et al.* (2005) found that the mobilizing effects of EDTA treatments were long-lived and this could be problematic in the agricultural field should micro-nutrients like copper and zinc become too readily available to plant roots or contrary be leached away from plant roots to readily. Studies have been done to recover used EDTA from contaminated soil for its reuse; however this may be impractical for farmers in the open agricultural field (Di Palma *et al.*, 2003; Lim *et al.*, 2005). If future studies should prove the use of EDTA suitable for use in extracting heavy metals form contaminated agricultural soils with properties such as those of Cape Town's agricultural lands, another consideration that will come into play is the means of applying the treatment. Since iron and calcium concentrations have been shown to affect the usefulness of EDTA as a remedial treatment, application of more than one dose of EDTA to a field may be needed (Finžgar and Leštan, 2007). The possibility of using more doses of EDTA to leach heavy metals such as lead and zinc from plant roots is however a concern in that these heavy metals amongst others could then become concentrated in underground water systems (Finžgar and Leštan, 2007; Wu *et al.*, 2004).

The initial application of EDTA treatments may render heavy metals momentarily more available to plant roots. Since EDTA is specifically used to mobilize heavy metals and is therefore often used in phyto-remediation treatments, thus it was expected that it would most likely enhance heavy metal uptake by cabbage plants in this experiment (Lai and Chen, 2004; Lai and Chen, 2005; Luo *et al.*, 2005; Luo *et al.*, 2006; Palma and Mecozzi, 2007; Sun *et al.*, 2001; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2003; Wu *et al.*, 2004). It was thus hypothesized that higher concentrations of heavy metals would be seen in cabbage plants that were treated with EDTA solutions compared to plants treated with triple super phosphate fertiliser. It was therefore hypothesized that application of triple super phosphate fertiliser treatments would be more effective at reducing the uptake of lead, cadmium and zinc than EDTA treatments. Phosphate fertiliser and phosphate containing fertilizers often contain heavy metals and if used in great amounts these heavy metals may become available to crop roots. Phosphates can however form complexes with heavy metals in the soil and so immobilize heavy metals and render then unavailable to plant roots (Cao *et al.*, 2003; Huang *et al.*, 2003; Jiao *et al.*, 2003; Melamed *et al.*, 2003; Singh *et al.*, 2010; Tang *et al.*, 2004;

Zhang *et al.*, 2003). It was thus also hypothesized that application of a moderate amount of triple super phosphate fertiliser would be more effective at reducing the uptake of lead, cadmium and zinc than application of greater amounts of triple super phosphate fertilizer.

3.2. Materials and Methods

The usefulness of this study's findings is very specific to the soils of the Philippi and Joostenbergvlakte/Kraaifontein farming areas, since the growth medium was prepared from a mixture of soils obtained from these areas. Cabbage is one of the main crops produced in these areas and as such was selected for this experiment. The uptake of specifically cadmium, lead and zinc by cabbage was monitored as these elements may become problematic in the near future. Crop performance was to be measured by comparing dry masses of the different plant organs and by comparing the amount of heavy metals taken up by the different plant organs across the different mitigation treatments. Chemical analysis of the plant samples from this experiment was done by BemLab, an independent research and test laboratory, based in the Strand. The statistical design and processing of data from this pot experiment was done by Ms. Mardé Booyse from the Biometry Unit of the Agricultural Research Counsel at Infruitec, based in Stellenbosch.

A multifactor experiment was designed to evaluate the effectiveness of triple super phosphate fertilizer and ETDA, for reducing the uptake of Cd, Pb and Zn, by cabbage. A randomised block design with three replicates for each treatment was constructed (Brown *et al.*, 2005; Cui *et al.*, 2004; Huang *et al.*, 2003; Jiao *et al.*, 2004; Lai and Chen, 2004; Lai and Chen, 2005; Luo *et al.*, 2006; Wu *et al.*, 2004). The pot experiment was conducted in a glasshouse at the Environmental Education and Resources Unit of the University of the Western Cape. For the duration of the experiment the average minimum temperature in the glasshouse was 13.5 °C, the average maximum temperature 26.6 °C and the average day temperature in the greenhouse 20.1 °C. The average humidity in the glasshouse for the duration of the study was 76.25% (standard deviation of 8.1), the maximum measured humidity was 90% and the minimum measured was 58%. The glasshouse was partly shaded.

3.2.1. Preparation of the growth medium

Soil freshly prepared for the planting of cabbage seedlings as well as soil from planted cabbage patches were collected from five farms from both the Philippi and the Joostenbergvlakte/Kraaifontein areas. At each site soil was collected across the sites and to a depth of 20 cm. The soils were air-dried over several months and care was taking to remove weeds as they emerged whilst the soil was still moist. The soils were crushed by hand and sieved through a 4 mm sieve to remove pebbles, pieces of building material, broken glass, plastic waste, plant roots, seeds, snail shells, worms etc. The soils were then mixed together in a newly manufactured concrete mixer that was hired from a local company. This soil mixture was used as growth medium for the entire pot experiment (Alvarez-Ayuso and Garcia-Sanches, 2003; Cui *et al.*, 2004; Huang *et al.*, 2003; Jiao *et al.*, 2004; Lai and Chen, 2004; Luo *et al.*, 2005; Luo *et al.*, 2006; Melamed *et al.*, 2003; Pardo, 2004; Sun *et al.*, 2001; Tang *et al.*, 2004; Turgut *et al.*, 2005; Wu *et al.*, 2004; Zhang *et al.*, 2003; Zhu *et al.*, 2004).

Pots with a top diameter of 20 cm were used. To ensure that no soil was lost through holes in the base of a pot, each pot was lined with a thin film of silica glass fibre before addition of the growth medium. The growth medium was sieved through a 2 mm sieve as it was poured into each pot to remove smaller pebbles, snail shells, seeds, insect cocoons and glass not removed upon prior sifting, so as to increase homogeneity within the growth medium. Each pot was weighed and amended to contain approximately 3.4 kg of the growth medium. Prior to altering the soil with heavy metals, five pots were randomly selected and soil collected from it to measure the background total concentrations of Ca, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, P, Pb, Se, Sn, V, Zn, and PBray II and soil pH by BemLab (Alvarez-Ayuso and Garcia-Sanches, 2003; Cui *et al.*, 2004; Geebelen *et al.*, 2002; Jiao *et al.*, 2004; Lai and Chen, 2004; Luo *et al.*, 2006; Ownby *et al.*, 2005; Sun *et al.*, 2001; Tang *et al.* , 2004; Wu *et al.*, 2004; Zhang *et al.*, 2003; Zhu *et al.*, 2004).

The growth medium's background concentrations for the selected elements were as follows;

Ca 22428.00 mg/kg, Cd 0.00 mg/kg, Co 0.22 mg/kg,
Cr 4.94 mg/kg, Cu 3.78 mg/kg, Fe 815.06 mg/kg,
Hg 0.00 mg/kg, Mg 433.68 mg/kg, Mn 28.70 mg/kg,
Mo 0.12 mg/kg, Ni 1.67 mg/kg, P 595.99 mg/kg,
Pb 2.18 mg/kg, Se 1.36 mg/kg, Sn 1.84 mg/kg,
V 1.82 mg/kg, Zn 16.71 mg/kg, P Bray II 586.00 mg/kg

and it had a pH of 7.6. Chemical analysis of the growth medium was done by BemLab and followed the same procedures for the analysis of soils as described in Chapter two and is summarized later in this section.

3.2.2. Heavy metal altering of the growth medium

The effectiveness of the selected two amendments was tested on three different concentration levels of the selected three heavy metals, Cd, Pb and Zn. The concentration levels of the heavy metals was decided upon against the background of the South African guidelines, for the maximum permissible, total concentration, of each heavy metal in South African soils (WRC, 1997). The different heavy metal concentration levels were; (1) the *in situ* concentration of each heavy metal in the growth medium, (2) the maximum permissible concentration for each heavy metal in South African soils and thus the growth medium and (3) double the maximum permissible concentration for each heavy metal in the growth medium. The resultant concentrations were thus:

In situ Cd (0.0 mg/kg soil),	2.0 mg Cd /kg soil,	4.0 mg Cd /kg soil
In situ Pb (2.2 mg/kg soil),	6.6 mg Pb /kg soil,	13.2 mg Pb /kg soil
In situ Zn (16.7 mg/kg soil),	46.5 mg Zn /kg soil,	93.0 mg Zn /kg soil

The uptake of Cd, Pb and Zn, by cabbage, was examined individually among treatments and not in combination. Mono-elemental aqueous stock solutions were prepared for each heavy metal at the mentioned concentrations and used to alter the growth medium/soil. Each solution was prepared by dissolving the appropriate amount of the specific metal-nitrate; Cadmium nitrate tetra hydrate (99%), Lead (II) nitrate (99%) and Zinc nitrate hex hydrate (99%) in 15 L of tap water. The concentrations of Cd, Pb and Zn in the tap water supply to the nursery was negligible, hence it was a practical source of water for irrigation of the potted plants and as such it was also used to prepare the various stock solutions. Each pot's soil was spiked by gradually pouring the required volume of a specific mono-elemental solution onto the soil to attain 70% of the soil's water holding capacity. To the pots, which were representative of the *in situ* heavy metal concentrations, the appropriate amount of tap water was added to attain 70% of the soil's water holding capacity. The altered soils were left to equilibrate for 45 days (Geebelen *et al.*, 2002; Illera *et al.*, 2004; Lai and Chen, 2004; Lai and Chen, 2005; Luo *et al.*, 2005**;** Luo *et al.*, 2006; Wu *et al.*, 2004; Ximenez-Embun *et al.*, 2002).

3.2.3. Addition of soil amendments

The two amendment types investigated in this study represented a heavy metal immobilizing amendment and a heavy metal mobilizing amendment. The immobilizing amendment was a triple super phosphate fertilizer treatment and the mobilizing amendment an EDTA solution treatment.

Phosphate amendments can theoretically bind heavy metals in the soil thus rendering them unavailable to plant roots for uptake while providing P, an essential plant mineral nutrient (Brown *et al.*, 2005). The average available phosphate concentration (P Bray II) of the Philippi and Joostenbergvlakte/Kraaifontein farming areas, is usually very high and when planting cabbage, phosphate is not often applied directly to the soil, but rather as a foliar spray (Personal communication with agriculturist, Ms P. Van Tonder). However, application of minor concentrations of a phosphate fertilizer, to the soil, could prove helpful to reduce the uptake of heavy metals by cabbage in these areas' soils. The effectiveness of a triple super phosphate fertilizer, used for the specific purpose of binding heavy metals in the soil, was tested at three different concentration levels.

Several studies that looked at the immobilization of Pb, Cd, Cu and Zn, using various phosphate treatments indicated that a 4.0 molar ratio of P/Pb was effective in immobilizing Pb and also to some extent other heavy metals. It was thus decided to use this molar ratio of P/Pb as starting point to determine an appropriate concentration range for the phosphate immobilization treatment in this experiment (Alvarez-Ayuso and Garcia-Sanches, 2003; Cao *et al.*, 2003; Kumpiene *et al.*, 2007; Melamed *et al.*, 2003; Ownby *et al.*, 2005; Zhu *et al.*, 2004). The three phosphate concentrations used in this experiment were: 1 mg P/kg soil (*in situ* Pb), 4 mg P/kg soil (Pb 6.6 mg/kg soil) and 8 mg P/kg soil (Pb 13.2 mg/kg soil).

A granular triple super phosphate (TSP) fertilizer was used as source for the phosphate amendment treatment. BemLab verified the total concentration of heavy metals, mineral elements and P in the fertilizer. BemLab tests of the TSP fertilizer used in this experiment showed that it contained;

11.2% Ca,	Cd 19.52 mg/kg,	Co 0.53 mg/kg,
Cr 52.67 mg/kg,	Cu 55.95 mg/kg,	Fe 1157.08 mg/kg,
Hg 0.00 mg/kg,	Mg 2606.93 mg/kg,	Mn 128.64 mg/kg,
Mo 60.42 mg/kg,	Ni 44.45 mg/kg,	Pb 0.29 mg/kg,
Se 9.49 mg/kg,	Sn 0.14 mg/kg,	V 179.10 mg/kg

and Zn 604.90 mg/kg. The appropriate amount of P needed for each treatment was calculated based on the percentage of P in the TSP fertilizer (19.8% P). Appropriate amounts of fertilizer were weighed out and then crushed and sieved through a 0.42 mm sieve before application to the soil. The fertilizer was mixed into the soil to a depth of 15 cm. After addition of fertilizer the soil was watered to 40% of its water holding capacity (Alvarez-Ayuso and Garcia-Sanches, 2003; Brown *et al.*, 2004; Brown *et al.*, 2005; Huang *et al.*, 2003; Jiao *et al.*, 2004; Tang *et al.*, 2004; Zhu *et al.*, 2004).

The second set of amendment treatments were three EDTA treatments. EDTA solution amendments are usually investigated for use in bio-remediation programmes, to facilitate and enhance the uptake of heavy metals by metal-accumulating plants. This study, however, investigated the possibility of applying an EDTA solution to the soil, prior to planting of vegetable seedlings, as means of washing/leaching heavy metals away from the root zone and thus diluting the concentration of heavy metals available for uptake by plant roots (Aldrich *et al.*, 2004; Cui *et al.*, 2004; Lai and Chen, 2004; Lai and Chen, 2005; Liphadzi and Kirkham, 2006; Luo *et al.*, 2005; Luo *et al.*, 2006; Palma and Mecozzi, 2007; Penalosa *et al.*, 2007; Sun *et al.*, 2001; Thayalakumaran *et al.*, 2003; Turgut *et al.*, 2005; Wu *et al.*, 2004).

For the EDTA amendment treatment, three different concentration levels were investigated and the solutions were prepared with Ethylenediaminetetraacetic acid disodium salt dihydrate (Na_2-EDTA.2H_2O) (99%). The heavy metal concentrations used in this study were considerably lower than those seen in most phyto-remediation type studies involving the use of EDTA, hence the use of EDTA concentrations based on equimolar concentrations of EDTA and Pb was used as starting point to select suitable EDTA concentration levels for this experiment (Aldrich *et al.*, 2004, Liphadzi and Kirkham, 2006). The three selected EDTA concentrations were: 4mg EDTA/kg soil (*in situ* Pb concentration), 12 mg EDTA/kg soil (Pb 6.6 mg/kg soil) and 24 mg EDTA/kg soil (Pb 13.2 mg/kg soil).

For each concentration an EDTA stock solution was prepared, by dissolving the appropriate amount of Na_2-EDTA.2H_2O in 12 L of tap water. The three EDTA concentrations were used across Cd, Pb and Zn concentration treatments. EDTA was added to the soil by gradually pouring it onto the soil surface. The volume of each EDTA solution used was such to attain 40% of the soil's water holding capacity (Cui *et al.*, 2004; Lai and Chen, 2005; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2004).

A seventh treatment served as a control and entailed the growth of cabbage seedlings at the three different concentrations of the heavy metals, Cd, Pb and Zn, without any added amendment treatments. To the control treatments only tap water was added to equal the moisture content of amendment treated soils (initially 40% of soil water holding capacity).

3.2.4. Soil incubation period

After preparation of the soils with the amendments, the soils were left to equilibrate for 15 days. After 15 days, all soils were watered with tap water to attain 20% of the soil's water holding capacity. The soils were then left for another 7 days to equilibrate, after which seedlings were planted in the soils (Cui *et al.*, 2004; Geebelen *et al.*, 2002; Jiao *et al.*, 2004; Zhu *et al.*, 2004).

3.2.5. Planting of cabbage seedlings

Performance tested "Drumhead" cabbage seeds, chemically treated and packaged by Starke Ayres, were obtained from a local supermarket. The seeds were sown in a non-contaminated silica soil substrate, in a seedling tray. The seeds were watered every second day with tap water and Chemicult hydroponics nutrient solution. The seedlings were transplanted into the treated soils after having grown in seedling trays for 27 days. One seedling was planted in each pot. Upon planting, the seedlings were watered with a known volume of tap water. As the treatment progressed known amounts of tap water were applied as needed. Each plant was watered so as to avoid the collecting of leachate in the saucer underneath its pot (Brown *et al.*, 2005; Cui *et al.*, 2004; Geebelen *et al.*, 2002; Huang *et al.*, 2003; Jiao *et al.*, 2004; Penalosa *et al.*, 2007; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2004; Ximenez-Embun *et al.*, 2002; Zhu *et al.*, 2004). Throughout the experiment weed seedlings were removed on a regular basis upon germination and emergence above the soil surface.

3.2.6. Harvesting of the cabbage

After 74 days the cabbage plants were harvested. The plants were divided into roots and shoots, and the fresh mass thereof determined. The shoots were further divided into stems and leaves, and the fresh mass of each was determined. The plant samples were oven-dried, dry mass determined for each sample and then each sample was ground. The root, stem and leave samples were sent to BemLab for determination of total Cd, Pb and Zn concentrations, as well as total Ca, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, P, Se, Sn, V and PBray II therein. The total concentration of Cd, Pb, Zn, Ca, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, P, Se, Sn, V, PBray II and pH of soil from each treatment pot was also determined by BemLab (Cui *et al.*, 2004; Geebelen *et al.*, 2002; Huang *et al.*, 2003; Jiao *et al.*, 2004; Lai and Chen, 2004; Wu *et al.*, 2004; Ximenez-Embun *et al.*, 2002; Zhu *et al.*, 2004).

3.2.7. Chemical analysis of samples

BemLab's chemical analysis of the soils and plant samples of this experiment was done according to the procedures described in Chapter two and is summarized here. Determining the total concentrations of Cd, Cu, Fe, Hg, Mn, Pb, Sn and Zn in each soil sample included its extraction from the soils with a 0.1 M hydrochloric acid solution, while determination of total Ca, K, Mg and Na concentrations included its extraction from soil with an ammonium acetate solution. Analysis of soil P Bray II involved its extraction from the soil with a Bray II extraction solution. To make the Bray II extraction solution an ammonium fluoride solution was made from 185.5 g ammonium fluoride diluted with water to 5 L. The Bray II extraction solution was made up in a 5 L volumetric flask and contained 150 ml of the above-mentioned ammonium fluoride solution, approximately 4 L of water, 50 ml of hydrochloric acid and was then made-up to 5 L. For the extraction of P Bray II from the soil 6.67 g of soil was placed in a stopper bottle, 50 ml of Bray II extraction solution added and the solution shaken by hand for 40 sec. All the resultant extractions were filtered and the total concentration of various elements determined with an ICP-OES. Cabbage leaf, stem and root samples were ashed and further digested with hydrochloric acid. The residue was made up to 50 ml with distilled water and submitted to the ICP-OES for measurement of total Ca, Cd, Cr, Cu, Hg, K, Mg, Mn, Na, Ni, Pb, Sn, V, Zn and other elements (Personal communication with Dr. W.A.G. Kotzé and A. Van Deventer, BemLab, 2006).

The data obtained from this experiment was used to compare the effectiveness of treatments at decreasing the uptake of respectively Cd, Pb and Zn by cabbage plants. Statistics that were used included Pearson correlation Coefficients, ANOVA's, T-tests and Univariate tests with focus on the Shapiro-Wilk 'p' value. T-tests were used for the post-hoc test since the sample numbers were vary low, there only being three replicates for each treatment. Analysis of variance was used to determine if any differences existed in the experiment as a whole and the least significant differences were calculated to find out what the differences were between any two means. The statistical analysis procedures were run by Ms. Mardé Booyse from the Biometry Unit of the Agricultural Research Counsel.

3.3. Results

The most significant results are reported on in this section. The heavy metals focused on in this experimental research are Cd, Pb and Zn. Table 3.1 reports on significant Pearson's correlations, Table 3.2 on significant variances and Table 3.3 till Table 3.13 records results from the T-test analysis and the mean concentrations and standard deviations for each element measured in each experimental treatment.

From Pearson's correlations in Table 3.1 it was deduced that Ca, Mg and K played a role in the uptake of certain elements and the growth of the cabbage plants (Marschner, 1995). A negative correlation between cabbage stem dry mass and the Cu content of stems indicate that excess Cu could stunt the growth of cabbage (Marschner, 1995; Salisbury and Ross, 1992). As can be expected, the concentration of Ca, Mg and K were significant in terms of indicating plant health, as was seen in its positive correlation to Ca, Mg and water content in cabbage stems (Marschner, 1995; Salisbury and Ross, 1992).

Table 3.1: Significant Pearson's correlations between elements in cabbage organs across all experimental treatments

Plant system or plant organ	Variable	Variable	Sample number (n)	Correlation r (p)
Shoot	Fresh mass	Dry mass	188	0.8596 (0.0001)
Shoot	Mg	Ca	188	0.8734 (0.0001)
Stem	Cu	Dry mass	188	-0.7033 (0.0001)
Stem	K	Water content	188	0.7530 (0.0001)
Stem	Mg	Ca	188	0.8527 (0.0001)

The minerals, Ca, Mg and K are macro nutrients for plants and in general applied to cropped soils along with other fertilisers. Analysis of variance between treatments for Ca, Mg and K are thus indicated in Table 3.2. Sodium and P are also macro nutrients for plants and are indicated in Table 3.2 (Marschner, 1995; Salisbury and Ross, 1992). Research done in Philippi in 2010 indicated that irrigation water was becoming increasingly more saline and for this reason also the Na content of cabbage organs is also indicated in Tables 3.2 and Table 3.8 (Aza-Gnandji, 2011). The sodium salt of EDTA was used in this experimental research and this emphasizes the need for sodium to be mentioned in the results. Variation in P concentrations between the various plant organs across the various treatments are also indicated since phosphate is the main constituent (19.8%) of the triple super phosphate fertiliser used in this experimental research. The concentrations of P in various cabbage plant organs are indicated in Table 3.2 and Table 3.7.

Analysis of variance for Ca, Cd, Cu, Fe, K, Mg, Na, P, Pb, Zn and dry mass of shoots and roots across all experiments are recorded in Table 3.2. Analysis of variance was measured at different levels. The information gathered at the different levels was sourced from respectively the experimental block as a whole, for each metal in totality only, for each set metal concentration only, for a combination of the metal and its different set concentrations only, the different treatments only, the different metals in conjunction with the different treatments only, the different concentration levels in conjunction with the different treatments only and finally the different metals with their different set concentrations in conjunction with the different treatments as a whole. Since the last level of comparing variances was most representative of each pot experiment as a whole, and thus the reality of each cabbage plant's response to its specific growth substrate and subjected treatment, it is mentioned in the results recorded here, despite significant variances being observed on other levels as well. Comments on the observed variances for the selected metals and minerals in cabbage organs are mentioned here below and discussed in more detail in the discussion section of this chapter.

Calcium was indicated as a % of each plant organs constituency in Table 3.2. In Table 3.2 it was observed that stems differed significantly across the different experimental treatments in terms of Ca content. It was observed that Ca was in general more concentrated in the leaves compared to the stems. In the case of Cd, significant variances were noted across the experimental treatments for all plant organs, roots, stems and leaves. Cabbage roots had a greater concentration of Cd compared to the stems and leaves. The fact that cabbage stems had a much lower Cd concentration than the roots indicate that the cabbage plant is probably able to partition Cd between its organs. Cabbage stems showed a lower Cd concentration than cabbage leaves.

In general the leaves had a lesser Cu concentration than the stems but no significant differences in Cu concentrations were observed across the various experimental treatments in either plant organ. The cabbage plants do however appear to be selectively taking up Cu and to differentially partition it between its organs since a much greater concentration of Cu was observed for the roots in general compared to that in the stems and leaves of the cabbage plants.

Table 3.2: Analysis of concentration variance of Ca, Cd, Cu, Fe, K, Mg, Na, P, Pb and Zn in cabbage leaves, stems and roots and variances in dry masses of cabbage shoots and roots across all the experimental treatments

Dependent variable	**Plant organs**	**DF**	**Means**	**F value**	**P value**
Ca	Leaves	24	3.917 %	1.41	0.1155
Ca	Stem	24	0.985 %	1.79	0.0212
Ca	Roots	24	2.013 %	1.48	0.0854
K	Leaves	24	4.458 %	0.86	0.6482
K	Stem	24	7.826 %	1.13	0.3199
K	Roots	24	2.077 %	0.89	0.6187
Mg	Leaves	24	0.615 %	1.56	0.0608
Mg	Stem	24	0.278 %	1.32	0.1657
Mg	Roots	24	0.232 %	1.03	0.4384
Na	Leaves	24	2.446 %	1.21	0.2437
Na	Stem	24	1.373 %	0.74	0.7071
Na	Roots	24	0.419 %	1.30	0.1802
P	Leaves	24	0.437 %	0.69	0.8498
P	Stem	24	0.432 %	1.02	0.4455
P	Roots	24	0.546 %	1.84	0.0167
Cd	Leaves	24	0.263 $mg.kg^{-1}$	2.98	<0.0001
Cd	Stem	24	0.176 $mg.kg^{-1}$	2.01	0.0071
Cd	Roots	24	8.741 $mg.kg^{-1}$	2.53	0.0005
Cu	Leaves	24	3.603 $mg.kg^{-}$	0.62	0.9114
Cu	Stem	24	5.563 $mg.kg^{-1}$	1.57	0.0594
Cu	Roots	24	19.554 $mg.kg^{-1}$	1.18	0.2728
Fe	Leaves	24	56.220 $mg.kg^{-1}$	1.01	0.4649
Fe	Stem	24	23.270 $mg.kg^{-1}$	1.01	0.4542
Fe	Roots	24	578.670 $mg.kg^{-1}$	1.16	0.2963
Pb	Leaves	24	0.304 $mg.kg^{-1}$	0.54	0.9589
Pb	Stem	24	4.003 $mg.kg^{-1}$	1.15	0.2974
Pb	Roots	24	11.208 $mg.kg^{-1}$	1.31	0.1699
Zn	Leaves	24	58.548 $mg.kg^{-1}$	2.01	0.0072
Zn	Stem	24	52.651 $mg.kg^{-1}$	0.82	0.7087
Zn	Roots	24	1906.461 $mg.kg^{-1}$	1.14	0.3149
Dry mass	Shoots	24	4.530 g	1.04	0.4178
Dry mass	Roots	24	0.459 g	1.32	0.1651

In the case of Fe, similar concentrations are seen in the roots and the shoots in general. No significant differences were seen across the experimental treatments and in the case of each plant organ (Table 3.2).

No significant differences were observed for K in any plant organ across the experiment as a whole. Active uptake of K seemed evident as the plant roots had a much lesser K concentration than seen in the stems and leaves of the cabbage plants in general. Active uptake of Mg also seemed evident since much greater concentrations of Mg were seen in the stems and leaves of the cabbage plants in general compared to the roots of the plants. No significant differences were however noted between the different treatments for each organ's Mg concentration in general (Table 3.2).

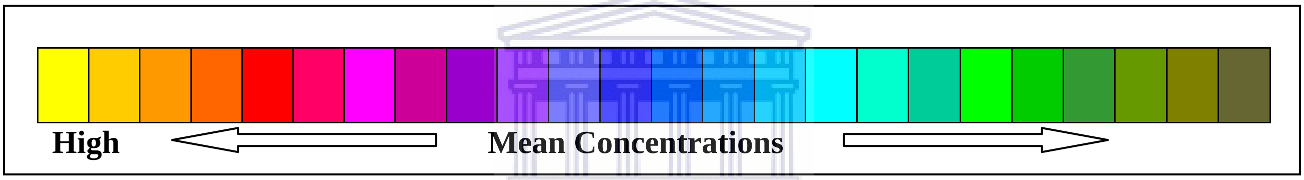
No significant variations were seen in the average Na concentration in each plant organ across the experiment as a whole. The cabbage plants did however seem to readily take Na up since a lower Na concentration was seen in the stems compared to the leaves of the cabbage plants. Phosphate on the other hand did show significant variations across the experimental treatments with regards to the concentration of P in the roots. This significant difference at root level was expected since P fertiliser was applied at differing concentrations in some treatments. No significant difference was seen in P concentration in stems and leaves respectively across the experiment as a whole (Table 3.2).

In the case of Pb, no significant difference was noted between the various experimental treatments in any of the plant organs. In general, however, Pb seemed to be more concentrated in the roots than in the stems and leaves. The cabbage plant thus seemed to differentially partition Pb between the plant organs. It was also noted that the leaves of the cabbage plants in general had a much lower concentration of Pb than the stems. Zinc also seemed to be partitioned differentially between cabbage plant organs. This assumption was made since the roots of the cabbage plants in general showed a significantly greater concentration of Zn than either the stems or leaves of the cabbage plant. The leaves of the cabbage plants varied significantly across the experimental treatments with regards to Zn concentration. No significant differences in Zn concentrations were evident in the case of stems and roots respectively across the experimental treatments (Table 3.2).

According to the analysis of variance tests, no significant differences were seen between dry masses of shoots across the pot experiment as a whole, since the ‘p’ value in this case was 0.4178. According to the analysis of variance for root dry masses, there seemed to be no significant differences across the pot experiment as a whole, since the ‘p’ value in this case was 0.1651. The dry masses of the shoot were in general significantly greater than the dry masses of the roots (Table 3.2). T-tests done for this pot experiment indicated a slightly different scenario to the analysis of variance tests and this may be because the T-tests looked specifically at each experimental treatment and its replicates within the greater pot experiment as a whole.

The results of the T-tests are given in this section of this chapter in Tables 3.3 to Table 3.13. Each experiment was represented by three replicates and a very high standard deviation was thus observed in almost all experiments for all measured variables. The standard deviations are indicated in brackets adjacent to each mean concentration given in the T-test tables. For all T-tests, Alpha was 0.05 and the Error Degrees of Freedom was 123. Interpretation of the T-test analysis tables should be done as explained here below. Each colour in a specific T-test analysis table denotes a significantly different concentration to that of another colour

(Figure 3.1). The greater concentrations are in hues of yellow, orange, red and purple with yellow ( ) indicating the greatest concentration or mass. The lesser concentrations are in hues of blue and green with dark green ( ) denoting the lowest concentration or mass. The colours used across all T-test tables are indicated in Figure 3.1. The same colours used in different tables do not necessarily refer to similar concentration ranges and any similarities are subject to coincidence or possible indirect correlations. As far as possible colours were used to not only indicate the T-test results but also subjectively the general trends in concentration ranges between cabbage leaves, stems and roots across all experiments in one table.



Low

Figure 3.1: Colour key to T-test tables

In Table 3.3 root dry mass yields can be compared across the different sections of the table assigned to either Cd, Pb or Zn and similarly shoot dry mass yield can be compared across the different sections of this table. Across all experiments the least significant difference between shoot mean dry masses was 1.947 g and between root mean dry masses it was 0.402 g. The most important trends in terms of root and shoot dry masses are emphasized here and elaborated on in the Discussion section of this chapter.

Across all experiments where different concentrations of either Cd, Pb or Zn were applied along with different treatments, the root dry masses remained significantly lower than the shoot dry masses. The greatest average root dry mass recorded was 1.006 g in the case where

Pb was at its maximum permissible soil concentration according to South African regulations and this experiment's soil was treated with 24 mg EDTA/kg soil. Most root dry masses however fell between 0.2 g and 0.5 g. The greatest average shoot dry mass was 6.070 g for the treatment of soil with 24 mg EDTA/kg soil where Pb was at the maximum permissible concentration set for South African soils. Shoots varied more in dry mass across the experiments than did roots. Most shoot dry masses seemed to lie between 3.9 g and 5.5 g (WRC, 1997; Table 3.3).

Several significant differences were seen in soils spiked with either Cd, Pb or Zn at different concentrations. The greatest shoot dry mass for cabbage planted in soils spiked with different concentrations of Cd and where different remediation treatments were applied, was obtained where Cd was at *in situ* concentration levels and triple super phosphate fertilizer (TSP) applied at the rate of 8 mg TSP/kg soil. A similar dry mass yield was obtained when Cd was present at the maximum permissible concentration and respectively remediation treatments of 4 mg EDTA/kg soil and 4 mg TSP/kg soil was applied. The highest average shoot yield where Cd was present at double the maximum permissible soil concentration was obtained where 8 mg TSP/kg soil was applied. The greatest shoot yield in the case where Cd was set at twice the maximum permissible concentration was however significantly lower than those mentioned in the cases where Cd was set at the maximum permissible concentration and *in situ* concentration (WRC, 1997; Table 3.3).

Where no remediation treatment was applied at *in situ*, maximum and double the maximum Cd concentrations set for South African soils, no significant difference was observed in shoot dry masses and thus shoot yields. The greatest root dry mass was obtained when cabbage planted in soils at *in situ* Cd concentration levels was treated with 8 mg TSP/kg soil. Root dry mass yields were also great, though significantly less than in the above-mentioned case, when Cd was present at *in situ* concentration and 1 mg TSP/kg applied as well as when Cd was present at the maximum permissible concentration and respectively 12 mg EDTA/kg soil and 4 mg TSP/kg soil was applied. Similar average root dry masses were recorded when Cd was present at twice the maximum permissible concentration and respectively 4 mg EDTA/kg soil and 4 mg TSP/kg soil was applied (Table 3.3).

In experiments where different Pb was present at *in situ* concentration level, the greatest root dry mass was seen when 12 mg EDTA/kg soil was applied. When Pb was present at the maximum permissible concentration for South African soils, the root dry mass yield was greatest when 24 mg EDTA/kg soil was applied. The greatest root dry masses obtained when Pb was present at double the maximum permissible concentration were measured when respectively 4 mg EDTA/kg soil and 8 mg TSP/kg soil was applied. The yields obtained in the last mentioned cases where Pb was at double the maximum permissible concentration was however much less than the greatest mentioned for Pb at maximum and *in situ* concentrations (Table 3.3).

The cabbages with the greatest root dry mass yields did not necessarily have the greatest shoot dry mass yields. For example, the greatest average root dry mass yield, where Pb was at *in situ* concentration and 12 mg EDTA/kg soil applied, had an average shoot dry mass yield that was significantly less than that measured where 4 mg TSP/kg soil was supplied. In the case however where the greatest root dry mass was observed, where Pb was at the maximum permissible concentration and 24 mg EDTA/kg soil was applied, the corresponding shoot dry mass yield was also the greatest seen across all other experiments. The second greatest shoot dry mass yield and corresponding root dry mass yield was seen where Pb was at the maximum permissible concentration in the soil and 8 mg TSP/kg soil was applied (Table 3.3).

Where Pb was present at double the maximum permissible concentration for South African soils, the greatest shoot yield was obtained when 4 mg EDTA/kg soil was obtained. This was the treatment with the greatest average shoot and root dry masses where Pb was at double the maximum concentration. This shoot mass was however not significantly different to that obtained where Pb was at double the maximum concentration and no treatment was applied (Table 3.3).

From Table 3.3 it is seen that the greatest shoot dry mass in the presence of Zn at *in situ* soil concentration was obtained when 1 mg TSP/kg soil was applied. A similarly great shoot yield was obtained when in the presence of Zn at twice the maximum permissible soil concentration respectively 4 mg EDTA/kg soil and 12 mg EDTA/kg soil was applied. When Zn was at the maximum permissible concentration set for South African soils a significantly lesser shoot dry mass yield was obtained when 12 mg EDTA/kg soil was applied, this was however significantly greater than the yields obtained at this Zn concentration with other remediation treatments. In general, the root dry masses corresponding with the above-mentioned shoot dry masses were significantly greater than the root dry masses observed in other treatments applied in the presence of Zn at different concentration levels (WRC, 1997).

Table 3.3: T-test analysis of differences in shoot mean dry masses and root mean dry masses in grams across all experimental treatments

	Cd *in situ*		Cd maximum		Cd double maximum	
	Root	Shoot	Root	Shoot	Roots	Shoot
LSD	0.402	1.947	0.402	1.947	0.402	1.947
No Treatment	0.360 (0.153)	4.740 (0.820)	0.496 (0.104)	4.700 (0.831)	0.366 (0.155)	4.180 (0.399)
4 mg EDTA/ kg soil	0.433 (0.210)	4.500 (1.191)	0.503 (0.142)	4.970 (0.356)	0.536 (0.105)	4.506 (0.930)
12 mg EDTA/ kg soil	0.310 (0.026)	4.036 (0.405)	0.543 (0.315)	4.663 (0.900)	0.403 (0.120)	4.076 (0.455)
24 mg EDTA/ kg soil	0.420 (0.137)	4.130 (1.676)	0.310 (0.196)	3.446 (1.197)	0.453 (0.304)	3.946 (1.397)
1 mg TSP/ kg soil	0.516 (0.170)	4.746 (0.828)	0.453 (0.312)	4.726 (2.263)	0.430 (0.193)	4.166 (1.613)
4 mg TSP/ kg soil	0.476 (0.132)	3.980 (1.516)	0.553 (0.225)	5.026 (1.012)	0.553 (0.246)	4.593 (1.528)
8 mg TSP/ kg soil	0.786 (0.583)	5.236 (1.955)	0.386 (0.150)	4.556 (1.151)	0.506 (0.331)	4.810 (2.193)
	Pb *in situ*		Pb maximum		Pb double maximum	
	Root	Shoot	Root	Shoot	Roots	Shoot
No Treatment	0.420 (0.271)	3.993 (1.078)	0.593 (0.061)	5.140 (0.841)	0.426 (0.310)	5.060 (2.706)
4 mg EDTA/ kg soil	0.503 (0.185)	4.846 (1.240)	0.270 (0.104)	3.300 (0.589)	0.460 (0.088)	5.096 (0.421)
12 mg EDTA/ kg soil	0.566 (0.478)	4.480 (1.510)	0.463 (0.231)	4.840 (1.568)	0.366 (0.204)	4.476 (1.596)
24 mg EDTA/ kg soil	0.393 (0.050)	4.510 (0.502)	1.006 (0.575)	6.070 (2.058)	0.226 (0.061)	3.676 (0.615)
1 mg TSP/ kg soil	0.266 (0.015)	3.656 (0.510)	0.520 (0.450)	4.553 (2.006)	0.225 (0.289)	2.940 (2.107)
4 mg TSP/ kg soil	0.440 (0.157)	4.960 (1.145)	0.490 (0.287)	4.773 (1.522)	0.293 (0.028)	4.236 (0.271)
8 mg TSP/ kg soil	0.456 (0.220)	4.500 (0.565)	0.906 (0.557)	5.953 (2.733)	0.390 (0.157)	4.306 (1.267)
	Zn *in situ*		Zn maximum		Zn double maximum	
	Root	Shoot	Root	Shoot	Roots	Shoot
No Treatment	0.480 (0.199)	4.506 (1.090)	0.416 (0.153)	5.063 (1.242)	0.390 (0.145)	4.523 (1.179)
4 mg EDTA/ kg soil	0.326 (0.151)	5.210 (0.408)	0.573 (0.448)	4.840 (3.150)	0.576 (0.115)	5.780 (0.292)
12 mg EDTA/ kg soil	0.206 (0.064)	2.780 (0.800)	0.553 (0.047)	5.250 (1.260)	0.583 (0.323)	5.690 (2.387)
24 mg EDTA/ kg soil	0.426 (0.357)	3.736 (1.382)	0.330 (0.183)	3.373 (1.230)	0.370 (0.175)	4.790 (0.524)
1 mg TSP/ kg soil	0.803 (0.667)	5.850 (2.587)	0.570 (0.453)	4.273 (1.485)	0.303 (0.200)	4.376 (0.768)
4 mg TSP/ kg soil	0.490 (0.199)	4.900 (0.424)	0.300 (0.060)	4.043 (0.764)	0.546 (0.643)	5.006 (2.774)
8 mg TSP/ kg soil	0.453 (0.360)	4.286 (1.428)	0.443 (0.158)	4.400 (1.009)	0.283 (0.110)	3.326 (0.165)

The T-tests results for the concentrations of Cd, Pb and Zn in cabbage leaves, stems and roots across all experiments are summarised in respectively Table 3.4, 3.5 and 3.6. The T-tests for the concentrations of P, Na, Cu, Fe, Ca, Mg and K in cabbage leaves, stems and roots are given in Table 3.7, 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13 in order of relevance to this specific study. In these T-test tables colours are used to denote significant differences between average concentrations of a specific element in either leaves, stems or roots across all treatments in conjunction with different Cd, Pb and Zn concentrations. Similar colours used for respectively leaves, stems or roots do not necessarily refer to the same concentration ranges under investigation. As far as possible colour was used to indicate relative concentration range differences between leaves stems and roots, but this was done with some subjectivity and any comparisons between leaves, stems and roots should be verified with information from Table 3.2. To be more objective with regard to interpretation of the T-test results, leaves should be looked at independently from stems and/or roots and *visa versa*. Comments regarding clear trends observed across the tables between leaves, stems and roots are mentioned and discussed in the Discussion section of this chapter.

Table 3.4 summarises T-test results and concentrations of Cd in cabbage leaves, stems and roots across all experiments conducted. As expected, in general, cabbage plants in experiments where Cd was increased to either the maximum or double the maximum permissible concentration set for South African soils, elevated Cd concentrations were seen in roots, leaves and to a lesser extent in stems across all remedial treatments, compared to experiments with *in situ* Cd concentrations and/or elevated levels of Pb and/or elevated levels of Zn. In the cases where Cd was present at maximum and double the maximum concentration set for South African soils, cabbage leaves, stems and roots exceeded the maximum permissible level set for South African foodstuffs of 0.05 $mg.kg^{-1}$ (WRC, 1997; DoH, 2004).

From Table 3.4 is observed that the Cd concentrations in roots in experiments where Cd was at *in situ* concentrations (this includes experiments with elevated levels of Pb and Zn), no significant differences were observed across any remedial treatments. The greatest average Cd root concentrations were seen when Cd was present at the maximum permissible soil concentration and 24 mg EDTA/kg soil was applied as well as when twice the maximum permissible Cd concentration and 12 mg EDTA/kg soil was applied. The lowest Cd concentration in roots was observed when no remedial treatments were applied in both the case of Cd set at the maximum permissible soil concentration and Cd at twice the maximum permissible soil concentration in South Africa (WRC, 1997).

Cabbage stems showed the greatest Cd concentration where 12 mg EDTA/kg soil was applied and Cd set at the maximum permissible soil concentration and in the case where it was set at double the maximum permissible concentration. In case of Cd at double the maximum permissible concentration for soil, similar Cd concentrations were seen in cabbage stems when 4 mg EDTA/kg soil was applied. The lowest Cd concentration in stems was seen when Cd was at the maximum permissible soil concentration and 1 mg TSP/kg soil applied. Where Cd was present at double the maximum permissible soil concentration, the lowest Cd in stems were seen where respectively 24 mg EDTA/kg soil, 1 mg TSP/kg and 4 mg TSP/kg soil was applied (WRC, 1997; Table 3.4).

From Table 3.4, the greatest Cd concentrations in leaves were seen in the treatment of 24 mg EDTA/kg soil, where Cd was set at the maximum permissible soil concentration and in the treatment where 12 EDTA/kg soil was applied and Cd present at double the permissible soil concentration. The lowest Cd concentrations in cabbage leaves were seen where Cd was set at the maximum permissible soil concentration and 1 mg TSP/kg soil applied and where Cd was set at twice the maximum permissible Cd soil concentration and 8 mg TSP/kg soil applied. Cabbage leaves are generally the part eaten by consumers and in the case where Cd was elevated to the maximum and double the maximum permissible soil concentrations both South African (0.05 $mg.kg^{-1}$) and European (0.10 $mg.kg^{-1}$) standards set for foodstuffs were exceeded (CoEC, 2006; DoH, 2004; WRC, 1997).

From Table 3.4 it would appear that the presence of Zn also affects the concentration of Cd across all treatments. Cd in leaves was the lowest in cases where Zn was present at twice the maximum permissible concentration across all treatments except where 4 mg TSP/kg soil was applied. In general, the uptake of Cd seemed significantly greater in the roots, followed by stems and leaves where Cd was at *in situ* soil concentration. When Cd was elevated in soils, the leaves appeared to accumulate Cd across all treatments.

The stems of cabbage in general, across all treatments and at various concentrations of Cd, Pb and Zn did not seem to accumulate much Pb. When the soil Pb concentration was at *in situ* level and 4 mg EDTA/kg soil applied and also when Pb was at *in situ* and together with Zn at its maximum permissible soil concentration and 12 mg EDTA/kg soil was applied, slightly higher concentrations of Pb were observed in stems than in the other experimental treatments. In general, across almost all experiments, Pb in stems exceeded the maximum permissible concentration allowed in food stuffs of both South Africa (0.10 $mg.kg^{-1}$) and Europe (0.30 $mg.kg^{-1}$) (CoEC, 2006; DoH, 2004; WRC, 1997; Table 3.5).

Table 3.4: T-test results for cadmium concentrations in mg.kg^{-1} in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 0.455 mg.kg^{-1}									
No Treatment	0.020 (0.020)	0.560 (0.215)	0.773 (0.325)	0.030 (0.030)	0.047 (0.021)	0.020 (0.026)	0.030 (0.017)	0.023 (0.025)	0.013 (0.023)
4 mg EDTA/kg soil	0.017 (0.021)	1.080 (0.848)	1.247 (0.648)	0.023 (0.006)	0.027 (0.038)	0.020 (0.026)	0.007 (0.006)	0.017 (0.029)	0.000 (0.000)
12 mg EDTA/kg soil	0.007 (0.006)	0.863 (0.438)	3.087 (1.682)	0.000 (0.000)	0.027 (0.015)	0.043 (0.025)	0.010 (0.010)	0.020 (0.020)	0.007 (0.012)
24 mg EDTA/kg soil	0.020 (0.035)	1.573 (0.552)	1.713 (0.236)	0.037 (0.006)	0.023 (0.032)	0.017 (0.029)	0.020 (0.020)	0.007 (0.006)	0.000 (0.000)
1 mg TSP/kg soil	0.013 (0.012)	0.470 (0.239)	1.270 (0.332)	0.033 (0.031)	0.023 (0.021)	0.050 (0.014)	0.027 (0.023)	0.003 (0.006)	0.010 (0.017)
4 mg TSP/kg soil	0.020 (0.020)	0.620 (0.115)	0.953 (0.228)	0.030 (0.010)	0.033 (0.015)	0.013 (0.015)	0.013 (0.006)	0.010 (0.017)	0.073 (0.081)
8 mg TSP/kg soil	0.013 (0.023)	0.580 (0.386)	0.710 (0.325)	0.027 (0.023)	0.017 (0.015)	0.007 (0.012)	0.023 (0.015)	0.023 (0.021)	0.013 (0.023)
Stems LSD 0.412 mg.kg^{-1}									
No Treatment	0.030 (0.052)	0.300 (0.316)	0.443 (0.417)	0.116 (0.125)	0.030 (0.052)	0.076 (0.124)	0.040 (0.036)	0.333 (0.577)	0.236 (0.230)
4 mg EDTA/kg soil	0.053 (0.092)	0.436 (0.171)	0.916 (0.618)	0.000 (0.000)	0.000 (0.000)	0.003 (0.005)	0.000 (0.000)	0.273 (0.398)	0.090 (0.115)
12 mg EDTA/kg soil	0.073 (0.127)	0.546 (0.450)	2.066 (0.998)	0.143 (0.239)	0.073 (0.127)	0.063 (0.085)	0.000 (0.000)	0.023 (0.032)	0.146 (0.127)
24 mg EDTA/kg soil	0.013 (0.015)	0.286 (0.234)	0.293 (0.295)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.266 (0.247)	0.143 (0.190)
1 mg TSP/kg soil	0.110 (0.190)	0.006 (0.011)	0.186 (0.172)	0.040 (0.069)	0.090 (0.155)	0.125 (0.176)	0.063 (0.065)	0.196 (0.258)	0.166 (0.147)
4 mg TSP/kg soil	0.280 (0.131)	0.380 (0.185)	0.393 (0.179)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.020 (0.034)	0.060 (0.095)	0.023 (0.040)
8 mg TSP/kg soil	0.000 (0.000)	0.296 (0.259)	0.490 (0.840)	0.126 (0.110)	0.096 (0.090)	0.003 (0.005)	0.000 (0.000)	0.253 (0.245)	0.130 (0.112)
Roots LSD 14.860 mg.kg^{-1}									
No Treatment	0.740 (0.085)	14.983 (3.389)	24.786 (18.565)	1.476 (0.557)	0.706 (0.261)	0.513 (0.392)	0.900 (0.246)	0.426 (0.273)	0.790 (0.298)
4 mg EDTA/kg soil	0.730 (0.726)	21.673 (5.500)	39.776 (12.339)	0.603 (0.234)	1.170 (0.375)	0.693 (0.130)	0.550 (0.020)	0.6000 (0.701)	0.973 (0.248)
12 mg EDTA/kg soil	0.976 (0.319)	28.346 (10.767)	105.650 (59.207)	0.623 (0.150)	0.750 (0.440)	0.833 (0.208)	0.663 (0.344)	0.476 (0.375)	0.870 (0.304)
24 mg EDTA/kg soil	0.846 (0.436)	30.856 (9.552)	63.923 (15.239)	1.076 (0.420)	0.580 (0.448)	1.293 (0.234)	0.786 (0.275)	0.956 (0.312)	0.653 (0.145)
1 mg TSP/kg soil	0.760 (0.329)	19.203 (9.076)	41.510 (13.115)	1.256 (0.839)	0.586 (0.560)	1.590 (0.919)	0.556 (0.159)	0.883 (0.220)	0.766 (0.241)
4 mg TSP/kg soil	0.636 (0.224)	18.653 (5.450)	50.600 (19.555)	0.676 (0.453)	0.610 (0.183)	1.010 (0.166)	0.900 (0.246)	0.903 (0.329)	0.503 (0.147)
8 mg TSP/kg soil	0.720 (0.308)	17.676 (2.880)	31.857 (13.727)	0.820 (0.602)	0.973 (0.447)	0.710 (0.190)	0.476 (0.109)	0.820 (0.390)	0.670 (0.255)

The leaves of cabbage, in general, do not appear to accumulate Pb however, in many of the experimental treatments, Pb exceeded the limits set for Pb in food stuffs according to South African regulations (Table 3.5). Lead did not even appear to be accumulated in leaves when it was elevated in experimental soils. Leaves had, in general, a lower Pb content than stems. In the case where Pb was at *in situ* soil concentration, Zn at the maximum permissible concentration and 12 mg EDTA/kg soil applied, the Pb concentration in cabbage leaves was greatest and exceeded the South African and European limits set for food stuffs. In general the stems and roots of cabbage plants exceeded the limits set in South Africa and Europe for Pb foodstuffs (CoEC, 2006; DoH, 2004).

Table 3.5. T-test results for lead concentrations in mg.kg^{-1} in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 1.290 mg.kg^{-1}									
No Treatment	0.277 (0.285)	0.297 (0.405)	0.167 (0.015)	0.300 (0.052)	0.450 (0.607)	0.210 (0.289)	0.257 (0.114)	0.253 (0.227)	0.203 (0.241)
4 mg EDTA/kg soil	0.087 (0.150)	0.230 (0.241)	0.083 (0.074)	0.300 (0.305)	0.183 (0.251)	0.293 (0.228)	0.147 (0.123)	0.000 (0.000)	0.027 (0.046)
12 mg EDTA/kg soil	0.190 (0.329)	0.333 (0.093)	0.193 (0.190)	0.200 (0.207)	0.497 (0.633)	0.783 (0.476)	0.273 (0.286)	0.077 (0.124)	2.450 (4.157)
24 mg EDTA/kg soil	0.077 (0.133)	0.143 (0.223)	0.407 (0.387)	0.147 (0.116)	0.460 (0.579)	0.527 (0.692)	0.013 (0.023)	0.153 (0.142)	0.613 (0.801)
1 mg TSP/kg soil	0.133 (0.231)	0.167 (0.231)	0.203 (0.200)	0.183 (0.127)	0.290 (0.292)	0.040 (0.057)	0.150 (0.095)	0.117 (0.153)	0.193 (0.200)
4 mg TSP/kg soil	0.253 (0.225)	0.190 (0.271)	0.217 (0.193)	0.150 (0.110)	0.430 (0.336)	0.087 (0.151)	0.160 (0.145)	0.070 (0.075)	2.003 (3.470)
8 mg TSP/kg soil	0.160 (0.197)	0.253 (0.439)	0.230 (0.128)	0.090 (0.082)	0.187 (0.242)	0.233 (0.110)	0.143 (0.136)	0.033 (0.031)	1.680 (2.679)
Stems LSD 7.578 mg.kg^{-1}									
No Treatment	2.620 (1.053)	2.260 (2.509)	7.116 (3.188)	8.933 (6.730)	4.153 (2.496)	5.310 (2.595)	2.760 (2.391)	2.853 (2.478)	6.070 (6.433)
4 mg EDTA/kg soil	0.010 (0.017)	1.026 (1.692)	3.373 (1.552)	9.206 (15.575)	3.786 (2.086)	0.880 (1.524)	0.170 (0.294)	3.893 (5.981)	2.256 (2.117)
12 mg EDTA/kg soil	4.086 (3.611)	1.156 (2.003)	4.846 (4.980)	0.000 (0.000)	0.976 (1.691)	3.500 (4.027)	2.533 (1.283)	20.490 (20.992)	6.300 (2.501)
24 mg EDTA/kg soil	6.536 (7.201)	5.856 (6.139)	2.800 (1.272)	1.096 (0.988)	3.636 (3.518)	4.236 (4.012)	4.083 (4.860)	4.270 (5.629)	3.573 (1.906)
1 mg TSP/kg soil	0.316 (0.548)	2.690 (1.216)	1.736 (1.562)	5.506 (1.421)	2.770 (2.943)	4.350 (5.119)	3.120 (2.548)	4.516 (3.932)	3.750 (4.549)
4 mg TSP/kg soil	8.083 (3.040)	5.270 (5.845)	5.006 (0.741)	4.460 (1.411)	3.066 (3.526)	5.183 (2.420)	4.500 (4.375)	2.613 (2.910)	4.036 (2.707)
8 mg TSP/kg soil	2.120 (2.781)	4.696 (2.810)	1.506 (1.973)	6.206 (2.101)	4.303 (3.456)	4.663 (2.044)	3.416 (3.042)	4.020 (2.615)	3.723 (3.957)
Roots LSD 10.105 mg.kg^{-1}									
No Treatment	9.273 (9.797)	10.443 (11.067)	2.230 (2.433)	11.646 (6.892)	11.336 (6.909)	19.110 (6.197)	8.630 (0.542)	9.210 (4.573)	9.476 (4.018)
4 mg EDTA/kg soil	12.573 (0.912)	4.486 (7.224)	4.670 (2.867)	5.426 (6.383)	24.010 (16.598)	24.403 (3.609)	4.973 (3.501)	8.093 (4.136)	7.306 (3.002)
12 mg EDTA/kg soil	10.313 (8.774)	15.046 (14.006)	11.506 (5.767)	7.506 (6.193)	14.130 (9.199)	30.010 (20.728)	7.923 (2.179)	7.743 (7.624)	1.693 (1.670)
24 mg EDTA/kg soil	6.726 (8.284)	10.443 (2.417)	8.113 (7.078)	4.993 (7.404)	22.706 (7.952)	34.150 (2.581)	6.863 (4.379)	10.163 (3.530)	9.233 (5.563)
1 mg TSP/kg soil	4.236 (2.177)	9.110 (8.993)	4.220 (6.298)	10.906 (9.079)	16.673 (10.900)	10.835 (15.323)	7.416 (2.754)	9.733 (4.487)	8.200 (7.930)
4 mg TSP/kg soil	13.110 (8.602)	8.356 (3.226)	15.696 (9.021)	7.190 (8.083)	11.910 (3.732)	26.333 (3.328)	11.446 (7.661)	13.480 (8.023)	10.986 (2.158)
8 mg TSP/kg soil	7.910 (1.391)	18.166 (14.351)	4.283 (3.333)	9.120 (10.352)	14.130 (4.650)	25.736 (4.274)	5.180 (5.032)	7.570 (9.439)	7.590 (7.552)

In general, cabbage leaves only exceeded South African limits set for Pb in food stuffs. Where Pb was at maximum concentration and twice the maximum concentration and either 12 mg EDTA/kg soil, 24 mg EDTA/kg soil or 4 mg TSP/kg soil applied, European standards set for Pb in foodstuffs was exceeded in cabbage leaves. When Zn was set at twice the maximum permitted concentration for South African soils, and respectively 12 mg EDTA/kg soil, 4 mg TSP/kg soil and 8 mg TSP/kg soil applied Pb also exceeded South African and European standards set for foodstuffs. Roots did not seem to accumulate much Pb as inconsistent concentrations of Pb were measured in treatments where Pb was at *in situ* concentration levels. Cabbage plants thus seemed able to tolerate the *in situ* level of Pb which was 2.2 mg/kg experimental soil (CoEC, 2006; DoH, 2004; Marschner, 1995; Prasad and De Oliveira, 2003; Salisbury and Ross, 1992; WRC, 1997; Table 3.5).

Table 3.6 reflects the T-test results for the accumulation of Zn across all experiments in cabbage leaves, stems and roots. Across all experiments, the trend seemed to indicate that cabbage roots accumulated more Zn than cabbage stems and leaves especially where Zn was elevated in the soil to both the maximum and twice the maximum concentration set for Zn in South African soils. In general, cabbage leaves across all experiments exceeded the maximum concentration set in South Africa for Zn (40.0 $mg.kg^{-1}$) in foodstuffs. In all the cases where Zn was elevated to the maximum and double the maximum concentration in soil according to South African limits set for soil, the concentration of Zn in cabbage leaves also exceeded that set for foodstuffs in South Africa (DoH, 2004; WRC, 1997).

When Zn was elevated to a maximum, the greatest concentration in roots was when 4 mg TSP/kg soil was applied. When Zn was elevated to twice the maximum concentration set for soil, the greatest Zn concentration in roots was seen when 1 mg TSP/kg soil was applied.

When Zn was at *in situ* concentration in soil and 4 mg EDTA/kg soil applied, Zn was greatest in roots. The lowest Zn concentration in roots occurred when no treatment was applied and Cd was present at twice the maximum concentration set for South African soils. The roots, though containing more Zn than the stems and leaves in general, did not show clear accumulation of Zn since its concentrations across all treatments and set concentrations of Cd, Pb and Zn, were inconsistent (WRC, 1997; Table 3.6).

In the stems of cabbage plants, the greatest Zn concentration was seen when Zn in the soil was at *in situ*, Cd at the maximum concentration and 24 mg EDTA/kg soil applied. The lowest Zn concentration in cabbage stems on the other hand was seen when Zn was at *in situ*, Pb at twice the maximum and 1 mg TSP/kg soil applied (Table 3.6). In the case of cabbage leaves the lowest Zn concentration was also seen where Zn was at *in situ* concentration in the soil and 1 mg TSP/kg soil applied as well as when Zn was at *in situ* concentration in the soil, Cd at twice the maximum concentration for soil and 1 mg TSP/kg soil applied. The greatest Zn concentration in cabbage leaves was seen when Zn was at twice the maximum concentration set for soil and 24 mg EDTA/kg soil applied. No clear accumulation of Zn in either leaves or stems could be pinpointed as much variation occurred across the treatments of this experiment as a whole (Table 3.6).

The percentage concentration of P across all experiments is summarised in Table 3.7. This element is present as a main ingredient in the TSP treatments, but was also present in the growth mediums prior to addition of TSP or EDTA treatments. The uptake of P is thus evaluated across experiments to see if the TSP treatments had any added nutritional value compared to treatments where TSP was not applied as remedial treatment.

Table 3.6. T-test results for zinc concentrations in mg.kg^{-1} in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 16.985 mg.kg^{-1}									
No Treatment	42.307 (5.587)	37.450 (4.848)	44.523 (12.441)	45.460 (10.388)	44.297 (9.721)	49.250 (16.364)	39.093 (7.728)	76.560 (3.855)	126.717 (9.435)
4 mg EDTA/kg soil	43.553 (16.722)	40.633 (3.333)	34.647 (3.811)	44.327 (12.366)	47.070 (3.968)	44.567 (1.735)	37.700 (8.494)	79.140 (21.631)	133.040 (10.039)
12 mg EDTA/kg soil	46.650 (1.014)	48.310 (3.444)	49.123 (3.902)	38.580 (8.142)	45.763 (4.627)	45.867 (3.332)	48.573 (11.953)	92.157 (23.320)	111.147 (15.820)
24 mg EDTA/kg soil	48.910 (0.053)	53.230 (6.956)	47.360 (5.073)	56.560 (6.089)	55.780 (6.925)	53.133 (7.370)	70.450 (21.040)	128.880 (5.221)	146.853 (12.925)
1 mg TSP/kg soil	37.150 (6.493)	35.860 (5.004)	33.033 (0.785)	42.290 (5.392)	43.873 (14.588)	38.770 (1.838)	33.350 (11.036)	89.530 (10.496)	132.967 (10.731)
4 mg TSP/kg soil	46.513 (18.981)	43.257 (9.737)	41.503 (5.475)	37.640 (8.132)	78.757 (26.105)	39.343 (2.695)	51.393 (17.761)	85.723 (15.128)	90.230 (7.876)
8 mg TSP/kg soil	34.833 (5.092)	39.940 (5.417)	39.183 (10.654)	37.757 (5.987)	44.703 (23.912)	43.050 (3.607)	36.537 (0.764)	93.880 (14.887)	112.903 (27.571)
Stems LSD 73.610 mg.kg^{-1}									
No Treatment	43.483 (34.564)	45.880 (24.570)	29.947 (3.776)	28.400 (7.810)	25.710 (5.677)	43.037 (17.972)	23.657 (5.490)	39.560 (5.246)	120.517 (112.462)
4 mg EDTA/kg soil	41.350 (24.240)	25.707 (7.513)	80.387 (40.524)	20.247 (5.031)	32.833 (1.510)	22.067 (2.537)	108.027 (50.206)	47.420 (15.719)	100.997 (64.454)
12 mg EDTA/kg soil	33.330 (11.157)	26.563 (3.972)	50.930 (11.204)	26.463 (11.242)	42.657 (24.826)	22.797 (5.194)	45.863 (19.348)	74.047 (10.770)	112.753 (107.218)
24 mg EDTA/kg soil	56.333 (25.667)	138.257 (148.945)	77.763 (47.557)	38.007 (11.305)	25.180 (11.280)	63.423 (43.468)	79.213 (79.829)	123.217 (71.510)	90.577 (18.078)
1 mg TSP/kg soil	20.575 (8.267)	33.723 (9.582)	28.947 (7.787)	39.120 (22.220)	66.210 (58.801)	14.025 (15.182)	39.480 (44.510)	41.677 (2.896)	71.403 (22.878)
4 mg TSP/kg soil	61.560 (25.192)	40.183 (30.162)	43.880 (20.586)	41.797 (24.526)	41.237 (23.438)	34.660 (15.633)	52.537 (18.155)	83.320 (86.622)	56.737 (45.563)
8 mg TSP/kg soil	118.163 (155.560)	46.277 (24.952)	26.763 (6.817)	83.677 (56.555)	53.150 (37.233)	29.573 (5.432)	31.607 (13.977)	47.663 (19.432)	47.703 (14.081)
Roots LSD 1980.300 mg.kg^{-1}									
No Treatment	1452.823 (1166.114)	3196.003 (2240.670)	640.177 (439.201)	2357.267 (342.778)	1837.873 (1870.977)	1101.623 (772.477)	1868.583 (184.733)	1605.830 (1119.425)	2691.277 (2033.280)
4 mg EDTA/kg soil	3528.180 (750.380)	1495.650 (255.271)	1265.583 (920.699)	2415.647 (2039.155)	1922.330 (687.987)	3104.563 (1973.595)	2661.470 (2090.231)	1444.443 (891.383)	1677.777 (1113.849)
12 mg EDTA/kg soil	1934.277 (1288.001)	1424.577 (652.278)	2355.247 (1645.982)	1090.483 (238.056)	1678.340 (1654.581)	1489.750 (849.603)	1889.073 (2084.564)	1648.790 (1424.494)	1419.553 (837.524)
24 mg EDTA/kg soil	2857.683 (2290.282)	2916.803 (881.335)	1093.487 (474.714)	1543.397 (1002.434)	1229.853 (963.419)	1766.197 (723.584)	2130.300 (292.114)	2244.827 (924.988)	2199.030 (853.888)
1 mg TSP/kg soil	1135.990 (612.437)	2568.327 (703.405)	1875.357 (1157.881)	2363.480 (970.553)	1017.570 (238.874)	1605.950 (870.859)	2135.663 (725.175)	1001.930 (1153.511)	3534.990 (1417.313)
4 mg TSP/kg soil	2093.157 (1246.631)	1835.923 (893.870)	2275.283 (1071.622)	1312.840 (695.931)	1894.040 (524.702)	747.533 (591.756)	1207.237 (1037.603)	3415.817 (3425.933)	1817.603 (530.456)
8 mg TSP/kg soil	1035.330 (107.736)	2894.820 (791.376)	1049.633 (770.915)	795.940 (280.743)	1719.540 (1280.990)	2346.840 (598.827)	1617.367 (2235.322)	2611.000 (1841.974)	2918.977 (3174.214)

From Table 3.7 it is clear that the greatest P % concentrations were seen in cabbage roots across all experiments. The greatest percentage concentration of P in cabbage roots was seen when Pb was at twice the maximum concentration and 1 mg TSP/kg soil applied. The second greatest root P % concentration was, however, seen where no treatment was applied and Pb was *in situ* soil concentration. Treatments with EDTA showed greater P levels in roots than treatments with TSP in general. The lowest percentage concentration of P was seen where no treatment was applied and Cd was at twice the maximum permissible concentration set for soils (WRC, 1997).

Looking at the percentage concentration of P in stems, in general, the lowest P % concentrations were seen where Zn was in excess in the soil. P was lowest in the presence of Pb at twice the maximum set soil concentration where 1 mg TSP/kg soil was applied. Equally low was the percentage concentration of P in stems when Zn was at twice the maximum permitted soil concentration and 1 mg TSP/kg soil applied. The exact influence of Zn was not investigated in the experiment and is unclear since the greatest percentage concentration of P in stems was seen where Zn was set at the maximum soil concentration and 12 mg EDTA/kg soil applied (WRC, 1997; Table 3.7).

In general, it seemed that P accumulated in cabbage leaves but similar P concentrations were also seen in cabbage stems. In the leaves of cabbage, the greatest P % concentration was seen where Zn was at *in situ* level and 24 mg EDTA/kg soil applied. The lowest P % concentration in cabbage leaves was seen where Cd was present at the maximum permissible level for South African soils and 1 mg TSP/kg soil applied. Equally low was the P % concentration in leaves where Zn was set at twice the maximum in the soil and 4 mg EDTA/kg soil applied. When Zn was present at the maximum set for South African soils and

4 mg EDTA/kg soil applied, the resultant P % concentration in cabbage leaves was only slightly greater than in the last mentioned treatment (WRC, 1997; Table 3.7).

Table 3.7. T-test results for phosphorus percentage concentrations in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
				Leaves LSD 0.068 %					
No Treatment	0.467 (0.006)	0.443 (0.012)	0.440 (0.017)	0.487 (0.012)	0.417 (0.040)	0.433 (0.076)	0.477 (0.051)	0.407 (0.040)	0.443 (0.061)
4 mg EDTA/kg soil	0.423 (0.045)	0.447 (0.032)	0.443 (0.051)	0.460 (0.036)	0.467 (0.050)	0.443 (0.006)	0.457 (0.025)	0.393 (0.076)	0.383 (0.025)
12 mg EDTA/kg soil	0.423 (0.021)	0.433 (0.032)	0.450 (0.056)	0.460 (0.062)	0.433 (0.045)	0.447 (0.031)	0.410 (0.046)	0.443 (0.023)	0.403 (0.051)
24 mg EDTA/kg soil	0.447 (0.059)	0.440 (0.035)	0.400 (0.046)	0.447 (0.025)	0.427 (0.051)	0.467 (0.025)	0.493 (0.047)	0.443 (0.015)	0.410 (0.050)
1 mg TSP/kg soil	0.420 (0.026)	0.380 (0.053)	0.423 (0.015)	0.447 (0.032)	0.417 (0.084)	0.435 (0.078)	0.420 (0.128)	0.430 (0.026)	0.433 (0.015)
4 mg TSP/kg soil	0.443 (0.035)	0.450 (0.026)	0.417 (0.017)	0.450 (0.020)	0.430 (0.092)	0.460 (0.035)	0.453 (0.049)	0.413 (0.012)	0.400 (0.046)
8 mg TSP/kg soil	0.447 (0.072)	0.467 (0.050)	0.413 (0.025)	0.447 (0.015)	0.423 (0.064)	0.447 (0.015)	0.480 (0.000)	0.453 (0.023)	0.440 (0.046)
				Stems LSD 0.211 %					
No Treatment	0.443 (0.092)	0.443 (0.041)	0.413 (0.032)	0.530 (0.036)	0.463 (0.066)	0.436 (0.076)	0.456 (0.090)	0.410 (0.096)	0.376 (0.056)
4 mg EDTA/kg soil	0.493 (0.051)	0.430 (0.078)	0.416 (0.055)	0.510 (0.087)	0.426 (0.005)	0.416 (0.049)	0.530 (0.055)	0.346 (0.030)	0.353 (0.055)
12 mg EDTA/kg soil	0.486 (0.055)	0.423 (0.037)	0.426 (0.005)	0.466 (0.066)	0.420 (0.087)	0.500 (0.098)	0.456 (0.015)	0.573 (0.319)	0.336 (0.020)
24 mg EDTA/kg soil	0.510 (0.095)	0.433 (0.095)	0.406 (0.058)	0.496 (0.020)	0.436 (0.040)	0.450 (0.026)	0.416 (0.089)	0.373 (0.041)	0.336 (0.072)
1 mg TSP/kg soil	0.436 (0.111)	0.370 (0.087)	0.436 (0.072)	0.396 (0.011)	0.363 (0.032)	0.255 (0.289)	0.460 (0.108)	0.356 (0.061)	0.310 (0.026)
4 mg TSP/kg soil	0.470 (0.034)	0.500 (0.043)	0.423 (0.075)	0.530 (0.079)	0.453 (0.047)	0.453 (0.106)	0.423 (0.072)	0.326 (0.150)	0.386 (0.077)
8 mg TSP/kg soil	0.440 (0.010)	0.493 (0.066)	0.493 (0.097)	0.436 (0.055)	0.493 (0.023)	0.433 (0.104)	0.486 (0.100)	0.330 (0.151)	0.343 (0.057)
				Roots LSD 0.211 %					
No Treatment	0.583 (0.060)	0.493 (0.090)	0.307 (0.222)	0.693 (0.276)	0.483 (0.055)	0.567 (0.144)	0.543 (0.038)	0.577 (0.095)	0.513 (0.067)
4 mg EDTA/kg soil	0.567 (0.125)	0.517 (0.085)	0.493 (0.083)	0.543 (0.071)	0.667 (0.112)	0.530 (0.026)	0.547 (0.133)	0.497 (0.083)	0.417 (0.046)
12 mg EDTA/kg soil	0.560 (0.040)	0.587 (0.117)	0.523 (0.102)	0.550 (0.069)	0.490 (0.092)	0.657 (0.057)	0.677 (0.050)	0.493 (0.150)	0.410 (0.101)
24 mg EDTA/kg soil	0.597 (0.101)	0.567 (0.064)	0.660 (0.114)	0.522 (0.047)	0.397 (0.083)	0.650 (0.131)	0.567 (0.212)	0.593 (0.186)	0.463 (0.040)
1 mg TSP/kg soil	0.517 (0.150)	0.483 (0.025)	0.520 (0.044)	0.570 (0.087)	0.497 (0.118)	1.275 (0.856)	0.527 (0.103)	0.493 (0.136)	0.553 (0.047)
4 mg TSP/kg soil	0.477 (0.067)	0.607 (0.101)	0.553 (0.091)	0.533 (0.060)	0.557 (0.040)	0.560 (0.061)	0.520 (0.046)	0.527 (0.106)	0.530 (0.184)
8 mg TSP/kg soil	0.457 (0.142)	0.587 (0.119)	0.590 (0.225)	0.510 (0.104)	0.577 (0.102)	0.566 (0.137)	0.570 (0.118)	0.470 (0.036)	0.610 (0.090)

It was noted that TSP treatments did not significantly elevate P % content in cabbage plant organs across all experiments compared to EDTA treatments at various Cd, Pb and Zn concentrations in the growth mediums. The contribution of EDTA which has Na as constituent of its salt, was also measured in terms of its addition of Na to cabbage organs across all treatments (Table 3.7; Table 3.8).

In Table 3.8 it can be seen that Na across all treatments and concentrations of Cd, Pb and Zn was in general greater in the leaves and stems of the cabbage plants than in the roots. The greatest Na concentration in roots was seen where Pb was set at double the maximum permissible soil concentration and 1 mg TSP/kg soil was applied as remedial treatment. The lowest Na concentration in roots was seen where Cd was set at twice the maximum permissible soil concentration and no treatment was applied and also where Pb was set at maximum in the soil and 24 mg EDTA/kg soil was applied (WRC, 1997).

In contrast the greatest Na concentration in stems was seen where Zn was at a maximum and 12 mg EDTA/kg soil was applied. Relatively high Na concentrations were also seen where Cd was at twice the maximum permissible soil concentration and respectively no treatment was applied and also when 24 mg EDTA/kg soil was applied. The same trend was seen when Cd was at the maximum permissible soil concentration and no treatment was applied but also when 12 mg EDTA/kg soil was applied. Of the higher Na concentrations in stems were also seen where Pb was set at twice the maximum permissible soil concentration and where Zn was set at the maximum and twice the maximum permissible soil concentration and 24 mg EDTA/kg soil was applied. The lowest stem Na concentration was seen when Pb was at twice the maximum permissible soil concentration and 1 mg TSP/kg soil was applied as well as when Cd was at *in situ* soil concentration and 8 mg TSP/kg soil was applied (Table 3.8).

A different trend was seen in the case of cabbage leaves across the experiments, where the higher Na concentrations were seen when Pb was at twice the maximum permissible soil concentration and respectively either 24 mg EDTA/kg soil, 1 mg TSP/kg soil and 4 mg EDTA/kg soil was applied. The greatest Na concentration in leaves was seen when Cd was set at twice the maximum permissible soil concentration and 12 mg EDTA/kg soil applied. The lowest Na concentration was seen where Zn was at twice the maximum permissible soil concentration and 4 mg TSP/kg soil applied as well as where Pb was set at the maximum permissible soil concentration and 8 mg TSP/kg soil was applied (WRC, 1997; Table 3.8).

The concentration of copper in cabbage plant organs is recorded in Table 3.9. Copper was observed to be very high in soils of the Philippi and Kraaifontein area as discussed in Chapter two and for this reason its uptake by cabbage plants across all remedial treatments was also noted. The concentration of copper in the soil medium for the treatments was at *in situ* level. Across all plant organs the trends seemed to indicate that Cu was accumulated in the plant roots, transferred to the stems with relatively little accumulating in the leaves. At no point did any plant organs exceed the South African maximum permissible concentration set for Cu (30.0 $mg.kg^{-1}$) in foodstuffs (DoH, 2004).

The maximum concentration of Cu in the leaves of cabbage, the edible portion of cabbage, was seen where no treatment was applied and Zn at *in situ* soil concentration. A slightly lower Cu concentration was seen where 1 mg TSP/kg soil was applied to soils with Zn and Pb at *in situ* soil concentrations. The lowest Cu concentration in leaves was seen where 12 mg EDTA/kg soil was applied and Cd at *in situ* soil concentration (Table 3.9).

Table 3.8. T-test results for sodium concentrations in mg.kg^{-1} in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 5122.800 mg.kg^{-1}									
No Treatment	22231.613 (1203.420)	24385.570 (2474.550)	27004.043 (653.337)	24863.963 (1759.097)	22910.187 (691.167)	21882.123 (3948.698)	24509.407 (5308.918)	21821.650 (2670.587)	22808.430 (1306.376)
4 mg EDTA/kg soil	21548.910 (2850.625)	25074.473 (3746.463)	24065.160 (2766.437)	24458.223 (3883.176)	26079.220 (1929.672)	22671.283 (3100.974)	24009.037 (2336.373)	22559.027 (7214.903)	23131.053 (2368.671)
12 mg EDTA/kg soil	23649.747 (3802.357)	28254.880 (2182.729)	29056.133 (2156.416)	25154.973 (2584.076)	25574.547 (4713.724)	26417.720 (1991.490)	25823.207 (111.213)	25184.143 (928.430)	23102.963 (1666.623)
24 mg EDTA/kg soil	20842.980 (3016.290)	26409.910 (2711.006)	28729.433 (2235.251)	26663.410 (3309.271)	24260.773 (6948.292)	27253.190 (2484.814)	24316.103 (1447.700)	24682.750 (4233.437)	26310.237 (1509.485)
1 mg TSP/kg soil	24548.893 (3883.002)	22884.143 (7157.665)	24129.330 (1974.221)	26856.057 (2194.190)	21147.163 (4768.905)	27153.515 (549.344)	21820.413 (9650.733)	25413.593 (3336.708)	24583.003 (1284.498)
4 mg TSP/kg soil	22829.343 (2360.916)	24639.227 (2662.176)	26104.730 (1442.246)	23805.897 (1083.185)	24846.930 (5146.397)	28606.143 (3105.913)	26810.443 (2500.881)	24471.153 (2102.127)	20879.593 (1920.580)
8 mg TSP/kg soil	21471.080 (7338.109)	25288.323 (4401.406)	21560.590 (6872.538)	25936.747 (1744.208)	20285.917 (6970.481)	24460.757 (2015.806)	23919.617 (1867.921)	26826.340 (2469.923)	23938.177 (2161.496)
Stems LSD 5917.400 mg.kg^{-1}									
No Treatment	12833.423 (3434.738)	16873.027 (4304.638)	17433.687 (1988.484)	13285.653 (548.100)	12324.993 (680.215)	11841.840 (4509.944)	11212.653 (4696.785)	11712.233 (1299.835)	12673.797 (3407.171)
4 mg EDTA/kg soil	12646.127 (4527.651)	13765.437 (3816.718)	11825.197 (3132.059)	12593.613 (2748.271)	15742.460 (3211.917)	9984.970 (893.817)	14500.757 (1147.323)	14074.677 (5186.715)	14524.757 (2058.335)
12 mg EDTA/kg soil	17198.917 (3972.990)	16773.527 (2204.413)	13908.677 (1281.112)	13902.593 (4263.319)	14843.023 (5715.544)	15490.087 (3472.306)	16587.397 (156.349)	19219.503 (5368.700)	11706.157 (470.843)
24 mg EDTA/kg soil	14028.863 (3795.880)	15479.183 (3671.947)	16906.810 (3863.890)	14129.967 (6023.769)	10657.063 (4840.923)	16259.613 (3463.675)	12935.147 (4803.675)	16417.380 (4154.161)	16608.477 (6734.368)
1 mg TSP/kg soil	12542.813 (481.703)	14123.380 (5454.036)	14083.653 (3811.432)	14242.290 (4061.489)	10035.327 (4253.617)	8911.110 (10015.277)	10389.390 (7789.236)	13828.700 (1477.040)	10984.617 (4529.952)
4 mg TSP/kg soil	14855.027 (5820.730)	12348.180 (2672.707)	15183.440 (2924.424)	14349.530 (3532.219)	14519.573 (1396.912)	15805.427 (1912.775)	14209.433 (3966.326)	12206.537 (5258.309)	12910.363 (4596.594)
8 mg TSP/kg soil	9560.913 (3561.406)	15932.240 (2402.839)	14206.730 (9602.329)	12577.273 (1713.227)	10786.657 (6845.737)	12684.460 (2989.339)	11173.447 (1684.260)	13930.187 (4025.545)	13896.430 (1842.933)
Roots LSD 1944.100 mg.kg^{-1}									
No Treatment	5108.300 (988.823)	4492.480 (2154.539)	2660.040 (1879.336)	4285.123 (1035.570)	3367.280 (648.399)	4121.493 (1330.809)	3118.160 (962.556)	4403.847 (1533.023)	4496.337 (824.481)
4 mg EDTA/kg soil	4527.980 (1353.932)	3688.483 (1496.616)	3146.277 (742.785)	3919.406 (795.649)	4773.800 (1353.986)	4051.053 (336.250)	5092.640 (2001.462)	3481.220 (502.285)	4041.170 (718.323)
12 mg EDTA/kg soil	5313.790 (86.572)	4320.680 (1089.430)	5233.413 (1471.041)	3871.443 (1423.189)	4105.700 (1309.451)	5794.887 (2075.157)	4431.097 (364.125)	3612.757 (427.524)	3210.680 (701.196)
24 mg EDTA/kg soil	3885.413 (693.901)	5853.287 (1353.111)	3966.817 (398.206)	4185.480 (1930.403)	2722.783 (1681.918)	4952.827 (678.423)	4134.733 (1602.267)	5372.877 (1131.028)	4557.300 (939.516)
1 mg TSP/kg soil	4272.337 (1343.486)	4404.900 (1464.386)	4145.910 (530.890)	4846.883 (1100.066)	3024.123 (684.741)	6894.360 (3072.421)	3552.720 (1691.203)	3825.210 (1562.588)	4507.107 (919.918)
4 mg TSP/kg soil	3711.187 (1344.028)	3919.267 (965.596)	3799.853 (662.470)	4175.927 (766.419)	4450.903 (615.325)	4156.153 (419.343)	4197.857 (1298.818)	3602.167 (1090.746)	4556.097 (2272.337)
8 mg TSP/kg soil	2981.910 (1344.744)	5243.123 (163.342)	3949.217 (1779.796)	3645.687 (549.361)	3487.773 (1892.989)	4370.170 (589.256)	3658.193 (1150.185)	4360.953 (1558.127)	4790.487 (2037.045)

In cabbage stems, the greatest concentration of Cu was seen where 4 mg TSP/kg soil was applied for Cu *in situ* while the lowest was seen where Pb was at twice the maximum concentration and 1 mg TSP/kg soil applied. A clear trend for accumulation of Cu in stems could not be traced across treatments. In the case of cabbage leaves, the average Cu concentration across all treatments was about 3.0 $mg.kg^{-1}$ while the maximum permitted in South African foodstuffs is 30.0 $mg.kg^{-1}$ (DoH, 2004; Table 3.9).

Copper seemed to accumulate in cabbage roots across all treatments with the greatest Cu concentration seen in roots where Pb was set at twice the maximum permissible soil concentration and 4 mg TSP/kg soil applied. The lowest concentration of Cu was seen where Zn was set at twice the maximum permissible soil concentration and 4 mg TSP/kg soil applied, but also where Cd was at twice the maximum permissible soil concentration and no treatment applied. In general, the greater Cu concentrations were seen in the roots of cabbage plants and the lowest concentrations in the leaves of cabbage across almost all treatments. In a few cases stems did appear to accumulate Cu and on average overall experimental treatments Cu in stems were around 5.0 $mg.kg^{-1}$ (WRC, 1997; Table 3.9).

Iron is also a metal and essential to plants and its uptake is often influenced by the presence of Pb (Meerkotter, 2003). The uptake of Fe was thus investigated and recorded in Table 3.10. A clear trend was observed across plant organs and all treatments, namely that roots appeared to accumulate Fe, that it was translocated to the leaves with stems having the lowest concentration of Fe in general.

Table 3.9. T-test results for copper concentrations in mg.kg^{-1} in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 1.727 mg.kg^{-1}									
No Treatment	3.090 (0.391)	2.917 (0.099)	2.747 (0.686)	4.340 (1.368)	4.310 (2.035)	4.527 (1.021)	6.010 (3.847)	3.413 (0.660)	3.420 (1.375)
4 mg EDTA/kg soil	2.543 (0.138)	2.543 (0.441)	3.293 (0.781)	4.673 (2.276)	3.923 (0.806)	3.293 (0.204)	3.660 (0.918)	3.200 (2.016)	3.137 (1.976)
12 mg EDTA/kg soil	2.247 (0.666)	3.180 (0.340)	3.770 (0.306)	4.453 (2.630)	4183 (1.665)	3.817 (1.466)	3.557 (1.683)	3.287 (1.202)	2.847 (0.637)
24 mg EDTA/kg soil	2.320 (0.789)	3.020 (0.760)	4.087 (1.789)	4.430 (2.245)	4.050 (1.767)	3.950 (0.938)	3.033 (1.793)	3.210 (1.150)	3.633 (0.615)
1 mg TSP/kg soil	3.363 (1.456)	2.993 (0.501)	3.057 (0.386)	5.533 (2.309)	3.533 (0.968)	4.600 (1.287)	5.353 (1.707)	3.417 (1.339)	4.303 (1.422)
4 mg TSP/kg soil	2.800 (1.018)	2.857 (0.653)	2.913 (0.523)	3.693 (0.195)	3.530 (1.054)	3.460 (0.665)	3.623 (1.223)	3.327 (1.740)	4.557 (1.803)
8 mg TSP/kg soil	3.150 (0.373)	3.430 (1.543)	4.010 (0.894)	3.607 (0.856)	3.247 (1.131)	3.483 (0.760)	3.747 (1.149)	4.177 (2.399)	3.463 (1.385)
Stems LSD 3.156 mg.kg^{-1}									
No Treatment	4.383 (1.725)	6.006 (3.859)	5.700 (2.792)	6.053 (0.930)	5.813 (3.537)	7.826 (6.568)	4.056 (0.763)	4.253 (2.283)	6.640 (3.307)
4 mg EDTA/kg soil	5.896 (3.015)	4.140 (1.977)	6.200 (3.796)	4.363 (1.540)	8.446 (0.906)	3.556 (0.675)	4.820 (1.361)	5.986 (4.580)	4.093 (0.867)
12 mg EDTA/kg soil	5.536 (2.596)	4.453 (0.921)	5.986 (1.521)	6.186 (4.297)	6.120 (2.311)	5.200 (2.388)	5.346 (1.033)	5.543 (1.483)	4.390 (1.538)
24 mg EDTA/kg soil	7.610 (2.242)	7.573 (2.774)	5.070 (3.230)	4.793 (2.058)	4.060 (0.532)	6.120 (1.965)	6.336 (4.359)	5.446 (0.429)	5.286 (2.220)
1 mg TSP/kg soil	3.896 (1.648)	5.650 (2.394)	6.703 (2.895)	5.383 (1.949)	5.690 (2.661)	2.580 (1.979)	6.563 (4.292)	6.280 (3.703)	4.876 (1.430)
4 mg TSP/kg soil	9.270 (5.248)	4.166 (0.861)	5.140 (2.687)	4.103 (2.912)	5.553 (2.174)	5.323 (1.475)	4.913 (1.037)	5.233 (0.756)	5.496 (1.874)
8 mg TSP/kg soil	5.676 (3.527)	5.586 (2.579)	5.960 (3.788)	5.066 (2.572)	5.206 (2.716)	6.523 (2.216)	7.320 (1.680)	4.870 (1.120)	7.130 (0.555)
Roots LSD 6.770 mg.kg^{-1}									
No Treatment	21.156 (5.312)	17.386 (0.355)	13.866 (10.285)	19.730 (0.726)	16.096 (0.185)	15.350 (1.031)	18.630 (3.131)	18.066 (3.669)	21.200 (4.570)
4 mg EDTA/kg soil	19.203 (3.638)	17.523 (2.988)	18.186 (1.709)	17.733 (1.557)	21.083 (1.950)	17.160 (4.176)	16.760 (7.266)	21.866 (6.178)	20.336 (2.667)
12 mg EDTA/kg soil	22.353 (2.930)	20.313 (3.963)	23.620 (3.307)	16.993 (4.840)	18.546 (2.627)	19.693 (2.545)	16.710 (4.671)	19.370 (2.860)	16.826 (3.958)
24 mg EDTA/kg soil	21.486 (2.333)	21.460 (3.309)	21.656 (7.801)	19.683 (1.393)	16.230 (6.398)	20.856 (4.881)	17.013 (3.264)	23.710 (6.485)	20.160 (0.790)
1 mg TSP/kg soil	20.106 (2.871)	23.050 (7.243)	22.376 (2.875)	23.413 (5.188)	22.716 (6.677)	17.730 (8.570)	18.610 (2.868)	22.866 (3.984)	20.550 (4.788)
4 mg TSP/kg soil	17.613 (5.870)	18.156 (1.008)	23.540 (2.771)	19.156 (1.583)	19.306 (4.400)	27.673 (7.643)	20.736 (1.436)	21.166 (1.576)	13.940 (0.748)
8 mg TSP/kg soil	18.000 (1.959)	22.426 (4.702)	19.473 (4.921)	20.163 (6.348)	20.203 (0.793)	20.913 (2.272)	14.206 (1.335)	19.370 (2.860)	15.900 (1.569)

Table 3.10. T-test results for iron concentrations in $mg.kg^{-1}$ in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
				Leaves LSD	48.002 $mg.kg^{-1}$				
No Treatment	69.510 (18.866)	50.290 (9.809)	52.233 (4.620)	47.380 (3.781)	53.597 (6.776)	62.367 (19.897)	141.987 (143.851)	49.150 (2.209)	46.253 (1.323)
4 mg EDTA/kg soil	84.847 (65.925)	53.670 (4.441)	47.003 (4.436)	52.737 (4.939)	47.073 (7.544)	59.567 (10.321)	46.080 (15.766)	50.723 (16.829)	71.553 (23.625)
12 mg EDTA/kg soil	62.153 (23.834)	46.110 (1.075)	49.977 (5.237)	45.870 (9.223)	53.890 (15.137)	59.270 (10.708)	55.883 (5.391)	56.757 (9.803)	51.350 (1.633)
24 mg EDTA/kg soil	51.790 (6.758)	42883 (7.776)	56.760 (5.670)	55.460 (4.789)	44.283 (5.235)	51.950 (8.244)	50.667 (5.391)	46.403 (7.918)	58.443 (12.105)
1 mg TSP/kg soil	55.763 (5.913)	41.583 (4.818)	46.730 (7.305)	52.267 (4.245)	53.210 (10.092)	49.965 (15.818)	49.747 (14.364)	51.587 (6.166)	67.233 (22.627)
4 mg TSP/kg soil	46.107 (10.254)	48.213 (3.475)	53.950 (7.788)	74.710 (16.315)	61.627 (13.162)	61.013 (25.711)	45.627 (8.313)	52.447 (6.427)	49.813 (1.858)
8 mg TSP/kg soil	42.463 (5.928)	55.657 (5.146)	49.423 (11.682)	79.880 (37.278)	42.413 (2.582)	58.063 (6.858)	46.557 (1.818)	48.787 (8.936)	44.393 (8.457)
				Stems LSD	34.038 $mg.kg^{-1}$				
No Treatment	12.187 (6.066)	22.670 (7.271)	38.637 (34.171)	22.287 (16.486)	14.957 (2.428)	25.170 (11.119)	17.857 (10.941)	27.893 (13.076)	23.403 (14.235)
4 mg EDTA/kg soil	34.600 (21.985)	19.370 (10.819)	31.470 (26.995)	10.393 (0.379)	14.323 (2.260)	24.223 (7.345)	16.073 (2.837)	22.010 (8.694)	20.670 (5.005)
12 mg EDTA/kg soil	22.040 (2.709)	13.310 (11.049)	15.317 (5.598)	23.283 (19.744)	16.960 (8.574)	11.280 (5.478)	17.260 (2.513)	29.447 (7.967)	26.507 (12.849)
24 mg EDTA/kg soil	20.313 (6.944)	10.317 (4.006)	14.213 (5.614)	19.343 (14.761)	14.290 (3.875)	23.353 (6.594)	35.693 (34.982)	27.753 (12.154)	18.217 (11.886)
1 mg TSP/kg soil	15.577 (3.056)	19.530 (6.279)	20.937 (4.884)	19.753 (11.760)	25.870 (7.042)	12.240 (11.186)	31.790 (28.488)	22.790 (9.537)	16.040 (4.494)
4 mg TSP/kg soil	27.753 (22.888)	13.697 (3.947)	21.050 (12.351)	19.900 (6.265)	24.150 (4.560)	21.463 (0.245)	31.615 (19.099)	21.360 (12.570)	21.067 (11.611)
8 mg TSP/kg soil	14.293 (3.282)	40.557 (38.853)	36.260 (13.552)	21.387 (6.212)	26.403 (7.732)	22.297 (11.766)	48.317 (34.675)	18.003 (14.419)	20.780 (7.461)
				Roots LSD	292.55 $mg.kg^{-1}$				
No Treatment	547.527 (18.080)	502.047 (133.651)	350.197 (249.411)	585.170 (141.347)	634.777 (51.836)	431.443 (125.457)	585.217 (161.908)	511.190 (143.766)	590.177 (23.623)
4 mg EDTA/kg soil	521.523 (48.880)	636.813 (97.114)	513.513 (39.649)	690.700 (126.660)	527.870 (45.375)	475.917 (60.531)	518.857 (228.538)	655.763 (128.034)	644.740 (211.399)
12 mg EDTA/kg soil	479.723 (59.949)	666.923 (160.338)	623.847 (64.221)	510.700 (21.145)	579.997 (131.270)	583.253 (240.683)	495.943 (93.425)	640.410 (169.607)	543.050 (77.335)
24 mg EDTA/kg soil	636.637 (96.686)	519.047 (129.788)	630.830 (172.532)	508.183 (28.283)	627.467 (158.204)	458.260 (44.265)	561.073 (20.188)	533.153 (159.978)	574.183 (142.008)
1 mg TSP/kg soil	652.690 (149.669)	580.907 (162.013)	554.107 (120.158)	556.710 (99.724)	597.170 (141.661)	393.035 (395.647)	484.740 (51.227)	715.433 (175.258)	678.863 (315.803)
4 mg TSP/kg soil	562.883 (73.167)	493.387 (37.061)	782.237 (193.494)	590.763 (22.340)	906.440 (803.245)	611.280 (154.854)	595.370 (26.850)	564.080 (156.235)	467.307 (80.878)
8 mg TSP/kg soil	502.087 (51.606)	538.557 (124.999)	475.067 (44.065)	615.390 (53.980)	650.073 (136.716)	940.853 (480.279)	669.567 (353.970)	580.097 (37.875)	539.143 (124.455)

Where Pb was at twice the maximum permissible soil concentration the greatest Fe concentration was seen in roots where 8 mg TSP/kg soil was applied. The lowest Fe concentration in roots was seen where Cd was set at double the maximum permissible South African soil concentration and no treatment applied. Equally low Fe concentrations in cabbage roots were seen when Pb was at twice the maximum permissible soil concentration and 1 mg TSP/kg soil applied. In the case of cabbage stems, the greatest Fe concentrations were seen when Zn was at *in situ* soil concentration and 4 mg TSP/kg soil applied, as well as when 8 mg TSP/kg soil was applied. The average lowest concentration of Fe across all other treatments and concentrations of Cd, Pb and Zn ranged between 11.0 $mg.kg^{-1}$ and 38.0 $mg.kg^{-1}$with very few significant differences. The average concentration of Fe in cabbage leaves in contrast across all experiments was between 41.0 $mg.kg^{-1}$ and 84.0$mg.kg^{-1}$. The highest concentration of Fe in cabbage leaves was seen where no treatments were applied and Cd as well as Zn respectively at their *in situ* soil concentrations (WRC, 1997; Table 3.10).

In Tables 3.11, 3.12 and 3.13, the T-test results for the percentage of Ca, Mg and K in cabbage organs across all treatments were recorded. These three elements are macro nutrients to plants and its uptake could be affected by remediation treatments and elevated levels of Cd, Pb and Zn in soils (Meerkotter, 2003). In the case of Ca, a clear pattern could not be seen in Ca concentrations in either leaves or stems across all the experimental treatments at various concentrations of Cd, Pb and Zn. On average, cabbage leaves varied in Ca % concentration between 3.3 % to 4.4 % of the dry mass.

The greatest Ca % in roots was seen when Pb was at double the maximum permissible soil concentration and 1 mg TSP/kg soil applied, while the lowest Ca % concentration was seen when Cd was at double the set maximum permissible soil concentration and no treatment applied and where Pb was at *in situ* concentration and 8 mg TSP/kg soil applied. In stems the lowest Ca % was seen where Pb was at twice the maximum permissible soil concentration and 1 mg TSP/kg soil applied, while the greatest was seen when Zn was at the maximum permissible soil concentration and 12 mg EDTA/kg soil applied (WRC, 1997; Table 3.11).

In cabbage leaves, the greatest Ca % concentration was seen when Pb was at twice the permissible maximum soil concentration and 4 mg TSP/kg soil applied, while the lowest Ca % concentration was when Zn was set at the maximum soil concentration allowed in South Africa and no treatment was applied. Great Ca % concentrations were also seen where Cd was set at double the maximum concentration allowed in South African soils and respectively 12 mg EDTA/kg soil and 1 mg TSP/kg soil applied, as well as when Pb was set at its maximum permissible soil concentration and 4 mg EDTA/kg soil applied. Similar concentrations to the last mentioned were also seen when Zn was set at twice its maximum permissible soil concentration and respectively 24 mg EDTA/kg soil and 8 mg TSP/kg soil applied (WRC, 1997; Table 3.11).

A clearer trend was seen in the case of Mg % concentrations in cabbage plant organs across the experiment as a whole. Magnesium seemed to be at greatest concentrations in the leaves, followed by similar concentrations in the stems as in the roots in general across all experiments. The greatest Mg % concentration seen in roots was when Pb was set at twice the maximum permissible concentration and 1 mg TSP/kg soil applied. The greatest Mg % concentration in stems was seen when Zn was at the maximum permissible soil concentration and 12 mg EDTA/kg soil applied. The lowest concentration in roots was seen where Cd was at double the maximum permissible soil concentration and no treatment applied, while in the case of stems the lowest Mg % concentration was seen where Pb was at twice the maximum permissible soil concentration and 1 mg TSP/kg soil applied (WRC, 1997; Table 3.12).

Table 3.11. T-test results for calcium percentage concentrations in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 0.573 %									
No Treatment	3.587 (0.084)	3.927 (0.006)	3.943 (0.222)	4.270 (0.530)	4.033 (0.440)	3.977 (0.605)	4.133 (0.389)	3.307 (0.380)	3.803 (0.222)
4 mg EDTA/kg soil	3.447 (0.501)	3.627 (0.181)	3.727 (0.373)	4.077 (0.412)	4.230 (0.166)	3.530 (0.322)	3.990 (0.171)	3.570 (0.802)	4.127 (0.422)
12 mg EDTA/kg soil	3.730 (0.436)	3.957 (0.427)	4.283 (0.312)	4.097 (0.087)	3.793 (0.648)	4.107 (0.240)	4.157 (0.040)	4.013 (0.682)	3.623 (0.484)
24 mg EDTA/kg soil	3.713 (0.482)	4.087 (0.156)	4.167 (0.153)	4.280 (0.491)	3.880 (0.732)	3.987 (0.308)	3.767 (0.117)	3.877 (0.396)	4.220 (0.328)
1 mg TSP/kg soil	3.957 (0.633)	3.773 (0.280)	4.203 (0.305)	4.003 (0.606)	3.490 (0.243)	3.925 (0.205)	3.853 (0.797)	3.977 (0.147)	4.173 (0.218)
4 mg TSP/kg soil	3.550 (0.447)	3.877 (0.197)	3.820 (0.096)	4.063 (0.315)	3.943 (0.897)	4.427 (0.371)	3.917 (0.251)	3.920 (0.277)	3.847 (0.552)
8 mg TSP/kg soil	3.383 (0.425)	3.820 (0.404)	3.957 (0.287)	4.140 (0.236)	3.563 (1.069)	4.423 (0.196)	3.613 (0.370)	3.873 (0.320)	4.250 (0.210)
Stems LSD 0.376 %									
No Treatment	0.797 (0.146)	1.080 (0.321)	1.233 (0.057)	1.157 (0.289)	0.827 (0.195)	0.933 (0.420)	1.010 (0.190)	0.983 (0.200)	0.950 (0.110)
4 mg EDTA/kg soil	0.940 (0.355)	0.937 (0.040)	0.783 (0.152)	0.997 (0.125)	1.123 (0.203)	0.723 (0.266)	0.813 (0.211)	1.006 (0.345)	1.047 (0.180)
12 mg EDTA/kg soil	0.907 (0.215)	1.187 (0.220)	1.057 (0.176)	0.957 (0.232)	0.813 (0.345)	0.827 (0.238)	1.290 (0.176)	1.497 (0.956)	0.860 (0.276)
24 mg EDTA/kg soil	1.030 (0.290)	1.060 (0.089)	1.150 (0.262)	0.803 (0.047)	0.790 (0.303)	1.093 (0.196)	1.016 (0.374)	1.197 (0.032)	1.040 (0.121)
1 mg TSP/kg soil	0.887 (0.047)	0.960 (0.308)	1.177 (0.251)	1.133 (0.201)	0.783 (0.182)	0.510 (0.608)	0.780 (0.350)	0.936 (0.235)	1.143 (0.154)
4 mg TSP/kg soil	1.013 (0.321)	0.797 (0.172)	0.923 (0.199)	0.950 (0.219)	0.923 (0.261)	1.340 (0.139)	0.836 (0.134)	0.983 (0.106)	0.900 (0.269)
8 mg TSP/kg soil	0.817 (0.267)	1.027 (0.286)	1.017 (0.244)	1.080 (0.171)	0.920 (0.380)	1.003 (0.091)	0.866 (0.124)	0.917 (0.361)	1.347 (0.163)
Roots LSD 0.800 %									
No Treatment	2.503 (0.677)	1.817 (0.340)	1.343 (1.168)	2.607 (1.048)	1.893 (0.381)	1.860 (0.837)	2.193 (0.281)	1.727 (0.221)	2.167 (0.124)
4 mg EDTA/kg soil	2.337 (0.631)	1.857 (0.771)	2.170 (0.255)	2.080 (0.311)	2.070 (0.407)	1.653 (0.156)	1.857 (0.854)	1.667 (0.285)	2.670 (0.606)
12 mg EDTA/kg soil	1.707 (0.547)	2.160 (0.950)	2.440 (0.348)	1.787 (0.530)	1.913 (0.540)	1.960 (0.252)	1.830 (0.386)	1.870 (0.381)	1.890 (0.589)
24 mg EDTA/kg soil	1.953 (0.544)	1.880 (0.730)	2.243 (0.168)	1.840 (0.297)	1.760 (0.985)	1.950 (0.141)	2.090 (0.401)	2.207 (0.338)	2.660 (0.853)
1 mg TSP/kg soil	2.087 (9988)	2.373 (0.915)	1.657 (0.300)	2.217 (0.692)	1.990 (0.785)	3.645 (1.450)	1.640 (0.342)	2.137 (0.683)	2.373 (0.777)
4 mg TSP/kg soil	1.793 (0.235)	1.797 (0.362)	2.390 (0.487)	2.010 (0.231)	1.840 (0.445)	1.873 (0.152)	2.270 (0.450)	1.787 (0.357)	1.880 (0.193)
8 mg TSP/kg soil	1.943 (1.004)	1.917 (0.470)	2.017 (0.761)	1.483 (0.146)	1.840 (0.481)	1.937 (0.524)	1.637 (0.096)	2.070 (0.624)	2.143 (0.076)

In the case of cabbage leaves, the greatest percentage concentration of Mg was seen where Cd was set at double the maximum permissible soil concentration and 12 mg EDTA/kg soil applied, while the lowest Mg % concentration in leaves was seen where Zn was at a maximum and no treatment applied to the soil (Table 3.12).

In the case of K % concentration across all treatments, K seems to accumulate in cabbage stems, with leaves having almost half as much K and roots about half as much K as leaves across all treatments. The greatest percentage concentrations of K in roots was seen where Pb was at *in situ* soil concentration and no treatment was applied. The lowest K % concentration in roots was seen when Cd was set at twice the maximum permissible soil concentration and no treatment was applied (Table 3.13).

In the case of cabbage stems, the lowest K % concentration was seen when Pb was set at twice the maximum soil concentration and 1 mg TSP/kg soil applied, while the greatest K % concentration was seen when Zn was set at the maximum soil concentration and 12 mg EDTA/kg soil applied. In the case of cabbage leaves the greatest K concentration was seen when Zn was at twice the maximum and 1 mg TSP/kg soil applied. The lowest K % concentration in leaves were seen when respectively Cd and Zn was at their *in situ* soil concentrations and respectively no treatment, 24 mg EDTA/kg soil and 1 mg TSP/kg soil applied. Similarly, K was also low when Cd was set at twice the maximum permissible soil concentration and 1 mg TSP/kg soil applied and also when Zn was set at the maximum permissible soil concentration and 4 mg EDTA/kg soil applied. In the case where Pb was at the maximum permissible soil concentration, a similar percentage concentration of K was seen, when 24 mg EDTA/kg soil and also when 8 mg TSP/kg soil was applied as remedial treatments (Table 3.13). These results and others highlighted in this section of Chapter three are discussed in the Discussion section of this chapter.

Table 3.12. T-test results for magnesium percentage concentrations in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 0.093 %									
No Treatment	0.560 (0.010)	0.610 (0.046)	0.630 (0.046)	0.653 (0.042)	0.613 (0.055)	0.560 (0.036)	0.640 (0.070)	0.503 (0.050)	0.630 (0.050)
4 mg EDTA/kg soil	0.553 (0.040)	0.563 (0.076)	0.590 (0.040)	0.623 (0.064)	0.677 (0.040)	0.587 (0.055)	0.587 (0.006)	0.580 (0.130)	0.673 (0.051)
12 mg EDTA/kg soil	0.563 (0.055)	0.627 (0.068)	0.697 (0.058)	0.620 (0.052)	0.600 (0.104)	0.623 (0.023)	0.630 (0.010)	0.620 (0.072)	0.590 (0.089)
24 mg EDTA/kg soil	0.590 (0.070)	0.683 (0.064)	0.660 (0.036)	0.657 (0.092)	0.583 (0.125)	0.647 (0.055)	0.597 (0.021)	0.643 (0.047)	0.657 (0.078)
1 mg TSP/kg soil	0.647 (0.090)	0.593 (0.093)	0.657 (0.086)	0.640 (0.115)	0.563 (0.064)	0.630 (0.042)	0.593 (0.144)	0.650 (0.036)	0.677 (0.035)
4 mg TSP/kg soil	0.583 (0.071)	0.577 (0.021)	0.620 (0.050)	0.637 (0.061)	0.607 (0.150)	0.647 (0.015)	0.617 (0.071)	0.613 (0.025)	0.610 (0.062)
8 mg TSP/kg soil	0.553 (0.064)	0.593 (0.029)	0.613 (0.118)	0.640 (0.035)	0.547 (0.150)	0.680 (0.036)	0.583 (0.059)	0.607 (0.059)	0.680 (0.061)
Stems LSD 0.113 %									
No Treatment	0.237 (0.006)	0.290 (0.052)	0.307 (0.023)	0.310 (0.026)	0.263 (0.085)	0.263 (0.076)	0.303 (0.120)	0.270 (0.030)	0.277 (0.015)
4 mg EDTA/kg soil	0.290 (0.087)	0.247 (0.042)	0.247 (0.032)	0.250 (0.036)	0.260 (0.017)	0.213 (0.092)	0.243 (0.055)	0.297 (0.067)	0.280 (0.026)
12 mg EDTA/kg soil	0.267 (0.061)	0.327 (0.071)	0.300 (0.010)	0.270 (0.053)	0.233 (0.080)	0.233 (0.045)	0.340 (0.087)	0.477 (0.341)	0.237 (0.031)
24 mg EDTA/kg soil	0.273 (0.047)	0.273 (0.049)	0.303 (0.031)	0.240 (0.020)	0.250 (0.100)	0.310 (0.075)	0.277 (0.071)	0.303 (0.021)	0.297 (0.049)
1 mg TSP/kg soil	0.247 (0.023)	0.287 (0.115)	0.327 (0.031)	0.363 (0.051)	0.230 (0.035)	0.140 (0.156)	0.243 (0.107)	0.267 (0.061)	0.290 (0.010)
4 mg TSP/kg soil	0.287 (0.064)	0.230 (0.062)	0.277 (0.100)	0.273 (0.006)	0.233 (0.058)	0.383 (0.042)	0.253 (0.055)	0.263 (0.055)	0.257 (0.051)
8 mg TSP/kg soil	0.240 (0.026)	0.267 (0.061)	0.340 (0.141)	0.303 (0.031)	0.273 (0.067)	0.293 (0.025)	0.247 (0.047)	0.267 (0.137)	0.323 (0.040)
Roots LSD 0.074 %									
No Treatment	0.257 (0.055)	0.247 (0.076)	0.140 (0.105)	0.293 (0.070)	0.237 (0.051)	0.233 (0.051)	0.240 (0.017)	0.253 (0.006)	0.193 (0.006)
4 mg EDTA/kg soil	0.243 (0.021)	0.210 (0.017)	0.260 (0.066)	0.227 (0.023)	0.227 (0.055)	0.203 (0.006)	0.210 (0.046)	0.230 (0.010)	0.193 (0.031)
12 mg EDTA/kg soil	0.240 (0.020)	0.237 (0.050)	0.243 (0.076)	0.273 (0.025)	0.217 (0.015)	0.273 (0.067)	0.230 (0.040)	0.217 (0.083)	0.220 (0.078)
24 mg EDTA/kg soil	0.220 (0.053)	0.253 (0.023)	0.240 (0.062)	0.233 (0.006)	0.213 (0.068)	0.270 (0.035)	0.230 (0.082)	0.213 (0.040)	0.203 (0.021)
1 mg TSP/kg soil	0.223 (0.076)	0.250 (0.026)	0.273 (0.040)	0.233 (0.031)	0.213 (0.040)	0.330 (0.085)	0.247 (0.042)	0.223 (0.090)	0.217 (0.040)
4 mg TSP/kg soil	0.230 (0.010)	0.257 (0.006)	0.220 (0.036)	0.223 (0.038)	0.253 (0.047)	0.213 (2.029)	0.250 (0.052)	0.200 (0.046)	0.223 (0.038)
8 mg TSP/kg soil	0.223 (0.085)	0.197 (0.015)	0.280 (0.026)	0.223 (0.032)	0.237 (0.025)	0.240 (0.070)	0.217 (0.012)	0.220 (0.017)	0.213 (0.021)

Table 3.13. T-test results for potassium percentage concentrations in respectively cabbage leaves, stems and roots in various remediation treatments at various concentrations of Cd, Pb and Zn

Concentration	Cd *in situ*	Cd maximum	Cd 2 x maximum	Pb *in situ*	Pb maximum	Pb 2 x maximum	Zn *in situ*	Zn maximum	Zn 2 x maximum
Leaves LSD 0.961 %									
No Treatment	4.446 (0.370)	4.673 (0.350)	4.930 (0.680)	4.703 (0.323)	4.597 (1.020)	4.497 (0.536)	3.997 (0.210)	4.153 (0.908)	5.063 (0.332)
4 mg EDTA/kg soil	4.460 (1.081)	4.877 (0.772)	4.320 (0.517)	4.887 (0.586)	4.447 (0.835)	4.413 (0.667)	4.790 (0.572)	3.957 (0.894)	4.243 (0.234)
12 mg EDTA/kg soil	4.280 (0.149)	4.523 (0.760)	4.817 (0.374)	4.450 (0.419)	4.093 (0.511)	4.610 (0.658)	4.110 (0.104)	4.257 (0.565)	4.420 (0.320)
24 mg EDTA/kg soil	3.953 (0.522)	4.780 (0.330)	4.263 (0.549)	4.790 (0.305)	3.973 (0.638)	4.923 (0.375)	4.560 (0.356)	4.680 (0.291)	4.830 (0.243)
1 mg TSP/kg soil	4.547 (0.505)	4.097 (0.847)	3.920 (0.917)	4.987 (0.585)	4.037 (0.925)	4.235 (0.544)	3.940 (0.975)	4.603 (0.679)	5.080 (0.350)
4 mg TSP/kg soil	4.619 (0.489)	4.390 (0.942)	4.333 (0.525)	4.410 (0.304)	4.130 (0.825)	4.587 (0.900)	4.297 (0.276)	4.867 (0.012)	4.367 (1.010)
8 mg TSP/kg soil	4.127 (1.115)	4.677 (0.547)	4.287 (0.116)	4.493 (0.348)	3.960 (0.824)	4.273 (0.472)	4.887 (0.886)	4.610 (0.537)	4.463 (0.724)
Stems LSD 2.719 %									
No Treatment	8.273 (1.467)	8.177 (2.885)	9.327 (1.797)	8.443 (0.948)	7.497 (3.639)	7.207 (3.577)	8.167 (1.891)	7.210 (0.386)	9.950 (0.785)
4 mg EDTA/kg soil	8.123 (2.086)	8.517 (1.976)	6.357 (2.336)	8.200 (1.707)	8.490 (1.811)	6.277 (1.610)	7.783 (1.617)	6.857 (2.910)	8.160 (0.173)
12 mg EDTA/kg soil	8.893 (0.800)	7.907 (1.484)	8.803 (0.340)	7.457 (1.920)	6.430 (2.826)	8.220 (2.626)	8.420 (1.733)	10.213 (3.020)	7.360 (1.581)
24 mg EDTA/kg soil	8.513 (1.662)	8.963 (1.282)	8.597 (1.684)	8.887 (0.775)	6.423 (3.090)	8.117 (0.705)	8.000 (1.389)	8.353 (0.162)	8.023 (0.103)
1 mg TSP/kg soil	7.237 (0.597)	7.390 (2.697)	7.603 (2.270)	8.963 (0.844)	7.087 (3.306)	4.255 (5.042)	6.593 (3.894)	7.687 (1.285)	8.673 (1.239)
4 mg TSP/kg soil	7.877 (1.648)	7.607 (2.830)	8.180 (1.846)	8.017 (1.405)	6.747 (2.241)	8.337 (2.034)	6.993 (1.302)	7.553 (1.916)	6.973 (0.924)
8 mg TSP/kg soil	7.710 (3.158)	8.037 (1.059)	7.513 (2.561)	7.613 (0.405)	6.520 (2.954)	7.937 (1.304)	7.527 (0.748)	6.403 (2.365)	8.233 (1.828)
Roots LSD 0.736 %									
No Treatment	2.520 (0.442)	1.827 (0.153)	1.347 (0.990)	2.677 (0.849)	1.813 (0.067)	2.127 (0.575)	2.140 (0.219)	2.037 (0.210)	2.197 (0.029)
4 mg EDTA/kg soil	2.067 (0.388)	2.047 (0.677)	2.090 (0.150)	1.887 (0.315)	2.343 (0.357)	2.143 (0.102)	1.980 (0.726)	1.867 (0.724)	1.893 (0.234)
12 mg EDTA/kg soil	2.407 (0.402)	2.080 (0.392)	2.070 (0.246)	2.193 (0.586)	1.867 (0.150)	2.150 (0.272)	2.397 (0.381)	1.863 (0.400)	1.920 (0.295)
24 mg EDTA/kg soil	2.163 (0.374)	1.983 (0.428)	2.397 (0.440)	2.060 (0.467)	1.470 (0.756)	2.343 (0.517)	2.043 (0.769)	2.557 (0.823)	2.050 (0.320)
1 mg TSP/kg soil	1.867 (0.165)	2.170 (0.297)	2.040 (0.285)	2.330 (0.350)	1.980 (0.630)	2.020 (0.735)	1.990 (0.299)	2.027 (0.427)	2.460 (0.231)
4 mg TSP/kg soil	1.787 (0.333)	2.270 (0.265)	2.107 (0.105)	1.930 (0.339)	1.953 (0.525)	2.110 (0.255)	2.130 (0.108)	2.160 (0.468)	1.967 (0.739)
8 mg TSP/kg soil	2.070 (0.694)	1.850 (0.333)	2.293 (0.650)	1.970 (0.288)	2.023 (0.544)	2.160 (0.344)	2.193 (0.245)	1.827 (0.300)	2.120 (0.606)

3.4. Discussion

The purpose of this study was to investigate the use of respectively EDTA and TSP as remediation treatments in case soils of Cape Town's agricultural areas should become so contaminated with specifically Cd, Pb and/or Zn, that the quality of specifically cabbage, a main crop produced here, is seriously compromised. The heavy metals Cd, Pb and Zn were studied at three different concentrations (*in situ*, maximum permissible, and double the maximum permissible soil concentration allowed in South Africa) in conjunction with seven different treatments independently (no treatment, 4 mg EDTA/kg soil, 12 mg EDTA/kg soil, 24 mg EDTA/kg soil, 1 mg TSP/kg soil, 4 mg TSP/kg soil and 8 mg TSP/kg soil). It is important to note that the levels of Cd, Pb and Zn used in this study were much lower than those seen in most other studies of this nature (Amrate and Akretche, 2005; Brown *et al.*, 2005; Clemente *et al.*, 2005; Madejón *et al.*, 2005; Meer *et al.*, 2005). Over the experiment, as a whole, the general appearance of cabbage plants were not significantly different. It was noted that, in almost all cases, the shoots of cabbage plants were significantly greater in dry mass than the roots, indicating that all experimental plants probably had enough nutrients at their disposal thus, differences seen across the individual experimental treatments were most likely due to the applied treatments and differing concentrations of respectively Cd, Pd and Zn in the experimental soils (Table 3.2; Table 3.3).

The greatest average root and shoot dry mass was obtained in the presence of Pb at 6.6 $mg.kg^{-1}$ soil (the maximum permissible soil concentration) when 24 mg EDTA was applied as a remediation treatment. It is possible that despite the risk that application of EDTA at such a large dosage could have led to the increased uptake of Pb, it could also have led to the increased uptake of macro- and micro-nutrients that stimulated shoot and root growth. In the presence of Zn at 46.5 $mg.kg^{-1}$ soil (the maximum permitted soil concentration) application of 12 mg EDTA/kg soil was effective to yield the greatest shoot and root growth expressed in terms of dry mass. In the presence of Cd at 2.0 $mg.kg^{-1}$ soil (the maximum permitted soil concentration) the use of 4 mg TSP/kg soil was most effective to produce the greatest root and shoot mass (Table 3.3). In the presence of either Cd at 4.0 $mg.kg^{-1}$ soil, Pb at 13.2 $mg.kg^{-1}$ soil or Zn at 93.0 $mg.kg^{-1}$ soil, the best remedial treatment in terms of shoot dry mass could not be determined but application of 4 mg EDTA/kg soil allowed for significantly greater root production compared to other concentrations of EDTA treatment (Table 3.3).

The fact that an equally great shoot mass was obtained when 4 mg EDTA/ kg soil was applied compared to application of no remedial treatment where Pb was at 13.2 mg/kg^{-1} in the soil, shows that both the EDTA and TSP remedial treatments are not necessarily the most effective and that other treatments should also be investigated. Supporting this argument is the fact that both the independent use of 4 mg EDTA/kg soil and 12 mg EDTA/kg soil produced similar root dry masses and also shoot dry masses when Zn was present at 93.0 mg.kg^{-1} soil. The suggestion that other remedial treatments should also be investigated is also supported in that, independently, similar root dry masses and similar shoot dry masses were obtained when Cd, Pb and Zn was at the *in situ* soil concentrations and treated independently with 1 mg TSP/kg soil and 8 mg TSP/kg soil, while none of the EDTA treatments showed similar great root or shoot dry masses (Table 3.3). The fact that shoot dry masses were not significantly different across the experiment as a whole according to analysis of variance tests, may have indicated that the presence of Cd, Pb and/or Zn in excess in these soils did not greatly affect plant growth (Table 3.2).

In general, heavy metals were more concentrated in the roots of cabbage plants than in the shoots across all experiments, as is seen in general literature (Greene, 1993; Marschner, 1995; Prasad and De Oliveira, 2003; Salisbury and Ross, 1992). The levels of Cd, Pb and Zn in this experiment was, however, relatively low compared to other studies and thus, not likely to stunt plant growth (Amrate and Akretche, 2005; Brown *et al.*, 2005; Clemente *et al.*, 2005; Madejón *et al.*, 2005; Meer *et al.*, 2005). The observation that plant growth was not affected much by elevated Cd, Pb or Zn concentrations in the soil, measured by comparing shoot dry mass, did not mean that the cabbages produced in these soil were suitable for consumer consumption. More important to consumers however is the concentration of macro-, micro-nutrients and heavy metals in the edible portion of the cabbage plant. Though some plants may be able to cope with elevated levels of Cd, Pb and/or Zn, this was not always the case and the uptake of macro-nutrients, Ca, Mg, K and P, amongst others may be hindered by the presence of excess levels of heavy metals in the soil (Marschner, 1995; Meerkotter, 2003; Salisbury and Ross, 1992).

In general, the uptake of Mg and Ca were found to be correlated in both the shoots and specifically the stems of cabbage plants in this experiment (Table 3.1). The absence of other clear statistical correlations between specifically Cd, Pb and Zn and the mentioned macro-nutrients in this experiment does not mean that it does not exist in the field. Active uptake of the macro-nutrients Ca, Mg and K seemed evident as the concentrations of these elements in the shoots were much greater than seen in the roots (Table 3.2).

From T-tests it was clear that in the presence of Cd at 4.0 mg.kg^{-1} in the soil, in the absence of any of the tested remedial treatments, Cd may have led to the inhibited uptake of Ca, Mg and K by cabbage roots (Tables 3.11, 3.12 and 3.13). Similarly in the presence of Zn at 46.5 mg.kg^{-1} soil, the non-application of a remedial treatment, but also the application of 4 mg EDTA/kg soil, lead to much lesser percentage concentrations of Ca and Mg in cabbage plant leaves (Tables 3.11 and 3.12). When Cd was present in the soil at 4.0 mg.kg^{-1} soil, the application of 1 mg TSP/kg soil also showed very low percentage concentrations of Ca, Mg and K in cabbage plant stems (Tables 3.11, 3.12 and 3.13).

These findings may have indicated that the use of any of the suggested remedial treatments at greater concentration levels would have been preferred to not applying a remedial treatment when either Cd, Pb or Zn was in excess, even if it should not necessarily contribute to the significant increase of root or shoot yield in terms of dry mass. The need for caution in selecting a remedial treatment was also observed, since in the case of K uptake and specifically K transport to cabbage leaves it seemed that the application of several different EDTA treatments and TSP treatments in the presence of respectively Cd, Pb and Zn at elevated levels yielded significantly low K % concentrations in the leaves of cabbage plants (Table 3.13). Contrary, the use of especially EDTA solutions at different concentrations and even the use of different TSP treatments were helpful to increase the percentage concentrations of both Ca and Mg in cabbage plant leaves and stems and roots in the presence of respectively elevated Cd, Pb and Zn soil concentrations (Tables 3.11 and 3.12).

In the case of the macro-nutrient P, significant differences were seen across the experiment as a whole (Table 3.2). This indicated that the concentrations of TSP used, or the absence thereof, was probably significant. It could also have indicated that in the presence of EDTA treatments, soil P could have become more available to plant roots for uptake, since great P concentrations were seen in roots, stems and leaves in several of the EDTA treatments. The mere application of TSP treatments clearly did not necessarily mean P would be taken up more readily by plants that received TSP treatments (Table 3.7).

It was for example observed that the lowest P % concentrations in cabbage plant stems were in the presence of respectively elevated Cd, Pb and Zn soil concentrations in conjunction with the application of TSP treatments (Table 3.7). In fact, despite the application of TSP treatments, in the presence of excess Zn in the soil, P uptake seemed to have been hampered

(Table 3.7). The treatments that seemed to enhance the uptake of P in the presence of excess Cd, Pb and Zn were mostly EDTA treatments. In the case of cabbage leaves, several EDTA treatments and only one TSP treatment (8 mg TSP/kg soil), resulted in the highest P concentrations in the leaves, while in the case of cabbage stems, the greater P concentrations were seen in case of the application of 12 mg EDTA/kg soil and the more concentrated TSP treatments (Table 3.7). Therefore, the use of TSP treatments did not necessarily contribute to the nutritional pool of cabbage plants in a significant measure, since the fluctuation in P concentrations across all treatments could also have been due to the application of EDTA treatments.

Though the concentration of P was significantly different in the roots of cabbage plants across the various treatments, the use of TSP fertilizers could not be singled out as the sole reason for this fluctuation, and similarly, the mere presence of Na in EDTA solutions did not seem to contribute to it being significantly different in cabbage plants across the various treatments and levels of Cd, Pb and Zn (Table 3.2). Na is a beneficial element to plants at certain concentration levels and the leaves of cabbage plants seemed accumulate Na in this experiment (Li *et al.*, 2010; Marschner, 1995; Table 3.2). Sodium can easily become toxic to plants and excessive uptake by cabbage plant is thus not necessarily wanted (Li *et al.*, 2010; Marschner, 1995; Salisbury and Ross, 1992).

In the presence of elevated levels of Cd, Pb and Zn, the use of EDTA treatments at various concentrations seemed to elevate the amount of Na accumulated in cabbage plant leaves and stems, while the use of use of TSP treatments seemed to lead to a lesser Na yield in cabbage stems and leaves (Table 3.8). In the presence of specifically excess Zn and Cd, the absence of any of the remedial treatments led to a much lower concentration of Na in respectively cabbage leaves, stems and roots (Table 3.8). Therefore, the use of a specific remedial treatment needs to consider the amount of Na that is desirable in the edible portions of the plant and the ability of the plant to cope with Na since it is not a beneficial element to all plants (Brownell and Crossland, 1972; Brownell, 1979; Li *et al.*, 2010; Marschner, 1995; Ohta *et al.*, 1988; Salisbury and Ross, 1992).

The concentrations of the micro-nutrients Cu, Fe and Zn were also investigated and are discussed here. In the case of Fe, in general the roots and leaves had the higher concentrations of Fe across all treatments and the leaves seemed to accumulate Fe, even though they had a lower Fe concentration than the roots of the plants (Table 3.10). In general, none of the remedial treatments seemed to significantly influence the amount of Fe that was eventually stored in the leaves of cabbage plants (Tables 3.2 and 3.10). It appeared that the application of any of the remedial treatments would have been effective to ensure that the uptake of Fe was not negated in the presence of elevated levels of either Cd, Pb or Zn. However, this may not be true, since in the absence of the application of any remedial treatment, Fe was equally great in cabbage leaves and in two cases even greater than that seen in any remedial treatment (Table 3.10).

The fact that the concentrations of Fe in both organs of the shoots were rather consistent across all the experiments, might indicate that the integrity of the roots were not compromised that much in the presence of the remedial treatments, despite the elevated levels of Cd, Pb and Zn in terms of Fe uptake (Table 3.10). Other elements that also seemed to show a consistent pattern of its specific uptake across either the shoot organs or roots, despite the elevated levels of Cd, Pb and Zn in the presence of any remedial treatment; or rather, irrespective of the applied remedial treatments were Pb, Mg and K (Tables 3.5, 3.12 and

3.13). This information again emphasized that the selection of a remedial treatment should not to be decided based on the concentration of one element in the soil and its subsequent concentration in the plant alone.

Like iron, copper is an essential micro nutrient to plants, however in excess it can be toxic to plants and stunt plant growth (Marschner, 1995, Meerkotter, 2003; Salisbury and Ross, 1992). Toxicity to crop plants is a concern since the soils of both Philippi and the Kraaifontein/Joostenbergvlakte area contain much Cu as discussed in Chapter two (Meerkotter 2003, Sogayise, 2003). This fact was supported by the results seen here in that a negative correlation was seen between Cu concentration in cabbage plant stems and the dry weight of the stems in general across all experiments (Table 3.1).

In general, analysis of variance showed that the roots of cabbage plants contained the greater concentrations of Cu while relatively, much less was found in the stems and leaves of cabbage plants. This indicated that the roots of cabbage plants were probably able to take Cu up selectively and partition it differentially between its organs despite elevated levels of Cd, Pb or Zn in the soil and to some extent irrespective of the remedial treatment applied (Table 3.2). This observation also supported, to some extent, the notion that the roots of cabbage plants were not compromised too much in the presence of elevated levels of either Cd, Pb or Zn in conjunction with the various remedial treatments or absence thereof in general. This may further support the emerging idea that the studied EDTA and TSP treatments were not necessarily the most appropriate to use in cases of marginal Cd, Pb and/or Zn contamination of soils, since none seemed to showed a particularly clear benefit or danger in terms of the uptake of the mentioned plant nutrients (Tables 3.9 and 3.10).

The limit set for Cu in foodstuffs in South Africa is 30.00 mg.kg^{-1} and despite the elevation of independently Cd, Pb and Zn and the use of the various remediation treatments, the concentrations of Cu accumulated in cabbage plant shoots never neared this limit (DOH, 2004). The various remedial treatments had such varying results in terms of its effect on the increased content of Cu in either the roots, stems or leaves of cabbage plants in the presence of any concentration of either Cd, Pb or Zn that a clear elimination or recommendation of any particular remedial treatment was not really possible (Table 3.9).

Pinpointing the treatments that resulted in the lower concentrations of Cu in plant organs was easier. In the presence of Cd at 2.0 mg.kg^{-1} soil, the use of 4 mg EDTA/kg soil gave low concentrations of Cu in both the stems and leaves of cabbage plants. In the presence of Pb at 6.6 mg.kg^{-1} soil, the absence of a remedial treatment or use of the lower concentration TSP treatments (1 mg TSP or 4 mg TSP per kilogram soil) was most effective to limit the Cu content in cabbage roots and leaves. In the case of Zn set at 46.5 mg.kg^{-1} soil, applying no treatment was best at limiting the concentration of Cu in cabbage leaves (Table 3.9).

"Counter productive" information was gained from the experiment in terms of limiting Cu in the roots of cabbage plants in the event of agricultural soils ever becoming polluted with great excess levels of Cd, Pb and/or Zn simultaneously. Where Cd was present in experimental soil at 4.0 mg.kg^{-1} soil for example, the absence of a remedial treatment resulted in the lowest Cu contents in cabbage roots, while in the case of Zn set at 93.0 mg.kg^{-1} soil, the use of 4 mg TSP/kg soil gave the lowest concentration of Cu in cabbage roots and contrary to this, the use of 4 mg TSP/kg soil in soils where Pb was set at 13.2 mg/kg soil, yielded the greatest Cu concentrations in cabbage roots (Table 3.9). This again emphasized the importance of not recommending a remedial treatment by looking at the concentration of one element in either the crop and/or soil only.

Zinc is also a micro-nutrient to plants and humans (Marschner, 1995, Meerkotter, 2003; Salisbury and Ross, 1992). The permissible concentration of Zn in foodstuffs in South Africa is 40.00 mg.kg^{-1} and across several of the experiments this limit was exceeded in plant roots, stems and leaves (DoH, 2004). The greatest Zn concentrations were seen in cabbage roots while cabbage stems and leaves had fairly similar concentrations of Zn, except where Zn was applied to the soil in excess, indicating that Zn is differentially partitioned between cabbage plant organs. The concentration of Zn varied significantly between the different experimental treatments (Tables 3.2 and 3.6). The use of 12 mg EDTA/kg soil, seemed to be a problematic treatment in that it led to excessive levels of Zn in cabbage leaves in the presence of Cd at 2.0 mg.kg^{-1} soil, 6.6 mg Pb/kg soil, 13.2 mg Pb/kg soil and 93.0 mg Zn/kg soil independently, as well as in stems in the case where soil was spiked to 2.0 mg Cd/kg soil (Table 3.6).

Treatment with 1 mg TSP/kg soil seemed particularly good at leading to a low Zn yield in cabbage leaves when Cd was present at both 2.0 mg.kg^{-1} soil and 4.0 mg.kg^{-1} soil. The non-application of a remedial treatment, however, also yielded low Zn concentrations in cabbage leaves in the presence of 2.0 mg Cd/kg soil, 6.6 mg Pb/kg soil and even in the presence of 46.5 mg Zn/kg soil (Table 3.6). These observations might support the idea that other factors could also have been at play and that the resultant Zn concentrations in the leaves were not necessarily only due to the application of 1 mg TSP/kg soil as a remediation treatment.

This idea was further supported by the observation that in the presence of 46.5 mg Zn/kg soil, the resultant concentrations of Zn in cabbage stems were also relatively low in both the case of applying 1 mg TSP/kg soil as well as when not applying a remedial treatment at all (Table 3.6). It would appear that the use of 12 mg EDTA/kg soil was most useful to reduce the uptake of Zn by plant roots in the presence of respectively 2.0 mg Cd/kg soil and 93.0 mg Zn/kg soil, while application of 1 mg TSP/kg soil was more useful in the presence of 6.6 mg Pb/kg soil and 46.5 mg Zn/kg soil. However, it is likely that more effective remediation treatments exist to reduce the uptake of Zn by cabbage plants than those mentioned here, since in the case of Cd being present in the soil at 4.0 $mg.kg^{-1}$ soil application of no remedial treatment yielded the lowest Zn concentrations in cabbage roots (Table 3.6). From the results in Table 3.6 it could be seen that in the presence of excess Zn in the soil, be it at the maximum or twice the maximum permissible soil concentration according to South African regulations; that cabbage plants actively took up Zn and translocated it to its stem and leaves, and that none of the remedial treatments studied here proved particularly useful to reduce the uptake of Zn to levels that did not exceed South African limits set therefore in foodstuffs.

The limit set for Cd in South African foodstuffs is 0.05 $mg.kg^{-1}$ and in Europe it is 0.20 $mg.kg^{-1}$ (CoEC, 2006; DoH, 2004). Cadmium is a non-essential element and toxic to both animals and plants in excess (Marschner, 1995, Meerkotter, 2003). In plants, Cd in excess can interfere with the metabolic processes that involve Zn, since it is similar to Zn. It can to some extent also inhibit respiration, photosynthesis, gas exchange and water-regulation processes in plants. Research has shown that cabbage production yields could be reduced by as much as 20% to 25% in the presence of a solution of only 1 $mg.l^{-1}$ Cd (DWAF, 1996; Meerkotter, 2003; WRC, 1997).

Significant differences in the concentration of Cd in both cabbage leaves and roots were seen across the experiment as a whole (Table 3.2). At *in situ* soil concentrations of Cd, the uptake of Cd was consistent across all remedial treatments. This indicated that cabbage roots were probably able to tolerate the *in situ* concentrations of Cd and to take Cd up selectively to some extent. Across all experiments, Cd concentrations in cabbage roots were greater than those of stems and leaves. The concentration of Cd in cabbage leaves were, however, almost twice that of Cd accumulated in cabbage stems across all treatments and where Cd was elevated to both 2.0 $mg.kg^{-1}$ soil and 4.0 $mg.kg^{-1}$ soil (Tables 3.2 and 3.4). The probability that Cd may exceed maximum permissible soil concentrations and may lead to its accumulation in cabbage leaves is a concern since it would mean the crops could become unsuitable for consumer consumption. It is thus extremely important to monitor the concentration of Cd in soils and to know which remedial treatments would be effective in limiting the uptake of Cd by cabbage plants.

The fact that Cd seemed to accumulate in cabbage leaves and stems under conditions where Cd was elevated above the maximum permissible soil concentrations, despite the application of either EDTA or TSP treatments, indicated that more suitable remediation treatments should be sought to cope with Cd contamination in agricultural soils (Table 3.4). In general, the uptake of Cd seemed significantly low in the presence of Zn at 93.0 $mg.kg^{-1}$ soil. Though 93.0 $mg.kg^{-1}$ soil is not permissible in South Africa, this finding could indicate that a remedial treatment that contains Zn might be more useful to cope with Cd in agricultural soils than either TSP or EDTA treatments (Table 3.4).

The absolute "worst" treatment in the presence of 2.0 mg Cd/kg soil was 24 mg EDTA/kg soil and the "worst" in the case of 4.0 mg Cd/kg soil the application of 12 mg EDTA/kg soil. These treatments seemed to make Cd more available to cabbage roots and hence resultant accumulation in the stem and leaves. These results were consistent with those seen in phytoremediation studies where EDTA was used to mobilize heavy metals in the soil (Cui *et al.*, 2004; Lai and Chen, 2004; Lai and Chen 2005, Liphadzi and Kirkham, 2006, Lou *et al.*, 2005; Luo *et al.*, 2006; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2004). In the presence of Cd at 2.0. $mg.kg^{-1}$ soil and 4.0 $mg.kg^{-1}$ soil, TSP treatments seemed more effective in limiting the uptake of Cd than EDTA treatments. In the presence of 2.0. mg Cd/kg soil the application of 1 mg TSP/kg soil was most effective to limit the uptake of Cd and its accumulation in stems and leaves. In the presence of 4.0 mg Cd/kg soil, however, a slightly confusing result was seen in that the lowest amounts of Cd in cabbage leaves were found when respectively 8 mg TSP/kg soil was applied and also when no remedial treatment was given. Similarly, in the case of cabbage stems in the presence of 4.0 mg Cd/kg soil, respectively the application of 1 mg TSP/kg soil, 4 mg TSP/kg soil and 24 mg EDTA/kg soil resulted in significantly low Cd concentration in stems (Table 3.4). These results indicated again that both EDTA and TSP treatments were not necessarily the most advantageous remedial treatments.

Where no remediation treatments were applied at *in situ*, at maximum and double the maximum permitted Cd concentrations set for South African soils, no significant differences were observed in shoot dry masses and thus shoot yields (Table 3.3). This may have indicated that excess Cd stunted plant growth. It may also have indicated that the various remediation treatments did in fact help increase plant growth but; not necessarily by decreasing Cd uptake by the roots but, rather by making micro- and macro-nutrients more available to the plant than in the absence of a remediation treatment.

Lead is also a non-essential element to plants and can be toxic to plants in that it could stunt plant growth (Marschner, 1995; Prasad and De Oliveira, 2003; Salisbury and Ross, 1992). Lead concentrations were in general greatest in the roots of cabbage plants, indicating that cabbage roots were probably able to store Pb thus little translocation of Pb to the stems and leaves occurred. Root growth did appear to be stunted however in the presence of Pb at 13.2 $mg.kg^{-1}$ soil, which is one of the best known effects of Pb in plants (Li *et al.*, 2010; Marschner, 1995; Prasad and De Oliveira, 2003; Salisbury and Ross, 1992; Zhu *et al.*, 2004; Tables 3.2 and 3.5). The probability that cabbage roots can regulate the uptake of Pb is good since Pb is not wanted in the edible portions of the plant.

It is important to note that across the majority of experimental treatments, even in the cases where Pb was at *in situ* soil concentration, Pb was accumulated in all plant organs above the limits set for South African foodstuffs which is 0.10 $mg.kg^{-1}$ (DoH, 2006). As expected, application of 12 mg EDTA/kg soil seemed particularly problematic, in that it resulted in the equally high Pb concentrations in leaves when Pb was present in the soil at 2.2 mg/kg^{-1}, 6.6 mg/kg^{-1} and 13.2 mg/kg^{-1}. When Pb was in the soil at *in situ* concentration and also when Zn was present in the soil at 93.0 mg/kg^{-1} soil, the use of 12 mg EDTA/kg soil led to excess Pb accumulation in cabbage stems. Application of 24 mg EDTA/kg soil was equally problematic when Pb in the soil was present at 13.2 $mg.kg^{-1}$ soil as it resulted in equally great concentrations of Pb in the leaves of cabbage plants (Table 3.5).

None of the remediation treatments seemed particularly useful at limiting Pb accumulation in cabbage stems and leaves and rather conflicting results were obtained. When Pb was at *in situ* soil concentration in some cases, the respective application of 4 mg EDTA/kg soil and 1 mg TSP/kg soil seemed to results in less Pb accumulating in the stems of cabbage plants. However, in some instances the use of 12 mg EDTA/kg soil also resulted in equally low concentrations of Pb in stems, which contradicted the above mentioned findings. It was also seen that in some cases the application of 12 mg EDTA/kg soil in the presence of 6.6 mg Pb/kg soil resulted in relatively low Pb concentrations in cabbage stems (Table 3.5).

It was hoped that TSP treatments would help alleviate the uptake of Pb specifically, but this could not be stated unequivocally by the results of this study. Though several other studies found phosphate treatments were useful at regulating and limiting the uptake of not only Pb but also Cd, Cu and Zn this could not be confirmed with clarity in this research at relatively low heavy metal concentrations (Alvarez-Ayuso and Garcia-Sanches, 2003; Brown *et al.*, 2005; Cao *et al.*, 2003; Kumpiene *et al.*, 2007; Melamed *et al.*, 2003; Ownby *et al.*, 2005; Singh *et al.*, 2010; Tan *et al.*, 2011; Zhu *et al.*, 2004). The use of EDTA as a remedial treatment is, however, not recommended because it has been found in other research to pose a risk to underground water resources and since it could also make heavy metals more available to crops as has been shown in other studies (Luo *et al.*, 2005; Luo *et al.*, 2006; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2004). The conflicting results in this study indicate mainly that the remedial treatments investigated here are not necessarily the most effective and that other treatments should be investigated to control the uptake of either Cd, Pb or Zn in excess, should agricultural soil in future become contaminated far above regulatory limits for either or all three of these heavy metals.

The best remedial treatment of all those tested here, to limit the translocation of Cd to cabbage leaves, in an event where Cd exceeded the maximum permissible soil concentration set in South Africa (2.0 $mg.kg^{-1}$) was thus 1 mg TSP/kg soil. The better remedial treatments to use, to limit the accumulation of Pb in cabbage leaves if Pb should ever be in the soil at the maximum permissible soil concentration set in South Africa (6.6 $mg.kg^{-1}$), are respectively 1 mg TSP/kg soil, 8 mg TSP/kg soil or even 4 mg EDTA/kg soil. If Zn should ever be in the soil at 46.5 $mg.kg^{-1}$ soil (the maximum permissible soil concentration set in South Africa) then application of 1 mg TSP/kg soil in the coinciding presence of Cd being present at 2.0 $mg.kg^{-1}$ soil, would be best. However, when Cd levels in the soil are not in excess but Zn is at 46.5 mg/kg^{-1} soil even the absence of any of the remedial treatments tested here could be preferred. Thus 1 mg TSP/kg soil was overall the best treatment.

It could, however, be seen that the use of 24 mg EDTA/kg soil when Cd was in the soil at 2.0 $mg.kg^{-1}$ was dangerous in that high levels of Cd were accumulated in cabbage leaves. It could also be seen that the application of 12 mg EDTA was problematic, as it led to Pb accumulation in cabbage leaves when Pb was present in the experimental soil at 6.6 $mg.kg^{-1}$. Similarly when Zn was present in the experimental soils at 46.5 mg/kg and 12 mg EDTA/kg soil was applied, more Zn accumulated in cabbage leaves than under normal circumstances, especially when Cd and Pb was also present in the soil in excess of the maximum permitted soil concentrations set for South Africa.

3.5. Conclusion

As stated in the Discussion section of this chapter, the remedial treatments investigated here did not appear to be sufficiently effective to negate excess accumulation of the selected heavy metals in the edible portions of cabbage plants. More tests will be needed to verify the true effectiveness of these specific treatments in specifically the soils of the Philippi and Kraaifontein/Joostenbergvlakte farming areas of Cape Town. Future studies could also investigate soil pH and its role in terms of heavy metal uptake by vegetable crops from these areas' soils. Other variables that could be monitored in future studies are respiration, photosynthesis and gas exchanges in various crops planted in heavy metal contaminated soils.

From the results it is clear that the selection of any specific remedial treatment is rather complicated since many variables must be considered. This again emphasizes the importance of not recommending a remedial treatment by examining the concentration of one element only. The first hypothesis set for this study was that TSP treatments would be more effective at reducing the uptake of Cd, Pb and Zn than EDTA treatments. This hypothesis is not supported fully by this study's results, since the use of TSP treatments were not necessarily more effective at reducing the uptake of Cd, Pb and Zn by cabbage plants, but rather that it was not as liable to elevate the uptake of Cd, Pb and Zn by cabbage plants as EDTA treatments seemed to be.

The second hypothesis for this study stated that application of a moderate amount of TSP fertilizer would be more effective at reducing the uptake of Cd, Pb and Zn than application of a greater concentration of TSP. Looking at the before mentioned results, one would think this hypothesis is supported but more correct would be to say the hypothesis is only partly supported. Though according to T-tests, on several occasions the use of 1 mg TSP/kg soil pointed to lesser concentrations of either Cd, Pb and Zn in cabbage plant organs, it did not unequivocally exclude the effectiveness of 4 mg TSP/kg soil or 8 mg TSP/kg in some cases.

Since neither the TSP nor EDTA remedial treatments were particularly effective at reducing the uptake of either Cd, Pb or Zn by cabbage plants in this study, it is advised that other remedial treatments be tested on soils of both the Philippi and Kraaifontein/Joostenbergvlakte areas to provide farmers with more plausible solutions in the event of their soils ever exceeding set limits for either Cd, Pb and/or Zn according to South African limits. Future studies should also take into consideration the cost of each remedial treatment's use in practice. The use of TSP or EDTA treatments that may not be that effective in reducing the uptake of heavy metals by crop plants for example, could lead to great financial losses to any particular farmer.

Not only should the financial implications to farmers themselves be considered, but also possible costs to the surrounding environments. Application of TSP as a remedial treatment may for example be the easiest to execute but, one needs to take into consideration that the surrounding environment's surface and subterranean waters may become polluted with excess levels of P. Similarly, the use of EDTA treatments could lead to the leaching of toxic chemicals and/or heavy metals to subterranean waters, which may not be reversible. A combination of EDTA and TSP as a remedial treatment could be investigated, but it needs to be considered that long term application of either of these could decrease soil quality. Further investigations to find more suitable remedial treatments are strongly advised.

3.6. Reference

Aldrich MV, Ellzey JT, Peralta-Videa JR, Gonzalez JH, Gardea-Torresday JL (2004) Lead uptake and the effects of EDTA on lead-tissue concentration in the desert species Mesquite (*Prosopis spp.*). International Journal of Phytoremediation 6: 195-207

Alvarez-Ayuso E, Garcia-Sanchez A (2003) Palygorskite as a feasible amendment to stabilize heavy metal pollutes soils. Environmental Pollution 125: 337-344

Amrate S, Akretche DE (2005) Modelling EDTA enhanced electrokinetic remediation of lead contaminated soil. Chemosphere 60: 1376-1383

Aza-Gnandji CDR (2011) Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa. Unpublished Masters thesis. Department of Earth Sciences. University of the Western Cape, Bellville

Bhattacharyya P, Tripathy S, Chakrabarti K, Chakraborty A, Banik P (2008) Fractionation and bioavailability of metals and their impacts on microbial properties in sewage irrigated soil. Chemosphere 72: 543-550

Bjelková M, Genčurová V, Griga M (2011) Accumulation of cadmium by flax and linseed cultivars in field-simulated conditions: A potential for phytoremediation of Cd-contaminated soils. Industrial Crops and Products 33: 761-774

Boisson J, Ruttens A, Mench M, Vangronsveld J (1999) Evaluation of hydroxyapatite as metal immobilizing soil additive for remediation of polluted soils. Part 1. Influence of hydroxyapatite on metal exchangeability in the soil, plant growth and plant material accumulation. Environmental pollution 104: 225-233

Brown S, Christensen B, Lombi E, McLaughlin M, McGrath S, Colpaert J, Vangronsveld J (2005) An inter-laboratory study to test the ability of amendments to reduce the availability of Cd, Pb, and Zn *in situ*. Environmental Pollution 138: 34-45

Brown S, Chaney R, Hallfrisch J, Ryan JA, Berti WR (2004) *In situ* soil treatments to reduce the Phyto- and bioavailability of lead, zinc and cadmium. Journal of Environmental Quality 33: 522-531

Brownell PF (1979) Sodium as an essential micronutrient element for plants and its possible role in metabolism. Advances in Botanical research 7: 117-224

Brownell PF, Crossland CJ (1972) The requirement for sodium as a micronutrient by species having the C4 dicarboxylic photosynthetic pathway. Plant physiology 49: 794-797

Cao RX, Ma LQ, Chen M, Singh SP, Harris WG (2003) Phosphate-induced metal immobilization in a contaminated site. Environmental Pollution 122: 19-28

Clemente R, Walker DJ, Bernal MP (2005) Uptake of heavy metals and As by *Brassica juncea* grown in contaminated soil in Aznalcóllar (Spain): The effect of soil amendments. Environmental Pollution 138: 46-58

Commission of the European Communities (CoEC) (2006) Setting maximum levels for certain contaminants in foodstuffs: Commission regulation 1881: 1-25

Cui Y, Wang Q, Dong Y, Li H, Christie P (2004) Enhanced uptake of soil Pb and Zn by Indian mustard and winter wheat following combined soil application of elemental sulphur and EDTA. Plant and Soil 261: 181-188

Department of Health (DoH) (2004) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 26279

Department of Water Affairs and Forestry (DWAF) (1996) South African water quality guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation, DWAF, Pretoria

Di Palma L, Ferrantelli P, Merli C, Biancifiori F (2003) Recovery of EDTA and metal precipitation from soil flushing solutions. Journal of Hazardous Materials B103: 153-168

Duan N, Wang XL, Liu XD, Lin C, Hou J (2010) Effect of anaerobic fermentation residues on a chromium-contaminated soil-vegetable system. Procedia Environmental Sciences 2: 1585-1597

Finžgar N, Leštan D (2007) Multi-step leaching of Pb and Zn contaminated soils with EDTA. Chemosphere 66: 824-832

Garcia MA, Chimenos JM, Fernandez AI, Miralles L, Segarra M, Espiell F (2004) Low-grade MgO used to stabilize heavy metals in highly contaminated soils. Chemosphere 56: 481-491

Geebelen W, Vangronsveld J, Adriano DC, Carleer R, Clijsters H (2002) Amendment-induced immobilization of lead in a lead-spiked soil: Evidence from phytotoxicity studies. Water, Air, and Soil Pollution 140: 261-277

Greene D (1993) Effects of lead on the environment. Lead Action News 1.2

Huang B, Kuo S, Bembenek R (2003) Cadmium uptake by Lettuce from soil amended with phosphorus and trace element fertilizers. Water, Soil , Air Pollution 147: 109-127

Illera V, Garrido F, Serrano S, Garcia-Gonzales MT (2004) Immobilization of heavy metals Cd, Cu and Pb in acid soil amended with gypsum- and lime-rich industrial byproducts. European Journal of Soil Science 55: 135-145

Jiao Y, Grant CA, Bailey LD (2004) Effects of phosphorus and zinc fertilizer on cadmium uptake and distribution in flax and durum wheat. Journal of the Science of Food and Agriculture 84: 777-785

Kumpiene J, Lagerkvist A, Maurice C (2007) Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments – A review. Waste Management (Article in press)

Lai HY, Chen ZS (2005) The EDTA effect on phytoextraction of single and combined metals-contaminated soils using rainbow pink (*Dianthus chinensis*). Chemosphere 60: 1062-1071

Lai HY, Chen ZS (2004) Effects of EDTA on solubility of cadmium, zinc and lead and their uptake by rainbow pink and vetiver grass. Chemosphere 55: 421-430

Li QS, Cai SS, Mo CH, Chu B, Peng LH, Yang FB (2010) Toxic effects of heavy metals and their accumulation in vegetables grown in a saline soil. Ecotoxicology and Environmental Safety 73: 84-88

Lim TT, Chui PC, Goh KH (2005) Process evaluation for optimization of EDTA use and recovery for heavy metal removal from contaminated soil. Chemosphere 58: 1031-1040

Liphadzi MS, Kirkham MB (2006) Availability and plant uptake of heavy metals in EDTA-assisted phytoremediation of soil and compost biosolids. South African Journal of Botany 72: 391-397

Luo C, Shen Z, Lou L, Li X (2006) EDDS and EDTA-enhanced phytoextraction of metals from artificially contaminated soil and residual effects of chelant compounds. Environmental Pollution 144: 862-871

Luo C, Shen Z, Li X (2005) Enhanced phytoextraction of Cu, Pb, Zn, Cd with EDTA and EDDS. Chemosphere 59: 1-11

Macdonald CA, Clark IM, Zhao FJ, Hirsch PR, Singh BK, McGrath ST (2011) Long-term impacts of zinc and copper enriched sewage sludge additions on bacterial, archaeal and fungal communities in arable and grassland soils. Soil Biology and Biochemistry 43: 932-941

Madejón E, De Mora AP, Felipe E, Burgos P, Cabrera F (2005) Soil amendments reduce trace element solubility in a contaminated soil and allow regrowth of natural vegetation. Environmental Pollution (Article in press)

Malandrino M, Abollino O, Buoso S, Giacomino A, La Gioia C, Mentasti E (2011) Accumulation of heavy metals from contaminated soil to plants and evaluation of soil remediation by vermiculite. Chemosphere 82: 169-178

Marschner H (1995) Mineral Nutrition of Higher Plants. 2nd Edition. Academic Press, London

Meer E, Ruttens A, Hopgood M, Lesage E, Tack FMG (2005) Potential of *Brassica rapa, Cannabis sativa, Helianthus annuus* and *Zea mays* for phytoextraction of heavy metals from calcareous dredged sediment derived soils. Chemosphere (Article in press)

Meerkotter, M (2003) Heavy metals, and vegetable farming in Cape Town. Unpublished Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Melamed R, Cao X, Chen M, Ma LQ (2003) Field assessment of lead immobilization in a contaminated soil after phosphate application. The Science of the Total Environment 305: 117-127

Miller G (1996) Living in the Environment. 9th Edition. Wadsworth Publishing Company, Belmont

Ohta D, Matsui J, Matoh T, Takahashi E (1988) Sodium requirement of monocotyledonous C4 plants for growth and nitrate reductase activity. Plant and Cell Physiology 29: 1429-1432

Ownby DR, Galvan KA, Lydy MJ (2005) Lead and zinc bioavailability to *Eisenia fetida* after phosphorus amendment to repository soils. Environmental Pollution 136: 315-321

Palma LD, Mecozzi R (2007) Heavy metals mobilization from harbour sediments using EDTA and citric acid as chelating agents. Journal of Hazardous Materials (Article in press)

Paradelo R, Villada A, Barral MT (2011) Reduction of the short-term availability of copper, lead and zinc in a contaminated soil amended with municipal solid waste compost. Journal of Hazardous Materials 188: 98-104

Pardo MT (2004) Cadmium Sorption-desorption by soils in the absence and presence of phosphate. Communications in Soil Science and Plant Analysis 35: 1553-1568

Penalosa JM, Carpena RO, Vazquez S, Agha R, Granado A, Sarro MJ, Esteban E (2007) Chelate-assisted phytoextraction of heavy metals in a soil contaminated with a pyritic sludge. Science of the Total Environment (Article in press)

Prasad MNV, De Oliveira FHM (2003) Metal hyperaccumulation in plants – Biodiversity prospecting for phytoremediation technology. Electronic Journal of Biotechnology 6.3

Qoko M (2003) Monitoring of heavy metals in the Kuilsriver and potential use of macrophytes in heavy metal remediation. Unpublished, Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Salido AL, Hasty KL, Jae-Min L, Butcher DJ (2003) Phytoremediation of arsenic and lead in contaminated soil using Chinese brale ferns (*Pteris vittata*) and Indian Mustard (*Brassica juncea*). International Journal of Phytoremediation 5: 89-103

Salisbury FB, Ross CW (1992) Plant Physiology. 4th Edition. Wadsworth Publishing Company. Belmont, California

Singh A, Agrawal M, Marshall FM (2010) The role of organic vs. inorganic fertilizers in reducing phytoavaiability of heavy metals in a wastewater-irrigated area. Ecological Engineering 36: 1733-1740

Sogayise M (2003) Contamination of vegetables with heavy metals. Unpublished, Honours thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Srivastava PK, Vaish A, Dwivedi S, Chakrabarty D, Sing N, Tripathi RD (2011) Biological removal of arsenic pollution by soil fungi. Science of the Total Environment 409: 2430-2442

Stirk WA, Van Staden J (2001) Some physical factors affecting adsorption of heavy metals from solution by dried brown seaweed material. South African Journal of Botany 67: 615-619

Sun B, Zhao FJ, Lombi E, McGrath SP (2001) Leaching of heavy metals from contaminated soils using EDTA. Environmental Pollution 113: 111-120

Tan WN, Li ZA, Qiu J, Zou B, Li NY, Zhuang P, Wang G (2011) Lime and phosphate could reduce cadmium uptake by five vegetables commonly grown in South China. Pedosphere 21: 223-229

Tang XY, Zhu YG, Chen SB, Tang LL, Chen XP (2004) Assessment of the effectiveness of different phosphorus fertilizers to remediate Pb-contaminated soil using *in vitro* test. Environment International 30: 531-537

Thayalakumaran T, Robinson BH, Vogeler I, Scotter DR, Clothier BE, Percival HJ (2003) Plant uptake and leaching of copper during EDTA-enhanced phytoremediation of repacked and undisturbed soil. Plant and Soil 254: 415-423

Turgut C, Katie Pepe M, Cutright TJ (2005) The effect of EDTA on *Helianthus annus* uptake, selectivity, and translocation of heavy metals when grown in Ohio, New Mexico and Colombia soils. Chemosphere 58: 1087-1095

Water Research Commission (WRC) (1997) Permissible utilization and disposal of sewage sludge. WRC, Pretoria

Wu LH, Luo YM, Xing XR, Christie P (2004) EDTA-enhanced phytoremediation of heavy metal contaminated soil with Indian mustard and associated potential leaching risk. Agriculture, Ecosystems and Environment 102: 307-318

Wu LH, Luo YM, Christie P, Wong MH (2003) Effects of EDTA and low molecular weight organic acids on soil solution properties of a heavy metal polluted soil. Chemosphere 50: 819-822

Ximenez-Embun P, Rodriguez-Sanz B, Madrid-Albarran Y, Camara C (2002) Uptake of heavy metals by lupin plants in artificially contaminated sand: preliminary results. International Journal of Analytical Chemistry 82: 805-813

Zeng F, Ali S, Zhang H, Ouyang Y, Qiu B, Wu F, Zhang G (2011) The influence of pH and organic matter content in a paddy soil on heavy metal availability and their uptake by rice plants. Environmental Pollution 159: 84-91

Zheljazkov VD, Nielsen NE (1996) Effect of heavy metal on peppermint and cornmint. Plant and Soil 178: 59-66

Zhang MK, He ZL, Calvert DV, Stoffella PJ, Yang XE, Li YC (2003) Division S-4 – Soil fertility & plant nutrition; Phosphorus and heavy metal attachment and release in sandy soil aggregate fractions. American Journal of the Soil Science Society 67: 1158-1167

Zhu YG, Chen SB, Yang JC (2004) Effects of soil amendments on lead uptake by two vegetable crops from lead-contaminated soil from Anhui, China. Environmental International 30: 351-356

CHAPTER 4

SURVEY OF AGRICULTURAL PRACTICES IN CAPE TOWN'S VEGETABLE FARMING AREAS

4.1. Introduction

The majority of vegetable farmers in the Joostenbergvlakte, Kraaifontein and Philippi areas of Cape Town are commercial farmers. The Joostenbergvlakte and Kraaifontein areas can be grouped together as a unit, while the Philippi area is further removed from these two areas (Figure 4.1 and Figure 4.2). This survey aimed to gather information around the farming practices in these main two vegetable farming areas of Cape Town. This survey also aimed to raise awareness amongst the farmers of the potential near future problem of soil and resultant crop contamination with heavy metals. A third aim was to inform farmers of possible mitigation methods in the event of a heavy metal pollution problem emerging in the future and fourthly to ascertain farmers' interest in and willingness to implement mitigation treatments should they be needed in the future. The survey also aimed at gathering information on farmers' identification of perceived risks to their agricultural lands from the surrounding areas, in terms of adding to the threat of heavy metal pollution of soils, water resources and ultimately crops.

Historically, mostly Dutch settlers engaged in commercial cattle farming in the Kraaifontein area in the 1600's according to Saayman (2010), while in 1870 German settlers started to engage in vegetable and flower farming in the Philippi area (Bamford, 2001; Chittenden Nicks Partnership, 1997; Meerkotter, 2003; Sawyer, 1994). Later commercial vegetable farms, fruit farms and vineyards became more prominent in the Kraaifontein and Joostenbergvlakte areas. Today, mostly vineyards and commercial vegetable farming continues in the Joostenbergvlakte and Kraaifontein area whereas, mainly, commercial vegetable farming continues in the Philippi farming area (Bamford, 2001; Chittenden Nicks Partnership, 1997; CoCTH, 2007; Meerkotter, 2003; Saayman, 2010; Sawyer, 1994). Produce from the Philippi, Joostenbergvlakte and Kraaifontein farms contribute largely to Cape Town's fresh produce market. As much as 50% of Cape Town's fresh produce market vegetables reportedly come from Philippi farms (Theobald, 2011). Cape Town's fresh produce market in turn, is one of the largest contributors to South Africa's total fresh produce market (Directorate Agricultural Statistics, 2000). Since the demand for vegetables is growing, sustainable agricultural practices are imperative.

Cape Town's farmers follow the traditional styles of farming practice as opposed to the types of modern mass production practices that are seen abroad. On Cape Town's vegetable farms soil is still tilled with a small one-man driven tractor, either driven by the farmer himself or a farm worker. Manure and other fertilizers are tossed onto cultivated soil from one-man operated tractors. Seedlings are planted by hand and seeds sown by hand or sprinkled onto the soil from a small tractor. Agrochemicals are sprayed onto crops from a small one-man driven tractor with an attached spray dispenser unit. Irrigation sprinklers are raised about a meter above the soil, connected to the farm dam's water pump and sprinkle crops as needed throughout the day, while harvesting of crops takes place by hand. Sometimes potatoes are bagged in the field upon harvesting, ready to be transported to the market as is. On several farms vegetables are carefully washed and packed according to stringent regulations for distribution to shops and export markets that require more quality packaging (Kinchen and King, 2003; Personal communication with farmers, 2006 - 2010).

Over the years, decades and in a few cases the last century, the practice of vegetable farming in Cape Town has resulted in the agricultural soils becoming more and more contaminated with heavy metals such as copper, zinc and today even lead and cadmium. On occasion the concentrations of cadmium and lead posed a risk to the production of quality crops and in future these events could become more frequent and thus of greater concern (Meerkotter, 2003; Sogayise, 2003). This has spurred on the research for this thesis.

From the results of a survey done by Sogayise (2003) in Kraaifontein and Meerkotter (2003) in Philippi, as well as the results from Chapter two of this thesis, actual direct heavy metal contamination threats to the Philippi, Kraaifontein and the Joostenbergvlakte agricultural areas would include the use of raw organic cattle and chicken manures and moreover the storage of these next to irrigation water dams. To a lesser extent the use of pesticides that contain copper or zinc as active ingredients and chemical fertilizers that contain nominal amounts of these and other heavy metals may also become problematic. Other possible future threats to these agricultural areas in terms of heavy metal contamination may be waste effluent from informal settlements, leakages from waste water treatment plants and effluent or leaching from dumping sites as well as illegal dumping of waste in the farming areas, air pollution and pollution of rivers, streams and aquifers used by these farmers (Aza-Gnandji, 2011; Bertram, 1989; CoCTH, 2007; Gophe *et al.*, 1998; Meerkotter, 2003; Miller; 1996; Qoko, 2003; Sawyer, 1994; Wright and Conrad, 1995; Yeld and Gophe, 1998).

From Orthophoto's produced between 1992 and 2001, possible indirect sources of heavy metals to the Joostenbergvlakte and Kraaifontein agricultural areas could include the following which may in the future become problematic; railway run-off along the boarders of the Joostenbergvlakte farms, run-off and air pollution from the national road (N1) passing through some farms of the Joostenbergvlakte area and potential petrol leakage from a filling-station's underground storage tanks adjacent to one of the Joostenbergvlakte farm water resources and cropped soils. Run-off and illegal dumping of waste from formal and informal settlements in Bloekombos could pose a threat to some Joostenbergvlakte farm lands. Run-off from higher lying vineyards poses a threat to respectively Joostenbergvlakte and Kraaifontein vegetable farms. Run-off and illegal waste dumping from formal and informal settlements in Wallacedene and Scottsdene pose a threat to Kraaifontein farms. Potential run-off and leakage from the Waste water treatment plant in Scottsdene along the Botfontein road poses a threat to some Kraaifontein farm lands as well as air pollution from Bottelary road (Orthophoto Map Series A, 1992; Orthophoto Map Series B, 1992; Orthophoto Map Series C, 2001; Orthophoto Map Series D, 2001; Figures 4.1 and 4.3; Personal communication with farmers).

Possible indirect sources of heavy metals to the Philippi agricultural area could be the following; air pollution from surrounding formal and informal residential areas as well as industrial areas and air pollution and run-off from roads around and through Philippi that connect various surrounding residential areas. The occurrence of illegal dumping of household waste, building rubble and even toxic chemicals on farms has been a problem in the past and could occur again (Gophe *et al.*, 1998; Yeld and Gophe, 1998; Yeld, 1998; Personal communication with farmers). Pollution of surface and underground water resources by surrounding residential and industrial activities is also a problem where water is extracted for irrigation from shared water resources (Bertram, 1989; Wright and Conrad, 1995). Pollution of underground water resources, which are used for irrigation, could happen through percolation of heavy metals to these water resources from surrounding informal settlements, residential areas and industrial areas. Surface water resources, from which farmers often extract water for irrigation, can be polluted with heavy metals through run-off from surrounding roads, railway lines, residential and industrial areas (Meerkotter, 2003; Orthophoto Map Series A, 2001; Orthophoto Map Series A, 1999; Orthophoto Map Series B, 2001; Orthophoto Map Series B, 1999; Figure 4.2).

Threats from the areas surrounding the Kraaifontein, Joostenbergvlakte and Philippi agricultural areas are summarised in Figure 4.1 and Figure 4.2, while Figures 4.3 and 4.4, indicate how these areas have changed to date. These figures have been composed by using the mentioned Orthophotos from 1992, 1999 and 2001 and by making the necessary adjustments as seen through physical observations made in these areas during 2011 as the researcher drove through the areas and as gleaned from road maps (Map Studio, 2007).

It is important to note that no geographic points were recorded to verify the exact start and end points of areas indicated in Figures 4.3 and 4.4. The changes indicated in Figures 4.3 and 4.4 could be verified in future research. Where smallholdings are indicated it may refer to plots where animals such as cattle or horses are kept, flowers are grown, small farm stalls are run or mechanical workshops operate. Formal residential areas refer to areas with formally built houses. Formal and informal residential areas refer to areas where formally built houses and shacks are found, while informal residential areas refer to areas where mostly shacks are found. Areas indicated as industrial areas refer to various industrial activities, ranging from metal and concrete and waste recycling plants, mechanical workshops, factory warehouses, storage warehouses, factory outlet shops and other commercial shops such as Macro and Ottery Pick ’n Pay Hypermarket. A legend/key for Figures 4.1, 4.2, 4.3 and 4.4 is given in Table 4.1.

Table 4.1: Key to Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4

Vegetable farms	
Vineyards	
Fruit farms	
Smallholdings	
Sand mining	
Formal residential area	
Formal and informal residential area	
Informal residential area	
Industrial area	
Waste water treatment plant	
Surface waters	
Sea	
Railway line	
Main road	
Road	
Contour line	
Height above sea level	• meters
Filling station	F

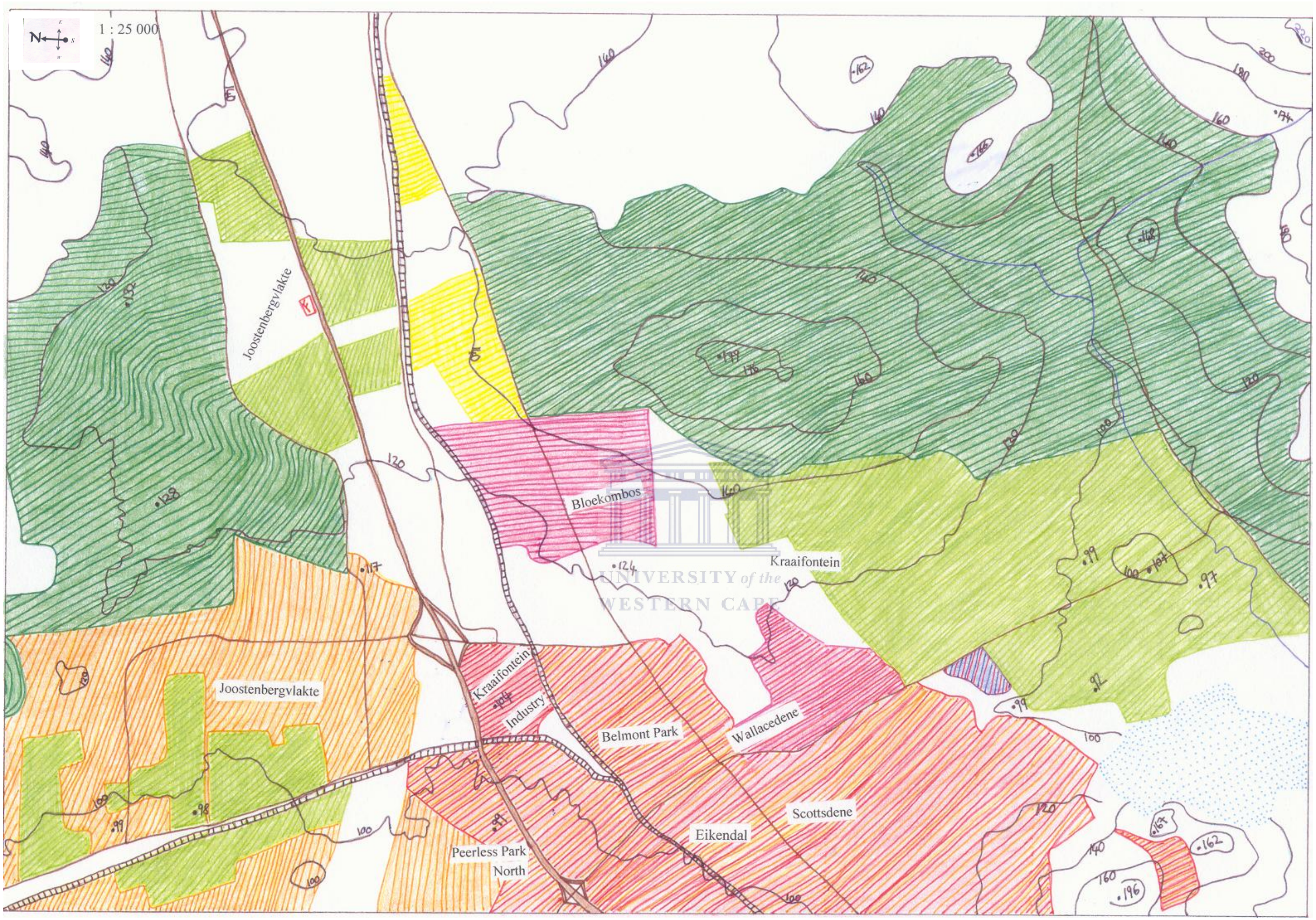


Figure 4.1: The Joostenbergvlakte and Kraaifontein vegetable farming areas and surrounding areas in 2000

(print to A3 size for correct scale)

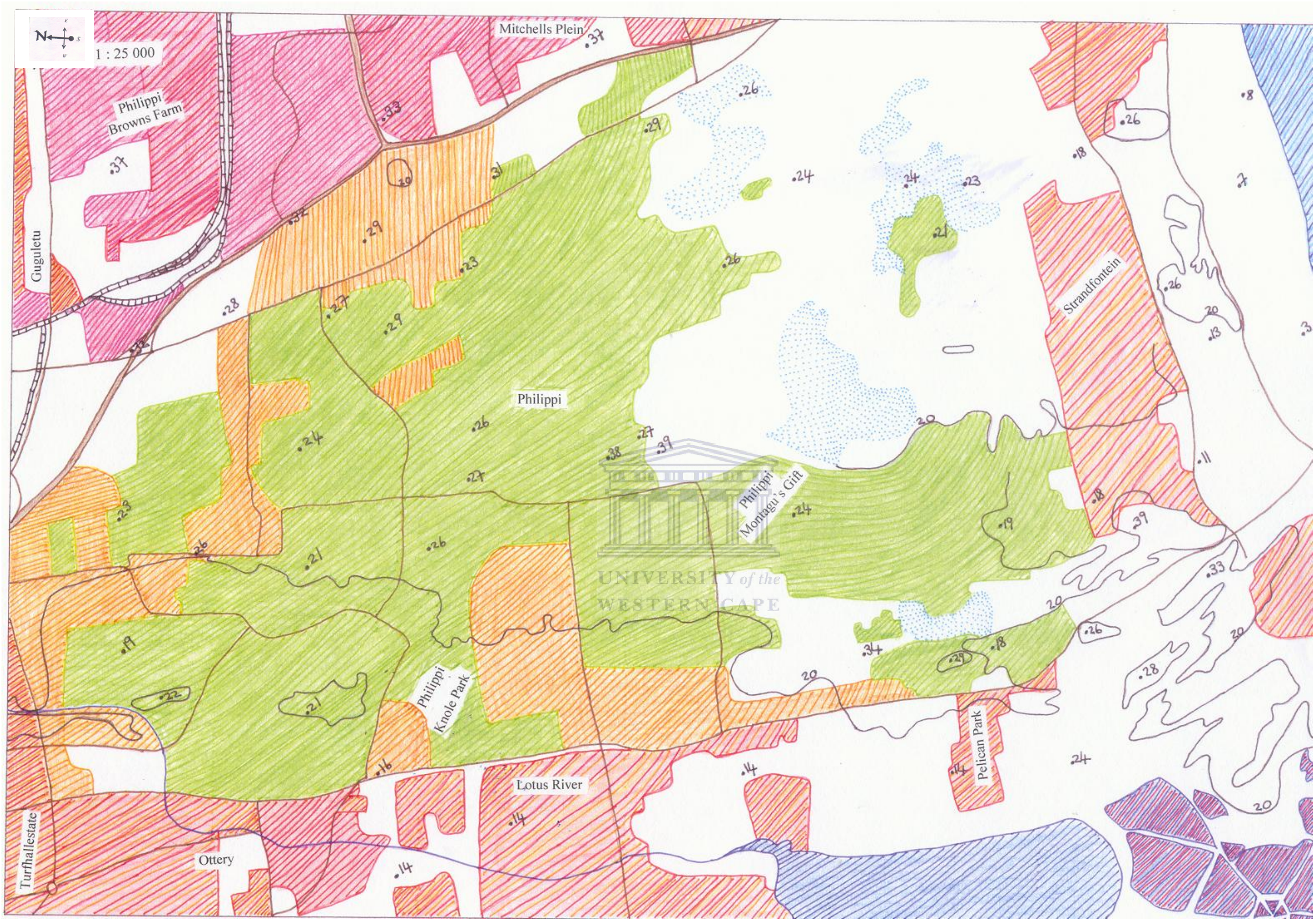


Figure 4.2: The Philippi vegetable farming area and surrounding areas in 2000

(print to A3 size for correct scale)

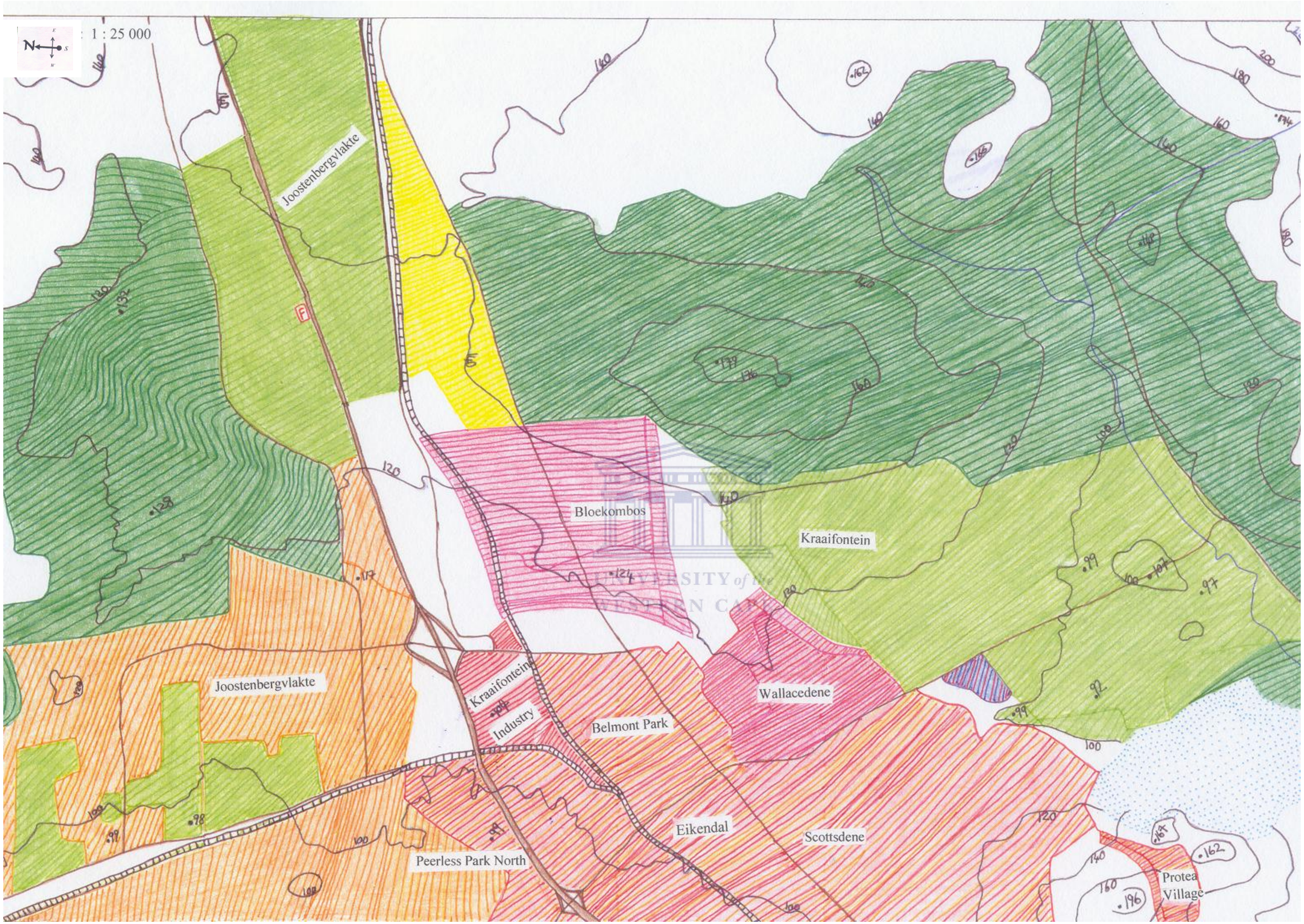


Figure 4.3: The Joostenbergvlakte and Kraaifontein vegetable farming areas and surrounding areas as seen in 2011

(print to A3 size for correct scale)

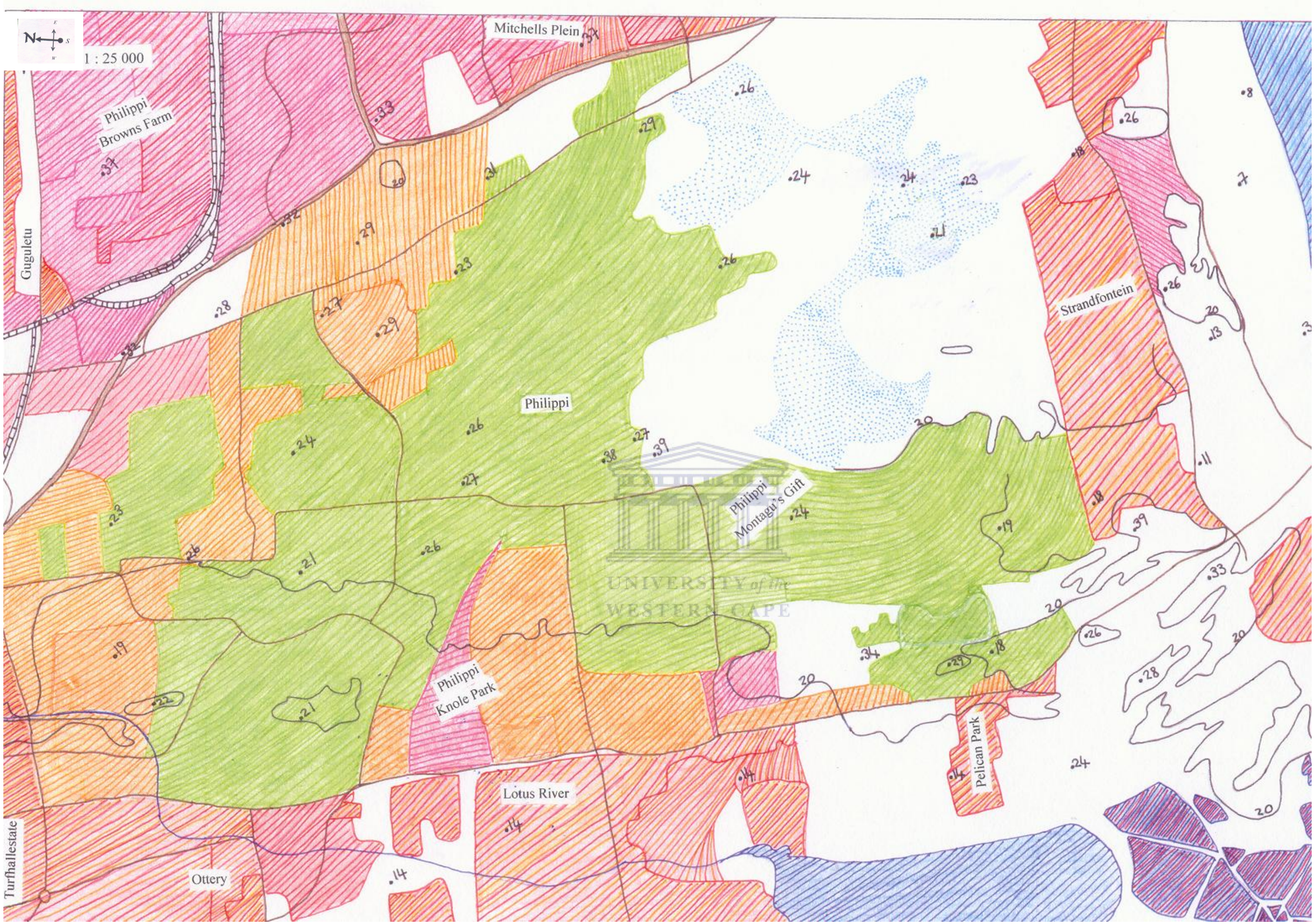


Figure 4.4: The Philippi vegetable farming area and surrounding areas as seen in 2011

(print to A3 size for correct scale)

Based on informal discussions the researcher has had with vegetable farmers from these areas, most farmers seemed to know of these threats even if it they were not directly linked to the possible heavy metal contribution thereof to their soils, irrigation waters and crops. The extent of farmer's knowledge and concern about these threats were investigated indirectly and is only alluded to through this survey's results.

From informal discussions with farmers it was not clear if farmers knew of the legal obligations they would have in case their land, irrigation waters or crops became too contaminated with heavy metals. Though farmers seemed aware of the existence of regulations, the actual implementation of legislative regulations and monitoring of specifically heavy metals in either their soils and/or water resources were apparently not done by local government, municipalities or the farmers themselves regularly. Farmers' crop quality was tested often to determine its suitability for distribution to different fresh produce markets, but these tests did not often, if at all, include testing for heavy metals, but rather tested bacterial counts and concentrations of organic-agrochemical residues thereon (Personal communication farmers).

The findings reported in Chapter three of this thesis and similar findings by Sogayise (2003) and Meerkotter (2003) regarding the heavy metal content of crops produced in these farming areas could be of great reputational risk to farmers if it should be interpreted out of context. It is thus important that the problem is not inflated and that no sensation is created around the issue but; it is also important to not underestimate the necessity of monitoring the now relatively clean soils, irrigation water resources and crops produced in these areas. It is important to note in cases where crops have exceeded South African and/or even European limits set for foodstuffs, that these limits often fell well beneath that allowed by the daily permissible dietary intake for humans (Meerkotter, 2003; Noss and Rolfes, 2002; Smith, 1994).

Informal discussions with farmers often revealed, from the researcher's perspective, a slight concern with farmers, that unnecessary questions around the general agricultural practices on their lands were being generated which may impact on their reputations as well as subsequent sales of their produce. Farmers did not seem to see the actual issue of heavy metal contamination of their agricultural soils, irrigation water resources and possibly crops as such a big risk compared to the reputational risk they could face if researchers ever misused the gathered information. This research did not specifically aim to ascertain farmers' feelings about the issue of heavy metal pollution on their agricultural lands, but instead aimed at gathering general information about farming practices on these farms and information about the actual agricultural land and environments themselves. Informal conversations with farmers about the research, and specifically on the topic of remedial treatments, gave the impression that farmers would be willing to make the necessary adjustments if in the future remediation of any kind should be needed. Nonetheless, farmers' views of the priority of remediation of agricultural soils with regard to heavy metal contamination did not seem very high in comparison to other issues farmers faced.

A study conducted by Grasmück and Scholz (2005) to evaluate the role of knowledge and emotional concern about an environmental risk on the perception of that particular risk, found that emotional concern was most important at leading to action, such as implementation of remedial treatments. The risk perception of heavy metal contamination of soils from which vegetables were harvested and eaten in a community in northern Switzerland, indicated that the risk was considered more seriously by those who were emotionally concerned and bore actual knowledge of the risk than those who through dissonance-reducing heuristics judged the problem as minimal and not worth much attention in terms of needing to take remedial action. In this case heuristics included observations by inhabitants that some have lived in the contaminated area for many years and since they have never seen the need to move away the problem could not have been that great (Grasmück and Scholz, 2005).

The same kind of factors may also be at play in the agricultural farming areas of Cape Town where farmers' perception of the heavy metal contamination risk to their farms is cardinal to effect implementation of preventative and/or remedial treatments. Emotional concern amongst farmers about the dangers of heavy metal contamination on their cropped lands in conjunction with appropriate knowledge about sources of heavy metal contamination to their agricultural lands would probably help reduce many of the dissonance-reducing heuristics encountered in conversations with farmers. Heuristics that seemed to reduce some farmers' perception of the risk of heavy metal pollution amongst other arguments included the following; that though heavy metals were probably added to cropped soils through application of agrochemicals and organic fertilizers (as indicated in Chapter two), farmers never had complaints from consumers about crop quality. Consequently farming practices have remained rather consistent over the years and since the agrochemicals used were from reputable sources farmers did not seem emotionally concerned about heavy metal contamination (Grasmück and Scholz, 2005; Personal communication farmers). This kind of argument could also be supported by the fact that cabbage plant growth, for example, was not stunted at the *in situ* concentrations of Cd, Cu, Pb and Zn in the growth medium prepared from soils of these farms for the pot experiment performed in Chapter three of this thesis.

Dissonance heuristics may play a big part in farmers perception of the risks associated with heavy metals contamination of agricultural lands in that farmers' non-encounter of problems relating to heavy metals with regard to crop quality and yield might lead them to conclude that there is not really a problem. This may lead to no action being taken in terms of monitoring the levels of heavy metals in the agricultural environment by farmers and even local municipalities. This may also lead to little attention being paid to recommendations for preventative or remedial farm practices as it might require “burdensome” changes to be made to current farming practices (Grasmück and Scholz, 2005; Personal communication farmers).

Farmers in certain cases use agrochemicals that contain specific heavy metals, but the usefulness of using these chemicals to ensure crop productivity is often of much greater benefit compared to the likelihood of ever encountering an event where consumers could be negatively affected by consumption of a specific crop. This is especially used as a heuristic to reduce the perception of the risk of heavy metal contamination since farmers take care to keep with holding periods between the last spraying of a crop with any agrochemical and its harvesting date. However, should the risk to the consumer become more pronounced farmers could possibly become more prone to consider taking remedial action especially if it would not negatively impact on crop productivity and financial gain (Grasmück and Scholz, 2005; Personal communication farmers).

An increased emotional involvement and concern about heavy metal pollution could probably increase the rating of the perceived risk and lead to a greater possibility that action might be taken to prevent or remedy further contamination. The results of this survey aimed at encouraging more emotional concern amongst farmers by making more knowledge available on the issue (Grasmück and Scholz, 2005). This study however did not focus on measuring farmers' emotional concern about heavy metal contamination on their lands. The view of farmers regarding the application of certain remedial treatments was tested indirectly. The farmers' perception of the risk of pollution from encroaching residential and industrial areas and thus the possible resultant increased heavy metal contamination was also measured indirectly through this study's survey about farming practices. The value and role of the community in preventing contamination of agricultural land should not be underestimated but it was not directly evaluated in this survey (Grasmück and Scholz, 2005).

As part of the research strategy, gaining cooperation from the farmers was of utmost importance as the outcomes of this research is ultimately aimed at benefitting these farming communities. The methods applied for this survey are discussed in the Materials and methods section of this chapter. Constitutionally, all South Africans have the right to receive or impart information freely therefore, clear and transparent communication with the farmers was compulsory. All South African citizens also have the right to access information held by another person that is necessary for protection of their rights thus, farmers were to some extent obliged to divulge information on farming practices that could affect consumers (The Constitution of the Republic of South Africa, 1996). This survey about the farming practices on Cape Town's vegetable farms aimed at gathering information that may be of use to implement preventative or remedial practices to curb heavy metal pollution on these farms.

According to the South African constitution everyone has the right to an environment that is not harmful to his/her health and therefore pollution must be prevented (The Constitution of the Republic of South Africa, 1996). Farmers could thus be held accountable for the level of contaminants in their soils, water resources and produce. Landowners are for example expected to pay for whatever mitigation should be needed in the event of a water pollution problem (Republic of South Africa, 1998). This survey thus also aimed to raise more awareness amongst farmers around the importance of addressing the need for at least monitoring the concentrations of heavy metals in the agricultural environment.

4.2. Materials and Methods

This research involved the interviewing of farmers to gathering information about their farming practices. The farmers' rights to privacy and the researcher's obligation to use the gathered information responsibly were ensured through ethics clearance of the survey procedure and survey questions by the University of the Western Cape's Ethics Committee. The Ethics statements for this survey are given in section 4.2.1, the survey method described in section 4.2.2 and the survey questionnaire discussed in section 4.2.3 of this chapter.

4.2.1. Survey ethics statement

The survey on farming practices and the collection of agricultural samples (for Chapter two) from the Joostenbergvlakte, Kraaifontein and Philippi vegetable farms was done in good faith towards the farmers and followed ethical guidelines of the South African Medical Research Council (Labuschagne, 2005). Interviews were only conducted on farms where farmers gave consent and a meeting time could be established and materialized.

According to the South African Constitution everyone has the right to an environment that is not harmful to his/her health and therefore pollution must be prevented (The Constitution of the Republic of South Africa, 1996). Farmers could thus be held accountable for the level of contaminants in their soils, water resources and produce. Farm owners could for example be expected to pay for whatever mitigation should be needed in the event of a water pollution event occurring (Republic of South Africa, 1998). This study thus ultimately aimed at helping farmers gain more knowledge about the need for prevention of heavy metal pollution and means of addressing it should it arise in the future. Due to the sensitivity of the issue, the identities of the farmers were to be protected as far as possible. The results of this study if ever published should be done using aliases and codes to protect the identities of farmers who participated (Labuschagne, 2005). It is imperative that awareness around the issue of heavy metal contamination be raised amongst farmers. The issue however was to be raised in a manner that would encourage sustainable development of these agricultural communities instead of causing harm through loss of agricultural activity in these areas in the future (The Constitution of the Republic of South Africa, 1996).

4.2.2. Survey method

Upon obtaining ethics clearance the survey was conducted among farmers of the Joostenbergvlakte/Kraaifontein and Philippi vegetable farming areas. The Joostenbergvlakte/Kraaifontein area had a total of approximately 12 land owning vegetable farmers while the Philippi area had about 24 land owning farmers, during the time period of this survey. An interview sample number representative of at least 80% of the farmers in each area was aimed for. In the end, however, 75% of the farmers in the Joostenbergvlakte/Kraaifontein area agreed to be interviewed and 71% of the farmers in the Philippi area. The survey was conducted as suggested by Serumaga-Zake *et al.*, (2004) and adhered to the South African Medical Research Council's ethics guidelines and thus followed the process described here below.

Farmers were firstly informed of the proposed survey through verbal communication and presentation of an information sheet about the proposed study as a whole. A copy of the English version of the information sheet can be found in the Appendix of this thesis. Each farmer who agreed to engage in the survey signed a consent form upon making an appointment for the survey interview. A copy of the English version of the consent form can also be found in the Appendix. Prior to the survey, general information was gathered about the surveyed areas, to help the researcher understand some dynamics of these two farming areas. Maps were obtained of Philippi, the Joostenbergvlakte and Kraaifontein vegetable farming areas to keep record of the locality of the farms surveyed.

To encourage homogeneity in the survey, the researcher conducted the survey using the same questionnaire for both farming communities and attempted to do the survey over the shortest period of time possible. The survey took two weeks to complete. The same researcher interviewed all the farmers (Serumaga-Zake *et al.*, 2004). During each interview the objectives of the survey was stated clearly to the interviewed farmer so that he/she could see the importance of the study even if they did not benefit from it directly. It was indicated to each interviewed farmer that their given information would remain anonymous through the use of an alias and/or codes. In each interview, the interviewer remained polite and neutral in attitude with regard to answers given by the farmers. The interviewer took care to clearly explain the questions where needed but avoided the making of comments that could influence or guide the interviewed farmer's answers.

The responses for each interview were recorded on a separate questionnaire. The answers were checked before entry into the database to ensure correctness of the entered data. Checking the answers also helped identify questions that were answered reluctantly and hence needed to be approached with caution during interpretation of the survey results. The survey data was entered into an Excel spread sheet in a way that would later allow for statistical comparisons between these two farming communities since different factors could have been at play in contributing to heavy metal pollution on the different farms (Figures 4.1, 4.2, 4.3 and 4.4). Statistical processing of the data was done by Ms. Marieta Van Der Rijst from the Biometry Unit of the Agricultural Research Counsel at Infruitec in Stellenbosch. Statistical analysis included the use of ANOVA's, T-tests, compilation of frequency tables and Chi-Square tests where possible. In some cases only descriptive analysis of the interview answers were possible.

4.2.3. Survey questionnaire

The researcher designed the questionnaire. The questionnaire was compiled according to principles and guidelines given by Serumaga-Zake *et al.* (2004). The questionnaire was evaluated by specialists, tested by colleagues and translated into Afrikaans before the actual survey was conducted. A copy of the actual survey questionnaire in English is given in the Appendix of this thesis. The questionnaire was constructed to gather the following information, which is discussed in the same order in the Results section of this chapter.

Question 1 focused on gathering a brief history of each surveyed farm in terms of the name of the farm, the size of the farm and age of the farm. Question 2 and 3 asked how many boreholes were present on the surveyed farm and what the depths of the different boreholes were, while Question 4 asked how many dams were present on the surveyed farm. Question 5 and 6 looked at how deep the water table was, on average, on the surveyed farms, in the winter and summer months, while Question 7 asked which water resources were used to supplement irrigation water resources on the particular farm surveyed.

To answer Question 7, farmers could choose from any of the following water resources, as sources used to supplement normal irrigation water resources; the drawing of water from storm water canals, municipal water resources and/or drawing water from a nearby stream or river. Farmers could also choose any of the following water resources to answer Question 7; the distributing of water from one borehole to more than one irrigation water holding dam and/or the drawing of water from one dam to fill another dam and/or making use of recycled irrigation water or waste water to supplement irrigation water resources. Farmers could also indicate if they made use of any other resources not mentioned here, which could add valuable information to the existing knowledge bank about these farming areas. In informal conversations with a few farmers in the Philippi farming area, the issue of salinization of irrigation waters was raised. Question 8 thus specifically asked farmers if their borehole waters were becoming more saline.

Determining what the main vegetables were that were grown on each farm, was done by asking Question 9. Question 9 not only asked which vegetable crops were farmed with but also how many hectares of each kind of crop were grown per year. With Question 10 it was hoped to ascertain how much of the different kinds of fertilizers was used for specific crops grown on the surveyed farm. The amount of agrochemicals and in particular pesticides used was covered by Question 11. Question 11 asked how many litres of each pesticide were used per hectare, per planting season for the respective crops grown on the particular farm.

Question 12 focused on the willingness of farmers to employ mitigation methods should heavy metals or other harmful chemicals become a problem in their farm soils or crops in the future. Question 12 listed several remedial methods and asked whether or not a farmer would employ each of the specific methods. The mitigation methods mentioned were the following; an increase in the amount of manure used, an increase in the amount of phosphate fertilizer used, the ceasing of use of a fertilizers that contained harmful chemicals, the ceased use of any pesticides that contain harmful chemicals, the addition of a chemical to the soil to immobilise the harmful chemicals and/or the planting of a crop that could remove harmful chemicals or heavy metals from their agricultural soil.

Question 13 aimed to gather information about the farm and surrounding areas in terms of the interviewed farmers' knowledge of activities in the area that led him/her to be concerned that it may affect the quality of irrigation water resources on the farm. The farmer was asked to identify the perceived threats to irrigation water on the farm. Question 14 supported Question 13 by asking if the farmer if he/she knew of any activities in the area that could decrease the quality of the soil on the specific farm. The interviewed farmer was asked to identify the activities that caused him/her concern around the sustained quality of the soil.

Lastly the awareness of each interviewed farmer about the legal implications in the event of excess levels of harmful chemicals being found in either farm soils, irrigation water resources and/or crops intended for sale was determined through Question 15. The answers to these questions, for the two main farming areas of Cape Town, are given in the Results section of this chapter. The results are given in order of the asked questions.

5.3. Results

Some farmers were reluctant to give full answers and in most cases farmers were in a hurry thus; despite making an official appointment with them, the questionnaire could often not be completed in detail. The information that could, however, be collected with confidence is represented in the tables and figures that follow. Information relating to the actual sizes of farms and the amounts of fertilizers and agrochemicals applied per hectare for specific crops was given reluctantly and vaguely. The answers that were given in these cases were treated with caution and in cases left out of statistical calculations since it was not possible to collect enough information for comparisons to be made with confidence. Where results are reflected but there was uncertainty as to the accuracy of any number of farmers answers “?” is indicated adjacent to the particular question result in the appropriate results table.

Question 1 focused on gathering some historical and general information about the farms in the Joostenbergvlakte/Kraaifontein farming area and the Philippi farming area. The results for Question 1 are summarized in Table 4.2. Information gathered for Question 2 and Question 3 regarding the number of boreholes found on each farm and thus in each farming area and the approximate depths of most boreholes in the two farming areas are also summarized in Table 4.2. Question 4 gathered information that reflected the number of dams present on each farming area and is also summarized in Table 4.2. The average depth of the water table in each farming area in winter and in summer answered Questions 5 and 6 and was also given in Table 4.2. This data is elaborated on in the Discussion section of this Chapter.

As reflected in Table 4.2, it was not easy to verify which farming area occupied the greatest amount of land surface since a great standard deviation was observed for the given hectares in both farming areas. The gathered data seemed to reflect that the Philippi farming area was slightly older than the Kraaifontein farming area, if one looks at the age of the older farms and this agrees with literature (Bamford, 2001; Chittenden Nicks Partnership, 1997; Meerkotter, 2003; Sawyer, 1994). Other comparisons are discussed in the Discussion section of this report. Through performing ANOVA’s and T-tests on the data displayed in Table 4.2, only the number of boreholes and approximate depth of the boreholes differed significantly between the Joostenbergvlakte/Kraaifontein (Kraaifontein) and Philippi farming areas. These results are given in Table 4.3.

Table 4.2: General and historical information about the Joostenbergvlakte/ Kraaifontein and Philippi farming areas gathered from farmers in 2007

Joostenbergvlakte/Kraaifontein farming area			
Variable	**n**	**Mean**	**Standard deviation**
Farm size (?)	9	75.4 hectares	73.9 hectares
Age of older farms	7	43 years	19 years
Age of new farms	5	15 years	11 years
Average number of boreholes on farm (1)	9	1	1
Approximate depth of most boreholes	6	85.4 meters	28.3 meters
Average number of dams on a farm	9	4	3
Average depth of water table in winter	5	0.9 meters	0.5 meters
Average depth of water table in summer	5	1.5 meters	0.4 meters
Philippi farming area			
Variable	**n**	**Mean**	**Standard deviation**
Farm size (?)	17	50.4 hectares	34.9 hectares
Age of older farms	14	59 years	23 years
Age of new farms	6	12 years	6 years
Average number of boreholes on farm	17	7	7.5
Approximate depth of most boreholes	17	52.4 meters	23.8 meters
Average number of dams on a farm	16	6	5
Average depth of water table in winter (?)	15	1.9 meters	2.6 meters
Average depth of water table in summer	9	4.2 meters	3.0 meters

Table 4.3: Analysis of variance and T-test results for the number of boreholes and approximate depth of boreholes from the Joostenbergvlakte/Kraaifontein and Philippi farming areas as indicated by farmers in 2007

Dependent variable	**Farming Area**	**Sample number (n)**	**Mean for dependent variable**	**P-value for ANOVA**	**LSD for T-tests**
Number of boreholes	Kraaifontein	n = 9	1.333	0.0374	5.253
	Philippi	n = 17	6.941		
Approximate depth of boreholes	Kraaifontein	n = 6	85.42 m	0.0111	24.64 m
	Philippi	n = 17	52.40 m		

The results in Table 4.3 indicate that farmers of the Philippi area are possibly more dependent on the availability of groundwater than farmers of the Joostenbergvlakte/Kraaifontein area.

The data also indicates that in general different aquifers probably supply these two areas, since the approximate depth of most boreholes from these two areas are significantly different. This is expanded on in the Discussion section of this chapter. Question 7 determined what supplementary water resources were used most often in these two farming areas apart from the primary source of irrigation water in the holding dams. These results were analyzed using Frequency tables and Chi-square tests and are represented in Figures 4.5, 4.6 and 4.7.

In Figures 4.5 and 4.6 it can be seen that in general there was a significant difference between farmers use and non-use of a specific supplementary water resource in both the Philippi and Joostenbergvlakte/Kraaifontein farming areas. Farmers of the Joostenbergvlakte/ Kraaifontein farming area mentioned under the category of "Other" supplementary water resources the Theewaterskloofdam scheme. From Figure 4.5 it seems that supplementary water resources that are used most often in the Joostenbergvlakte/Kraaifontein area are water from storm water canals (containing rain water and water from the local waste water treatment plant) and water from the Theewaterskloofdam. From Figure 4.6 it seems that the most important supplementary water resources in the Philippi farming area are waters gained from recycling irrigation water and by pumping water from a more profitable borehole into more than one dam.

Figure 4.5: Percentage use of supplementary water resources for irrigation in the Joostenbergvlakte/Kraaifontein area (Chi-Square = 0.0008)

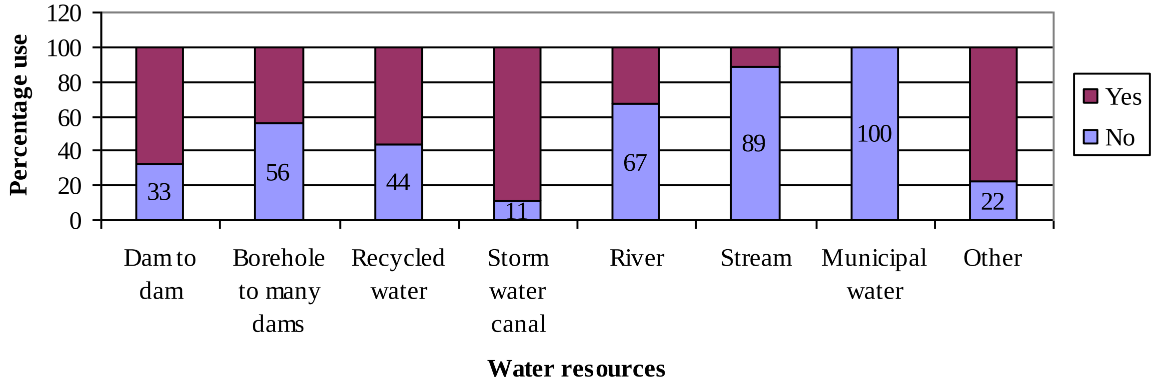
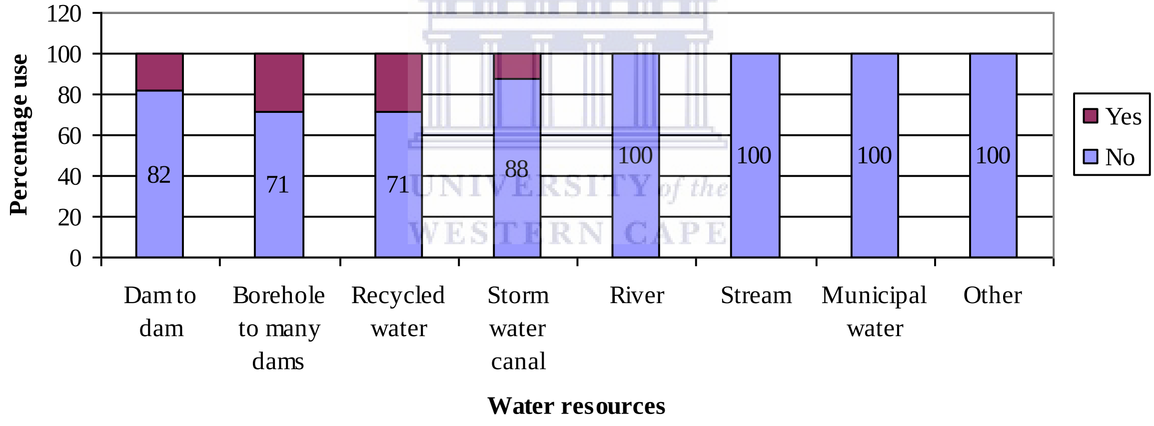
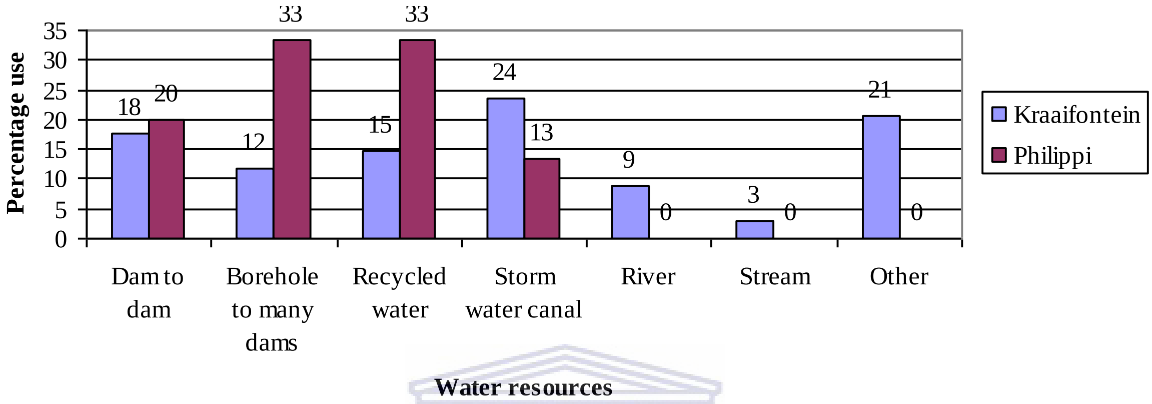


Figure 4.6: Percentage use of supplementary water resources for irrigation in the Philippi area (Chi-Square = 0.0039)



In Figure 4.7 no significant difference was seen between the types of supplementary water resources used in the Joostenbergvlakte/Kraaifontein and Philippi farming area since the Chi-square value was 0.1324. The trend however supports that seen in Figures 4.5 and 4.6 in that the farmers from the Philippi farming area seem to use relatively more borehole water and recycled water than farmers of the Joostenbergvlakte/Kraaifontein farming area. Farmers of the Joostenbergvlakte/Kraaifontein area also seem to have a greater variety of supplementary water resources than those in the Philippi farming area. Joostenbergvlakte/Kraaifontein farmers can for example make use of water from rivers and the Theewaterskloofdam to supplement their irrigation water resources.

Figure 4.7: Comparison of use of supplementary irrigation water resources for irrigation in the Joostenbergvlakte/Kraaifontein and Philippi area as a percentage of the total use per area (Chi-Square = 0.1324)



Salinization and mineralization of underground water in the Philippi farming area has been reported (Aza-Gnandji, 2011; Bertram, 1989). Question 8 was used to specifically ask farmers if their borehole waters were becoming more saline. The farmers' responses are reflected in Figures 4.8, 4.9 and 4.10. Aza-Gnandji (2011) aimed to determine if sea water had already intruded the Cape Flats aquifer from which water is drawn by Philippi farmers. One of the parameters used to determine sea water intrusion is the presence of Cl in concentrations greater than 100 mg.l^{-1} and Na in concentrations greater than 70 mg.l^{-1} in borehole water. It was found that sea water intrusion had not happened in the Philippi area to date, but that salinization of underground water resources could become problematic in the near future (Aza-Gnandji, 2011). From Figure 4.8 and Figure 4.9 a significant difference between answering “yes” and “no” was seen when farmers were asked if their borehole waters were becoming more saline. Farmers from both the Philippi and Kraaifontein areas seemed not to be experiencing problems with salinization of their borehole waters.

Figure 4.8: Salinization of borehole water in the Joostenbergvlakte/Kraaifontein area (Chi-Square = 0.0342)

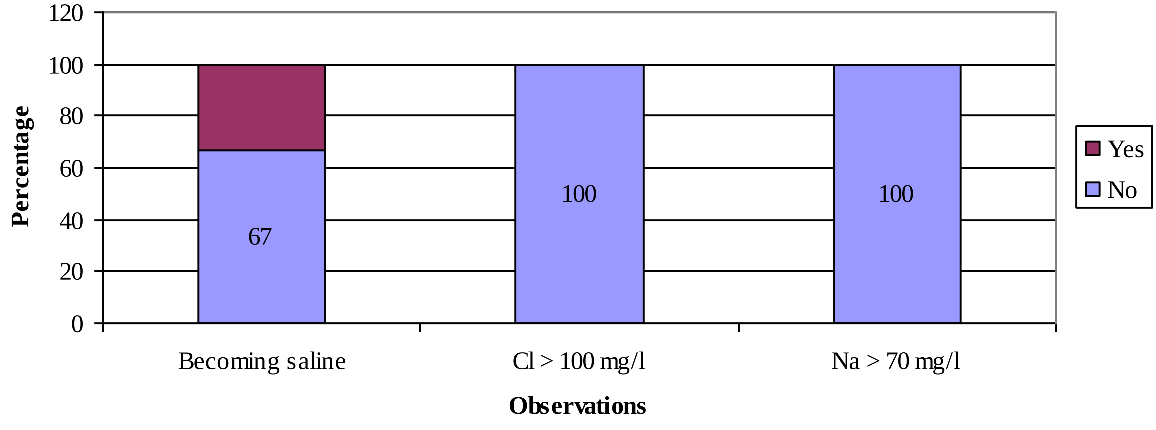
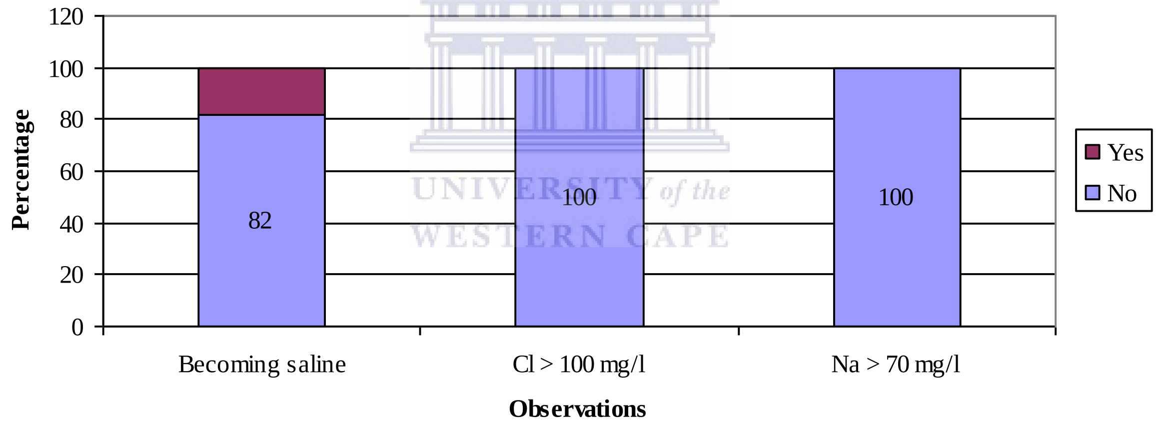
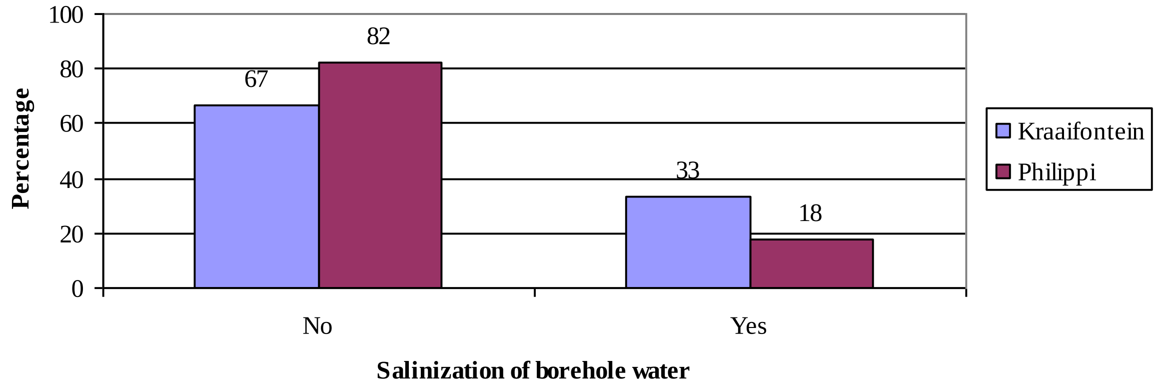


Figure 4.9: Salinization of borehole water in the Philippi area (Chi-Square = 0.0342)



Comparing the answers to Question 8 between the two farming areas, as represented in Figure 4.10, no significant difference was observed in farmers' responses. Farmers from both areas claimed to not be experiencing salinization of their underground water resources in 2007.

Figure 4.10: Comparison of salinization of borehole water in the Joostenbergvlakte/Kraaifontein and Philippi area (Chi-Square = 0.0366)



Question 9 determined which vegetable crops were farmed with during the year. Farmers were reluctant to disclose the number of hectares they planted of the specific crops per year and this detail was thus excluded from statistical analysis. The gained data is summarized in Figures 4.11, 4.12 and 4.13. From both Figures 4.11 and 4.12 a significant difference between answering "yes" and "no" was seen when farmers were asked which crops they planted. Farmers in the Joostenbergvlakte/Kraaifontein area seemed to plant carrots, cabbage, cauliflower, lettuce and beetroot most frequently, while garlic was not planted by these farmers as a rule (Figure 4.11). Farmers in the Philippi area seemed to plant cabbage, carrots, cauliflower and potatoes most frequently (Figure 4.12).

In Figure 4.13 a comparison is made between the kinds of crops grown in the Philippi area and the Joostenbergvlakte/Kraaifontein farming area. The Chi-square value of 0.8086 indicated that there was not a significant difference in the kinds of crops grown in these two areas. However, from Figure 4.13 it could be seen that farmers from the Joostenbergvlakte/ Kraaifontein area tended to grow more beetroot and lettuce compared to Philippi farmers, while in comparison farmers from the Philippi area seemed to grow more garlic, leaks and spinach. Cabbage, carrots and cauliflower are the major crops grown in both areas and thus in Cape Town's vegetable farming areas.

Figure 4.11: Vegetable crops grown by farmers in the Joostenbergvlakte/Kraaifontein area (Chi-Square = < 0.0001)

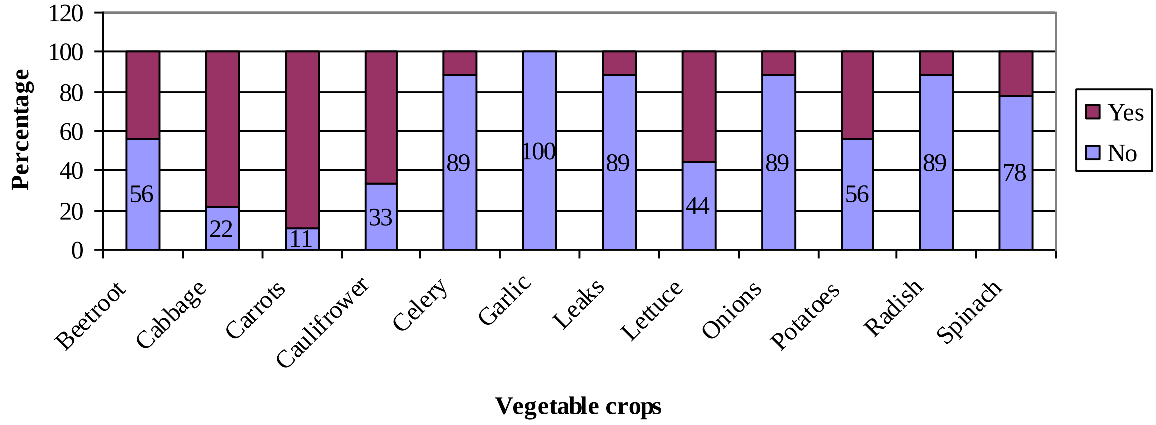


Figure 4.12: Vegetable crops grown by farmers in the Philippi area (Chi-Square = < 0.0001)

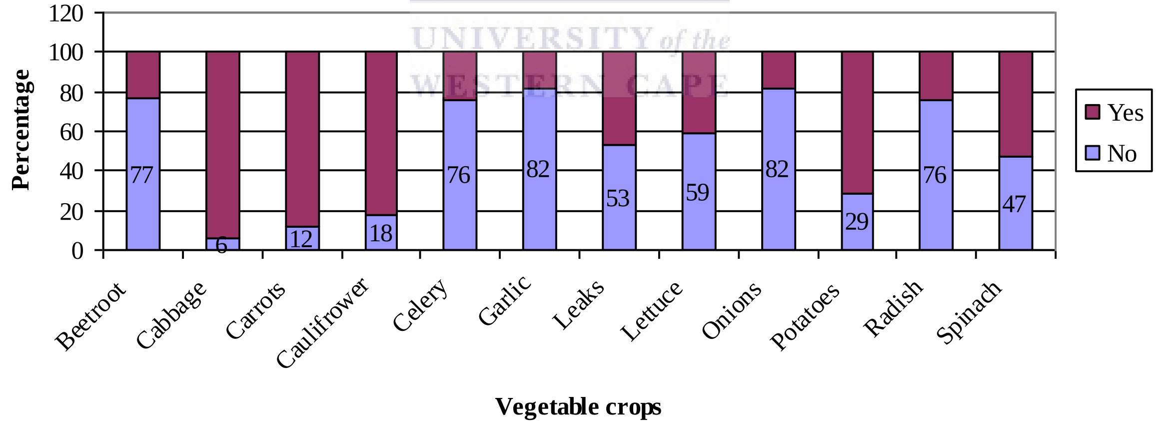
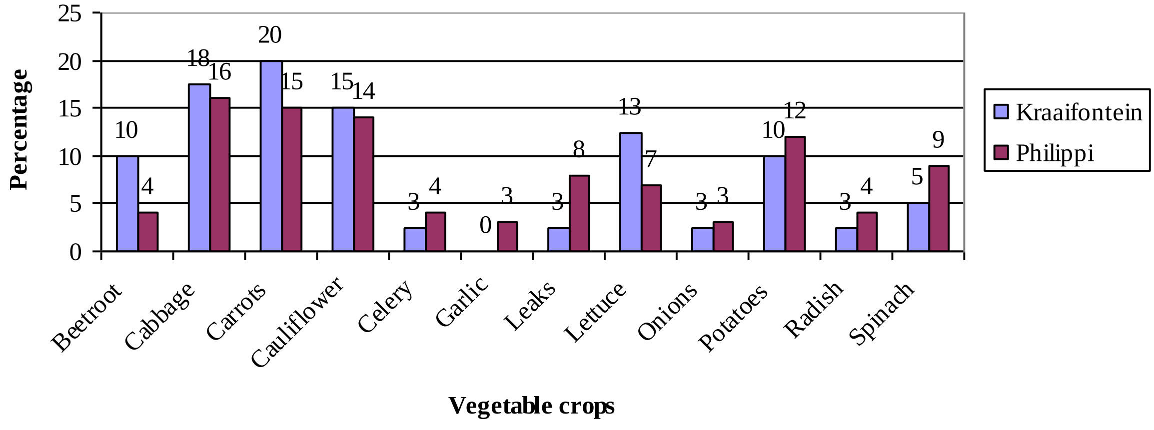


Figure 4.13: Comparison of vegetable crops grown in the Joostenbergvlakte/Kraaifontein and Philippi area as a percentage of the total crops produced per farming area (Chi-Square = 0.8086)



With Question 10 it could be ascertained which kinds of fertilizers were used most frequently in the two farming areas. With Question 10 it was also hoped to determine how much was used of each fertilizer kind. Farmers however did not always have the necessary data at hand to be able to answer this question completely and thus it could not be determined how much of the different kinds of fertilizers were used on the surveyed farms. The data that could be gathered for Question 10 is summarized in Figures 4.14, 4.15 and 4.16. From Figure 4.14 it could be seen that farmers from the Joostenbergvlakte/Kraaifontein area used cattle manure, chicken manure and chemical fertilizers and that the frequency of its use or non-use was not significantly different even though the trend seemed to be that cattle manure was used less frequently. From Figure 4.15 it could be seen that farmers from the Philippi area used the three fertilizer groups with significantly different frequency. Chemical fertilizers and chicken manure were used frequently while cattle manure was used significantly less in Philippi. Figure 4.16 compared the frequency of use of the three main fertilizer types between the Philippi and the Joostenbergvlakte/Kraaifontein farming areas. The differences in use were not indicated as truly significant since the Chi-square value was 0.4910.

Figure 4.14: Most frequently used fertilizers in the Joostenbergvlakte/Kraaifontein area (Chi-Square = 0.1282)

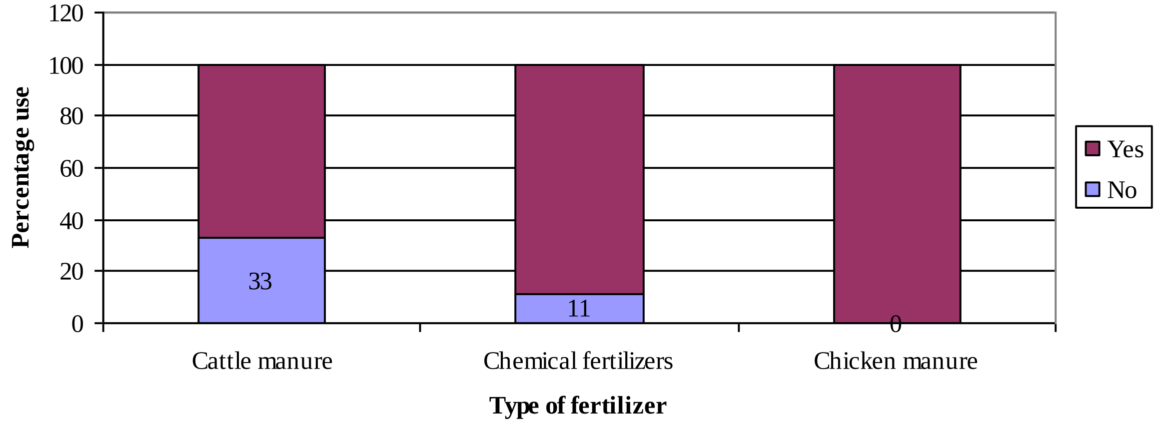


Figure 4.15: Most frequently used fertilizers in the Philippi area (Chi-Square = 0.1282)

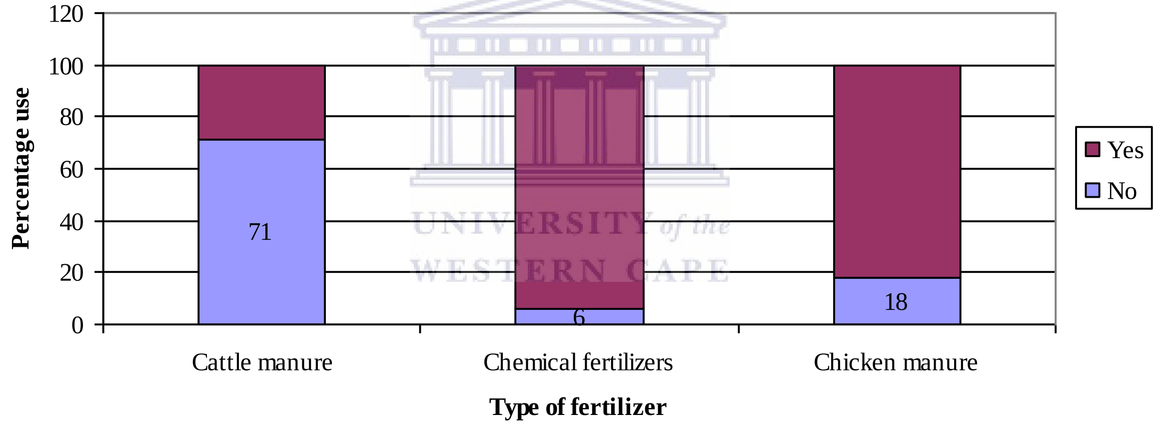
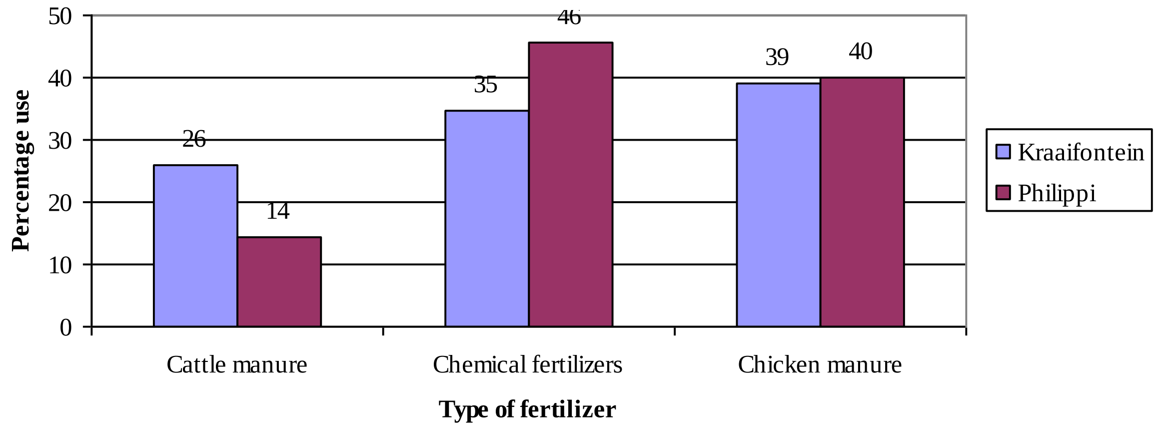


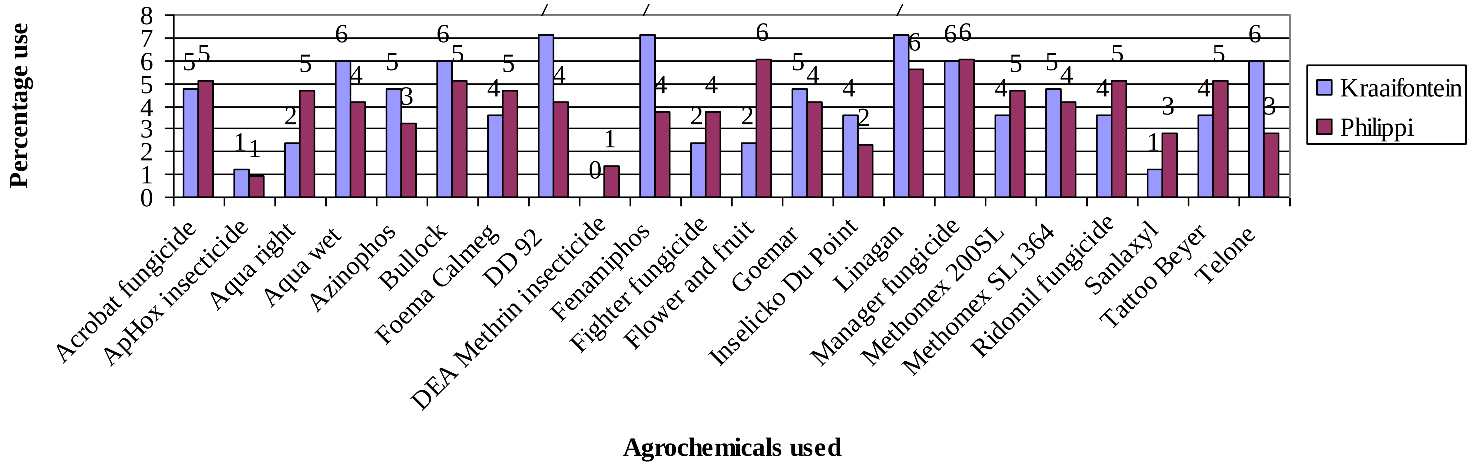
Figure 4.16: Comparison of use of fertilizers in the Joostenbergvlakte/Kraaifontein and Philippi area as a percentage of the total use per farming area (Chi-Square = 0.4910)



With Question 11 it could only be ascertained which pesticides from a given list of agrochemicals found on some farms during 2007 were used most frequently in the two farming areas. Question 11 also meant to determine how much of each pesticide was used but in most cases farmers were not willing or able to give this information in enough detail. In most cases farmers were also reluctant to declare the use of agrochemicals not found on the presented list of agrochemicals. It is important to note that at the time of this survey the names of the various agrochemicals used were different to those seen in Chapter two. In several cases the same companies manufactured the agrochemicals mentioned here and in Chapter two and for some the basis of the chemical remained the same but only the name changed (Personal communication farmers; Personal communication consultants, Agri Mark, Durbanville, 2011).

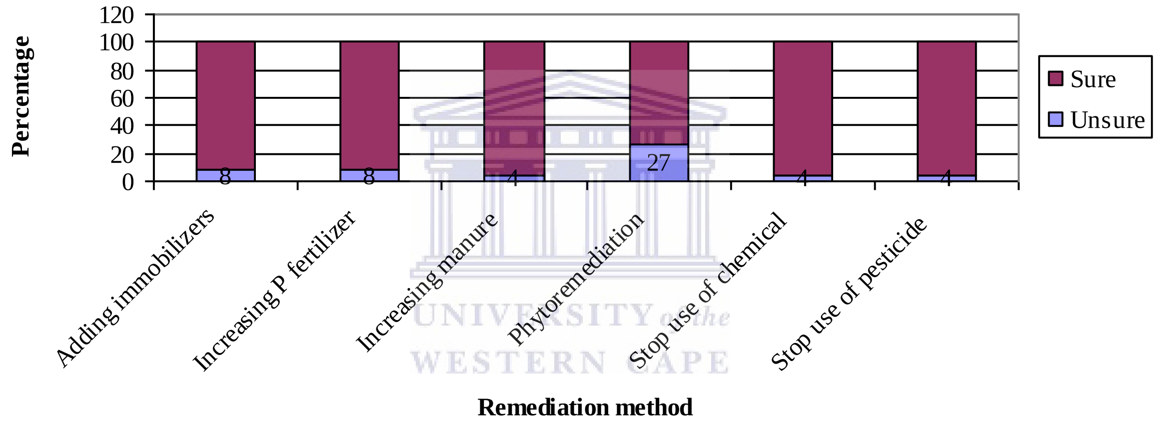
Figure 4.17 summarized the differences in use of the various listed agrochemicals by farmers from both farming areas. The results for Question 11 as seen in Figure 4.17 indicate that farmers from these two areas use the same agrochemicals and that their frequency in use is not significantly different between the two areas since the Chi-square was 0.9663.

Figure 4.17: Comparison of use of selected agrochemicals in the Joostenbergvlakte/Kraaifontein and Philippi area as a percentage of the total use per farming area (Chi-Square = 0.9663)



The answers to Question 12 reflected the willingness or unwillingness of farmers to use remedial methods to alleviate contamination of their agricultural resources, soil, water and crops, with harmful chemicals and or heavy metals. The results to Question 12 are summarized in Figures 4.18, 4.19, 4.20 and 4.21. From Figure 4.18 it is seen that in general all farmers, from both areas, were willing to apply remedial methods should it ever be necessary.

Figure 4.18: Willingness of farmers to use specific ds remediation methods (Chi-Square = 0.0246)



Farmers from the Joostenbergvlakte/Kraaifontein area showed a clear willingness to apply any remedial method needed to keep their agricultural resources which are soil, water and crops relatively free from harmful contaminants such as heavy metals as can be seen in Figure 4.19.

Farmers from the Philippi area had some significantly different yes/no responses pertaining to their willingness to use remediation methods. From Figure 4.20 it can be seen that farmers from the Philippi area were significantly hesitant to indicate their willingness to use phytoremediation as means of alleviating contamination of their agricultural soil with harmful chemicals and or heavy metals. Figure 4.21 compared the willingness of farmers from the two areas to use certain remediation methods and it was seen that their overall responses were not significantly different.

Figure 4.19: Willingness of Joostenbergvlakte/Kraaifontein farmers to use specific remediation methods (Chi-Square = 0.4045)

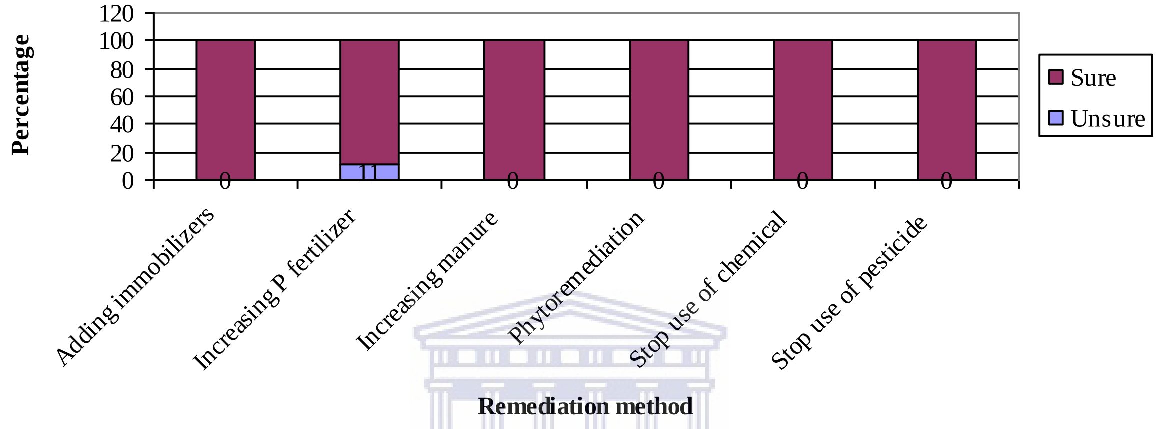


Figure 4.20: Willingness of Philippi farmers to use specific remediation methods (Chi-Square = 0.0093)

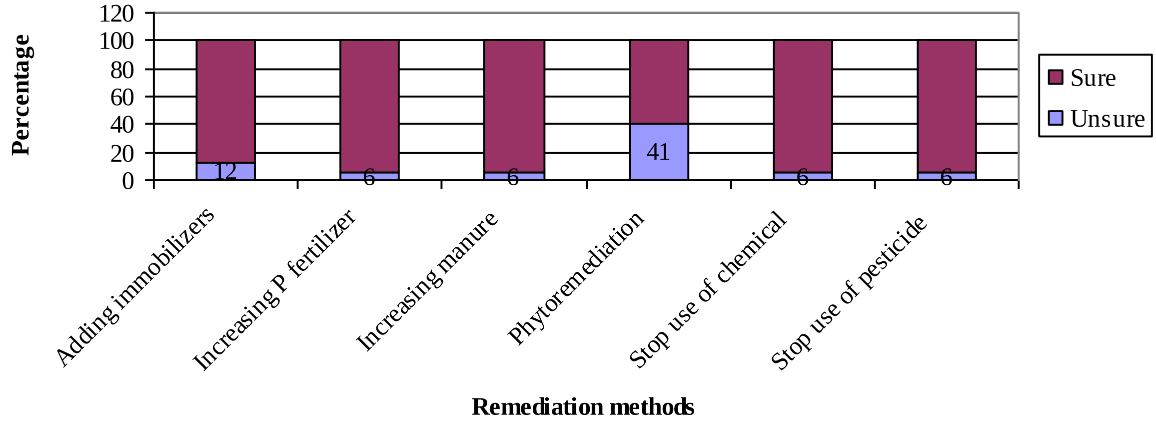
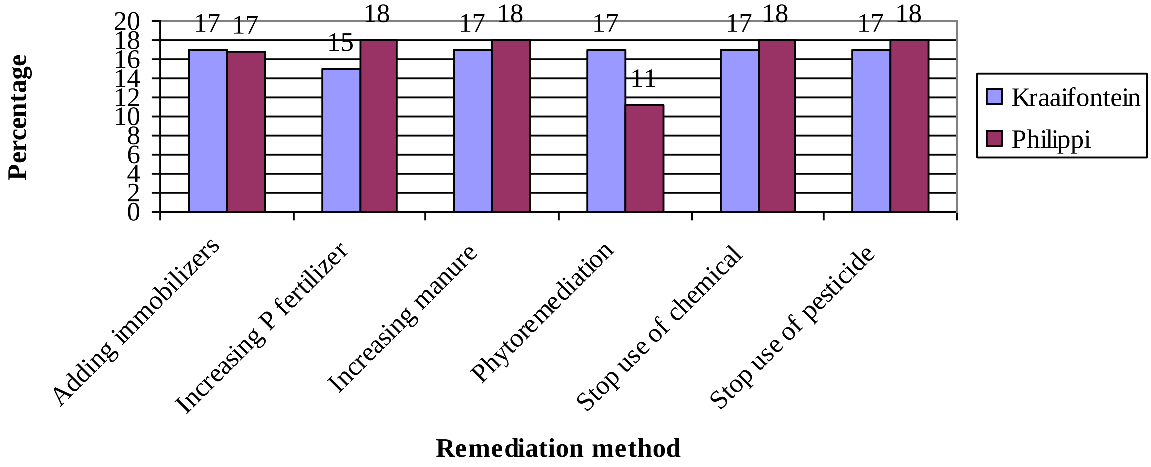


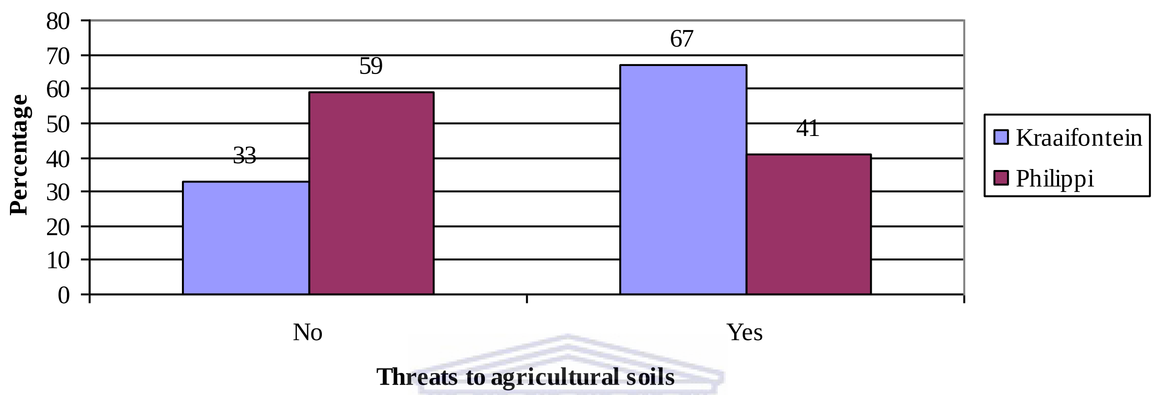
Figure 4.21: Comparison of willingness of Joostenbergvlakte/Kraaifontein and Philippi farmers as a percentage of total use of specific remediation methods per farming area (Chi-Square = 0.9593)



Verbally, farmers from both the Joostenbergvlakte/Kraaifontein and Philippi areas indicated their willingness to apply remediation methods once tests proved it absolutely necessary. Farmers were also only willing to apply remediation methods if they were not so costly as to affect their profits negatively. Some farmers indicated that they were already using "soft agrochemicals" and that they used well balanced programmes designed by well-known agriculturists and hence they did not believe the mentioned remediation methods would be of much greater benefit to them.

Activities in the areas surrounding the Philippi and the Joostenbergvlakte/Kraaifontein farming areas could pose a threat to various agricultural resources such as irrigation waters and cropped soils. By answering Question 13 farmers were able to indicate if they were concerned about activities in their area that could lead to contamination of their irrigation water resources. Figure 4.22 summarized whether farmers, from both areas, were concerned that their irrigation water resources could become contaminated due to activities in the surrounding areas. From Figure 4.22 it was deduced that farmers in both areas were not significantly concerned about threats to their irrigation water resources as Chi-square was 0.2162.

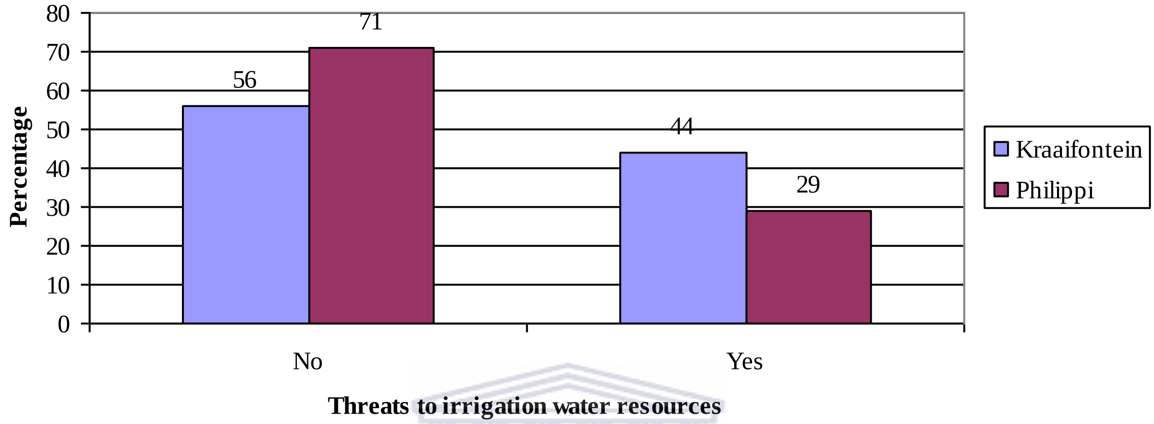
Figure 4.22: Comparison of awareness of environmental threats to the quality of irrigation water resources in the Joostenbergvlakte/ Kraaifontein and Philippi area (Chi-Square = 0.2162)



Farmers from the Philippi area indicated that treatment of soils with Methyl bromide, run-off from badly sanitized informal settlements, poor town planning that caused poor flood water drainage from agricultural land, pollution from nearby factories, dumping of various kinds of rubble, competition for water with surrounding industries and mineralization of underground water resources were the greatest potential threats to their irrigation water resources. Sea water intrusion was also raised as a concern by a farmer whose farm land was close the Strandfontein area and approximately 4 km from the coast (Figure 4.2 and Figure 4.4). The Joostenbergvlakte/Kraaifontein area farmers indicated that poor sanitation in informal settlements and subsequent run-off from these informal settlements as well as littering were the greatest threats to their irrigation water resources at the time of this survey.

Question 14 was to ascertain farmers concern about activities in the surrounding areas that could decrease the quality of their agricultural soils. The results for this question were summarized in Figure 4.23 and showed that farmers from neither area were significantly concerned about soil pollution due to activities in surrounding areas.

Figure 4.23: Comparison of awareness of environmental threats to the quality of agricultural soils in the Joostenbergvlakte/Kraaifontein and Philippi area (Chi-Square = 0.4434)



Farmers from the Philippi area mentioned that dumping along some roads in the area could become problematic while fumigation of the soil every three years was probably a greater threat to the quality of their soils than activities in surrounding areas. Farmers from the Joostenbergvlakte/Kraaifontein area also mentioned that littering, dumping and specifically methyl bromide fumigation treatment of their agricultural soils could become problematic in the future.

It was important to find out if farmers were aware of the legal implications that come into play if agricultural resources are contaminated with harmful chemicals and or heavy metals. Question 15 was used to determine farmers' awareness of these legal implications and the results were summarized in Figures 4.24, 4.25 and 4.26. From Figure 4.24 it was clear that farmers from both farming areas were equally unsure of the legal implications should their soil be contaminated excessively with heavy metals and or harmful chemicals. Figure 4.25

indicated that farmers of both areas were equally unsure of the legal implications should their irrigation water resources be contaminated with heavy metals or harmful chemicals, while in Figure 4.26 it was shown that farmers from both areas were unsure about the legal consequences if their crops were ever found to be contaminated with excess amounts of heavy metals or harmful chemicals.

Figure 4.24: Comparison of Joostenbergvlakte/ Kraaifontein and Philippi area farmers' knoweledge of legal implication around soil contmination (Chi-Square = 0.2147)

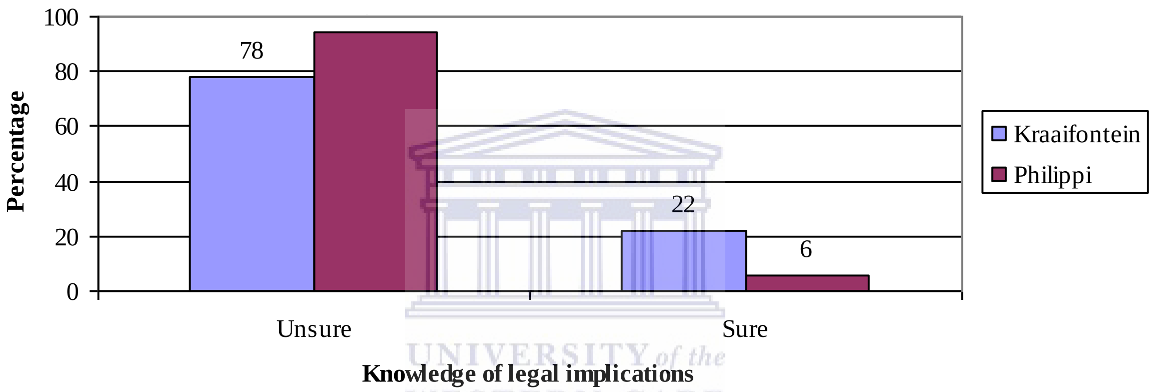
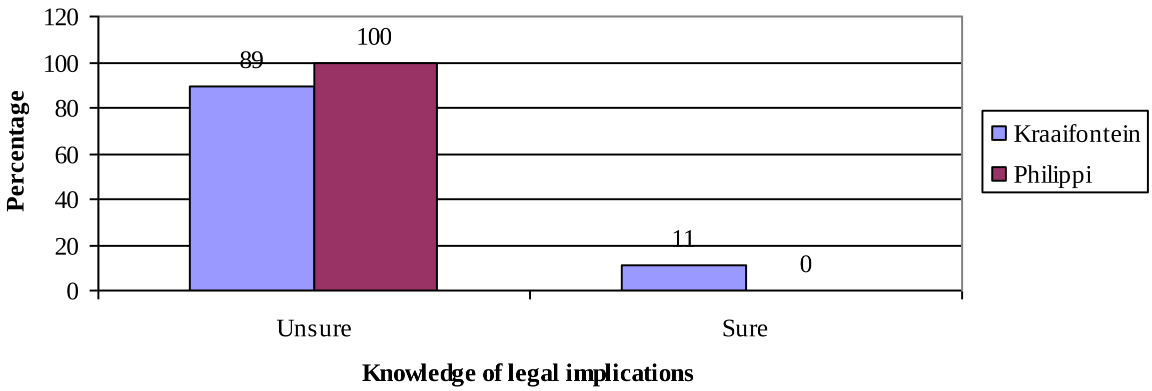


Figure 4.25: Comparison of Joostenbergvlakte/ Kraaifontein and Philippi area farmers' knoweledge of legal implication around irrigation water contmination (Chi-Square = 0.1610)



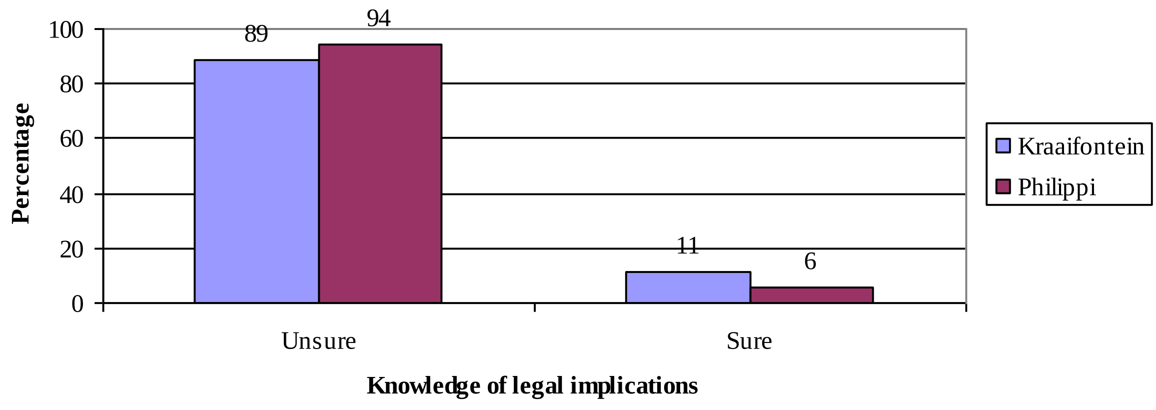


Figure 4.26: Comparison of Joostenbergvlakte/ Kraaifontein and Philippi area farmers' knoweledge of legal implications around crop contmination (Chi-Square = 0.6341)

4.5. Discussion

The information gained in this survey was useful to verify existing common knowledge that is not necessarily recorded in literature. General information about the two farming areas was summarized in Table 4.2 and is elaborated on here. From Figures 4.1, 4.2, 4.3 and 4.4 it can be seen that the Joostenbergvlakte/Kraaifontein area and Philippi farming area differ in size, with the Philippi area appearing slightly larger in terms of cropped soils. In Table 4.2 it is shown that farmers claimed the average farm sizes in the Joostenbergvlakte area to be 75.4 hectares each while Philippi farmers claimed average farm sizes of 50.4 hectares each. The farm sizes given by farmers in this survey calculated to roughly a total of 678 hectares farmed on in the Joostenbergvlakte/Kraaifontein area and 856 hectares farmed on in the Philippi area, which agrees with the visual observations that the Philippi farming area is the larger area (Orthophoto Map Series A, 2001; Orthophoto Map Series A, 1999; Orthophoto Map Series A, 1992; Orthophoto Map Series B, 2001; Orthophoto Map Series B, 1999; Orthophoto Map Series B, 1992; Orthophoto Map Series C, 2001; Orthophoto Map Series D, 2001; Figures 4.1, 4.2; 4.3 and 4.4).

From Figure 4.1 a total of approximately 687.5 hectares was calculated as vegetable cropped land between 1992 and 2000 in the Joostenbergvlakte/Kraaifontein area, which did not differ much from that given by farmers in this survey in 2007. Using Figure 4.2 a total of approximately 1440.9 hectares was calculated as used for vegetable propagation in the Philippi farming area between 1999 and 2000 and this was more than indicated by farmers in this survey in 2007.

Literature would suggest that the Philippi vegetable farming area is older than the Joostenbergvlakte/Kraaifontein vegetable farming area (Bamford, 2001; Chittenden Nicks Partnership, 1997; Meerkotter, 2003; Saayman, 2010; Sawyer, 1994). The literature is supported slightly in that current land owners of the older farms in the Philippi area claim their land to be about 59 years old while the current owners of the older farms in the Joostenbergvlakte/Kraaifontein area claim their land to be about 43 years old (Table 4.2). The fact that vegetables have been farmed with longer in the Philippi area might attribute to this area being slightly larger than the Joostenbergvlakte/Kraaifontein vegetable farming area to date.

In both areas new farms were indicated as roughly 12 to 15 years of age and this may indicate that these vegetable farming areas are not dwindling but still very productive despite encroaching industries and residential areas (Table 4.2; Figures 4.3 and 4.4). Using Figures 4.3 and 4.4 an approximate 1214.1 hectares was calculated for the Joostenbergvlakte/ Kraaifontein area and an approximate 1534.4 hectares for the Philippi area as being farmed on with vegetables in 2011. This needs to be verified in the actual field but indicates that both vegetable farming areas are growing or are at least stable despite urbanization. These figures translate to approximately 2128 to 2749 hectares of land being used for vegetable farming in the greater City of Cape Town (Table 4.2; Figures 4.1, 4.2, 4.3 and 4.4). The types of vegetable crops grown in the two farming areas are not significantly different and the major crops include cabbage, carrots and cauliflower (Figures 4.11, 4.12 and 4.13). Some crops, though grown significantly less than cabbage, carrots and cauliflower, seemed to be able to open niche markets to farmers from the two different areas, thus potentially reducing competition between farmers of these two farming areas on the Cape Town fresh produce market. Garlic, leaks, potatoes and spinach for example seemed to be grown more frequently in the Philippi area, while beetroot and lettuce seemed to be more frequently grown in the Kraaifontein area (Figure 4.13). These farming areas are thus precious resources to Cape Town as a whole and local government should help farmers safeguard their resources especially vulnerable water resources.

General practice in both areas seems to be the storing of irrigation water in surface holding dams (Personal communication farmers). The dams in the Joostenbergvlakte/Kraaifontein area are often larger than those seen in the Philippi area and thus comparatively lower in number (Table 4.2). In both areas boreholes fill these irrigation water holding dams, but in the Philippi area more boreholes are used than in the Kraaifontein farming area (Tables 4.2 and 4.3). Farmers from the Joostenbergvlakte/Kraaifontein area seem to have a greater variety of supplementary water resources than those in the Philippi farming area. Joostenbergvlakte/Kraaifontein farmers can for example make use of water from nearby rivers and the Theewaterskloofdam to supplement their irrigation water resources (Figure 4.5 and Figure 4.7). Philippi farmers on the other hand seem to rely more heavily on underground water resources by having relatively more boreholes and by recycling water on their farms to supplement the existing irrigation water resources in holding dams (Figure 4.6 and Figure 4.7). Apart from the differences in supplementary irrigation water resources, in general the farmers from both areas seem to have similar practices around which resources they use for irrigation water and how they use it (Figure 4.7).

Farmers of the Philippi area seem to depend more heavily on ground water emphasizing the need to protect underground water resources in Cape Town. In Table 4.2 and Table 4.3, it is indicated that the approximate depth of boreholes in the Philippi area are 52.4 meters, while the approximate depth of boreholes in the Joostenbergvlakte/Kraaifontein area are 85.4 meters, and that it was significantly different with a p-value of 0.0111 for the ANOVA and a LSD of 24.64 meters in the T-test. The significant difference in approximate depth of boreholes from these two farming areas may indicate that different aquifers are used to draw irrigation waters from. This information supported literature that indicated that Philippi farmers drew water from the Cape Flats aquifer while Kraaifontein farmers most likely drew groundwater from secondary aquifers in the Malmesbury shales meta-sediment (Cole and Roberts, 1996; Fraser and Weaver, 2000; Harris *et al.*, 1999; Rose, 1996; Saayman and Adams, 2002; Wright and Conrad, 1995).

In Table 4.2 it was indicated that both the Kraaifontein and Philippi areas had rather high water tables which often lead to waterlogging in the winter in these areas (Personal communication with farmers). The changes in the water table level can play a role in the circulation of elements in the soil and thus salinization and mineralization of irrigation waters could occur (Aza-Gnandji; 2011; Miller, 1996). Farmers from both areas claimed however that their borehole waters were not becoming more saline in 2007, while Aza-Gnandji (2011) reported that in 2010 salinization was becoming a problem in the Philippi farming area. The fact that in 2007 Cl and Na concentrations in borehole waters did not exceed 100 $mg.l^{-1}$ Cl and 70 $mg.l^{-1}$ Na could have been a heuristic that caused farmers to be rather unconcerned in

2007, about the possibility of salinization of their irrigation waters in the future compared to Philippi farmers' concern about irrigation water and soil salinization today (Aza-Gnandji, 2011; Grasmück and Scholz, 2005; Figures 4.8, 4.9 and 4.10). Salinization and mineralization of irrigation waters can be a result of years of application of fertilizers (Miller, 1996).

In Chapter two, it was concluded that cattle manure and chicken manure were the greatest sources of heavy metals on farms of these two farming areas. It was noted that farmers from both areas used relatively less cattle manure compared to the use of chicken manure and chemical fertilizers (Figures 4.14, 4.15 and 4.16). The use of cattle manure was significantly less in the Philippi area compared to the use of chicken manure and chemical fertilizers in this area (Figure 4.15) which should preferably be maintained since salinization of water resources and soil in this area is a concern (Aza-Gnandji, 2011). Agrochemicals other than fertilizers could also be harmful if in excess in the agricultural system and the use of certain general agrochemicals was compared between the two farming areas in Figure 4.17.

In general, similar agrochemicals seemed to be used by farmers from the Philippi and the Joostenbergvlakte/Kraaifontein farming areas (Figure 4.17). The names of the agrochemicals listed in Figure 4.17, which represents 2007 data, is different to those seen in Table 2.8 of Chapter three, which represents data gathered in 2011, but this is due to product name changes as the original patents for agrochemicals expired and the products may subsequently have been marketed under several new names (Personal communication consultant, Agri Mark, Durbanville, 2011). Nonetheless the trend shows that farmers from these two areas used similar products. The similarity in fertilizer and agrochemical use between these two areas indicated indirectly that providing similar information with regards to chemical and heavy metal contamination prevention and remediation to farmers would be appropriate (Figures 4.16 and 4.17).

In general farmers from both areas were willing to apply remedial methods providing it was proven to be necessary (Figure 4.18; Personal communication with farmers). Farmers from the Joostenbergvlakte/Kraaifontein farming area were only slightly hesitant to apply more P fertilizer than usual as a remedial method but, this was not significant to indicate their unwillingness to do so if needed (Figure 4.19). Farmers from the Philippi farming area though willing to apply remedial methods if needed, were more cautious to say "yes" to remedial methods that called for the use of additional immobilizers and or phytoremediation. Farmers commented in both areas that the application of a remedial method should preferably not reduce their profits and not be too costly to employ. The possibility of using phytoremediation was thus not as readily said "yes" to by Philippi farmers as it would imply the temporary non-use of land for vegetable cropping which would probably impact on their income (Figure 4.20).

It was thus in general shown that farmers from both areas were willing to apply remediation treatments (Figure 4.21). It was clear from discussions with farmers in both areas that they would only employ remedial methods if the benefits of doing so outweighed the costs of not doing so. Some farmers commented that they were using "soft agrochemicals" that were environmentally friendly and part of well-balanced programmes designed specifically for the farmers by agriculturists in the local sector. This may have created a sense of security with farmers in terms of the safety they may perceive to have from contamination of their agricultural systems with excess harmful chemicals and heavy metals. This kind of dissonance heuristic may cause farmers to be less motivated to monitor the presence of heavy metals in their soils, water resources and crops which could be problematic in the future. Greater emotional awareness of the threats to these specific farming areas among farmers might cause farmers to use less heuristics to avoid the issue of heavy metal contamination and the consequent need to know about preventative and remediation methods (Grasmück and Scholz, 2005).

From the data in Figures 4.22 and 4.23, it can be seen that farmers from both areas are not significantly concerned about threats to their agricultural lands from the surrounding areas. It may be that the threats from surrounding areas are not really significant, but it could also be that farmers might underestimate these threats. Farmers in both areas for example, indicated that the fumigation of their soils with Methyl bromide, amongst other chemicals, could be a threat to their irrigation water resources and soils yet, from Figures 4.22 and 4.23 no significant difference was evident as to farmers being aware of threats or not. Farmers also indicated that illegal dumping of various forms of waste and run-off from informal settlements were also threats to their irrigation water resources and soils, but again it was not clearly evident that farmers truly perceived any real threats to their resources since, their "yes" and "no" responses to perceiving any threats to their waters and soils were not significantly different (Figures 4.22 and 4.23). Emotional awareness of surrounding threats to these agricultural areas may increase the risk perception farmers may have of particular threats and thus their willingness to take action to protect their agricultural resources from future threats (Grasmück and Scholz, 2005).

Farmers were aware of some particular threats to their agricultural resources, but it was not clear if they were planning to change their farming practices, by for example, not fumigating their soils with Methyl bromide any longer, or by asking the local municipalities to penalize those who dump waste on their farms illegally. It would be of great value to inform the communities surrounding these farming areas of the importance of ensuring that the activities they take part in around these farming areas must encourage sustainability of these farms for the benefit of all vegetable consumers. It was also noted from Figures 4.24, 4.25 and 4.26, that farmers themselves were unsure of the legal responsibilities that rested upon them in terms of ensuring that their agricultural resources are used sustainably and are of good quality. Local authorities could thus play a valuable role in educating the broader communities in these two farming areas about means of preventing pollution of these agricultural resources.

4.5. Conclusion

As stated in the Discussion section, these two farming areas together account for about 2749 hectares of vegetable farming land in Cape Town. It is imperative that the local government should thus protect this valuable resource and work closely with farmers and communities around these farming areas to ensure sustainable growth in these areas. These agricultural systems are fragile and intimately connected to all who get vegetables from them. The communities surrounding these farming areas also need to be made more aware of the fact that these agricultural areas are of importance to them also and not only to the farmers. The communities surrounding these farming areas can play a valuable role in protecting these agricultural lands from pollution by reducing their contribution to pollution, by for example, ceasing to dump litter along farm roads.

The local municipalities should also ensure that the communities in the areas surrounding these farmlands have proper sanitation. Proper sanitation is not only a basic right the members of these communities have, but it will reduce run-off pollution to the farmlands.

Farmers can also play a role by insisting that local municipalities deliver basic sanitation to the communities surrounding their farms, which will in turn reduce the risk of pollution to their farmlands. Future studies could thus look at means of evaluating and increasing legitimately the emotional concerns of local farmers and the surrounding communities about activities they are involved in that could pollute these agricultural areas and lead to loss in the sustainability of these areas as a vegetable basket for Cape Town.

Future studies could include raising awareness amongst the communities of these two farming areas with regard to heavy metal pollution and other forms of environmental pollution. Since pollution in these agricultural environments could ultimately affect groundwater resources another study could look at the quality of the secondary and primary aquifers used in the Joostenbergvlakte/Kraaifontein and Philippi farming areas to abstract irrigation water from. Farmers also need to be informed of the legal consequences and obligations in the event of contamination of agricultural resources with excess amounts of heavy metals and other harmful chemicals and this kind of environmental education study could be done by those who have some expertise in environmental law.

Overall the results of this chapter seemed to indicate that farmers from the Joostenbergvlakte/ Kraaifontein area had relatively similar agricultural practices to those of the Philippi farming area. The differences between these farming areas would thus seem to stem from physical parameters such as differences in soil types, topography and availability of surface and groundwater resources as well as if industries or residential areas were encroaching.

4.6. References

Aza-Gnandji CDR (2011) Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa. Unpublished Masters thesis. Department of Earth Sciences. University of the Western Cape, Bellville

Bamford H (2001) Despair of Philippi's forgotten people. Cape Argus, 26 June, p.3. ref no. 3770

Bertram WE (1989) Geohidrologiese opname in die Philippi-landbougebied, Kaapse Vlakte. Tegniese verslag Gh 3595. Direktoraat Geohidrologie, Departement van Waterwese (DWAF), Pretoria

Chittenden Nicks Partnership (1997) The future of the Philippi horticultural area. Chittenden Nicks Partnership, Cape Town

City of Cape Town Heritage (CoCTH) (2007) Philippi Heritage Information Brochure 16. City of Cape Town Municipality

Cole DI, Roberts DL (1996) Lignite from the western coastal plain of South Africa. Journal of African Earth Sciences 23: 95-117

Directorate Agricultural Statistics (2000) Statistics on fresh produce markets. Department of Agriculture, Pretoria, Report 38

Fraser L, Weaver J (2000). Cape Flats Aquifer: Bulk Water for Cape Town Now. Contract Report submitted to Ninham Shand Consulting Engineers, Stellenbosch

Grasmück D, Scholz RW (2005) Risk perception of heavy metal contamination by high-exposed and low-exposed inhabitants: The role of knowledge and emotional concerns. Risk Analysis 25: 611-622

Gophe M, Joseph N, Yeld J (1998) City launches probe as contractors dump toxic waste in Philippi. Cape Argus, 20 October, p. 2. Ref no. 3613 a

Harris C, Oom BM, Diamond RE (1999) A preliminary investigation of the oxygen and hydrogen isotope hydrology of the greater Cape Town area and an assessment of the potential for using stable isotopes as tracers. Water SA 25: 15-24

Kinchen J, King C (2003) Inventions and Inventors. Volume 4, farming, food and biotechnology. Grolier. Danbury, Connecticut

Labuschagne A (2005) South African Medical Research Council: Ethics and Human Rights. http://www.mrc.ac.za/ethics/ethicshuman.htm Downloaded on 26/10/2005

Map Studio (2007) Map Studio Street Guide: Cape Town. New Holland Publishing Ltd. South Africa

Meerkotter M (2003) Heavy metals, and vegetable farming in Cape Town. Unpublished Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Miller GT (1996) Living in the environment. 9th Edition. Wadsworth Publishing Company, Belmont

Noss WE, Rolfes SR (2002) Understanding nutrition. 9th Edition. Wadsworth Thomson Learning, Belmont

Orthophoto Map Series A (2001) 3418 BA 1 Lotus River. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series A (1999) 3418 BA 2 Philippi. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series A (1992) 3318 DD 6 De Novo. 3rd Edition. Chief Directorate Survey and Landformation, Mowbray

Orthophoto Map Series B (2001) 3418 BA 6 Zeekoevlei. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series B (1992) 3318 DD 11 Hooggeleë. 3rd Edition. Chief Directorate Survey and Landformation, Mowbray

Orthophoto Map Series B (1999) 3418 BA 7 Strandfontein. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series C (2001) 3318 DC 10 Kraaifontein (north). 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Orthophoto Map Series D (2001) 3318 DC 15 Kraaifontein. 4th Edition. Chief Directorate Survey and Mapping, Mowbray

Qoko M (2003) Monitoring of heavy metals in the Kuilsriver and potential use of macrophytes in heavy metal remediation. Unpublished, Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Republic of South Africa (1998) National water act. Act no. 36 of 1998. http://www.polity.org.za/html/govdocs/legislation/1998/act36.pdf Downloaded on 31/08/2005

Rose R (1996) An assessment of the groundwater quality of the area southwest of Philippi, Cape Town. Unpublished, Honours thesis. Department of Geology. University of the Western Cape, Bellville

Saayman O (2010) Culture and Heritage: Art and culture history museum Kraaifontein, Northeast bound, Western Cape, South Africa, TraveliInformation. My Destination. http://www.mydestination.co.za/travel/infolen_US?parent_id/1442/country_name/southafrica Downloaded on 04/10/2011

Saayman IC, Adams S (2002) The use of garden boreholes in Cape Town, South Africa: lessons learnt from Perth, Western Australia. Physics and Chemistry of the Earth 27: 961 - 967

Sawyer C (1994) Fick's legal eagles lock vegetable store. Weekend Argus, 26 June, p. 15. Ref no. 1814 b

Serumaga-Zake PAE, Arnab R, Kotze D, Stiegler N (2004) An introduction to statistical survey methods. Unpublished book. University of North West, Mafikeng

Smith SR (1994) Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. II. Cadmium uptake by crops and implications for human dietary intake. Environmental Pollution 86: 5-13

Sogayise M (2003) Contamination of vegetables with heavy metals. Unpublished, Honours thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

The Constitution of the Republic of South Africa (1996) Act 108, Chapter 2: Bill of rights, Section 24: Environment. One law for one nation

Theobald M (2007) Philippi Horticultural Area: To farm or not to farm? http://www.futurecapetown.com/post/4463622890/phlippi-horticultural-area-to-farm-or-not-to Downloaded on 04/10/2011

Wright A, Conrad J (1995) The Cape Flats aquifer current status. Council for Scientific Research, Stellenbosch

Yeld J, Gophe M (1998) Now municipal cleansers join Philippi waste dumping. Cape Argus, 21 October, pp. 1-3. Ref no. 3614 a

Yeld J (1998) Probe into dumping by council tanker, threat to underground water. Cape Argus, 22 October, pp. 5. Ref no. 3612 a

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSION: WHAT IS THE HEAVY METAL SITUATION ON CAPE TOWN VEGETABLE FARMS?

5.1. Introduction

Taking into consideration that the Philippi and Joostenbergvlakte/Kraaifontein vegetable farming areas are currently Cape Town's most prominent and commercially viable in terms of vegetable production, it is imperative that these agricultural areas be taken care of. It has been indicated that over the past few years the concentrations of heavy metals, with specific reference to cadmium, copper, lead and zinc had neared and on a few occasions, exceeded the limits set therefore in irrigation water resources, agricultural soils and vegetable crops as stipulated in the South African regulations and guidelines (DoH, 2003; DWAF, 1996; Meerkotter, 2003; Sogayise, 2003; WRC, 1997). Since the Philippi, Joostenbergvlakte and Kaaifontein farmers are major suppliers of vegetables to Cape Town's fresh produce market this study aimed to investigate some issues around heavy metal contamination of agricultural resources from these farming areas (Directorate Agricultural Statistics, 2000).

This research also falls under the "Sustainable utilization of subterranean water resources for the improvement of life" project, which is but one of many projects that falls under the "Dynamics of Building a Better Society Programme (DBBS)" at the University of the Western Cape in collaboration with various Flemish universities. Investigation of the heavy metal contents of various agricultural water resources in this study, and how they may have become contaminated due to certain farming practices in the mentioned farming areas thus added to the knowledge bank of the DBBS programme as a whole. This thesis looked to meet more specifically the following aims; the analysis of various inputs to farms to find possible sources of heavy metals, the investigation of the effectiveness of using triple super phosphate fertilizer (TSP) and EDTA respectively as means of mitigating heavy metal pollution in a pot experiment using soils from these farms and the gathering of farming practice information from the Philippi and the Joostenbergvlakte/Kraaifontein farming areas.

The research process for this thesis was divided into three main studies each of which is discussed, in terms of, their main outcomes, means of improving the materials and methods that were used and suggestions for future research relating to these specific studies. The overall success of this research as a whole is also discussed in the sections that follow and concludes this thesis.

5.2. Analysis of inputs to the farms as possible heavy metal sources

This study looked at the heavy metal contents of various inputs to the farms of the two main study areas (the Philippi area and then the Joostenbergvlakte and Kraaifontein areas grouped together as one large area). The following hypotheses were formulated about the heavy metal contents of various samples that were to be collected on the farms from these areas: It was expected that raw/unprocessed manures would contain significant amounts of heavy metals and more specifically Cd, Pb and Zn. It was also expected that Zn concentrations would be high in chicken manure. The concentrations of Cd, Pb and Zn were also expected to be high in phosphate fertilizers (Kane, 2002; Meerkotter; 2003; Webber and Singh, 2003). It was also expected that copper concentrations would be great in various agrochemicals such as fungicides and pesticides.

Results indicated that cattle and chicken manure were the greatest sources of heavy metals and specifically Cd, Pb and Zn. The levels of Zn and Cu found in cattle and chicken manure exceeded limits set therefore in agriculturally applied dry sludge (Dach and Starmans, 2005). Compared to chicken and cattle manure, phosphate fertilizers contained comparatively lower levels of most heavy metals except for Hg. Individual agrochemicals could not be collected and the only way to test the heavy metal contents of the agrochemicals used on these farms was to obtain already mixed solutions of various undisclosed agrochemicals that were being sprayed on crops from small tractors with crop-spray-dispensers attached. The amount of Cu measured in crop spray samples was very low and almost negligible which was unexpected. The main direct sources of heavy metals to the agricultural soils of both farming areas thus appeared to be cattle manure as well as chicken manure.

This part of the research also aimed to determine the heavy metal content of various water resources on these farming areas, soils and vegetable crops. Significant concentrations of Cd, Cu, Pb and Zn were expected in surface waters used to supplement irrigation water resources (Qoko, 2003). None of the irrigation water resources were however found to exceed the limits set for these heavy metals by South African regulatory guidelines (DWAF, 1996). It was further expected that the concentrations of heavy metals in collected soil samples would be greater than seen in previous studies due to possible accumulation of heavy metals in agricultural soils (Brown, 1996; Marschner, 1995; Miller, 1996; Rice and Rice, 1997; Summerfield, 1994). This hypothesis was not supported as the collected soils were in general not more contaminated than measured in studies of previous years (Meerkotter, 2003; Sogayise, 2003). The maximum permissible concentrations for Cu, Pb and Zn in soils were however, exceeded in several soil samples from the Philippi area but, these samples did not exceed limits set by the European Community (CoEC, 2006; Murphy, 1997; WRC, 1997).

The concentration of heavy metals in vegetables produced in these two farming areas was expected to be marginally greater than seen in studies of previous years (Meerkotter, 2003; Sogayise, 2003). The levels of heavy metals, measured in this study, in various vegetable crops were, however, less than those measured in vegetables in previous years. Overall there was not a significant difference in the concentration of heavy metals in cabbage, carrots and lettuce sampled in the two main farming areas. The limits set by South African regulations for Pb and Zn was exceeded in cabbage, carrots and lettuce samples from both areas, while the concentration limit set for Cd was exceeded in carrots and lettuce produced in the Philippi area only (DoH, 2003). Though South African limits for Cd, Pb and Zn were exceeded in some vegetables, European limits set for heavy metals in the specific vegetable types were not exceeded (Murphy, 1997).

The results of this study could have been improved by increasing sample numbers but this was complicated by various factors that will be mentioned below. These factors should, where possible, be avoided or at least lessened in future surveys. It is important to note that the collecting of enough samples, of a crop species that is of similar age, was very difficult and could realistically only be achieved if several sampling periods were established during a research period/year. The collection of a large number of comparable samples over a short time period was not possible in this research. Finding out what the time schedules for irrigation and crop spraying on farms are, may also help to increase the amount of sprinkler water and crop spray samples that could be collected in future studies. In future studies it could also improve the quality of the research results if the researcher were in a position to determine when crops have passed the withholding period prior to harvesting and since the last crop spray application. The reason being that measurements of contaminants in the crops are then, more likely to be representative of the actual quality of the crops and not partly due to residues of crop sprays thereon.

Future studies that relate to this part of this thesis could include the extensive listing of agrochemicals used in the two main farming areas and the determination of heavy metal content of these agrochemicals, prior to the mixing thereof for the crop spraying process. The actual amounts of heavy metals added to soils through addition of various fertilizers could also be studied and determined by sourcing fertilizer application programmes from agriculturists that serve the farmers and by making the necessary calculations from there. A similar process could be followed with regard to the contribution of heavy metals through spraying crops with various agrochemicals such as fungicides, pesticides and other growth stimulants (Nicholson *et al.*, 2003).

Future studies could, in addition, draw attention to the contribution of air pollution in terms of deposition of heavy metals on crops, soils and water resources in these farming areas. A study that investigated both primary and secondary aquifers used by farmers from these areas in terms of heavy metal content would be useful. Further, a more in-depth study that looks at the differences between maximum limits set for heavy metals in soils and crops in South African and in Europe could also be useful. Using both South African and the less stringent European standards, to measure the quality of crops and soils from these two farming areas, it was clear that compared to other case studies across the globe, the agricultural systems of the Philippi and Joostenbergvlakte/Kraaifontein areas were reasonably “clean” in terms of heavy metal pollution (DoH, 2003; Murphy, 199, Republic of South Africa, 1998).

5.3. Assessment of mitigation techniques (Pot experiment)

Although the Philippi and Joostenbergvlakte/Kraaifonyein farming areas are not as contaminated as seen elsewhere in the world, it is important to ascertain which remedial methods would be useful to inhibit the effects of heavy metals in the agricultural system if ever heavy metals became too concentrated in these agricultural systems. The use of a triple super phosphate fertilizer (TSP) at three different concentrations and respectively, the use of three different EDTA solutions, were investigated as means of reducing the uptake of heavy metals and more specifically Cd, Pb and Zn by cabbage plants grown in growth mediums prepared from soil from these two farming areas, altered with different concentrations of Cd, Pb and Zn respectively. It was hypothesized that the use of TSP treatments would be more effective than EDTA treatments in reducing the uptake of specifically Cd, Pb and Zn by cabbage plants, since TSP was expected to be able to immobilize these heavy metals and thus render them unavailable for uptake by plant roots, while EDTA was expected to increase the solution of Cd, Pb and Zn in the soil solution, thus making them more available for uptake by plant roots. Secondly, it was hypothesized that a lower TSP concentration treatment would be most effective at reducing the uptake of Cd, Pb and Zn by cabbage plants than greater TSP concentration treatments, since heavy metals are often byproducts in TSP fertilizers and greater TSP concentrations could increase the concentrations of these heavy metals in the soil medium (Aldrich *et al.*, 2004; Brown *et al.*, 2005; Cao *et al.*, 2003; Cui *et al.*, 2004; Finžgar and Leštan, 2007; Huang *et al.*, 2003; Illera *et al.*, 2004; Jiao *et al.*, 2004; Lai and Chen, 2004; Lai and Chen, 2005; Liphadzi and Kirkham, 2006; Luo *et al.*, 2005; Luo *et al.*, 2006; Melamed *et al.*, 2003; Owenby *et al.*, 2005; Palma and Mecozzi, 2007; Pardo, 2004; Sun *et al.*, 2001; Tan *et al.*, 2011; Tang *et al.*, 2004; Thayalakumaran *et al.*, 2003; Wu *et al.*, 2003; Wu *et al.*, 2004; Zhu *et al.*, 2004).

The results partly supported the first hypothesis that TSP treatments would be better to use than EDTA treatments in that it was indicated that the use of 24 mg EDTA/kg soil in the presence of Cd at 2.0 mg/kg soil (the maximum concentration allowed in South African soils) was dangerous in that it lead to accumulation of much Cd in the leaves of cabbage plants. Furthermore, the application of 12 mg EDTA/kg soil in the presence of respectively 6.6 mg Pb/kg soil and 46.5 mg Zn/kg soil (their maximum permissible concentrations in South African soil) lead to accumulation of respectively Pb and Zn in cabbage leaves above permissible levels set therefore in foodstuffs in South Africa. The second hypothesis which stated that concentrations of TSP at lower levels would be more effective at reducing the uptake of respectively Cd, Pb and Zn, was only partly supported in that the use of 1 mg TSP/kg soil overall seemed to lead to lesser accumulation of these heavy metals in cabbage leaves, although it did not unequivocally exclude the possibility that using 4 mg TSP/kg soil or 8 mg TSP/kg soil could also be effective under certain circumstances.

What was clear from the results of this study was that the recommendation of remedial treatments of any kind should not be made by looking at the concentration of only one or two particular elements in the soil but, rather, that a number of variables need to be considered. Nonetheless, the results of this study did seem to indicate that 1 mg TSP/kg soil would be the most appropriate treatment to use in the presence of excess Cd, Pb and/or Zn in the soils from the two study areas at levels near the maximum permissible concentrations set therefore in South African soils. The results of this study could have been more conclusive if, perhaps, a greater number of replicates were used for each treatment. The application of the results from this experiment might also be different for other varieties of cabbage and other crops. Taking the above-mentioned into consideration, it is clear that several factors need to be taken into consideration before recommending a remedial treatment to farmers.

Future studies could look at other remedial treatments that may be more appropriate in the soils of the Philippi, Joostenbergvlakte and Kraaifontein areas, while field trials could be done on particular portions of land in these farming areas, which may be more contaminated with heavy metals than other portions. Running future pot experiments could also investigate the movement of heavy metals to deeper layers, in soils from these farming areas, in order to ascertain the risk of remedial methods leaching heavy metals and other elements to underground water resources. Ultimately, for remedial tests and trials to be more useful, by leading to the best methods being employed on farms if ever needed, collaboration with agriculturists that serve the farmers of the study areas is essential in the selection of appropriate remedial treatments to be tested.

5.4.Farming practice survey

In the end this research was intended to benefit farmers who could gain most from the information gathered. It was thus important to establish what farmers' views were about addressing possible pollution threats to their farmlands, as well as, farmers' willingness to employ remedial methods. It was expected that farming practices would be summarized more accurately by conducting a survey with farmers from the two study areas. Informal discussions with farmers lead to the following expectations; firstly, that farmers would be proved willing to employ remedial treatments but, secondly, that farmers did not view addressing heavy metal contamination of agricultural resources as a priority.

The results did support the expectation that farmers from both areas would be willing to consider the application of remedial methods. Farmers from both areas did comment, however, that they would only employ remedial methods should they be needed, have been proven to work and will outweigh the cost of applying them. It was also found that farmers from neither area were significantly concerned about threats specifically related to heavy metal pollution of their agricultural resources. Farmers, for example, indicated their awareness of threats such as those related to the fumigation of their soils with Methyl bromide, run-off from ineffectively sanitized nearby informal settlements and illegal dumping along roads in these farming areas but, even these threats mentioned by farmers themselves did not seem to be viewed as needing urgent attention.

Gathering information around farming practices in the Philippi and Joostenbergvlakte/ Kraaifontein farming areas revealed that both areas had similar farming patterns. Farmers from both areas used significantly less cattle manure than chicken manure and chemical fertilizers. Similar agrochemicals were used in the two areas. Farmers in both areas grew cabbage, carrots, cauliflower and lettuce in abundance as their main produce. Farmers from the Joostenbergvlakte/Kraaifontein area seemed however to have more supplementary irrigation water resources to draw from than farmers from the Philippi area. Farmers from the Philippi farming area seemed to rely heavily on underground water resources while farmers in the Joostenbergvlakte/Kraaifontein area used underground water resources but also drew water from nearby rivers, storm water canals and the Theewaterskloofdam.

Although both areas are surrounded by urban areas that are expanding it was found that in both farming areas the latest farms were between 12 and 15 years old and that the farming areas seemed to have expanded to some extent. Farmers were however reluctant to answer questions that probed the actual size of land they farmed on, the amount of hectares they planted of a crop type per year and how much fertilizer and agrochemicals they applied per year. Since it is the right of farmers to withhold this information if they so desired all the information desired could not be gathered as planned (The Constitution of the Republic of

South Africa, 1996). Although it was envisaged to interview at least 80% of the farmers from both areas, about 71-75% of the farmers were interviewed in each area.

Nonetheless, from the survey with farmers several ideas for future studies became evident. Firstly future studies could look at issues around farmers' views and knowledge about pollution threats to their agricultural resources, secondly, their emotional concern about the threats and thirdly, their consequent likeliness to act upon these threats (Grasmück and Scholz, 2005). Another study could investigate the ways in which local municipalities and authorities could educate communities around these farming areas about the importance of these farming areas to all citizens and the importance of reducing pollution to these areas to allowing sustainability of these farming areas. Other studies could compare the two studied agricultural systems with other farming methods related to pollution, not mentioned here, in commercial, rural and organic farming systems across the globe. Studies could also be carried out to determine the physical growth of these farming areas and their surrounding urban communities.

It would be interesting to study the changes in these farming areas and their surrounding communities by redefining the makeup of areas that were once defined as smallholdings, informal residential areas and industrial areas, but have now expanded and perhaps been restructured to include various other activities. More scientific studies could be conducted to determine the effects of years of fertilizer application to soils in these farming areas in terms of salinization and mineralization of these soils. Studies that could link to soil sustainability might evaluate the effect of the seasonal fluctuation in the water table in these areas on the mineral and salt concentrations in soil and water resources in these agricultural systems (Aza-Gnandji, 2011; Miller, 1996).

5.5. Final conclusion

Judging by the number of possible future studies around pollution issues in the Philippi, Joostenbergvlakte and Kraaifontein farming areas that have been raised in this chapter alone, the research of this thesis could be considered useful and even successful. One of the aims of this thesis was to identify major sources of heavy metals to these farming areas, which was successfully done by identifying cattle manure and chicken manure as the greatest sources of heavy metals, as discussed earlier in this chapter and in Chapter two. Another aim was to investigate the usefulness of either TSP or EDTA as a remedial treatment in the possible event of excess Cd, Pb and/or Zn contamination of agricultural soils from the study areas. Though it could not be conclusively said which TSP treatment would be the best option, at least it was clear that EDTA treatments would most likely not be suitable for use in the agricultural soils of these areas, as was discussed in detail in Chapter three. Lastly, it was aimed to gather information on the farming practices in the study areas and also to ascertain farmers' willingness to employ remedial methods if needed in the future. To a great extent the last aim was achieved in that much information around farming practices could be verified and it was found that farmers were willing to employ suitable remedial methods if they ever proved necessary in the future to ensure sustainability of their agricultural resources, as was discussed in Chapter four.

Linking this thesis research to the DBBS programme, it is clear that, as increased pressure is being placed on subterranean water resources of Cape Town due to limited surface water resources, the management and protection of subterranean water resources by monitoring agricultural activities that can affect them is important. Since farmers may be held accountable for the contamination of water resources on their farms by needing to bear the cost of remediation, the monitoring of not only heavy metals such as Cd, Cu, Pb and Zn in agricultural resources, but also other harmful chemicals is essential, even if their concentrations are not necessarily problematic at present.

Though the concentration of some heavy metals have exceeded limits in certain agricultural resources according to South African regulations, it is important to note that in comparison to European regulations ours are very restrictive and as such the results of this study need to be dispensed with much caution. Unnecessary sensation that could cause harm to farmers' reputations should be avoided at all costs. The information gathered through this study is to benefit farmers and thus the results of this study will be shared with farmers as it is the farmers' right to have access to this information relating to their farming. In conclusion, the findings of this thesis are to be used as a measure to encourage sustainable farming practices and activities around the Philippi, Joostenbergvlakte and Kraaifontein farming areas and elsewhere.

5.6.References

Aldrich MV, Ellzey JT, Peralta-Videa JR, Gonzalez JH, Gardea-Torresday JL (2004) Lead uptake and the effects of EDTA on lead-tissue concentration in the desert species Mesquite (*Prosopis spp.*). International Journal of Phytoremediation 6: 195-207

Aza-Gnandji CDR (2011) Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa. Unpublished Masters thesis. Department of Earth Sciences. University of the Western Cape, Bellville

Brown S, Christensen B, Lombi E, McLaughlin M, McGrath S, Colpaert J, Vangronsveld J (2005) An inter-laboratory study to test the ability of amendments to reduce the availability of Cd, Pb, and Zn *in situ*. Environmental Pollution 138: 34-45

Brown LV (1996) Applied Principles of Horticultural Science. Butterworth-Heinemann, Oxford

Cao RX, Ma LQ, Chen M, Singh SP, Harris WG (2003) Phosphate-induced metal immobilization in a contaminated site. Environmental Pollution 122: 19-28

Commission of the European Communities (CoEC) (2006) Setting maximum levels for certain contaminants in foodstuffs: Commission regulation 1881: 1-25

Cui Y, Wang Q, Dong Y, Li H, Christie P (2004) Enhanced uptake of soil Pb and Zn by Indian mustard and winter wheat following combined soil application of elemental sulphur and EDTA. Plant and Soil 261: 181-188

Dach J, Starmans D (2005) Heavy metals balance in Polish and Dutch agronomy: Actual state and provisions for the future. Agriculture, Ecosystems and Environment 107: 309-316

Department of Health (DoH) (2003) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 25015

Department of Water Affairs and Forestry (DWAF) (1996) South African water quality guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation, DWAF, Pretoria

Directorate Agricultural Statistics (2000) Statistics on fresh produce markets. Department of Agriculture, Pretoria, Report 38

Finžgar N, Leštan D (2007) Multi-step leaching of Pb and Zn contaminated soils with EDTA. Chemosphere 66: 824-832

Grasmück D, Scholz RW (2005) Risk perception of heavy metal contamination by high-exposed and low-exposed inhabitants: The role of knowledge and emotional concerns. Risk Analysis 25: 611-622

Huang B, Kuo S, Bembenek R (2003) Cadmium uptake by Lettuce from soil amended with phosphorus and trace element fertilizers. Water, Soil , Air Pollution 147: 109-127

Illera V, Garrido F, Serrano S, Garcia-Gonzales MT (2004) Immobilization of heavy metals Cd, Cu and Pb in acid soil amended with gypsum- and lime-rich industrial by products. European Journal of Soil Science 55: 135-145

Jiao Y, Grant CA, Bailey LD (2004) Effects of phosphorus and zinc fertilizer on cadmium uptake and distribution in flax and durum wheat. Journal of the Science of Food and Agriculture 84: 777-785

Kane WM (2002) Health Matters! Volume 6, Environmental Poisoning. Grolier. Danbury, Connecticut

Lai HY, Chen ZS (2005) The EDTA effect on phytoextraction of single and combined metals-contaminated soils using rainbow pink (*Dianthus chinensis*). Chemosphere 60: 1062-1071

Lai HY, Chen ZS (2004) Effects of EDTA on solubility of cadmium, zinc and lead and their uptake by rainbow pink and vetiver grass. Chemosphere 55: 421-430

Liphadzi MS, Kirkham MB (2006) Availability and plant uptake of heavy metals in EDTA-assisted phytoremediation of soil and compost biosolids. South African Journal of Botany 72: 391-397

Luo C, Shen Z, Lou L, Li X (2006) EDDS and EDTA-enhanced phytoextraction of metals from artificially contaminated soil and residual effects of chelant compounds. Environmental Pollution 144: 862-871

Luo C, Shen Z, Li X (2005) Enhanced phytoextraction of Cu, Pb, Zn, Cd with EDTA and EDDS. Chemosphere 59: 1-11

Marschner H (1995) Mineral Nutrition of Higher Plants. 2nd Edition. Academic Press, London

Meerkotter M (2003) Heavy metals, and vegetable farming in Cape Town. Unpublished Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Melamed R, Cao X, Chen M, Ma LQ (2003) Field assessment of lead immobilization in a contaminated soil after phosphate application. The Science of the Total Environment 305: 117-127

Miller GT (1996) Ecosystems and how they work. In: Living in the Environment. Wadsworth Publishing Company, Belmont

Murphy K O'H (1997) Municipal sewage sludge disposal: development of guidelines and expert systems. Background information and literature survey. Water Research Council report 6056/1/97

Nicholson FA, Smith SR, Alloway BJ, Carlton-Smith C, Chambers BJ (2003) An inventory of heavy metals inputs to agricultural soils in England and Wales. The Science of the Total Environment 311: 205-219

Ownby DR, Galvan KA, Lydy MJ (2005) Lead and zinc bioavailability to *Eisenia fetida* after phosphorus amendment to repository soils. Environmental Pollution 136: 315-321

Palma LD, Mecozzi R (2007) Heavy metals mobilization from harbour sediments using EDTA and citric acid as chelating agents. Journal of Hazardous Materials (Article in press)

Pardo MT (2004) Cadmium Sorption-desorption by soils in the absence and presence of phosphate. Communications in Soil Science and Plant Analysis 35: 1553-1568

Qoko M (2003) Monitoring of heavy metals in the Kuilsriver and potential use of macrophytes in heavy metal remediation. Unpublished, Masters thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Republic of South Africa (1998) National water act. Act no. 36 of 1998. http://www.polity.org.za/html/govdocs/legislation/1998/act36.pdf Downloaded on 31/08/2005

Rice LW, Rice RP (1997) Practical Horticulture. 3rd Edition. Prentice Hall, New Jersey

Sogayise M (2003) Contamination of vegetables with heavy metals. Unpublished, Honours thesis. Department of Biodiversity and Conservation Biology. University of the Western Cape, Bellville

Summerfield MA (1994) Fluvial processes. In: Global Geomorphology. Longman Scientific and Technical, New York

Sun B, Zhao FJ, Lombi E, McGrath SP (2001) Leaching of heavy metals from contaminated soils using EDTA. Environmental Pollution 113: 111-120

Tan WN, Li ZA, Qiu J, Zou B, Li NY, Zhuang P, Wang G (2011) Lime and phosphate could reduce cadmium uptake by five vegetables commonly grown in South China. Pedosphere 21: 223-229

Tang XY, Zhu YG, Chen SB, Tang LL, Chen XP (2004) Assesment of the effectiveness of different phosphorus fertilizers to remediate Pb-contaminated soil using *in vitro* test. Environment International 30: 531-537

Thayalakumaran T, Robinson BH, Vogeler I, Scotter DR, Clothier BE, Percival HJ (2003) Plant uptake and leaching of copper during EDTA-enhanced phytoremediation of repacked and undisturbed soil. Plant and Soil 254: 415-423

The Constitution of the Republic of South Africa (1996) Act 108, Chapter 2: Bill of rights, Section 24: Environment. One law for one nation

Water Research Commission (WRC) (1997) Permissable Utilisation and Disposal of Sewage Sludge. 1st Edition. WRC, Pretoria

Webber MD, Singh SS (2003) Contamination of Agricultural Soils. Agriculture and Agri-Food Canada http://www.agr.gc.ca/n/wis-snite/index_e.cfm?s1=pubands2=hs_ssandpage=15 Downloaded 28/07/2005

Wu LH, Luo YM, Xing XR, Christie P (2004) EDTA-enhanced phytoremediation of heavy metal contaminated soil with Indian mustard and associated potential leaching risk. Agriculture, Ecosystems and Environment 102: 307-318

Wu LH, Luo YM, Christie P, Wong MH (2003) Effects of EDTA and low molecular weight organic acids on soil solution properties of a heavy metal polluted soil. Chemosphere 50: 819-822

Zhu YG, Chen SB, Yang JC (2004) Effects of soil amendments on lead uptake by two vegetable crops from lead-contaminated soil from Anhui, China. Environmental International 30: 351-356

APPENDEX

DBBS
DYNAMICS OF BUILDING A BETTER SOCIETY

Sustainable Utilisation of Subterranean Water Resources for the Improvement of the Quality of Life

RESPICE PROSPICE
UNIVERSITY of the WESTERN CAPE

"Sources of heavy metals in vegetables in Cape Town, and possible methods of remediation"

Study areas

Cape Town has two major vegetable farming areas; the Joostenbergvlakte/ Kraaifontein area near the N1 and the Philippi farming area south of the N2.

The Problem

These farming areas are vulnerable to various forms of pollution from adjacent urban and industrial areas. Pollutants from the adjacent areas can reach these agricultural areas via streams, through leaching into the soil and subterranean water resources, through air pollution and even application of contaminated fertilizers and pesticides.

Heavy metal contamination of agricultural land is a global problem. Some crops readily take up heavy metals from the soil and consumption of these contaminated crops can lead to the onset of health problems. Contamination of subterranean water resources through leaching of heavy metals and other harmful chemicals from polluted soils is also a concern, particularly in a water scarce country.

Unfortunately studies conducted in these two farming areas between 1999 and 2005 revealed that the heavy metals; cadmium, copper, lead and zinc were present at relatively high concentrations in soils and various crops. The importance of monitoring these heavy metals in these areas must thus be emphasized, and done regularly.

How do you fit into this study?

The Aims of this study

1. To determine the main sources of cadmium and lead to these farming areas.
2. To monitor the levels of heavy metals in irrigation water, soils, crops, fertilizers, pesticides and other amendments.
3. To help find mitigation methods which can be used to reduce the uptake of cadmium, lead and zinc by crops.

Methods to be used

1. Conducting interviews with farmers.
2. Analysis of various samples collected from these farms; e.g. irrigation water, soil, crops, fertilizers, pesticides etc.
3. Conducting a pot experiment to identify effective methods for mitigation.

Benefit to farmers and farming communities

- Farmers will be informed of mitigation methods that may help reduce the uptake of the heavy metals; cadmium, lead and zinc, by their crops.
- Farmers will have access to results of this study which may be of interest to them.
- Advisory support will be given to farmers upon request.
- A friendly and supportive relationship will be established between farmers of these two areas and the university which may benefit both parties in future.

This research is forms the basis of a doctoral thesis. Ethics guidelines of the South African Medical Research Council will be adhered to during this study.

We invite you to participate in this study to help build a better society

You are welcome to contact us

How can you contribute?

1. By participating in interviews.
2. By allowing sample collection on your farm.
3. By giving soil from your farm for use in pot experiments.

Researcher:
Marÿke Meerkotter
Cell phone: 083 534 2460
E-mail: mmeerkotten@uwc.ac.za

Researcher's Supervisor:
Prof. Lincoln Raitt
Phone: 021 959 2306
E-mail: lraitt@uwc.ac.za

Department of Biodiversity and Conservation Biology
University of the Western Cape
Private Bag X17
Bellville
7535

Sustainable Utilisation of Subterranean Water Resources for the Improvement of the Quality of Life

DBBS
DYNAMICS OF BUILDING A BETTER SOCIETY

UNIVERSITY *of the* WESTERN CAPE

"Bronne van swaar-metale in groente van Kaapstad, en moontlike versagtings behandelinge"

Studie areas

Kaapstad se vernaamste groente boerderye is in die Joostenbergvlakte/ Kraaifontein area (naby die N1) en in die Philippi area (suid van die N2) geleë.

Die Probleem

Die landbou areas is onderhewig aan besoedeling van omliggende voorstede en industriële gebiede. Besoedeling van omliggende stedelike areas bereik landbougebiede deur onder andere; afvoerkanale, loging tot landbougrond en ondergrondse waterbronne, lugbesoedeling en deur die toediening van gekontamineerde kunsmis en pesdoders.

Swaar-metaal besoedeling van landbougrond is 'n probleem regoor die wêreld. Sommige gewasse neem graag swaar-metale uit die grond op en die verbruik van dié gewasse kan tot verskeie gesondheidsprobleme lei. Besoedeling van ondergrondse waterbronne met swaar-metale is ook 'n bron van kommer. Swaar-metale kan vanaf gekontamineerde grond na ondergrondse waterbronne deurspoel.

Ongelukkig het studies in dié twee landbou areas, tussen 1999 en 2005, aangetoon dat daar wel kontaminasie van die landbougrond en gewasse was met spesifiek die swaar-metale; kadmium, koper, lood en sink. Dit is dus belangrik dat die situasie op 'n gereelde basis gemonitor word.

Hoe pas u by die studie in?

Doelwitte van die studie

1. Om te bepaal wat die hoofbronne van kadmium en lood tot die twee landbou areas is.
2. Om swaar-metaal konsentrasies in besproeïngswater, landbougrond, gewasse, kunsmis, pesdoders en ander stowwe te monitor.
3. Om doeltreffende versagtingsmetodes te help vind, wat die opname van kadmium, lood en sink deur gewasse kan verminder.

Metodes

1. Onderhoudvoering met boere.
2. Analise van verskeie monsters verkry van dié plase; bv. besproeïngswater, landbougrond, groente gewasse, kunsmis, pesdoders ens.
3. Pot eksperiment om verskeie versagtingsmetodes te toets en 'n doeltreffende een te help vind.

Voordele vir boere en landbougemeenskap

- Boere sal informasie verkry oor versagtingsbehandeling wat die opname van kadmium, lood en sink deur gewasse kan help verminder.
- Boere sal toegang tot die resultate van die studie hê indien hulle belangstel daarin.
- Advies sal op aanvraag aan boere toegestaan word.
- 'n Vriendelike en ondersteunende verhouding sal tussen boere van die areas en die universiteit opgebou word waaruit beide partye voordeel sal kan trek.

Die studie vorm die hoeksteen van 'n doktorale studie. Etiese riglyne van die Suid-Afrikaanse Mediese Navorsingsraad sal onderhou word tydens die studie.

U word uitgenooi om aan die studie deel te neem en te help bou aan 'n beter samelewing
Kontak ons gerus

Hoe kan u bydra?

1. Deur om aan onderhoude deel te neem.
2. Deur monsters op u plaas te laat neem.
3. Deur grond van u plaas te skenk vir gebruik in pot eksperimente.

Navorser:
Marÿke Meerkotter
Selfoon: 083 534 2460
E-pos: mmeerkotter@uwc.ac.za

Navorsings toesighouer:
Prof. Lincoln Raitt
Telefoon: 021 959 2306
E-pos: lraitt@uwc.ac.za

Departement van Biodiversiteit en Bewaringsbiologie
Universiteit van Weskaapland
Privaatsak X17
Bellville
7535

University of the Western Cape

DEPARTMENT OF BIODIVERSITY AND CONSERVATION BIOLOGY
Private Bag X17 Bellville 7535 South Africa
Telephone +27-21-959-2301
Fax +27-21-959-2312

Consent Form

I, ………………………………………………… hereby confirm that I have been informed of the purpose of the study "Sources of heavy metals in vegetables in Cape Town, and possible methods of remediation".

I agree to participate in:

The survey for gathering farm practice information	yes / no
The collecting of various samples on my farm	yes / no
Giving soil from my farm to be used in a pot experiment	yes / no

I understand that I have the right to withdraw from this study at any time without giving a reason and without incurring displeasure or penalty.

I also understand that the information given by me will not be used against me or any other person or institution and will be treated as if anonymous through use of codes and aliases.

____
Respondent

____
Researcher: Marÿke Meerkotter

Cell phone: 083 534 2460

E-mail: mmeerkotter@uwc.ac.za

Date ____________________

University of the Western Cape

DEPARTEMENT VAN BIODIVERSITEIT EN BEWARINGSBIOLOGIE
Privaatsak X17 Bellville 7535 Suid-Afrika
Telefoon +27-21-959-2301
Fax +27-21-959-2312

Toestemmingsvorm

Ek, ………………………………………………… bevestig hierdeur dat ek bewus gemaak is van die studie "Sources of heavy metals in vegetables in Cape Town, and possible methods of remediation" se doelwitte.

Ek stem in om deel te neem aan die volgende:

Die opname aangaande toegepaste plaas praktyke	ja / nee
Die versameling van verskeie monsters op my plaas	ja / nee
Vereskaffing van grond van my plaas vir gebruik in 'n pot eksperiment	ja / nee

Ek verstaan dat ek die reg het om enige tyd te onttrek van die studie, sonder verduideliking en sonder enige onaangename gevolge.

Ek verstaan ook dat die inligting wat ek verskaf nie teen my of enige ander persoon of instansie gebruik sal word nie, en dat die informasie as anoniem behandel sal word deur die gebruik van skuilname en kodes.

____
Respondent

____
Navorser: Marÿke Meerkotter

Selfoon: 083 534 2460

E-pos: mmeerkotter@uwc.ac.za

Datum ____________________

Survey for Gathering Farm Practice Information

Interviewee is farm:	
………	………
Owner	Manager

1. What is the history of this farm?

Name of this farm (at present)	Size of farm in hectare	Name of farm owner (optional)	Started farming	Stopped farming

2. How many bore holes do you have on this farm? ……………………………………………………………………………………

3. How deep are the different boreholes? ……………………………………………………………………………………

4. How many dams do you have on this farm? ……………………………………………………………………………………

5. How deep is the water table in winter? ……………………………………………………………………………………

6. How deep is the water table in summer? ……………………………………………………………………………………

7. Do you add water from any of the following sources to your irrigation water? When do you add it to your irrigation water?
   a. Storm water canal Y/N **summer/winter/both** b. Municipal water Y/N **summer/winter/both**
   c. From one borehole to more than one dam Y/N **summer/winter/both** d. River Y/N **summer/winter/both**
   e. From one dam to another dam Y/N **summer/winter/both** f. Stream Y/N **summer/winter/both**
   g. Recycled waste water Y/N **summer/winter/both** h. Other Y/N **summer/winter/both**

8. Is your borehole water becoming more saline? Y/N If yes, since when have you noticed the change? ……………………………
   Has a sodium concentration greater than 70mg/l been measured in your borehole water? Y/N
   In how many boreholes has this been measured? …………
   Has a chloride concentration greater than 100mg/l been measured in your borehole water? Y/N
   In how many boreholes has this been measured? …………

9. Which vegetable crops do you farm with?
   How many hectares of a crop do you plant per season? (Please indicate units if other than hectare)
   When do you harvest and plant each crop? (Please indicate planting with a **P** and harvesting with an **H**)

Crop	Hectare	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beet													
Cabbage													
Cauliflower													
Carrots													
Celery													
Garlic													
Lettuce													
Leaks													
Potatoes													
Radish													
Spinach													
Onions													
Other													

1 hectare = 10000m^2
1 hectare = 2.471 acres

1 ton = 1000kg
1 ton = 2,000 pounds

Recycled waste water: Refers to re-use of water that has already been used for any combination of the following activities; irrigation, washing of crops, domestic use etc.

Definition of saline: A saline substance contains salt or consists of salt. Irrigation water may become saline when the concentration of various salts therein increases. Irrigation with saline water can cause physical damage to some crops. Mixing of sea water with surface or subterranean fresh water resources may also cause the fresh water to become more saline. In this case the concentration of both sodium and chloride is expected to be greater than what it originally was in the fresh water.

10. How many kilograms of fertilizer do you use, per hectare, per planting season for these different crops?

(Please indicate units if other than kilogram)

Crop	Poultry manure	Cattle manure	Pig manure	fertilizer a	fertilizer b	fertilizer c	fertilized d	fertilizer e	fertilizer f	fertilizer g
Beet										
Cabbage										
Cauliflower										
Carrots										
Celery										
Garlic										
Lettuce										
Leaks										
Potatoes										
Radish										
Spinach										
Onions										
Other										

11. How many litres of pesticide do you use, per hectare, per planting season for these different crops?

(Please indicate units if other than litre)

Crop	pesticide a	pesticide b	pesticide c	pesticide d	pesticide e	pesticide f	pesticide g	pesticide h	pesticide i	pesticide j
Beet										
Cabbage										
Cauliflower										
Carrots										
Celery										
Garlic										
Lettuce										
Leaks										
Potatoes										
Radish										
Spinach										
Onions										
Other										

12. Which methods would you be willing to use to decrease the effects of harmful chemicals in the soil on crops and the environment?

a. Increase amount of manure used per hectare Y/N
b. Increase amount of phosphate fertilizer used per hectare Y/N
c. Stop use of fertilizers that contain harmful chemicals Y/N
d. Stop use of pesticides that contain harmful chemicals Y/N
e. Add a chemical to the soil to immobilise the harmful chemicals Y/N
f. Plant a crop that can remove the harmful chemicals from the soil Y/N

13. Are you concerned about any activities in the area that may affect the quality of your irrigation water? Y/N

What are they? ……………………………………………………………………………………………

14. Are you concerned about any activities in the area that may affect the quality of your soil? Y/N

What are they? ……………………………………………………………………………………………

15. Are you aware of the legal implications in the event of exceeding limits set for harmful chemicals in soil? Y/N

Are you aware of the legal implications in the event of exceeding limits set for harmful chemicals in irrigation water? Y/N

Are you aware of the legal implications in the event of exceeding limits set for harmful chemicals in crops intended for sale? Y/N

Do you want more legal information?	
Yes	No

Opname Ten Opsigte Van Plaaspraktyke

Respondent is plaas:
.... Eienaar .... Bestuurder

1. Wat is die plaas se geskiedenis?

Naam van plaas (huidiglik)	**Grootte van plaas in hektaar**	**Naam van plaaseienaar (opsioneel)**	**Aanvang van boerdery**	**Beëindiging van boerdery**

2. Hoeveel boorgate is daar op die plaas? ....

3. Hoe diep is die verskillende boorgate? ....

4. Hoeveel damme is daar op die plaas? ....

5. Hoe diep is die watertafel in die winter? ....

6. Hoe diep is die watertafel in die somer? ....

7. Voeg u water van enige van die volgende bronne by u besproeïngswater? Wanneer doen u die byvoeging?
   - a. Stormwaterkanaal **J/N** **somer/winter/beide**
   - b. Munisipale water **J/N** **somer/winter/beide**
   - c. Van een boorgat na meer as een dam **J/N** **somer/winter/beide**
   - d. Rivier **J/N** **somer/winter/beide**
   - e. Van een dam na 'n ander dam **J/N** **somer/winter/beide**
   - f. Stroompie **J/N** **somer/winter/beide**
   - g. Hersirkulerings-water **J/N** **somer/winter/beide**
   - h. Ander **J/N** **somer/winter/beide**

8. Is u boorgatwater besig om te versout? **J/N** Indien ja, van wanneer af het u dit opgemerk? ....
   Is 'n natriumkonsentrasie hoër as 70mg/l in u boorgatwater gemeet? **J/N**
   In hoeveel boorgate is 70mg /l natrium of hoër gemeet? ....
   Is 'n chloorkonsentrasie hoër as 100mg/l in u boorgat water gemeet? **J/N**
   In hoeveel boorgate is 100mg/l chloor of hoër gemeet? ....

9. Met watter gewasse boer u?
   Hoeveel hektaar van 'n gewas plant u per seisoen? (Dui asseblief die eenhede aan indien nie hektaar)
   Wanneer plant en oes u elke gewas? (Dui asseblief planting aan met 'n **P** en oeste met 'n **O**)

Gewas	**Hektaar**	**Jan**	**Feb**	**Mrt**	**Apr**	**Mei**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Des**
Beet													
Kool													
Blomkool													
Wortels													
Seldery													
Knoffel													
Kropslaai													
Prei													
Aartappels													
Rape													
Spinasie													
Uie													
Ander													

1 hektaar = 10000m^2
1 hektaar = 2.471 akkers

1 ton = 1000kg
1 ton = 2,000 ponde

Hersirkulerings-water: Verwys na hergebruik van water wat reeds vir 'n kombinasie van enige van die volgende aktiwiteite gebruik was; besproeïng, was van gewasse, huishoudelike gebruike ens.

Definisie van versout: 'n Versoute stof bevat sout of bestaan uit sout. Besproeïngswater mag versout wanneer die konsentrasie van verskeie soute daarin verhoog. Besproeïng met versoute water kan fisiese skade aan gewasse veroorsaak. Vermenging van seewater met bogrondse of ondergrondse varswaterbronne mag versouting van die vars water veroorsaak. In die geval van versouting weens vermenging van varswater en seewater kan 'n verhoging in natrium en chloor konsentrasies verwag word.

10. Hoeveel kilogram kunsmis dien u per hektaar, per seisoen toe vir die verskillende gewasse?

(Dui asseblief eenhede aan indien nie kilogram)

Gewas	Hoedermis	Kraalmis	Varkmis	kunsmis a	kunsmis b	kunsmis c	kunsmis d	kunsmis e	kunsmis f	kunsmis g
Beet										
Kool										
Blomkool										
Wortels										
Seldery										
Knoffel										
Kropslaai										
Prei										
Aartappels										
Rape										
Spinasie										
Uie										
Ander										

11. Hoeveel liter plaagdoder/bestrydingsmiddel gebruik u per hektaar, per seisoen vir die verskillende gewasse?

(Dui asseblief eenhede aan indien nie liter)

Gewas	plaagdoder a	plaagdoder b	plaagdoder c	plaagdoder d	plaagdoder e	plaagdoder f	plaagdoder g	plaagdoder h	plaagdoder i	plaagdoder j
Beet										
Kool										
Blomkool										
Wortels										
Seldery										
Knoffel										
Kropslaai										
Prei										
Aartappels										
Rape										
Spinasie										
Uie										
Ander										

12. ,Watter metode sal u gebruik om die effek van skadelike chemikalië in die grond op gewasse en die omgewing toe verminder?

a. Verhooging van mistoediening per hektaar **J/N**

b. Verhooging van fosfaatkunsmis toediening per hektaar **J/N**

c. Staak toediening van kunsmis wat skadelike chemikalië bevat **J/N**

d. Staak toediening van pesdoder wat skadelike chemikalië bevat **J/N**

e. Byvoeging van 'n chemikalië tot die grond wat die effek van skadelike chemikalië in die grond stuit **J/N**

f. Aanplant van 'n gewas wat skadelike chemikalië uit die grond kan verwyder deur opname **J/N**

13. Is u bekommerd oor aktiwiteite in die omgewing wat u besproeëngswater se kwaliteit bedreig? **J/N**

Noem die aktiwiteite? ....

14. Is u bekommerd oor aktiwiteite in die omgewing wat u grond se kwaliteit bedreig? **J/N**

Noem die aktiwiteite? ....

15. Is u bewus van die geregtelike implikasies indien u grond die konsentrasielimiet oorskry vir bepaalde chemikalië? **J/N**

Is u bewus van die geregtelike implikasies indien u besproeïngswater die konsentrasielimiet oorskry vir bepaalde chemikalië? **J/N**

Is u bewus van die geregtelike implikasies indien u verkoopsgewasse die konsentrasielimiet oorskry vir bepaalde chemikalië? **J/N**

Verlang u meer regs informasie?	
Ja	Nee

Sustainable Utilisation of Subterranean Water Resources for the Improvement of the Quality of Life

DBBS
DYNAMICS OF BUILDING A BETTER SOCIETY

UNIVERSITY *of the* WESTERN CAPE

"Sources of heavy metals in vegetables in Cape Town, and possible methods of remediation"

Research results

The Joostenbergvlakte/Kraaifontein and Philippi farming areas are Cape Town's most important vegetable farming areas. Protection of these agricultural areas is thus of great importance. Previous studies in these areas have found that cadmium, copper, lead and zinc concentrations in some soils and crops were high and could become a problem in the future.

Philippi farming area

Kraaifontein farming area

Through this study it was found that vegetable crops from both areas were fit for human consumption. It was found that cattle and chicken manure were the greatest sources of cadmium, copper, lead and zinc. The levels of these harmful metals should thus be monitored in the soil and crops.

Tractors moving manure

One threat to both these agricultural areas is the illegal dumping of waste along farm roads. Other possible threats are pollution of irrigation waters and soils through run-off and air pollution from nearby roads, informal settlements, industries and residences.

Illegal dumping along farm roads

Thank you for your cooperation!

An experiment with cabbage, grown on soil from these farms, tested two ways of limiting the uptake of cadmium, copper, lead and zinc by cabbage plants.

Respectively, the addition of EDTA and triple super phosphate fertilizer was tested.

It was found that addition of extra triple super phosphate fertilizer was better than application of EDTA at limiting the uptake of these metals by cabbage plants. There may be more appropriate treatments not tested in this study.

Remedial treatments would only be needed if cadmium, copper, lead or zinc became too high in these farm soils and irrigation water resources.

Mixing experimental soil

Table of South African maximum limits for cadmium, copper, lead and zinc in agricultural resources

	Soil	Irrigation Water	Crops
Cadmium	2.00 mg/kg	0.05 mg/L	0.05 mg/kg
Copper	6.60 mg/kg	5.00 mg/L	30.00 mg/kg
Lead	6.60 mg/kg	2.00 mg/L	0.10 mg/kg
Zinc	46.50 mg/kg	5.00 mg/L	40.00 mg/kg

Planting cabbage seedlings

References for South African maximum limits

Soil: Water Research Commission (1997) Permissible Utilization and Disposal of Sewage Sludge. 1st Edition. Pretoria

Irrigation water: Department of Water Affairs and Forestry (1996) South African Water Quality Guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation. Pretoria

Crops: Department of Health (2004) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 26279

Weighing harvested cabbage

Washing cabbage roots

Researcher's contact information

Marÿke Meerkotter
Department of Biodiversity and Conservation Biology
University of the Western Cape
Private Bag X17, Bellville, 7535
E-mail: mmeerkotter@uwc.ac.za

The researcher and the experiment

Sustainable Utilisation of Subterranean Water Resources for the Improvement of the Quality of Life

DBBS
DYNAMICS OF BUILDING A BETTER SOCIETY

UNIVERSITY of the WESTERN CAPE

"Bronne van swaar-metale in groente van Kaapstad, en moontlike versagtings behandelinge"

Studie bevindings

Die Joostenbergvlakte/Kraaifontein en Philippi landbougebiede is Kaapstad se belangrikste omgewings vir die verbouings van groente. Beskerming van dié landbougebiede is dus van uiterste belang. Vorige studies in die gebiede het bevind dat die konsentrasies van kadmium, koper, lood en sink in sommige grond- en groentemonsters hoog was en in die toekoms problematies kan word.

Philippi-landbougebied

Kraaifontein-landbougebied

Hierdie navorsing toon dat groente van die twee landbougebiede tans geskik is vir menslike verbruik. Dit was bevind dat bees en hoender mis die grootste bronne van kadmium, koper, lood en sink was. Die konsentrasies van die skadelike metale moet dus in die grond en gewasse gemonitor word.

Trekkers vervoer mis

Een bedreiging in albei die landbougebiede is die onwettige storting van allerlei rommel langs plaaspaaie. Ander moontlike bedreigings rakende die besoedeling van waterbronne vir besproeiing en landbougrond hou verband met naby geleë paaie, industrieë, informele nedersettings en woonbuurte.

Onwettige storting langs plaaspaaie

Baie dankie vir u samewerking!

Twee versagtings behandelings was getoets op koolplante, wat gekweek was in grond van dié landbougebiede. Dié behandelings sou koolplante kon help om minder kadmium, koper, lood en sink op te neem in besoedelde landbougrond.

Die toevoeging van onderskeidelik EDTA en triple super fosfaat-kunsmis was getoets. Daar was bevind dat die toevoeging van bykomende triple super fosfaat-kinsmis 'n doeltreffender versagtings behandeling was as EDTA. Daar mag wel beter versagtings behandelings wees wat nie in die studie getoets was nie.

Versagtings behandelings sou slegs benodig word as kadmium, koper, lood of sink te gekonsentreerd in landbougrond en besproeiingswater sou word.

Meng van groeimedium

Geplante koolsaailinge

Weeg van geoeste kool

Was van kool wortels

Tabel van Suid Afrikaanse maksimumlimiete vir kadmium, koper, lood en sink in landbouhulpbronne

Hulpbron	Grond	Besproeiings-water	Groente
Kadmium	2.00 mg/kg	0.05 mg/L	0.05 mg/kg
Koper	6.60 mg/kg	5.00 mg/L	30.00 mg/kg
Lood	6.60 mg/kg	2.00 mg/L	0.10 mg/kg
Sink	46.50 mg/kg	5.00 mg/L	40.00 mg/kg

Bronne vir Suid Afrikaanse maksimumlimiete

Grond: Water Research Commission (1997) Permissible Utilization and Disposal of Sewage Sludge. 1st Edition. Pretoria

Besproeiingswater: Department of Water Affairs and Forestry (1996) South African Water Quality Guidelines. 2nd Edition. Volume 4: Agricultural Use: Irrigation. Pretoria

Groente: Department of Health (2004) Regulations relating to maximum levels for metals in foodstuffs: Amendment to Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972. Government Gazette 26279

Navorser se kontak informasie

Marÿke Meerkotter
Departement van Biodiversiteit en Bewaringsbiologie
Universiteit van Wes-Kaapland
Privaatsak X17, Bellville, 7535
E-pos: mmeerkotter@uwc.ac.za

Die navorser en die eksperiment