Extremely Low Frequency Magnetic Fields in Electrical Substations and Residential Areas of Mangaung Metropolitan Municipality

by

PHOKA CAIPHUS RATHEBE

Dissertation submitted in fulfillment of the requirements for the Degree

MAGISTER TECHNOLOGIAE:

ENVIRONMENTAL HEALTH

In the

Faculty of Health and Environmental Sciences, Department of Life Sciences

at the

Central University of Technology, Free State

Supervisor: Dr. C Weyers, D.Tech (Environmental Health)

Co-Supervisor: Dr. SF Raphela, D.Tech (Environmental Health)

BLOEMFONTEIN, SOUTH AFRICA

August 2016

Declaration

DECLARATION WITH REGARD TO

INDEPENDENT WORK

I, **PHOKA CAIPHUS RATHEBE**, identity number [redacted] and student number [redacted], do hereby declare that this dissertation submitted to the Central University of Technology, Free State for the Degree MAGISTER TECHNOLOGIAE: ENVIRONMENTAL HEALTH, is my own independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself or any other person in fulfillment (or partial fulfillment) of the requirements for the attainment of any qualification.

_____________________________ _____________________

SIGNATURE OF STUDENT **DATE**

Acknowledgements

I would like to thank all those people who made this thesis possible and an unforgettable experience for me.

First of all, I would like to express my deepest sense of gratitude to my supervisor **Dr. C. Weyers** and co-supervisor **Dr. S.F. Raphela** at the Central University of Technology, Free State who offered their continuous advice and encouragement throughout the course of this dissertation. I thank them for the systematic guidance and great effort they put into training me in the scientific field.

I am thankful to all Environmental Health staff for their selfless support and encouragement given to me during the course of this thesis, especially **Prof. A. Fossey** for her flawless statistical guidance.

Finally, I take this opportunity to express the profound gratitude from my deep heart to my beloved family, especially **Lehlohonolo Rathebe**, **Pontsho Christina Rathebe**, **Omolemo Mahase** and **Nthabiseng Mahase** for their love and continuous support – both spiritually and materially.

"la salud del medio ambiente cerca del corazón humano"

Table of Contents

List of Tables

List of Figures

Abstract

Mangaung is one of the biggest metropolises in the Free State and is located within the central region of South Africa. It consists of 44 distribution substations (132 kV) that convert electrical voltages. The spatial distribution of electrical power amongst residential environments depends mainly on the size of the residential area and its properties. As a metropolis, residents must have access to electricity and along the electrical generation process, electromagnetic fields are produced. Furthermore, depending on the electrical usage, the generation of electricity creates different frequencies and magnitude of magnetic fields and thus various exposure levels. According to literature, the point of magnetic fields generation to residential homes is approximately 15 to 20 m; this implies that residents may not be far from an exposure. The magnitude of magnetic field decreases quite rapidly with an increase in distance from the source. Although residents and electric-utility workers may be exposed, there is no conclusive evidence with regard to the health implications of such exposures. The International Commission for Non-Ionising Radiation Protection (ICNIRP) requires magnetic field emissions to be regulated to further protect the general public and workforce. The exposure levels of magnetic fields vary intensely per residential environment and thus contribute significantly.

This study characterises the exposure levels of extremely low frequency (ELF) magnetic fields that exist in the distribution substations and residential areas of Mangaung Metropolitan Municipality. The health and safety conditions of 132 kV distribution substations and immediate residential environments were assessed. Two different checklists were used to assess health and safety conditions of substations and to further assess the risks that may result in the residential environments due to EMF external sources. Due to unequal geographical proportions within the main regions of Mangaung, 15 distribution substations (132 kV) and residential environments were measured in Bloemfontein, nine and six were measured in Botshabelo and Thaba Nchu respectively. Furthermore, the occurrences of magnetic fields were also measured inside the distribution substations to determine the exposure levels of workers. A walk-through survey was conducted inside substations and floor plans were obtained. The grid model was also used to facilitate the data collection process inside substations.

Statistical analyses were performed to determine whether exposure levels of magnetic fields from the distribution substations and residential environments are above the ICNIRP guidelines or not. Descriptive statistical analysis was also performed to determine health and compliance of substations according to Institute of Electrical and Electronics Engineers standards, Occupational Health and Safety, Act 85 of 1993, total cumulative compliance index and total compliance risk values. Although the peak magnetic field levels were detected but all distribution substations and residential environments emit ELF magnetic fields below the ICNIRP guidelines. Some minor housekeeping non-compliances were also observed but the health and safety conditions of substations complies with the requirements of IEEE standards and OHS act.

This study provides preliminary data on ELF magnetic field exposure levels within substations in South Africa and also seeks to create awareness on magnetic fields exposure.

Keywords: ELF magnetic fields, distribution substations, exposure levels, residential environments, occupational exposure

Chapter 1

Introduction

1.1 Introduction

Since the beginning of the twenty first century electricity has become an integral part of every human‟s life. Without electricity some of the human activities on planet earth would have never been brought into existence and some of them will not be possible (Fews, 1999). Electricity is supplied to old and current technology apparatus such as computers, different types of machinery, laboratory and medical devices, household appliances, automobiles, and treatment plant equipment.

Electricity moves from power generation plants (power stations) in a form of high voltage to urban and rural electrical substations where it will be converted into low voltage to suit residential electrical processes (Ilonen, 2008). According to Kaune (1993), high voltage electricity moves through overhead and underground power lines and it is converted into low voltage once it reaches electrical distribution substations in the residential areas. Furthermore, electrical substations serve many functions, such as controlling, collecting and transferring power on electrical systems (Kaune, 1993).

Along the transportation and conversion of voltages, the two invisible fields known as magnetic and electric fields are produced (Kovetz, 2000). Both magnetic and electric fields are produced by movement of charged and stationary electrical particles as described in the Maxwell‟s equation (Lee, 1996). These fields are expressed in hertz (Hz) and can be classified as very low frequency (VLF), low frequency (LF), extremely low frequency (ELF) and high frequency fields (HFF) (Brent, 1999). Extremely low frequency (ELF) magnetic fields are fields with frequency that ranges between 3 to 3000 Hz and they are usually formed when the electrical current flows (World Health Organisation, 2007). According to Sinatra (2002), once there is higher current flow during conversion or transmission, high voltages are produced as a result of increased magnetic field flux. High voltages are mainly used when transferring power over long distances from generation plants to final distribution substations (Portier and Wolfe, 1998). When electricity is being transferred and has reached distribution substations, the intensity of the electric and magnetic fields changes. Lacy-Hulbert, Metcalfe and Hesketh (1998) indicated that an intensity of electric fields created is determined by the amount of voltages transferred and the flow of current determines the magnitude of magnetic fields that will be produced. The force of both magnetic and electric fields is induced by different substation devices which include wirings, cables and installations.

According to the National Institute for Environmental Health (NIEH) (2002), most substations use alternating current (AC) in distributing and converting current, which produces magnetic and electric fields at various magnitude levels. The level of exposure to magnetic fields is determined by the distance between the source and the receiver (Portier and Wolfe, 1998). According to Loomis and Savitz (1995), individuals in close proximity to distribution substations are more likely to be exposed to high levels of magnetic fields than those residing far from them. Individuals exposed to magnetic fields are likely to develop detrimental health effects, such as childhood leukaemia. However there is still controversy on this matter (Draper, 2005).

1.2 Problem statement

The cheapest, most convenient and well-known method to convert electricity from high to low voltage is by means of substations (Thuróczy, 2008). In most cases, substations are located 15 to 20 meters (m) away from the buildings and this include flats, office spaces, mechanical workshops, health facilities, retail stores and households properties in particular, so individuals may not be that far from an exposure (Kaune, 1993). Moreover, the sizes of distribution substations may vary depending on whether they serve manufacturing industries, residential properties, schools or health care facilities (Cavin, 1996). According to WHO (2007), it is the responsibility and a requirement by law for substations custodian to warn the general public and electrical workers about the electrical shocks and other related health and safety risks that can emanate from substations. However, substations have danger warning signs displayed on installations and this is intended to warn the public and workers.

Distribution substations are well fenced or within wall enclosures. The WHO and International Commission on Non-ionising Radiation Protection (ICNIRP) have developed the guidelines with an intention of protecting the general public and employees against ELF magnetic and electric field exposure from substations. Additionally, to increase electrical supply means to maximise power provision facilities, high sources of exposure to ELF magnetic fields (Kheifets, 2001). According to Safigianni and Tsompanidou (2005), power stations are built few kilometres away from residential areas while electrical substations are closer to the residents. Many studies have been conducted about the risk of exposure emanating from extremely low magnetic fields in power lines and other electrical devices in homes, but none have observed the risks that emanate from electrical distribution substations built in close proximity to residential sites. Distribution substations have transformers which step-down or step-up electrical voltage transferred to households (Ilonen, 2008). A 2007 report by WHO indicated that the non-ionising radiation in the form of invisible fields called extremely low frequency magnetic and electric fields is produced by electronic devices within substation. These fields can be produced by different sources, such as live electrical wires and devices containing coil and magnet (Kovetz, 2000).

Mangaung Metropolitan Municipality consists of 42 distribution substations within its main regions and others are still under construction. The residents and employees working in the substations are not aware that the closer they are to the substations the higher the intensity of magnetic fields they expose themselves to. Although people do not choose to be exposed, but whenever there is environmental impact assessment prior to the building of new substations, residents are not informed to participate as interested and affected parties. Magnetic fields are different from electric fields in terms of physical and electronic movement properties and cannot be screened. Electric fields are unlikely, under certain circumstances to escape the substation, as they are isolated practically by all building materials (Thuróczy, 2008). Substations must be well wall-fenced as electric fields will unlikely be able to extend beyond housing equipment. ELF magnetic fields are generated inside substations and tend to drop away quite rapidly with the distance unless substation is very powerful (Kaune, 2000). It has never been proven before that exposure to magnetic fields is associated with the development of specific health effects in humans and animals, but in either way workers and residents are still exposed without their knowledge to any form of radiation (Draper, 2005).

1.3 Aim and objectives

The aim of this study was to determine the exposure levels of ELF magnetic fields inside substations and in the residential environments of Mangaung Metropolitan Municipality.

The objectives of the study were to:

- Develop and use of health and safety checklist to determine compliances in terms of stipulated electrical safety requirements by Institute of Electrical and Electronic Engineers (IEEE) and ICNIRP guidelines and electrical safety regulations.

- Measure exposure levels to ELF magnetic fields inside the distribution substations.

- Use of the grid model to obtain measurements for occupational exposure.

- Measure exposure levels to ELF magnetic fields in the residential areas.

- Compare the findings with basic restrictions and reference levels in the ICNIRP magnetic field guidelines limits of exposure to static magnetic fields.

- Assess health and safety aspects using a checklist.

1.4 Hypothesis

H_{0}- There is no difference between exposure to ELF magnetic fields and the distance.

H_{a}- There is significant difference between exposure to ELF magnetic fields and the distance.

1.5 Layout of the dissertation

The layout of the dissertation will be as follows:

- Chapter 1: In Chapter 1, the title is introduced and problem statement is outlined together with the aim and objectives of the study.

- Chapter 2: In Chapter 2, a comprehensive review of the literature relating to electromagnetic fields is provided.

- Chapter 3: In Chapter 3, the measurements of ELF magnetic fields in residential environments are clearly stated and the outcomes are discussed.

- Chapter 4: In Chapter 4, the measurements of ELF magnetic fields in the distribution substations are clearly stated and the outcomes are discussed.

- Chapter 5: in Chapter 5, the health and safety conditions of distribution substations and immediate residential environments are assessed and the outcomes are discussed.

- Chapter 6: Recommendations, general discussion and conclusion are clearly stated.

1.6 Annexures

Annexure A, the distribution substation checklist is provided.

Annexure B, the residential environment checklist is provided.

Annexure C 1 and C 2, data collection sheet for both residential and substation measurements are provided.

1.7 References

Brent, R.L. 1999. Utilization of developmental basic science principle in the evaluation of reproductive risks from pre-and post- conception environmental radiation exposures. *Teratology*; 59: 182-204.

Cavin, B. 1996. EMF Checklist for school buildings and grounds construction, California EMF Program. New York: Oxford University press.

Draper, G. 2005. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. *British Medical Journal;* 11: 1290-1293.

Fews, A.P. 1999. Corona ions from powerlines and increased exposure to pollutant aerosols. *International Journal of Radiation Biology;* 75 (12): 1523-1531.

Ilonen, K. 2008. Indoor transformer stations as predictors of residential ELF magnetic field exposure. *Bioelectromagnetics*; 29 (3): 218.

Kaune, W.T. 1993. Assessing human exposure to power-frequency electric and magnetic fields. *Environmental Health Perspectives;* 101: 121-133.

Kheifets, L. 2001."The Precautionary Principle and EMF." *Journal of Risk Research*; 4 (2): 72-110.

Kovetz, A. 2000. Electromagnetic Theory. New York: Oxford University Press.

Lacy-Hulbert, A., Metcalfe, J.C and Hesketh, R. 1998. Biological responses to electromagnetic fields. *Federation of the American Society of Experimental Biology (FASEB) Journal;* 12: 395-420.

Lee, G. 1996. California Exposure Assessment Study (preliminary findings), California EMF Program. New York: Oxford University press.

Loomis, D.P and Savitz, D.A. 1995. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. *American Journal of Epidemiology*; 141: 123-134.

National Institute for Occupational Safety and Health (NIOSH). 1995. EMF in the workplace. National Institute of Environmental Health Sciences, U.S. Department of Energy

Portier, C.J and Wolfe, M.S. 1998. Assessment of health effects from exposure to power-line frequency electric and magnetic fields-NIEHS Working Group Report NIH Publication No. 98-3981. Research Triangle Park, National Institute of Environmental Health Sciences.

Safigianni, A.S and Tsompanidou, C.G. 2005. Measurements of electric and magnetic fields due to the operation of indoor power distribution substations. *Institute of Electrical and Electronics Engineers Transport Power Delivery*; 20 (3): 1800-1805.

Sanitra, S.T. 2002. EMFs a health risk worthy of your attention. *Total Health;* 24 (2): 21.

Thuróczy, G. 2008. Exposure to 50 Hz magnetic field in apartment buildings with built-in transformer stations in Hungary. *Radiation Protection Dosimetry;* 131 (4): 469-473.

World Health Organisation (WHO). 2007. Environmental Health Criteria 55, Extremely Low Frequency (ELF) fields, Geneva 2006-2007**.**

Chapter 2

Literature review

2.1 Introduction

Electricity is considered to be a valuable part of every human in their daily lives, but whenever electricity is generated, transmitted and used, electromagnetic fields (EMFs) are produced. Electromagnetic fields are invisible fields of electric and magnetic force associated with the movement of charged electrical particles (Kovetz, 2000). EMFs are mainly produced by two dynamic sources, namely natural and human-made sources (Brent, 1999). According to Moriyama and Yoshitomi (2005), natural sources of EMFs include locally built-up electric charges in the atmosphere that are associated with thunderstorm, while the man-made sources are x-rays, radio waves from television antennas, communication devices and mobile phone base stations. The man-made sources involve the production and distribution of electricity which arise from the operation of electronic equipment and appliances in our homes and businesses (Kovetz, 2000).

Furthermore, EMFs are comprised of both electric and magnetic fields (Sinatra, 2002). The strength of electric and magnetic fields in the electrical system is directly linked to the magnitude of the voltage and current present in the system (Sinatra, 2002). According to Matthes, Bernhardt and Repacholi (2000), the relationship between these two aspects can purely be described as the stronger the voltage and current in the electrical system the stronger the magnitude of electric and magnetic fields produced.

Due to EMF emission by different sources, people are constantly exposed to different types and levels at homes, workplaces and outside residential properties (Salinas, 2001). According to Trulsson, Anger and Estenberg (2007), sources of low frequency EMFs are the ones not mostly considered risk factors as the duration of exposure is considered short-termed and the strength of the fields diminishes rapidly with increased distance.

2.2 Problem Statement

The major occupational and public concerns on EMFs appear to arise from media reports and doubtful internet sites, particularly in the United States and European countries (Wilén and De Vocht, 2011). These reports and internet posts contain inaccurate, controversial and contradictory information regarding the health impacts of exposure to EMFs. According to Urbinello and Röösli (2013), public concerns mainly arise when there is a proposed construction of new substations, installation of power lines, high-voltage electrical projects and upgrading of existing electrical facilities. Moreover, the concerns from the public to such proposals are mostly influenced by factors that include health issues and environmental degradation. However, some experts and organisations are encouraging safe precautions by limiting employees‟ exposure periods and contact time with sources of EMFs (Matthes, *et al*., 2000).

The public exposure to EMFs and development of adverse health effects has led to the regulation of power industries and sources of EMFs. According to Yamaguchi-Sekino, Sekino and Ueno (2011), the recent regulations formulated by the Radiation Protection Committee (RPC) in Canada stipulate that risk management for adverse health effects, monitoring of scientific developments and provision of information on EMFs sources must be implemented. In South Africa, the health and safety of both employees and the general public within electrical industries is regulated and administered by the Occupational Health and Safety Act, Act 85 of 1993 (OSHAS, 1993). In addition, the regulation of EMFs sources and electrical facilities is not only considered by the legislation but also the different scientific articles addressing and contributing towards the restrictions of emissions of EMFs at certain levels (Zhou, Chen and Chen, 2012).

Throughout the past decades, different scientific studies have been carried out to investigate the possible link between EMF exposures and development of adverse health effects. These investigations were conducted as a result of an incidence rate of cancer cases that are suspected to be caused by exposure to EMF emissions (Yamaguchi-Sekino, *et al*., 2011). Several laboratory experiments on biological organisms and epidemiological analyses were performed, but it was found that there is no causal relationship between exposure to EMFs and existing cancer cases. According to Chu, Song, Kim and Lee (2011), some epidemiological studies suggest that there is a weak statistical link between EMF exposures and certain types of cancer, while some laboratory studies do not confirm this link (Dehghan and Taeb, 2013). In 2013, the International Agency for Research on Cancer (IARC) indicated that the power-frequency magnetic fields are classified as possibly carcinogenic to humans, but the international EMF exposure guidelines have been developed to protect the health of both general public and employees against the danger of exposure to EMFs.

2.3 Electric and magnetic fields in electrical power systems

Electric and magnetic fields are always created, at various levels, when electrical power systems are operated at different frequencies. They are invisible and classified as non-ionising radiation within the electromagnetic field spectrum (Trulsson, *et al*., 2007). When electrical power is produced, EMFs are created. The density and magnetic flux of EMFs depend on the flow of electrical current in the power systems. According to Mild, Mattsso, Hadell, Bowman and Kundi (2005), in South Africa and most European countries, electric power is supplied as an alternating current (AC) at a frequency of 50 Hertz (Hz) and this illustrate that the current flowing in the system changes direction 50 times per second, and thus producing EMFs at different frequencies. Furthermore, electric fields are produced by the presence of electric charges and voltage in a conductor (Sinatra, 2002). The magnitude of these fields decreases when screening materials and objects are introduced near the emission source and the levels of electric fields are measured in volts per meter (V/m) (Kheifets, 2001).

According to INTERPHONE Study Group (2010), as electric fields are produced, the movement of electric charges flowing on a conductor creates magnetic fields. Magnetic field levels are measured in tesla (T), but because of the range of the levels encountered in power system environments, field levels are mostly expressed in microtesla (μT) (Mild, *et al*., 2005). Magnetic fields decrease with an increase in distance from the source, but as the load in the electric power system changes, the magnetic field also changes (INTERPHONE Study group, 2010). According to Kheifets (2001), reducing magnetic fields requires special engineering techniques and designs and as for electric fields, they are easily screened by conducting objects.

2.4 Distribution substations and EMFs emissions

In South Africa, a normal distribution substation that converts electrical power of 132 kilovolts (kV) can be found 15 to 20 meters (m) away from apartments particularly in urban environments (Sakurazawa, Iwasaki, Higashi, Nakayama and Kusaka, 2003). Most individuals, especially urban occupants and workers will never be far from one. Some of these substations have been built into a structure of a flat apartment, work environment and possibly in the basement level. In rural and peri-rural environments, the size of substations differs quite a lot, and they depend on the type and size of properties they serve (Sakurazawa, *et al*., 2003). In most cases, these properties include residential chattels, commercial and industrial divisions, educational institutions and health care facilities.

All distribution substations are well-fenced, can be found with wall enclosures and have warning signs displayed at installations (Ilonen, 2008). According to Feychting, Ahlbom and Kheifets (2005), the warning signs warn the general public and workers about the danger of electrical shock, which can result in serious injuries and fatality in case of contact. Many substations such as the mini-substations convert a high voltage of electricity from 11 to 132 kV, but a voltage converted depends on a type and size of a mini-substation (Sakurazawa, *et al*., 2003). According to Thuróczy (2008), distribution substations can only convert high voltage from 132 kV and above. In addition, distribution substations have large transformers, underground and overhead power lines leading to or away from them (Thuróczy, 2008).

Whenever substation is functioning, electric and magnetic fields are produced. Electric and magnetic fields are emitted by electrical devices inside substations (Ilonen, 2008). These devices may include transformers, overhead and underground cables, bus bars, breakers and earth mats in particular (Feychting, *et al.*, 2005). The magnitude of magnetic fields decreases quite rapid as the distance from the emitting source increases (INTERPHONE Study group, 2010). Electric fields are easily screened by any surrounding object or material present in or outside the substation. According to Thuróczy (2008), the intensity of magnetic fields usually decreases to approximately 0.1 μT within a distance of 5 m of equipment except near areas where power lines enter or exit the substation.

2.5 Occupational exposure to EMFs and related health effects

On a broad view, occupational magnetic field exposure is likely to be higher than that experienced by the general public. Li and Héroux (2014) reported incidents of potentially developed health implications such as headache, insomnia and tinnitus, due to a localised impairment of outer hair cells were caused by exposure to low frequency magnetic fields among electronics workers. Although workers at electrical industries may be highly exposed, studies suggest that not all exposures may be responsible for the development of adverse health effects. The greater the exposure to ELF magnetic fields, the higher the effects, particularly the exposure level of 100 μT and above (Khullar, Sood and Sood, 2013). Furthermore, the study conducted by Kovetz (2000) in European welding industries found that workers exposed to more than 100 μT ELF magnetic fields at welding industries are more likely to develop some form of cancer, particularly liver and kidney cancer, brain tumors and leukemia. Kim and Im (2014), suggested that ELF magnetic field exposure may play an important role in the promotion and progression of brain tumor growth and not only to welding employees but to all employees in electrical industries. Employees exposed to low frequency magnetic fields have significant damage to lymphocytes which can be associated with subsequent cancer development (Dehghan and Taeb, 2013). According to Kovetz (2000), female workers who smoke and are highly exposed to ELF magnetic fields of 50 μT and above may possibly have an increased risk of severe cognitive dysfunction, Alzheimer‟s disease and breast cancer. In addition, Liu, Wen and Fan (2011) recommend that the mitigation of exposure through changes in equipment design and environmental placement of electrical equipment should be introduced.

2.6 General public exposure to EMFs and related health effects

The most vital sources of exposure for the general public to magnetic fields are household electrical appliances, transmission power lines, built-in transformer stations, wires in the buildings, electric transportation systems and electric-operated medical apparatus (Morehouse and Owen, 2000). According to Leitgeb (2014), the most important sources of exposure are household electrical appliances, and millions of these devices are used in everyday life. Exposures from these devices are localised and strongly depend on the distance from the appliance (Tarone, *et al*., 1998). A high intensity of magnetic fields can be found close to several domestic appliances that incorporate motors, transformers, and heaters (Thuróczy, 2008). According to Yamaguchi-Sekino, *et al.* (2011), different types of epidemiological studies were conducted on animals to evaluate potential adverse health effects of electric and magnetic fields exposures. However, in the past decades *ex vivo* studies revealed the linkage between EMF exposure and development of adverse biological effects. The focus of the study conducted by Zareen, Khan and Ali Minhas (2009) was more on the changes at cellular and molecular structure but later human health experiments provided information on the occurrence and distribution of EMF exposure-related diseases in human populations. Previously, between 1997 and 2004 general public exposure to ELF magnetic fields has received increased attention and a potential influence for different long-term health effects has been identified (Tuengler and Von Klitzing, 2013). As more research studies are being conducted in the field of occupational health, researchers investigate the health effects associated with exposure to ELF magnetic fields in Europe, among residents and workers in electrical industries. They have found that exposure is associated with leukemia in residents (Leitgeb, 2014), Alzheimer"s disease in both workers and residents (Dehghan and Taeb, 2013) and brain tumor in workers (Szemersky, Koteles, Lihi and Bardos, 2010).

2.7 The effects of EMFs on plants

The effects of EMFs on plants is a question that scientists have been investigating since plants are just as readily exposed to low frequency EMFs as is humans (Belyavskaya, 2004). Plants are mainly exposed to EMFs emission through power lines and other industrial technologies that uses electrical power to function (Trulsson, *et al*., 2007). Many studies have shown that low frequency EMFs have an effect on the growth of the plants (Speit, Gminski and Tauber, 2013). Belyavskaya (2004) indicated that this exposure may suppress plant growth, particularly cell division, disintegrate the roots and increase protein production.

Furthermore, Ramezani Vishki, Majd, Nejadsattari and Arbabian (2012) found that EMFs increases plant growth while Davies (1996) indicated that some of the plants that are exposed show no effects. One of the most misunderstood concepts is how magnetic fields affect plants. Ramezani Vishki, *et al*. (2012) suggest that an increase in plant growth near power lines is due to an increase in metabolism of irradiated seeds. However, a study conducted by Pazur, Rassadina, Dandler and Zoller (2006) support that low frequency EMFs interfere with plant physiology but the effects are species-specific and depends on the duration of exposure.

In 2005, WHO also undertook a study to observe the characteristics of plants and crops exposed to EMFs at frequency ranging from 50 to 60 Hz. The study in South Africa focused only on vegetation planted under overhead power lines and near distribution substations and there were no significant effects on plant growth and cell division, particularly on plants exposed to EMFs from 745 kV power lines.

2.7.1 The exposure of crops to EMFs near overhead power lines

Eighty-five plant species were studied in USA laboratory, where plants were exposed to electric fields up to 50 kV/m. In addition, crops (including corn and wheat) grown in a greenhouse, exposed to a 30 kV/m electric field. It was found that some plant species with sharp pointed leave tips showed minor tip damage starting to occur at electric field levels of 15 to 20 kV/m (Pazur, *et al.*, 2006). This effect was not observed on plants with rounded leaf tips, even at 50 kV/m. The germination, plant growth and productivity were also not affected at these exposure levels of electric fields. With regard to corn and other crops growing near 765 kV lines, including a test line, producing electric field levels respectively up to

12 kV/m and 16 kV/m, there was no noticeable influence on crop growth and productivity. Even if, some crops growing in the 16 kV/m field of the test line showed some leaf tip damage, but the overall plant growth was not impaired (Belyavskaya, 2004).

2.7.2 The germination of seeds and performance of crops exposed to EMFs

In Europe, Ramezani Vishki, *et al*. (2012) reported that exposure of seeds to 50 μT magnetic fields cannot enhance the germination process. The results were confirmed after 60 different species of seeds had been exposed to 70 μT magnetic fields under 500 kV/m overhead power line for 2 months and showed no significant association between exposure and germination process. Furthermore, in a study conducted over a period of four years in Washington DC by Li and Héroux (2014), physiological effects of corn and wheat grown in electric fields up to 3,9 kV/m and magnetic fields up to 4,5 μT in plots at varying distance near a 380 kV line were observed. The results indicated a significant association between plants physiological reaction and EMF strength.

2.8 The effects of EMFs on animals

In 2011, two researchers Meg Tseng and Lin conducted an experiment in Canada towards discovering whether exposure to EMFs created by transmission lines affects the health, reproductive performance and behavior of livestock. The study was conducted on a farm, under a 765 kV transmission line and varieties of livestock that include beef cattle, dairy cattle, pigs, hogs and horses were examined. However, the results indicated that EMFs emitted by transmission lines do not affect the health, behavior and reproductive performance of livestock. Furthermore, a study conducted over six years by Lukac, Massanyi, Roychoudhury, Capcarova, Tvrda, Knazicka, Kolesarova and Danko (2011) on 55 dairy farms that were located near 765 kV transmission lines in Ohio, indicated that EMFs emitted by transmission lines have no impact on the milk production and health of cattle. The effects of EMFs on the reproductive performance of livestock have been widely studied, particularly in Sweden and Canada. According to Lukac, *et al*. (2011), the results obtained from a study that observed exposure of cows for 120 days under 400 kV transmission lines indicated that fertility on cows is not influenced by exposure to EMFs. These studies confirm and strongly support the view that electric and magnetic fields created by transmission lines and other EMF sources near farms do not affect the health or reproductive capacity of livestock.

2.8.1 The fertility of livestock exposed to EMFs

During 1983, Lee and Reiner conducted a study in Xanthi, Greece on the fertility of livestock exposed to EMFs from power lines. The pilot study was conducted on 36 herds during which artificial insemination was applied. The herds were exposed to ELF magnetic fields at a level of 100 μT emitted by 400 kV overheard power lines. The results of the study indicated that there was no significant association between EMFs exposure and the fertility of livestock. It is further noted that exposure to EMFs from any source cannot impose health consequences on the fertility of livestock. Furthermore, a larger study by Greene (1979), looking at the effects of EMFs on the fertility of cattle on 106 farms in Sweden did not show a decrease in fertility among the cows. On average, they were exposed to the 400 kV overhead power lines for more than 15 days per year and to maximum electric fields of 5 kV/m on some of the farms. Another experimental study by Hodges and Mitchel (1984) showed that the fertility parameters of 58 cows studied were not affected by exposure to a 400 kV line. In another study by Hodges and Mitchel (1984) breeding was achieved by artificial insemination and the fertility parameters included were estrous cycle, number of inseminations per pregnancy and conception rate. The cattle were exposed on average to 50 Hz electric and magnetic fields of 4 kV/m and 2 μT respectively for 120 days.

2.9 The exposure to ELF magnetic fields and development of cancer

The potential oncogenicity in experimental animals of exposure to ELF magnetic fields was evaluated in 40 different tissues using standard chronic toxicity testing designs. According to Astumian, Weaver and Adair (1995), three of the studies were conducted in rats (two in both sexes including one with restricted histopathological evaluation, and one in females only) and one in mice (males and females). Three of the four studies (two rat studies and one mouse study) provide no evidence that exposure to ELF magnetic fields causes cancer in any target organ. The fourth study found an increased incidence of thyroid C-cell tumours (adenomas plus carcinomas) in male rats exposed to ELF magnetic fields at two intermediate flux densities, which did not demonstrate a dose–response relationship, and a marginal increase at the highest flux density of 1000 μT. In the lowest-exposure group of 200 μT, thyroid C-cell carcinomas significantly exceeded control response and were above the historical control range. Thyroid C-cell carcinomas were not seen in male and female mice or female rats exposed chronically to ELF magnetic fields in these oncogenicity bioassays.

The most comprehensive study of EMFs as a potential carcinogen was conducted at the IIT Research Institute for the National Toxicology Program (NTP, 1998). In this study, male and female rats (n=344) were exposed to 60 Hz linearly polarised ELF magnetic fields of varying intensities as follows: (i) 200 μT, (ii) 1000 μT continuously and (iii) 1000 μT occasionally (1 hour on and 1 hour off). The rats were divided into two groups (i.e. exposed and control groups) and one group received sham exposure; none of the groups were exposed to transient magnetic fields. Furthermore, exposure began when the animals were 67 weeks of age and continued for 18.5 hour per day for two years. They were monitored and evaluated over a course of their lifetime for survival, body weight, and clinical signs of neoplasia. At death (average age, 112 to 113 weeks), all animals underwent complete necropsy and histopathological evaluation.

The results of the study showed that there was no significant difference between the exposed and control groups in terms of their survival. There were no exposure-related clinical findings. The only significant increase in tumor incidence in field-exposed rats was for thyroid gland C-cell adenomas and carcinomas combined in male rats, with incidences of 16% in sham-exposed controls, 30% in those at 200 μT (p= 7 0.01), 25% in those at 1000 μT continuously (p= 0.06), and 22% in those at 1000 μT intermittently (p= 0.15). The incidence of mononuclear-cell leukemia in males was 50, 44, 47, 50, and 36% (p= 7 0.05, intermittent group) for the five groups, respectively.

2.10 Causal relationship between low frequency EMFs and adverse health effects

A very broad review of the scientific literature from studies that were conducted by the National Institute of Environmental Health (2002), National Research Council (1997) and World Health Organisation (2007) indicated that the recent scientific evidence does support a causal relationship between the existence of health consequences and exposure to EMFs, particularly the low frequency fields. However, some of the epidemiological studies show a weak association between chronic exposure to low levels of power frequency magnetic fields and a small increased risk for childhood leukemia. These studies have largely focused on the potential relationship between childhood cancers and proximity to high voltage transmission lines. In addition, laboratory studies have failed to demonstrate a reproducible effect that is consistent with the hypothesis that magnetic fields cause or promote cancer (Polk, 1974). For this reason, scientists do not generally believe that a cause and effect relationship exist between magnetic field exposure and childhood leukemia (Szemersky, *et al*., 2010). Table 1 below summarises the health effects that develop as a result of exposure to EMFs and supporting evidence based on the findings by the National Radiological Protection Board (NRPB).

Table 1: Human health outcomes and supporting evidence

Health effects	Evidence supporting health outcomes			
	Strong	**Weak**	**Inadequate**	**None**
Alzheimer"s disease	X			
Cardiovascular disease			X	
Heart rate variability			X	
Affected hematological system				X
Changes in sleep disturbance		X		
Adverse effects on pregnancy outcomes			X	
Amyotrophic lateral sclerosis				X
Affected bone repair and adaptation				X
Reproductive effects from paternal exposure			X	
Adverse birth outcomes from maternal occupational exposure		X		

National Radiological Protection Board (NRPB) (2001).

2.11 The adverse effects on birth and pregnancy outcomes

The study conducted by Kim and Im (2010) focused on the exposure of pregnant women to EMFs at electrical industries. They were exposed to ELF magnetic fields from power lines for eight working hours at a magnitude of 0.1 μT. It was later found that exposure to ELF magnetic fields that is equal to or greater than 0.1 μT cannot cause any birth defects. Furthermore, Sekino (2011) indicated that in most cases there are few cases that showed significant health impacts resulting from exposure to 0.3 μT; therefore 0.1 μT is very low to cause adverse health effects. In some cases the small or moderate effects may be undetected, but major effects due to magnetic field exposure during early pregnancy are unlikely to occur (Kim and Im, 2010).

2.12 The affected bone repair and adaptation

In 2005, the study was undertaken in the United States to demonstrate that exposure to magnetic fields equivalent to 100 and 500 μT can affect properties of bone in both animals and humans respectively. The focus was particularly more on the biomechanical and geometrical structure of bones in rats (Moriyama, and Yoshitomi, 2005). It was found that exposure to EMFs affects the chemical structure and metabolism of bone by changing the levels of calcium, zinc and magnesium (Salinas, 2001). Furthermore, Lacy-Hulbert, *et al*. (1998) reviewed studies on EMF effects on bone repair and development. The authors determined that there was consistency in an increase of minor skeleton alterations such as bone repair, red blood cells and development of bone marrow in several experiments.

2.13 The reproductive effects and sleep disturbance

In Greece, the studies on reproductive effects and sleep disturbance caused by exposure to EMFs above 100 μT near substations raised awareness among electrical workers and residents living near electrical industries (Kuster and Schönborn, 2000). Early 2005, Kooperberg, Aragaki, Strand and Olson undertook a study in Europe to observe the effects of exposure to EMFs among electrical workers and residents. The study was undertaken on rats to observe the consequences of exposure and it was found that low frequency magnetic fields exposure had some adverse effects on sleep disturbance, reproduction, including miscarriage, fetal loss and malformation and developmental delay in the offspring. Kumar, Kesari and Behari (2011) found functional changes in the ovary and uterus after exposure to EMFs for over 50 days. Changes in estrogen levels in the first trimester cells were found after 72 hours of exposure to magnetic fields of 0.4 μT (Kooperberg, *et al*., 2005).

2.14 The effects on cardiovascular and heart rate variability

Many of the occupational and general public studies by Wilkins and Wellage (1996) looking at cardiovascular effects and EMFs have found a negative association between exposure to EMFs and development of cardiovascular effects (Szemersky, *et al*., 2010). A review of studies looking into the possible changes in human heart rate as a result of exposure to EMFs by Dehghan and Taeb (2013) reported a decrease in heart rate, while a study by Kheifets (2001) found no relation between low-frequency EMF exposure and cardiovascular diseases. Furthermore, a study by Kaune (1993) found that the EMFs produced by incubators in the health care sectors influenced the heart rate variability in newborn babies. This heart rate variability could obstruct the development of the nervous system which would in turn lead to cot death (Kunz, Grove and Fischer, 2012). As children may be exposed to high EMFs from incubators for some considerable time, it was felt that further research should be undertaken to establish whether there are any long-term health consequences. The fields are low and are similar to those that babies could be exposed to as a result of electrical equipment near their bed or the presence of power lines near their home (Lerchl and Wilhelm, 2010).

2.15 The development of Alzheimer's disease, Amyotrophic lateral sclerosis (ALS) and affected hematological system due to an exposure to EMFs

In Rancho Los Amigos, a case-control study was conducted by Sobel, Dunn, Davanipour, Qian and Chui (1993) to observe the possible association of occupations with likely exposure to EMFs and Alzheimer's disease among patients in from the Alzheimer and hematologic disease treatment in Rancho Medical Center. Patients with definite or probable Alzheimer"s disease were classified as case subjects (86 male, 240 female) while patients with affected hematological system were assigned to control group (76 male, 76 female). The study was limited to patients who were at least 65 years old at the time of their first examination. Furthermore, the probability ratio for both sexes combined was adjusted for sex, education, and age at onset. The adjusted probability ratio was

3.93 (p = 0.006), 95% CI = (1.5 to 10.6). For males the adjusted odds ratio was 4.90 (p = 0.01), 95% CI = (1.3 to 7.9), and for females was 3.40 (p = 0.10), 95% CI = (0.8 to 16.0). In addition, it was found that exposure to EMFs is etiologically associated with the occurrence of Alzheimer"s disease and affected hematological system.

Savitz, Loomis and Tse (1998) have hypothesised that occupations involving electric and magnetic field exposure are associated with a variety of health problems, including Alzheimer"s disease. The researchers conducted a case-control study, and they used U.S. death certificates with occupational coding to compare male cases of Alzheimer's disease (n = 256) and amyotrophic lateral sclerosis (n = 114) with controls matched for age and calendar time. The researchers selected controls in a 3:1 ratio to cases from persons who died of causes other than leukemia, brain cancer, and breast cancer. The overall associations with electrical occupations were modest (i.e. adjusted probability ratios of 1.2, 1.1, and 1.3 for Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis, respectively). Individuals in electrical occupations were at high risk of developing Alzheimer"s disease than overall electrical occupations, particularly amyotrophic lateral sclerosis, for which relative risks ranged from 2 to 5 across several job categories. There was a great association of exposure to EMFs and all three diseases among the power plant operators.

2.16 The emission of Low Frequency EMFs from electric sources

Natural electric and magnetic fields at extremely low frequencies are very weak, while those categorised as man-made origin are being regarded as much stronger (Brent, 1999). It has been widely indicated that EMFs with a frequency below 300 Hz are classified as extremely low frequency (Mild, *et al*., 2005). The debate around specific frequencies that can be accepted by different countries as extremely low frequency is on-going (Manjhi, Kumar, Behari and Mathur, 2013). According to Polk (1974), in Europe, the frequency range between 30 Hz to 300 Hz is labeled as extremely low frequency and the range below this ELF band is unnamed, while in the USA, the frequency is sometimes labeled as 0 - 100 Hz.

2.16.1 The power lines as sources of EMFs

Electricity is transported from power stations to substations by means of power lines and they are supported by transmission towers (Farag, Dawoud, Cheng and Cheng, 1999). The movement of electricity through power lines produces both electric and magnetic fields at different intensities. The largest power lines in South Africa, which transfer voltages of approximately 400 kV and 275 kV are owned and maintained by ESKOM. Some of the 132 kV power lines are owned by the local power distribution companies (such as Centlec in the Mangaung Metroplitan Municipality). The parallel 132 kV power lines are often unstable, and this happens as a result of different current on both sides of the cables. The differences lead to much higher EMFs than if they were both the same (Farag, *et al*., 1999). A study conducted by Tarone, *et al*. (1998) in the United States at the Bristol University showed that there were approximately 40 000 houses within 30 m of 132 kV and 400 kV power lines. The power lines with a voltage of 132 kV and below are assumed to comply with the ICNIRP exposure guidelines (ICNIRP, 2010).

2.16.2 The EMFs and rail maintenance

Wenzl (1997) investigated exposure to ELF magnetic fields among rail maintenance workers near Philadelphia, in Pennsylvania. The workers were exposed to ELF magnetic fields equivalent to 25 μT from electrified rail lines. Spot measurements for magnetic fields were taken using a multiwave system and fast Fourier transform to analyse the frequency. Personal exposure was also monitored. The current flowing in the overhead power lines was the primary source of ELF magnetic fields when a train was near the maintenance work site. Furthermore, the peak magnetic fields were 3.4 μT near a transformer, while the medians at other five locations were 0.7 μT, respectively. The time-weighted-average (TWA) personal exposures were estimated by combining spot measurements at occupied locations with estimates of the amount of time spent at each location; the values were 0.3 μT and 1.8 μT, depending on the location and how frequently trains passed the work site. According to Wilkins and Wellage (1996), the personal exposure readings showed significant association between EMFs emissions in rail maintenance sections and personal exposure. Cohen and Ellwein (1990) indicated that characterisation of personal exposures in rail maintenance environments could be justified, since workers and passengers on trains are highly exposed and for longer period of time.

2.16.3 The exposure to EMFs in office spaces

In Denmark, Skotte (1994) observed the 24 hour exposure of office workers, industrial workers, electric utility workers and residents near high power lines to power-frequency EMFs. A total number of 396 measurements were collected from 301 subjects, of which 55 were among office workers outside the utility companies. The mean exposure observed for office workers was 0.09 μT. In normal residences, those not near high-voltage transmission lines, the mean exposure of all study participants was 0.05 μT with a standard deviation of 2.1. Furthermore, Breysse, Lees, McDiarmid and Curbow (1994) also measured ELF magnetic fields in office environments by taking spot and personal measurements of ELF magnetic fields in a large payroll department. Personal exposure measurements were collected from 15 female employees with using EMDEX exposure meter. The spot measurements revealed an exposure of 0.13 μT where office equipment such as video display terminals (VDTs) and photocopiers were present. The highest measured magnetic field was emitted by an electrical utility duct. The TWA personal work exposures were 0.1 μT.

2.17 Electrical health and safety practices in distribution substations

There are a number of safety hazards unique to substations and the first consideration in distribution substation safety is to make sure that the substation is properly protected and secured from the outside. According to Ahlbom, Day, Feychting, Roman, Skinner, Dockeerty, Linet, McBride, Michaelis, Olsen, Trnes, and Verkasalo (2000), the possible effects of magnetic field exposure in occupational and residential environments raise the concept on how electric and magnetic fields are created inside substations, and what effects they may have. Preece, Hand, Clarke and Stewart (2000), stated that substations must be well-fenced and warning signs posted about the amount of voltages produced.

However, it is recommended that only trained and authorised personnel should be allowed to work inside or near capacitors, reactors and other fenced-in areas inside substations (Kovetz, 2000). Untrained individuals may not be aware that some of these structures may be energised. Furthermore, Shun-Li, Ghin, Ching-Lien and Lu (1999) outlined the following safety measures:

- Workers should be protected against the hazards of live or induced voltage,
- Housekeeping should at all times be taken into consideration as it not sound to store any useful equipment or material inside substation, and
- Hazard warnings regarding battery systems in the substation should be observed.

2.18 Exposure guidelines

In North America, the National Radiation Laboratory recommends all electrical industries and companies evaluating EMFs to use the guidelines that are published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The ICNIRP is an international scientific body and is recognized by the WHO for its expertise in this area.

The ICNIRP guidelines are mainly based on research data on the health effects of exposure to electric and magnetic fields, and include restrictions on safety concerns. The guidelines were set with an intention of protecting the general public and workers in electrical industries against the risks of exposure to EMFs. These guidelines received world-wide support by many electrical industries, particularly in Europe, North America and South Africa and the exposure limits summarised in Table 2 below represents the EMFs frequency at 50 Hz.

Table 2. Electric and magnetic field exposure guidelines at 50 Hz by ICNIRP (2010).

	Electric fields (kV/m)	**Magnetic Fields (µT)**
Reference levels		
Occupational	10	1000
General public	5	200
	Current density (mV/m)	
	Head	**Whole body**
Basic restrictions		
Occupational	100	800
General public	20	400

These guidelines are more centered on basic restrictions and reference levels. The basic restrictions are referred to as safe induced current density and are measured in milli-volts per meter (mV/m) (ICNIRP, 2010) while reference levels are field levels easily measured and spatially averaged across the volume taken up by the body of the exposed person, and should this levels be exceeded, a further assessment is required to ensure that the basic restrictions are also not exceeded (ICNIRP, 2010).

2.18.1 Basic restrictions and reference levels

In the most recent guidelines issued by ICNIRP (2010) for limiting exposure in the frequency range of 1 Hz - 100 kilohertz (kHz), some of the physical magnitudes used for setting the basic restrictions cannot be easily measured. However, on the guidelines, the reference levels are mainly used to assess practical exposures and to determine the likeliness of basic restrictions been exceeded. Reference levels are basically derived from basic restrictions using measurement techniques and their main purpose is to address the adverse effects of exposure to EMFs.

2.19 EMF strength, shielding and distance

The strength of electric and magnetic fields is directly linked to the magnitude of the voltage and current respectively present in the power system. The stronger the voltage and current within electrical systems the higher the levels of electric and magnetic fields produced (Delpisso, 1992). The intensity of both electric and magnetic fields deteriorates with an increased distance from the source (Lacy-Hulbert, Metcalfe and Hesketh, 1998). The rate at which the field weakens depends on the specific configuration of the electrical equipment involved. However, the strength of electric fields are further weakened, or shielded, by common materials such as buildings, trees, fences and walls and most of these materials, on the other hand, do not reduce magnetic fields.

2.20 Conclusion

Despite the scientific reports regarding the causality between exposure to different types and levels of power frequency EMFs and adverse human health effects, different organisations have encouraged a precautionary approach aimed at reducing the potential risks by decreasing public and occupational exposures (Kheifets, 2001). Farag, *et al.* (1999) indicated that such practical avoidance strategies must include the placement of high voltage transmission lines and substations away from schools and childcare facilities, special configurations for power line conductors and buffer zones along high voltage transmission right-of-ways (Preece, *et al.,* 2000).

The protection of general public and employees against EMF exposures should not only be in a form of engineering-related measures and personal protection. A co-ordinated research agenda that addresses the scientific issues raised by increasing environmental EMF levels must also exist (Liu, *et al*., 2011). However, much of the existing scientific work around this area has been disseminated in approach and uneven in quality.

2.21 References

Ahlbom, A., Day, N., Feychting, M., Roman, E., Skinner, J., Dockeerty, J., Linet, M., McBride, M., Michaelis, J., Olsen, J., Trnes, T and Verkasalo, P. 2000. A pooled analysis of magnetic fields and childhood leukemia. *British Journal of Cancer*; 83 (5): 692-698.

Astumian, R.D., Weaver, J.C and Adair, R.K. 1995. Rectification and signal averaging of weak electric fields by biological cells. *Proceedings of the National Academy of Science*; 92: 3740-3743.

Belyavskaya, N.A. 2004. Biological effects due to weak magnetic field on plants. *Advances in Space Research*; 34: 1566-1574.

Brent, R.L. 1999. Utilization of developmental basic science principle in the evaluation of reproductive risks from pre-and post- conception environmental radiation exposures. *Teratology*; 59: 182-204.

Breysse, P., Lees, P.S.J., McDiarmid, M.A and Curbow, B. 1994. ELF magnetic field exposures in an office environment. *American Journal of Industrial Medicine*; 25: 177-185.

Chu, M, K., Song, H, G., Kim, C and Lee, B, C. 2011. Clinical features of headache associated with mobile phone use: a cross-sectional study in university students. *BMC Neurology*; 11: 115.

Cohen, S.M and Ellwein, L.B. 1990. Cell proliferation in carcinogenesis. *Science*; 249: 1007-1011.

Davies, M.S. 1996. Effects of 60 Hz electromagnetic fields on early growth in three plant species and a replication of previous results. *Bioelectromagnetics*; 17 (2): 154-161.

Dehghan, N and Taeb, S. 2013. Adverse health effects of occupational exposure to radiofrequency radiation in airport surveillance radar operators. *Indian Journal of Occupational and Environmental Medicine*; 17 (1): 7-11.

Delpisso, P. 1992. Position Statement for the General Public on the Health Effects of Power-frequency (60 Hz) Electric and Magnetic Fields. New York: Oxford University Press.

Farag, A, S., Dawoud, M, M., Cheng, T, C. and Cheng, J, S. 1999. Occupational exposure assessment for power frequency electromagnetic fields. Electrical Power System. *Scand Journal of Work Environmental Health*; 48: 151–175.

Feychting, M., Ahlbom, A and Kheifets, L. 2005. EMF and health. *Annual Revolution Public Health*; 26: 165-189.

Greene, R. W. 1979. Study of the Biological Effects of UHV Transmission Line Electric Fields, A Report to the American Electric Power Service Corporation by the Department of Biology, University of Notre Dame.

Hodges, T. K and Mitchel, C. A. 1984. Influence of High Intensity Electric Fields on Yield of Sweet Corn and Dent Corn, A Report for the American Electric Power Service Corporation, 1984.

Ilonen, K. 2008. Indoor transformer stations as predictors of residential ELF magnetic field exposure. *Bioelectromagnetics*; 29 (3): 218.

International Agency for Research on Cancer. 2013. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 102. Radiofrequency Electromagnetic Fields. IARC press, Lyon, France.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 2010. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). *International Journal of Radiation Biology*; 72 (3): 233-241.

INTERPHONE Study Group. 2010. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. *International Journal of Epidemiology*; 39 (3): 675-694.

Kaune, W.T. 1993. Assessing human exposure to power-frequency electric and magnetic fields. *Environmental Health Perspectives;* 101: 121-133.

Kheifets, L. 2001. "The Precautionary Principle and EMF." *Journal of Risk Research*; 4 (2): 72-110.

Khullar, S., Sood, A and Sood, S. 2013. Auditory Brainstem Responses and EMFs Generated by Mobile Phones. *Indian Journal of Otolaryngol Head Neck Surg*; 65 (3): 645-649.

Kim, S and Im, W. 2010. Static magnetic fields inhibit proliferation and disperse subcellular localization of gamma complex protein3 in cultured C2C12 myoblast cells. *Cell Biochem Biophysics*; 57 (1): 1-8.

Kooperberg, C., Aragaki, A., Strand, A.D and Olson, J.M. 2005. Significance testing for small microarray experiments. *Statistics Medicine*; 24: 2281-2298.

Kovetz, A. 2000. Electromagnetic Theory. New York: Oxford University Press.

Kumar, S., Kesari, K.K and Behari, J. 2011. Influence of microwave exposure on fertility of female rats. *Fertil Steril*; 95 (4): 1500-1502.

Kunz, S.N., Grove, N and Fischer, F. 2012. Acute pathophysiological influences of conducted electrical weapons in humans: A review of current literature. *Forensic Science International*; 221 (1): 1-4.

Kuster, N and Schönborn, F. 2000. Recommended minimal requirements and development guidelines for exposure setups of bio-experiments addressing the health risk concern of wireless communications. *Bioelectromagnetics*; 21: 508–514.

Lacy-Hulbert, A., Metcalfe, J.C and Hesketh, R. 1998. Biological responses to electromagnetic fields. *Federation of the American Society of Experimental Biology (FASEB) Journal*; 12: 395-420.

Lee, J.M and Reiner, G.L. 1983. Transmission Line Electric Fields and the Possible Effects on Live Stock and Honeybees. *Transactions of the American Society of Agricultural Engineers*; 26 (1): 279 – 286.

Leitgeb, N. 2014. Childhood Leukemia Not Linked with ELF Magnetic Fields. *Journal of Electromagnetic Analysis and Applications*; 6: 174-183. http://dx.doi.org/10.4236/jemaa.2014.67017 [online] Access date: 06 March 2015.

Lerchl, A and Wilhelm, A.F.X. 2010. Critical comments on DNA breakage by mobile-phone electromagnetic fields [Diem *et al*., Mutat Res, 583 (2005) 178–83]. *Mutat Res*; 697: 60-65.

Li, Y and Héroux, P. 2014. Extra-low-frequency magnetic fields alter cancer cells through metabolic restriction. *Electromagnetic Biol Med*; 33 (4): 264-275.

Liu, M. L., Wen, J. Q and Fan, Y. B. 2011. Potential protection of green tea polyphenols against 1800 MHz electromagnetic radiation-induced injury on rat cortical neurons. *Neurotoxicity research*; 20: 270-276.

Lukac, N., Massanyi, P., Roychoudhury, S., Capcarova, M., Tvrda, E., Knazicka, Z., Kolesarova, A and Danko, J. 2011. In vitro effects of radiofrequency electromagnetic waves on bovine spermatozoa motility. *Journal of Environmental Science and Health*; 46 (12): 1417-1423.

Manjhi, J., Kumar, S., Behari, J and Mathur, R. 2013. Effect of extremely low frequency magnetic field in prevention of spinal cord injury-induced osteoporosis. *J Rehabil Res Dev*; 50 (1): 17-30.

Matthes, R., Bernhardt, J and Repacholi, M. 2000. ICNIRP editors: Proceedings of the International Seminar on Effects of Electromagnetic Fields on the Living Environment. Ismaning, Germany (ICNIRP 10/2000).

Meg Tseng, M. C., Lin, Y. P and Cheng, T, J. 2011. Prevalence and psychiatric comorbidity of selfreported electromagnetic field sensitivity in Taiwan: A population-based study. *J Formos Med Assoc;* 110 (10): 634-641.

Mild, K., Mattsso, M., Hadell, L., Bowman, J and Kundi, M. 2005. Occupational carcinogens; ELF MFs. *Environmental Health Perspective*; 113 (11): 726-727.

Morehouse, C. A and Owen, R. D. 2000. Exposure of Daudi cells to low-frequency magnetic fields does not elevate MYC steady-state mRNA levels. *Radiation Research*; 153: 663-669.

Moriyama, K. and Yoshitomi, K. 2005. Apartment electrical wiring: a cause of extremely low frequency magnetic field exposure in residential areas. *Bioelectromagnetics*; 26: 238-241.

National Institutes for Environmental Health. 2002. EMF Questions and Answers: Electric and Magnetic Fields Associated with Use of Electric Power. Research Triangle Park, NC.

National Radiological Protection Board (NRPB). 2001. Available at http://www.hpa.org.uk/radiation/ 15 Apr 2006. [Online] Access date: 12 September 2015

National Toxicology Program. 1998. Studies of Magnetic Field Promotion in Sprague-Dawley Rats. US Department of Health and Human Services, Public Health Service, *National Toxicology Program:* Research Triangle Park, NC.

Pazur, A., Rassadina, V., Dandler, J and Zoller, J. 2006. Growth of etiolated barley plants in weak static and 50 Hz electromagnetic fields turned to calcium ion cyclotron resonance. *BioMagnetic Research and Technology*. 4: 1 doi: 10.1186/1477-044X-4-1.PLoS One, 7 (11), e48354.

Polk, C. 1974. Sources, propagation, amplitude, and temporal variation of extremely low frequency (0 - 100 Hz) electromagnetic fields. In: Llaurado, J.G., Sances, A and Battocletti, J .H., ed. Biologic and clinical effects of low frequency magnetic and electric fields, Springfield, Illinois, Charles C. Thomas, pp. 21-48.

Preece, A, W., Hand, J, W., Clarke, R, N. and Stewart, A. 2000. Power frequency electromagnetic fields and health. Where‟s the evidence?. *Physics Medical Biology*; 45: 139-154.

Ramezani Vishki, F., Majd, A., Nejadsattari, T and Arbabian, P.S. 2012. Study of Effects of Extremely Low Frequency Electromagnetic Radiation on Biochemical Changes in Satureja Bachtiarica L. *International Journal of Scientific & Technology Research Volume 1, Issue 7*. ISSN 2277-8616 77 IJSTR. pp- 28- 31.

Sakurazawa, H., Iwasaki, A., Higashi, T., Nakayama, T. and Kusaka, Y. 2003. Assessment of exposure to magnetic fields in occupational settings. *Journal of Occupational Health*; 45: 104-110.

Salinas, E. 2001. Magnetic field management at the transmission and distribution stages, in Proc. 5th Int. Power Engineering Conference, Singapore, pp. 325–330.

Sanitra, S.T. 2002. EMFs a health risk worthy of your attention. *Total Health*; 24 (2): 21.

Savitz, D.A., Loomis, D.P and Tse, C.K. 1998. Electrical occupations and neurodegenerative disease: analysis of U.S. mortality data. *Arch Environ Health*; 53 (1): 71-74.

Shun-Li, L., Ghin, L, E., Ching-Lien, L, E. and Lu, H, T. 1999. "Power substation magnetic field measurement using digital signal processing techniques. *Institute of Electrical and Electronics Engineers Transport. Power Delivery*; 14: 1221-1227.

Skotte, J.H. 1994. Exposure to power-frequency electromagnetic fields in Denmark. *Scandinavian Journal of Work, Environment and Health*; 20: 132-138.

Sobel, E., Dunn, M., Davanipour, Z., Qian, Z and Chui, H.C. 1996. Elevated risk of Alzheimer's disease among workers with likely electromagnetic field exposure. *Neurology*; 47 (6): 1477-1481

South Africa. 1993. Occupational Health and Safety Act. Act 85 of 1993. Pretoria: Government Printer.

Speit, G., Gminski, R and Tauber, R. 2013. Genotoxic effects of exposure to radiofrequency electromagnetic fields (RF-EMF) in HL-60 cells are not reproducible. *Mutat Res*; 755: 163-166.

Szemersky, R., Koteles, F., Lihi, R and Bardos, G. 2010. Polluted places of polluted minds? An experimental sham-exposure study on background psychological factors of symptom formation in „idiopathic environmental intolerance attributed to electromagnetic fields." *International Journal of Hygiene and Environmental Health*; 213 (5): 387-394.

Tarone, R.E., Kaune, W.T., Linet, M.S., Hatch, E.E., Kleinerman, R.A., Robison, L.L., Boice, J.D and Wacholder, S. 1998. Residential wire codes: Reproducibility and relation with measured magnetic fields. *Occupational and Environmental Medicine;* 55: 333-339.

Thuróczy, G. 2008. Exposure to 50 Hz magnetic field in apartment buildings with built-in transformer stations in Hungary. *Radiation Protection Dosimetry*; 131 (4): 469-473.

Trulsson, J., Anger, G and Estenberg, U. 2007. Assessment of magnetic fields surrounding electronic article surveillance systems in Sweden. *Bioelectromagnetics*; 28 (8): 664-666.

Tuengler, A and Von Klitzing, L. 2013. Hypothesis on how to measure electromagnetic hypersensitivity. *Electromagn Biol Med*; 32 (3): 281-290.

Urbinello, D and Röösli, M. 2013. Impact of one's own mobile phone in stand-by mode on personal radiofrequency electromagnetic field exposure. *Journal of Exposure Science and Environmental Epidemiology*; 23 (5): 545-548.

Wenzl, T.B. 1997. Estimating magnetic field exposure of rail maintenance workers. *American Industrial Hygiene Association Journal*; 58: 667-671.

Wilén, J., De Vocht, F. 2011. Health complaints among nurses working near MRI scanners- A descriptive pilot study. *European Journal of Radiology*; 80 (2): 510-513.

Wilkins, J.R and Wellage, L.C. 1996. Brain tumor risk in offspring of men occupationally exposed to electric and magnetic fields. *Scandinavian Journal of Work, Environment and Health*; 22: 339-345.

World Health Organisation. 2005. Extremely Low Frequency Fields. Environmental Health Criteria Monograph No. 238. Geneva.

Yamaguchi-Sekino, S., Sekino, M and Ueno, S. 2011. Biological effects of electromagnetic fields and recently updated safety guidelines for strong static magnetic fields. *Magnetic Reson Medical Sciences*; 10 (1): 1-10.

Zareen, N., Khan, M.Y and Ali Minhas, L. 2009. Derangement of chick embryo retinal differentiation caused by radiofrequency electromagnetic fields. *Congenit Anom* (Kyoto); 49 (1): 15-19.

Zhou, H., Chen, G and Chen, C. 2012. Association between extremely low-frequency electromagnetic fields occupations and amyotrophic lateral sclerosis: a meta-analysis. New York: Oxford University press.

Chapter 3

Evaluation of exposure to ELF magnetic fields in the residential areas of Mangaung Metropolitan Municipality

Abstract

This study aimed to evaluate the levels of exposure to ELF magnetic fields in the residential environments of Mangaung Metropolitan Municipality. Due to unequal geographical proportion within Mangaung, 15 residential sites were randomly selected in Bloemfontein, nine in Botshabelo and six in Thaba Nchu areas. The measurements were collected at the distances of 3 meters (m), 6 m and 9 m outside substations, near every corner, using a Trifield meter model XE 100. Furthermore, the exposure levels were also measured from four different corners inside substations, near barrier screening and these measurement points were referred as a distance of 0 m. The results from the analysis of variance (ANOVA) test indicated a non-significant difference among the 15 residential environments in Bloemfontein (BRE1 to BRE15) and six residential environments in Thaba Nchu (TNRE1 to TRNE6). The exposure levels of magnetic fields was significantly higher in one residential site (BORE1) as compared to other residential sites in Botshabelo ($p<0.001$). The results obtained from the measurements also show a statistically significant difference between the residential environments BORE4 and BORE8 ($p<0.01$) as well as BORE4 and BORE9 ($p<0.006$). The four distance interims also demonstrated a highly significant difference ($p<0.0001$) when compared to one another. The Tukey test indicated that there is a statistically significant difference in terms of the exposure levels recorded at distances of 3 m, 6 m and 9 m in comparison to 0 m ($p<0.01$). The exposure levels recorded at a distance of 3 m were significantly different to those recorded at 6 m ($p<0.05$) and 9 m ($p<0.01$). The exposure levels of ELF magnetic fields measured at all distances were below the ICNIRP guidelines and the fields decrease rapidly when the distance from the source of exposure is increased.

Keywords: ELF magnetic fields, exposure levels, residential environments, substations, distance interims

3.1 Introduction

The distribution substations are part of the electrical power supply network. In every community, distribution substations enables the common use of electricity at residential properties, workplaces, learning institutions, recreational parks and health care facilities (Kovertz, 2000). Most importantly, the sizes of distribution substations are variable; it depends on whether they serve residential area or institutional structures (Sakurazawa, Iwasaki, Higashi, Nakayama and Kusaka, 2003). According to Kovetz (2000), every institution such as hospitals, schools, commercial and industrial units have their own substations called mini-substations, and this also include the different residential sections and shopping complexes served by the distribution substations.

The purpose of distribution substations is mainly to transform high voltage power that is transferred over long distances by power lines into low common-use voltage that is suitable for households (Thuróczy, 2008). Furthermore, as soon as a substation is constructed and well operating it generates EMFs, both electric and magnetic fields are generated at different magnitudes. Electromagnetic fields are mainly produced by the equipment inside the substations, and such equipment includes underground and overhead cables, transformers and junction boxes nearby (Thuróczy, 2008). It is required that measurements of EMFs on human exposures, including both head and whole body are conducted (ICNIRP, 2010). The measurements are mainly conducted to characterise sources and levels of exposure to humans (WHO, 2007).

3.2 Problem statement

Exposure to EMFs is not a new phenomenon, in fact, during the 21st century environmental exposure to EMFs has been gradually increasing due to an increased demand for electricity, advancing technology by manufacturing industries and changes in social behavior. Changes in social behavioral processes and ever-advancing technology have created more sources of EMFs that primarily result in high exposure levels (Wilén and De Vocht, 2011). During the past decades, the general public became more concerned about what effects EMF exposures can have on their health. A recent study by Urbinello and Röösli (2013) had provided better evidence than was available in the past on the relationship between ELF magnetic field exposure and the risk of cancer. It is, however, suggested that the average exposure levels of 0.4 μT and above is associated with a doubling of the risk of leukemia in children less than 15 years of age but the evidence is not conclusive (Urbinello and Röösli, 2013). Although there have been fewer cases on association of cancer and exposure to ELF magnetic fields in adults, there is no conclusive evidence to indicate that ELF magnetic fields may be involved in the development of cancer and other health related impacts (Leitgeb, 2014).

A study by Speit, Gminski and Tauber (2013) showed that cattle, plants and crops exposed to high exposure levels of magnetic fields that are normally found in the environment (nearby overhead power lines) have no effects on growth of plants and milk production on cattle. However, a study by Ramezani Vishki, Majd, Nejadsattari and Arbabian (2012) indicated that the only parameter that can affect plant growth is electric fields and such plants have to be in close proximity with the electric field source, particularly high voltage power lines (HVPL). In South Africa, the data about the exposure levels of ELF magnetic fields in the environment and residential sites are currently lacking, this study aims to evaluate the exposure levels of ELF magnetic fields in the environmental and residential sites of Mangaung Metropolitan Municipality.

3.3 Materials and methods

3.3.1 Study design: environmental and residential measurements

Mangaung Metropolitan Municipality consists of 42 distribution substations (132 kV) within its main regions (Botshabelo, Bloemfontein and Thaba Nchu). Out of the entire number of distribution substations found in Mangaung, only distribution substations (n=30) and residential sites (n=30) were selected using simple random sampling method. The purpose was to ensure adequate representation of environmental and residential exposure levels. Although there is an unequal geographical proportion in the Mangaung region, 15 distribution substations and 15 residential sites were randomly selected in Bloemfontein. Nine distribution substations and nine residential sites in Botshabelo, as well as six distribution substations and six residential sites in Thaba Nchu were selected. A total number of 120 samples were taken for a single parameter (ELF magnetic fields) on different distribution substations and 360 for residential environments on different interims.

Furthermore, all substations and residential environments were coded to ensure that there is no exposure data allocated falsely and inaccurately to some measurement spots. The coding for substations was as follow: BS1 to BS15 for Bloemfontein substations; BOS1 to BOS9 for Botshabelo substations; and TNS1 to TNS6 for Thaba Nchu substations. The residential environments were coded as BRE1 to BRE15 for Bloemfontein, BORE1 to BORE9 for Botshabelo and TNRE1 to TNRE6 for Thaba Nchu respectively. Before the measurements were taken, a proper walk-through survey was conducted in the substations and induction was also provided by the chief development planner and assistant engineer both from metropolis. The purpose of induction was to introduce the researcher to different equipment used in the substations and also to comply with the requirements of the Institute of Electrical and Electronic Engineers (IEEE) stipulations. The technical steps below were followed when taking measurements for environmental and residential exposures.

3.3.2 Sampling: environmental and residential measurements

The basic purpose of the measurements was to determine the exposure levels of ELF magnetic fields in the environmental and residential sites. During sampling, four measurement points (four corners) were selected for each substation among those that were randomly selected. The measurements were taken at four different corners inside each selected distribution substation, near the barrier screening, and the distance interim was referred to as 0 m and indicated as the reference point. Measurements were taken at the distances of 3 m, 6 m and 9 m at every corner outside the substations. Furthermore, ELF magnetic field exposure levels were measured using a calibrated hand-held Trifield meter model XE 100 and the battery status was checked before taking measurements. The meter is designed to measure extremely low frequency magnetic fields ranging from 3 to 3000 Hz. The meter was held at a distance of 1 m above the ground to ensure that any emissions from underground cables do not affect the readings on the meter.

Inside the substations, at reference points (0 m), the meter was held facing to the direction of electrical sources. This is to ensure that the measurements recorded are directly from the source and not from any reflection surface. In the residential sites (outside the substations), the meter was held facing the corners of substations for each and every measured distance interim (3 m, 6 m and 9 m). The distances were selected as according to literature, the magnitude of magnetic fields decreases quite rapidly with increased distance from the source. The figure below illustrates the sampling points in relation to distance interims.

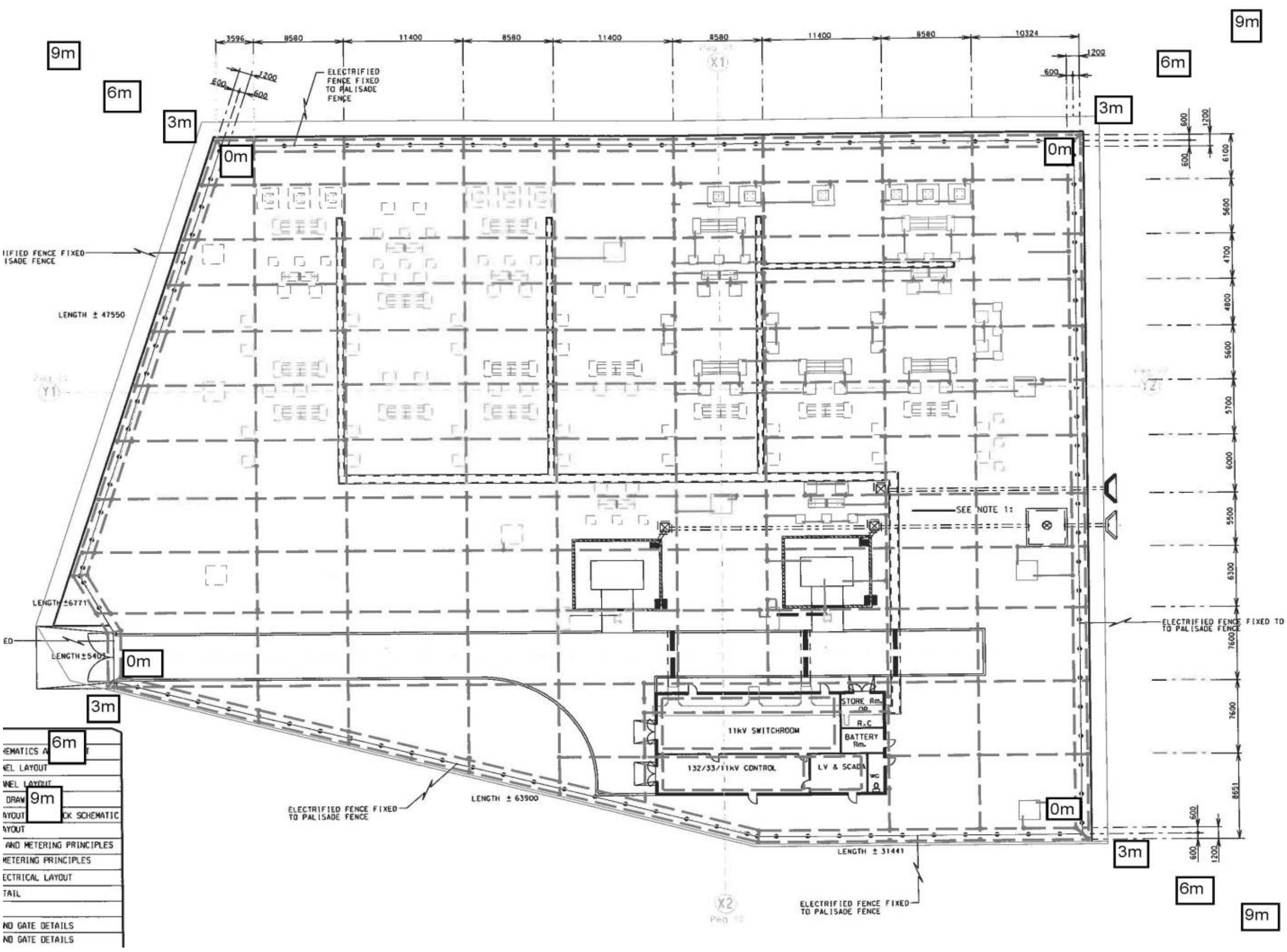

Figure 3.1: Sampling points and distance interims

3.3.3 Data analysis

The data was analysed using Excel programme (Microsoft 2010) to obtain the descriptive summary statistics. The summary statistics obtained represent the levels of ELF magnetic fields measured in the three core regions of Mangaung Metropolitan Municipality (Bloemfontein, Botshabelo and Thaba Nchu). The analysis of variance (ANOVA) was also performed to statistically compare the exposure levels of ELF magnetic fields in the residential environments. Furthermore, a Tukey test was performed to test whether the exposure levels recorded at different distances are significantly different or not.

3.4 Results

3.4.1 The environmental exposure to ELF magnetic fields

The descriptive statistics was performed to analyse the environmental exposure data. All residential sites in Bloemfontein were statistically compared to one another, including the ones in Botshabelo and Thaba Nchu, to observe the significant difference in the occurrence of ELF magnetic field levels. The comparison between the residential sites of Bloemfontein, Botshabelo and Thaba Nchu was also performed. The overall occurrence of ELF magnetic fields in the residential sites of Bloemfontein was compared to the residential sites of Botshabelo and Thaba Nchu, respectively.

Table 3.1 shows the summary statistics of environmental exposure to ELF magnetic field emissions in the three core residential areas of Mangaung Metropolitan Municipality (Bloemfontein, Botshabelo and Thaba Nchu). The results indicate that there is no statistically significant difference on the overall occurrence of ELF magnetic fields in the three residential areas, Bloemfontein (p<0.73), Botshabelo (p<1.85) and Thaba Nchu (p<0.35). A statistically significant difference was only observed when ELF magnetic field levels in the residential sites of Botshabelo were compared to one another (p<0.001). The non-significant difference was observed when ELF magnetic field levels in the residential sites of Bloemfontein as well as Thaba Nchu were compared.

Table 3.1: Summary statistics of environmental exposure levels for magnetic fields from residential sites

Residential environments	Mean (µT)	Variance	Standard deviation	Maximum	Minimum	Range	*Significant and **non-significance *p*-values
BRE 1	0.42	0.04	0.19	0.80	0.18	0.62	**n/s
BRE 2	0.28	0.01	0.11	0.48	0.12	0.36	
BRE 3	0.26	0.03	0.18	0.80	0.09	0.71	
BRE 4	0.19	0.01	0.11	0.36	0.04	0.32	
BRE 5	0.23	0.01	0.10	0.38	0.09	0.29	
BRE 6	0.16	0.01	0.12	0.36	0	0.36	
BRE 7	0.17	0.01	0.11	0.37	0	0.37	
BRE 8	0.21	0.01	0.12	0.40	0.04	0.36	
BRE 9	0.14	0.01	0.10	0.30	0	0.30	
BRE 10	0.22	0.03	0.17	0.50	0	0.50	
BRE 11	0.18	0.02	0.14	0.40	0	0.40	
BRE 12	0.21	0.01	0.11	0.39	0.02	0.37	
BRE 13	0.15	0.01	0.10	0.32	0	0.32	
BRE 14	0.15	0.01	0.12	0.39	0	0.39	
BRE 15	0.22	0.01	0.09	0.38	0.04	0.34	
TNRE 1	0.38	0.04	0.19	0.70	0.12	0.58	**n/s
TNRE 2	0.22	0.03	0.17	0.55	0.02	0.53	
TNRE 3	0.29	0.04	0.20	0.60	0.02	0.58	
TNRE 4	0.17	0.01	0.12	0.40	0	0.40	
TNRE 5	0.24	0.03	0.17	0.54	0	0.54	
TNRE 6	0.38	0.12	0.34	1.10	0.03	1.07	
BORE 1	0.55	0.08	0.29	1.20	0.16	1.04	
BORE 2	0.26	0.28	0.53	1.80	0	1.80	BORE 1 to BORE9 (*p*<0.001) BORE 4 vs. BORE 8 (*p*<0.01) BORE 4 vs. BORE 9 (*p*<0.006)
BORE 3	0.13	0.02	0.15	0.46	0	0.46	
BORE 4	0.14	0.01	0.09	0.35	0.02	0.33	
BORE 5	0.15	0.01	0.10	0.36	0.02	0.34	
BORE 6	0.15	0.01	0.12	0.40	0	0.40	
BORE 7	0.17	0.02	0.13	0.38	0	0.38	
BORE 8	0.22	0.01	0.10	0.42	0.08	0.34	
BORE 9	0.23	0.01	0.09	0.40	0.10	0.30	

*Tukey test. **n/s- non-significance

Table 3.2 below indicates the analysis of variance between nine residential sites in Botshabelo. All residential sites in Botshabelo were statistically compared to one another to observe the significant difference in the exposure levels of ELF magnetic field levels. The results show a statistical significant difference among the residential sites BORE 1 to BORE 9 (p<0.001), BORE 4 v/s BORE 8 (p<0.01), and BORE 4 v/s BORE 8 (p<0.006). The overall statistical analysis of the residential sites in Botshabelo indicated a non-significant difference in the ELF magnetic field exposure levels (p<1.85).

Table 3.2: Overall comparison of magnetic field measurements from Botshabelo residential sites

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Square*	*F-ration*	*P-value*	*F-critical value*
Between Groups	3.11	8	0.39	5.89	<1.85	2.01
Within Groups	8.90	135	0.07			
Total	12.01	143				

BORE 1 demonstrated a highly significant difference in the exposure levels of ELF magnetic field levels when compared to all other residential sites of Botshabelo (p<0.001) from BORE 1 to BORE 9. Furthermore, also in Botshabelo, the BORE 4 demonstrated the significant difference when compared to BORE 8 (p<0.01) and BORE 9 (p<0.006) respectively.

The analysis of variance between 15 residential sites in Bloemfontein is shown in Table 3.3. All residential sites in Bloemfontein (BRE1 to BRE15) were statistically compared to one another to observe the significant difference in the exposure levels of ELF magnetic field levels.

Table 3.3: Overall comparison of magnetic field measurements from Bloemfontein residential sites

Source of Variation	***Sum of Square***	***Degree of freedom***	***Mean Square***	***F-ratio***	***P-value***	***F-critical value***
Between Groups	0.73	14	0.05	0.75	<0.73	1.74
Within Groups	15.70	225	0.07			
Total	16.43	239				

The results indicated that there is non-significant difference ($p<0.73$) when all residential sites in Bloemfontein are compared to one another.

Table 3.4 below indicates the analysis of variance that was performed between six residential sites of Thaba Nchu. All residential sites in Thaba Nchu were statistically compared to one another to observe the significant difference in the exposure levels of ELF magnetic field levels.

Table 3.4: Overall comparison of magnetic field measurements from Thaba Nchu residential sites

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Square*	*F-ratio*	*P-value*	*F-critical value*
Between Groups	0.45	5	0.09	1.12	<0.35	2.32
Within Groups	7.24	90	0.08			
Total	7.69	95				

The results indicated that there is a non-significant difference ($p<0.35$) when all residential sites in Thaba Nchu are compared to one another.

3.4.2 Residential environmental exposure to ELF magnetic fields

Descriptive statistical analysis was performed to determine the residential environmental exposure data. The statistical comparison between four distance interims was also performed to observe the significance difference in the occurrence of ELF magnetic field between the distances. A statistical significant difference was found and a Tukey test was performed to test the significance.

Table 3.5 below indicates the summary statistics of different distance interims in Botshabelo, Bloemfontein and Thaba Nchu. The means for magnetic fields measured at 0 and 3 m were 0.62 and 0.30 μT, respectively; and 0.22 and 0.16 μT at 6 and 9 m respectively.

Table 3.5: Residential magnetic field measurements at 0, 3, 6 and 9 meters from the substations.

Distance interims	Mean (µT)	Variance	Standard deviation	Maximum	Minimum	Range	*Significant and non-significant *p*-values
0 m	0.62	0.08	0.28	1.70	0	1.70	0 m v/s 3 m (p<0.01). 0 m v/s 6 m (p<0.01) 0 m v/s 9 m (p<0.01)
3 m	0.30	0.03	0.16	1.20	0	1.20	3 m v/s 6 m (p<0.05) 3 m v/s 9 m (p<0.01)
6 m	0.22	0.02	0.15	0.84	0	0.84	**n/s
9 m	0.16	0.06	0.24	1.80	0	1.80	**n/s

*Tukey test. **n/s- non-significance

The table 3.6 below indicates the analysis of variance between three distance interims. The levels of ELF magnetic fields between the distance interim of 0 m, 3 m, 6 m and 9 m were statistically compared to one another to observe a statistical significant difference in the occurrence of ELF magnetic field levels. The comparison between distance interims was also performed and the results indicated that there is highly significant difference between all four distance interims (p<0.0001) when compared to one another. A Tukey test was performed to test the significance.

Table 3.6: Comparison of residential magnetic field measurements at distances of 0, 3, 6 and 9 meters.

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Square*	*F-ratio*	*P-value*
Between Groups	14.58	3	4.86	104.05	<0.0001
Within Groups	22.24	476	0.05		
Total	36.82	479			

The results from a Tukey test indicated that there is statistically significant difference of exposure levels when 0 m is compared to 3 m (p<0.01), 6 m (p<0.01) and 9 m (p<0.01), respectively. Furthermore, there is a statistically significant difference between the exposure levels measured at a distance of 3 m and 6 m (p<0.05) as well as 3 m and 9 m (p<0.01). It has also been found that there is no statistical significant difference in the occurrence of ELF magnetic fields when 6 m is compared to 9 m.

Figure 3.2 below represents the overall average emission of ELF magnetic fields between different distance interims, from 0 m, 3 m, 6 m and 9 m for Botshabelo, Bloemfontein and Thaba Nchu residential environments. The distance interim of 0 m is observed to have a high level of ELF magnetic fields (0.62 μT), with reference from the figure below, when compared to 3 m (0.30 μT), 6 m (0.22 μT) and 9 m (0.16 μT) respectively. This indicates that the measured ELF magnetic field is inversely proportional to the distance. As the distance between the substation and the point of measurement increases, the levels of ELF magnetic field decreases.

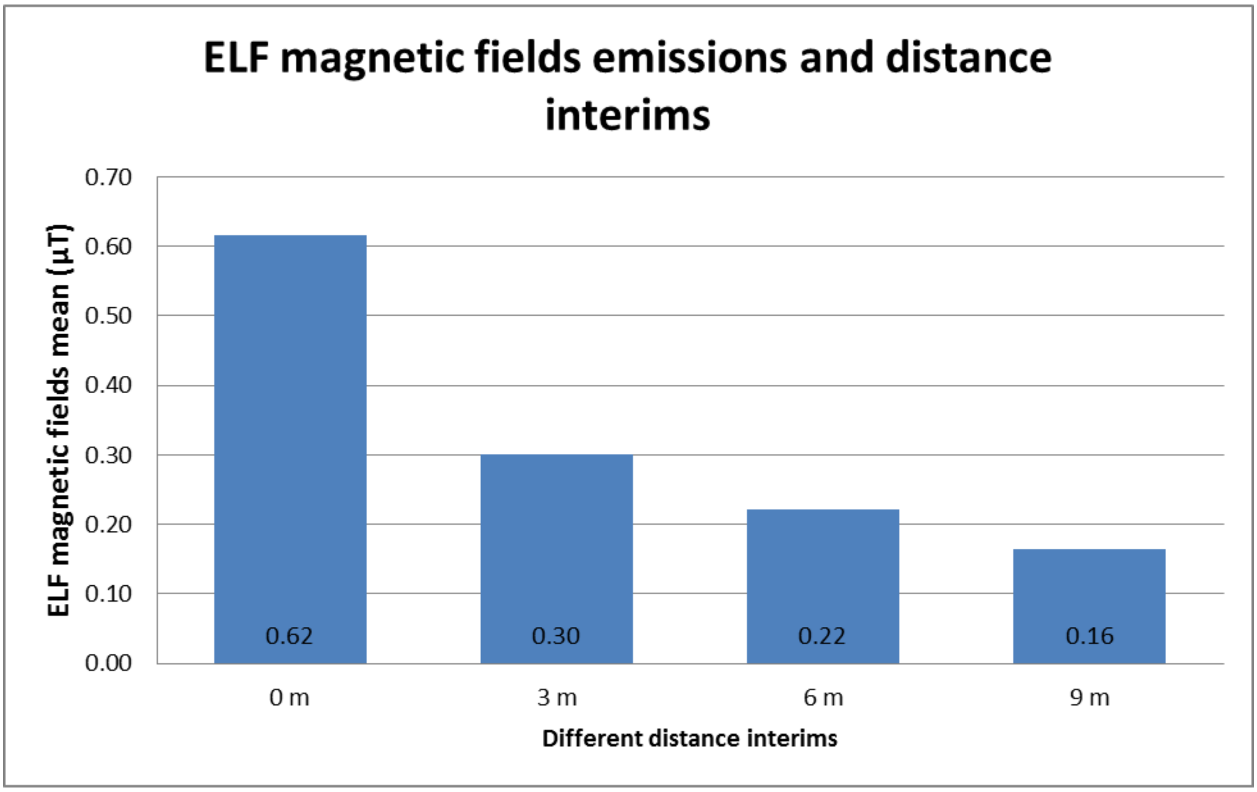

Figure 3.2: The mean magnetic field measurements at distances of 0, 3, 6 and 9 meters from the substations.

3.5 Discussion

3.5.1 Environmental exposure to ELF magnetic fields

The identified average exposure levels of ELF magnetic field found in the residential sites of Thaba Nchu (0.28 µT) are high as compared to Botshabelo (0.22 µT) and Bloemfontein (0.21 µT) residential sites and they are all found to be non-significant. In Thaba Nchu, TNRE 1 (0.38 µT) and TNRE 6 (0.38 µT) contributed significantly towards the increased ELF magnetic field exposure levels. A statistically significant difference observed between the residential sites may be due to the fact that TNRE1 and TNRE6 are located near the fuel station and overhead power lines (60 kV) respectively. A study by Li and Héroux (2014) indicated that an overhead power line of 60 kV emits ELF magnetic fields with an average of 1 μT. Furthermore, BORE 1 (0.55 μT) in Botshabelo and BRE 1 (0.42 μT) in Bloemfontein show a high exposure levels of ELF magnetic fields. The residential site BORE 1 is within the vicinity of telecommunication signal transmitter (tower) and it is located approximately 105 m away from the sampling point. At a distance of 7.5 m from BORE 1 there is also visibility of protruding underground power line leaving the substation. According to Cardis, Varsier and Bowman (2011), the wireless telecommunication systems are major sources of microwaves and can emit ELF magnetic fields at an average of 0.7 μT. The underground power lines also form part of the electric system network and can emit ELF magnetic field at an average exposure level of 0.3 μT (Kim and Im, 2010).

The residential site BRE 1 is in the urban area and located approximately 175 m in vicinity of a shopping complex, office spaces and a fuel station and 3 m from overhead power line (380 kV). An average exposure of 0.13 μT has been measured in more than 15 office spaces and shopping complexes through spot measurement in Denmark (Skotte, 1994). The study revealed that ELF magnetic fields can elevate above an average exposure levels identified, but the magnitude of emission of ELF magnetic fields will depend on the amount of electronic devices utilised. In 2013, Tell and Sias undertook a study in the residential areas of Australia to observe the average ELF magnetic fields that can be emitted by gasoline-powered cars within 150 m from the fuel station. It was found that minimum of four gasoline-powered cars can emit an average ELF magnetic field of 0.051 µT in the residential areas.

3.5.2 Residential environmental exposure to ELF magnetic fields

The distance of 0 m is referred to as a reference level and it is a distance interim that exist inside the four corners of a substation, near barrier screenings. The mean exposure levels of magnetic fields were significantly higher at 0 m (0.62 µT), decreasing to 0.30 µT at 3 m, 0.22 µT at 6 m and 0.16 µT at 9 m. Through the results obtained, this study demonstrated that ELF magnetic fields cannot be screened practically by any object in the substations and residential environments nearby. It has also being observed that the magnitude of ELF magnetic fields decreased when a distance from the source of exposure increases. Thuróczy (2008) indicated that the strength of magnetic fields decrease to approximately 0.1 µT within a distance of 5 m of equipment except near areas where power lines enters or exit the substation. Furthermore, at a point where the overhead power line leaves the substation (0 m), the exposure levels was higher (0.3 µT) than at a distance of 5 m.

3.6 Conclusion

The findings from this study indicate that the measured ELF magnetic fields in residential environments of the Mangaung Metropolitan Municipality (Bloemfontein, Botshabelo and Thaba Nchu) have an average exposure level that is below 0.2 µT, with just a few exposure levels below the level 0.4 µT, where an association with cancer and other related health effects has been found in many epidemiological studies (Tuengler and Von Klitzing, 2013). The results also indicate that the measured ELF magnetic fields are below the recommended exposure level of 200 µT by ICNIRP of 2010, under the general public, reference levels.

Furthermore, the results also show that the ELF magnetic field exposure levels decreased as the distance from the substation and the measurement point increased. This supports the finding that were made by Trulsson, Anger and Estenberg (2007) that the sources of low frequency EMFs are not risk factors as in many instances the duration of exposure is considered short-termed and the strength of the fields diminishes rapidly with an increased distance. It is also assumed that other factors that can increase the levels of ELF magnetic fields in the residential environments include overhead and underground power lines, movement of vehicles, junction boxes, telecommunication devices and street lights that are in close proximity to the sampling points.

There is lack of data on the exposure levels of ELF magnetic fields in the residential environments of South Africa for general public awareness. Although the exposure levels are below ICNIRP guidelines, the results from this study will create general public awareness on the exposure to ELF magnetic fields in the residential environments of Mangaung Metropolitan Municipality. Furthermore, the data obtained will also be of value within the discipline of environmental health as it will form part of the general public awareness on exposure to non-ionising radiation.

3.7 References

Cardis, E., Varsier, N and Bowman, J. D. 2011. Estimation of RF energy absorbed in the brain from mobile phones in the Interphone Study. *Occup Environ Med*; 68 (9): 686-69.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). electromagnetic fields (up to 300 GHz). *International Journal of Radiation Biology*; 72 (3): 233-241.

Kim, S and Im, W. 2010. Static magnetic fields inhibit proliferation and disperse subcellular localization of gamma complex protein3 in cultured C2C12 myoblast cells. *Cell Biochem Biophysics*; 57 (1): 1-8.

Kovetz, A. 2000. Electromagnetic Theory. New York: Oxford University Press.

Leitgeb, N. 2014. Childhood Leukemia Not Linked with ELF Magnetic Fields. *Journal of Electromagnetic Analysis and Applications*; 6: 174-183. http://dx.doi.org/10.4236/jemaa.2014.67017 [online] Access date: 06 March 2015.

Li, Y and Héroux, P. 2014. Extra-low-frequency magnetic fields alter cancer cells through metabolic restriction. *Electromagnetic Biol Med*; 33 (4): 264-275.

Ramezani Vishki, F., Majd, A., Nejadsattari, T and Arbabian, P.S. 2012. Study of Effects of Extremely Low Frequency Electromagnetic Radiation on Biochemical Changes in Satureja Bachtiarica L. *International Journal of Scientific & Technology Research Volume 1, Issue 7*. ISSN 2277-8616 77 IJSTR.

Sakurazawa, H., Iwasaki, A., Higashi, T., Nakayama, T. and Kusaka, Y. 2003. Assessment of exposure to magnetic fields in occupational settings. *Journal of Occupational Health*; 45: 104-110.

Skotte, J.H. 1994. Exposure to power-frequency electromagnetic fields in Denmark. *Scandinavian Journal of Work, Environment and Health*; 20: 132-138.

Speit, G., Gminski, R and Tauber, R. 2013. Genotoxic effects of exposure to radiofrequency electromagnetic fields (RF-EMF) in HL-60 cells are not reproducible. *Mutat Res*; 755: 163-166.

Tell, R.A and Sias G. 2013. ELF magnetic fields in electric and gasoline-powered vehicles. *Bioelectromagnetics;* 34 (2): 156-161.

Thuróczy, G. 2008. Exposure to 50 Hz magnetic field in apartment buildings with built-in transformer stations in Hungary. *Radiation Protection Dosimetry*; 131 (4): 469-473.

Trulsson, J., Anger, G and Estenberg, U. 2007. Assessment of magnetic fields surrounding electronic article surveillance systems in Sweden. *Bioelectromagnetics*; 28 (8): 664-666.

Tuengler, A and Von Klitzing, L. 2013. Hypothesis on how to measure electromagnetic hypersensitivity. *Electromagn Biol Med*; 32 (3): 281-290.

Urbinello, D and Röösli, M. 2013. Impact of one's own mobile phone in stand-by mode on personal radiofrequency electromagnetic field exposure. *Journal of Exposure Science and Environmental Epidemiology*; 23 (5): 545-548.

Wilén, J and De Vocht, F. 2011. Health complaints among nurses working near MRI scanners- A descriptive pilot study. *European Journal of Radiology*; 80 (2): 510-513.

World Health Organisation. 2007. Extremely Low Frequency Fields. Environmental Health Criteria Monograph No. 238. Geneva.

Chapter 4

Occupational exposure to extremely low frequency magnetic fields in electrical substations

Abstract

This study aimed to evaluate occupational exposure to ELF magnetic fields in the electrical distribution substations (132 kV) of Mangaung Metropolitan Municipality. The substations were randomly selected and ELF magnetic field exposure levels were measured in four distribution substations located in Bloemfontein, Botshabelo and Thaba Nchu. The measurement points were divided into 50 m^2 blocks from the substation floor plans and the measurements were collected using a Trifield meter model XE 100. The data was analysed using descriptive statistics programme from Microsoft Excel (2010) software. The descriptive data for four substations were compared to one another using ANOVA test and the results indicated that there is a non-significant difference of exposure levels to ELF magnetic fields amongst the four distribution substations ($p < 0.39$). Furthermore, all employees working at the distribution substations (132 kV) in Mangaung Metropolitan Municipality are exposed to the same exposure level of ELF magnetic fields. Although the average exposure may be equal but the substation setting is different and the exposure levels are below the ICNIRP guidelines.

Keywords: occupational exposure; distribution substations; employees; exposure levels; magnetic fields

4.1 Introduction

Electricity has been used all over the world for 100 of years without society being aware of its adverse health implications and safety injuries. The generation and transmission of electrical energy is highly associated with the emission of EMFs (Sinatra, 2002). Occupational exposure to ELF magnetic fields has been a fragmentary concern that all employers at electric utility workplaces are facing. Dehghan and Taeb (2013) undertook a study to evaluate the health implication of employees exposed to EMFs at the electric-utility industries. In the said study, potential health risks of cancer, dementia, Alzheimer and Parkinson"s diseases resulting from exposure to EMFs were assessed. However, epidemiological analyses were performed, but it was found that there is no causal relationship between exposure of employees to EMFs and existing cancer cases. The focus of the said study was to evaluate the possible epidemiological measures and not to develop the effective occupational hygiene measures.

A study by Stewart (2003) indicated that occupational hygiene measures can reduce workplace health and safety incidents to 80% if the hierarchy of controls is adhered to. Although employees are protected by the Occupational Health and Safety Act (OHSA), Act 85 of 1993, exposure to EMFs within electrical industries can be described as a condition that most of the employees cannot avoid. Moriyama and Yoshitomi (2005) stated that employees that are highly exposed to EMFs are those ones working at electrical power stations, substations, telecommunication, metal plumbing, rail maintenance, power lines and welding industries. According to WHO (2007), ELF magnetic fields are classified as group 2B (possibly carcinogenic to humans) and epidemiological evidence to support this statement is not conclusive.

The National Institutes for Environmental Health (NIEH) (2002) does not consider EMF exposures as a potential health hazard and this is due to lack of epidemiological evidence. Furthermore, Chu, Song, Kim and Lee (2011) have indicated that workers exposed to high levels of magnetic fields have increased incident cases of leukemia. This trend has also been reported in children younger than five years. In addition, due to high levels of ELF magnetic field emissions in electric industries (Chu, *et al*., 2011), this study aimed to evaluate occupational exposure to ELF magnetic fields in distribution substations.

4.2 Problem Statement

Most of the electric-utility workers including maintenance workers in the substations are exposed to ELF magnetic fields without being aware (Sinatra, 2002). Magnetic fields cannot be screened and most importantly they have been regarded as a potential risk to workers‟ health (Draper, 2005). In European countries, the most common sources of EMFs are substations, high voltage power lines and electrical power stations (Mild, Mattsso, Hadell, Bowman and Kundi, 2005). All of these sources are found in close proximity to households, office spaces, agricultural farms, recreational parks, educational institutions and health care facilities (Salinas, 2001). However, workers may be easily exposed as the strength of the magnetic field depends on equipment design, distance from the source and current flow, not on equipment size and complexity (INTERPHONE Study group, 2010). ELF magnetic fields are always created whenever electric charges flow (Lee, 1996). According to Szemersky, Koteles, Lihi and Bardos (2010), excessive exposure can result in severe health implications such as leukemia in children under the age of five years, brain tumor and Alzheimer‟s disease.

A study by Leitgeb (2014) revealed that ELF magnetic fields induces small amounts of electric current in the workers‟ body and at high ELF field intensities, it can exceed the naturally occurring current densities typically found in the human body. In 2009, Sharifi indicated that a prolonged exposure to magnetic fields emitted by 132 kV high voltage substations can cause dementia, sleep disturbance and Parkinson‟s disease. Furthermore, this study will evaluate the exposure levels of ELF magnetic fields in the 132 kV distribution substations and the findings will be compared to the reference levels found in the ICNIRP of 2010 under occupational exposures.

4.3 Materials and methods

4.3.1 Study design: Occupational exposure measurements

The Mangaung Metropolitan Municipality comprises of 42 distribution substations (132 kV). The substations are located in the core regions of Mangaung which is Bloemfontein, Botshabelo and Thaba Nchu. These substations mainly serve schools, residential households, shopping complexes, health care facilities, gas stations and recreational facilities. Out of the entire 42 distribution substations, four ("around 10 %") were selected using simple random sampling method. The purpose of simple random selection was to ensure adequate representation of occupational exposure levels. Substations were also coded (Bloemfontein: BODS1 and BDS2, Thaba Nchu: TNDS1, and Botshabelo: BDS1) to ensure that there is no exposure level allocated falsely and inaccurately. A systematic walk-through survey was conducted within four selected substations to observe the equipment and electrical processes. Furthermore, during an induction with the chief development planner, the maintenance schedule for substations was explained as well as the responsible employees. The electrical engineers and assistants are responsible for maintenance on different time intervals. The maintenance is undertaken twice a month and when there is an emergency electrical fault on substations and power lines.

4.3.2 Sampling: Occupational exposure measurements

The Grid model was used to facilitate the measurement procedure. The Grid assessment model is recommended by the National Institute of Occupational Safety and Health (NOISH, 1998), manual for measuring occupational electric and magnetic field exposures and it is used to evaluate the exposure levels of EMFs in the electrical occupational settings and also for electrical power plant modeling. The model describes the recommended points where measurements should be taken, particularly within the grid. Initially, in four electrical distribution substations (132 kV) namely BDS1, BDS2, TNDS1 and BODS1, floor plans were obtained and they were divided into grids of square meter blocks. Fifty square meter blocks were drawn from the floor plan of each distribution substation and measurements were taken in the centre of each and square meter block to obtain a representative sample. Furthermore, a hand-held Trifield meter with a frequency range of 40 – 100 kHz was used to measure ELF magnetic field exposure levels. The meter is designed to pick up extremely low frequency magnetic fields ranging from 3 to 3000 Hz. A total number of 50 samples were taken for a single parameter (ELF magnetic fields) on a single substation and 200 samples were taken for all four distribution substations. The battery level on the meter was also tested to ensure that it is fully charged and to avoid any deviations in the readings. The figure below illustrates the floor plan of distribution substation where measurements were taken within the grid.

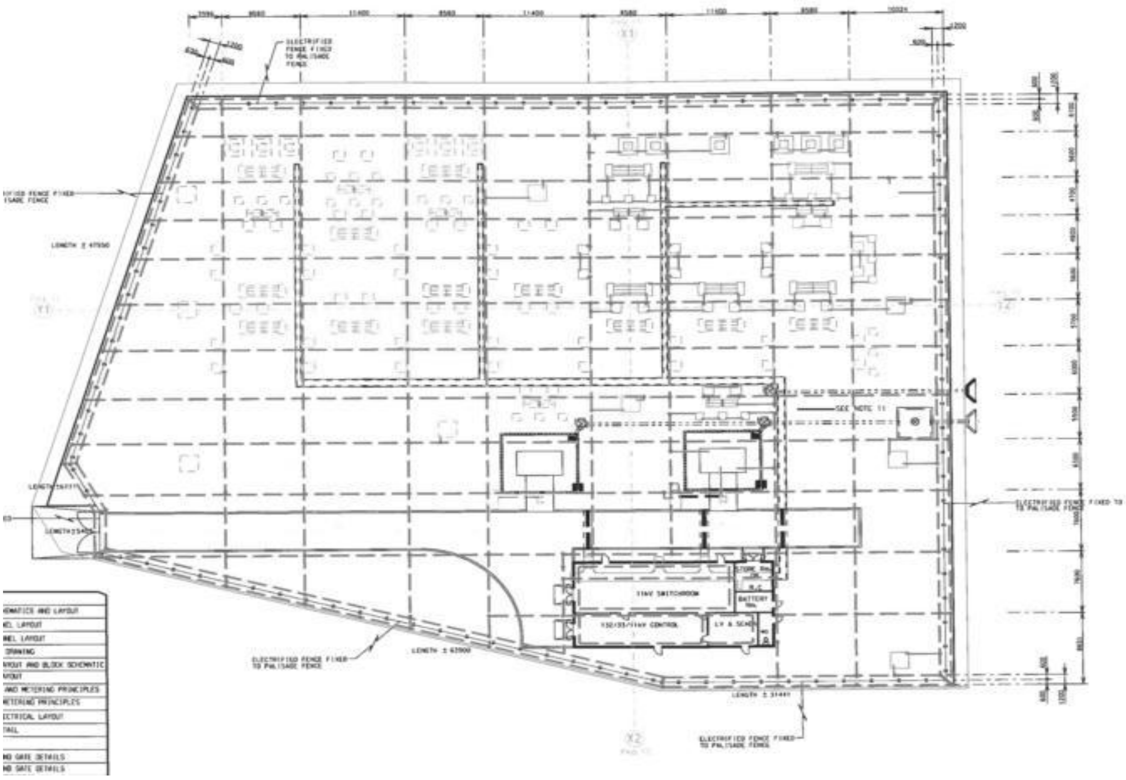

Figure 4.1: illustration of sampling points

4.3.3 Data analysis

The data was analysed using Excel programme (Microsoft 2010) to obtain the descriptive summary statistics. The data obtained represent the levels of ELF magnetic fields measured in four distribution substations (132 kV) found in Mangaung Metropolitan Municipality (Bloemfontein 2, Botshabelo 1 and Thaba Nchu 1). The results obtained from the four distribution substations were statistically compared to one another, using ANOVA to test the significant difference of ELF magnetic field exposure levels.

4.4 Results

4.4.1 Occupational exposure

Descriptive statistical analysis was performed to determine the occupational exposure data. However, the results from ANOVA indicated that there is no statistical significant difference in the exposure levels of ELF magnetic fields between the four distribution substations ($p<0.39$).

Table 4.1 below indicates the summary statistics of occupational exposure to ELF magnetic field emissions within four distribution substations (132 kV) in Bloemfontein (BDS1 and BDS2), Botshabelo (BODS1) and Thaba Nchu (TNDS1). The mean values for magnetic fields measured in the distribution substations were 1.14 and 1.15 µT in TNDS1 and BODS1 respectively, increasing to 1.24 and 1.27 µT in BDS2 and BDS1 respectively. The peak values for magnetic fields in TNDS1 and BODS1 were 2.20 and 2.30 µT respectively. The peak value for magnetic fields measured in Bloemfontein substations BDS1 and BDS2 was 2.23 µT for each.

Table 4.1: Summary statistics of occupational exposure levels for magnetic fields from distribution substations

Substations	Mean (µT)	Variance	Standard deviation	Maximum	Minimum	Range
BODS1	1.15	0.22	0.47	2.30	0.48	1.82
TNDS1	1.14	0.20	0.45	2.20	0.39	1.81
BDS1	1.27	0.23	0.48	2.23	0.68	1.55
BDS2	1.24	0.21	0.46	2.23	0.67	1.56

Table 4.2 below indicates the results for analysis of variance performed between four distribution substations.

Table 4.2: Comparison of magnetic field measurements from the distribution substations

Source of Variation	***Sum of Square***	***Degree of freedom***	***Mean Square***	***F-ratio***	***P-value***
Between Groups	0.65	3	0.22	1.01	<0.39
Within Groups	42.37	196	0.22		
Total	43.02	199			

All four distribution substations demonstrate a non-significant difference ($p< 0.39$) when compared to one another.

The figure below represents the average emission levels of ELF magnetic fields measured in four distribution substations. Two distribution substations in Bloemfontein (BDS1 1.27 μT and BDS2 1.24 μT) show high emission levels of ELF magnetic fields as compared to Botshabelo (BODS1 1.15μT) and Thaba Nchu (TNDS1 1.14μT) respectively.

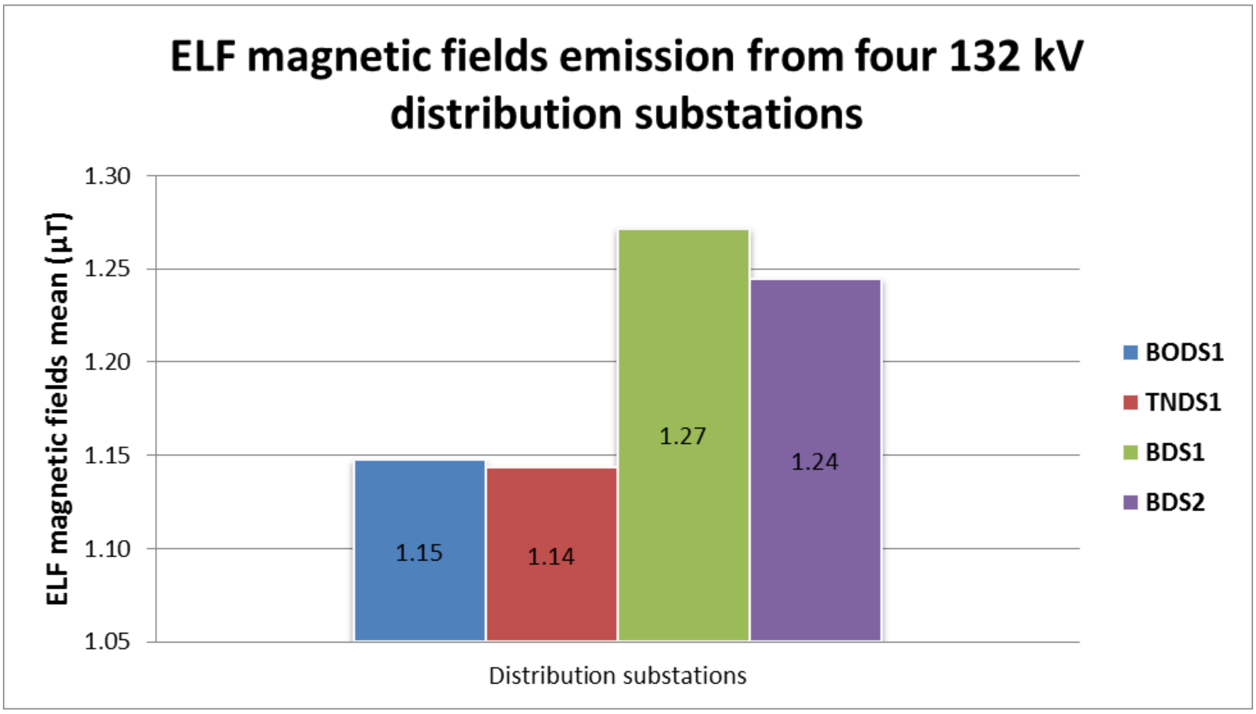

Figure 4.2: The average exposure levels of ELF magnetic fields at 132 kV distribution substations

4.5 Discussion

The results indicate a non-significant difference between the four distribution substations. The major source of magnetic field emissions in the substations is a transformer (Grainger and Preece, 2000). However, during sampling it was observed that amongst all four distribution substations the electrical capacity of transformers and incoming electrical power were the same. Although BODS1 indicates a high peak value (2.30 µT) as compared to TNDS1 (2.20 µT), BDS1 (2.23 µT) and BDS2 (2.23 µT), but ANOVA test proved to be non-significant. The BODS1 is located in a rural area of Botshabelo, approximately 100 m away from industrial office spaces. Breysse, Lees, McDiarmid and Curbow (1994) indicated that magnetic fields at the substations near office spaces can increase significantly due to electric-utility ducts and electrical devices used in the offices. In the said study, the spot measurements revealed an average exposure of 0.13 μT where office equipment such as video display terminals (VDTs) and photocopiers were present and the highest measured magnetic field was emitted by an electrical utility duct at 1 μT. It is evident from findings of the study that electric-utility ducts can increase the measured peak values of magnetic fields at 0.1 μT. Furthermore, TNDS1 serves residential households and it is located in a rural area of Thaba Nchu, approximately 80 m away from the residential properties. According to Leitgeb (2014), household electrical devices produce higher localised EMF and emissions strongly depend on the distance from the source. Magnetic fields produced by household electrical devices can extent to 15 m outside residential houses and therefore have no effects on the magnitude of magnetic fields produced from the substations (Leitgeb, 2014).

In Bloemfontein, BDS1 and BDS2 are located in an urban area and they supply electricity to the railway power lines. BDS1 is located 10 m away from the electrified railway while BDS2 is approximately 15 m from the railway maintenance area. In 1997, Wenzl undertook a study in Philadelphia to observe the different peak values of magnetic fields between 132 kV substation near railway maintenance and overhead power lines. In the study, the measured peak value near substation transformers was 3.4 μT and the railway maintenance workers were exposed to 25 μT near electrified rail line. In the said study, it was found that the average exposure levels to magnetic fields from the substations near electrified rail lines are similar (2 μT), this was due to equal provision of incoming power and capacity of transformers to support the frequent movement of trains. It was also concluded that the railway maintenance workers are exposed to the same levels of magnetic fields at an average of 20 μT. Furthermore, the average exposure levels of ELF magnetic field at the distribution substations of Mangaung are observed to be lower than a high exposure of 100 μT, which is associated with severe health effects within electric-utility workers in a study conducted by Khullar, Sood and Sood (2013).

4.6 Conclusion

It is assumed that workers in the distribution substations (132 kV) of the Mangaung Metropolitan Municipality are exposed to the same levels of ELF magnetic fields from different substation settings. It has also been observed that the emissions of ELF magnetic fields from the distribution substations in Mangaung are below ICNIRP guidelines of 1000 μT for occupational exposure, under reference levels.

This study provides preliminary data about exposure levels to magnetic fields in the distribution substations of South Africa. Furthermore the data will be made available to all electric utility companies for the purpose of occupational hygiene and to raise awareness. It is within the scope of practice of environmental health that all workers and the general public be protected against exposure to non-ionising radiation. This study will also contribute towards the development of guidelines for protection of workers and the general public against ELF magnetic fields exposure within the discipline of environmental health and also in Mangaung Metropolitan Municipality.

4.7 References

Breysse, P., Lees, P.S.J., McDiarmid, M.A and Curbow, B. 1994. ELF magnetic field exposures in an office environment. *American Journal of Industrial Medicine*; 25: 177-185.

Chu, M, K., Song, H, G., Kim, C and Lee, B, C. 2011. Clinical features of headache associated with mobile phone use: a cross-sectional study in university students. *BMC Neurology*; 11: 115.

Dehghan, N and Taeb, S. 2013. Adverse health effects of occupational exposure to radiofrequency radiation in airport surveillance radar operators. *Indian Journal of Occupational and Environmental Medicine*; 17 (1): 7-11.

Draper, G. 2005. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. *British Medical Journal;* 11: 1290-1293.

Grainger, P and Preece, A. W. 2000. The contribution of local distribution substations and associated area distribution system to personal exposure to power frequency magnetic fields. *International Journal of Environmental Health Research*; 10: 285–290.

INTERPHONE Study Group. 2010. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. *International Journal of Epidemiology*; 39 (3): 675-694.

Khullar, S., Sood, A and Sood, S. 2013. Auditory Brainstem Responses and EMFs Generated by Mobile Phones. *Indian Journal of Otolaryngol Head Neck Surg*; 65 (3): 645-649.

Lee, G. 1996. California Exposure Assessment Study (preliminary findings), California EMF Program. New York: Oxford University press.

Leitgeb, N. 2014. Childhood Leukemia Not Linked with ELF Magnetic Fields. *Journal of Electromagnetic Analysis and Applications*; 6: 174-183. http://dx.doi.org/10.4236/jemaa.2014.67017 [online] Access date: 06 March 2015.

Mild, K., Mattsso, M., Hadell, L., Bowman, J and Kundi, M. 2005. Occupational carcinogens; ELF MFs. *Environmental Health Perspective*; 113 (11): 726-727.

Moriyama, K. and Yoshitomi, K. 2005. Apartment electrical wiring: a cause of extremely low frequency magnetic field exposure in residential areas. *Bioelectromagnetics*; 26: 238-241.

National Institute for Occupational Safety and Health (NIOSH). 1998. Manual for measuring occupational electric and magnetic field exposures. Center for Disease Control and Prevention, U.S. Department of Health and Human Services.

National Institutes for Environmental Health. 2002. EMF Questions and Answers: Electric and Magnetic Fields associated with Use of Electric Power. Research Triangle Park, NC.

Salinas, E. 2001.Magnetic field management at the transmission and distribution stages, in Proc. 5th Int. Power Engineering Conference, Singapore,pp. 325–330.

Sanitra, S.T. 2002. EMFs a health risk worthy of your attention. *Total Health*; 24 (2): 21.

Sharifi, M., Nasiri, P andMonazzam, M. R. 2010.Measurement of the Magnetic Fields from High-Voltage (230 kV) Substations in Tehran and Assessment of Their Effects.*Iranian Journal of Med Phys*; 7 (3): 49–56.

Stewart, J. 2003. Occupational hygiene: control of exposures through intervention.*Encyclopedia of Occupational Health and Safety, ILO (Ed.)*. Available at: http://www.ilo.org/safework_bookshelf/english/ [online] Access date: 10 April 2016.

Szemersky, R., Koteles, F., Lihi, R and Bardos, G. 2010. Polluted places of polluted minds? An experimental sham-exposure study on background psychological factors of symptom formation in „idiopathic environmental intolerance attributed to electromagnetic fields. *International Journal of Hygiene and Environmental Health*; 213 (5): 387-394.

Wenzl, T.B. 1997. Estimating magnetic field exposure of rail maintenance workers. *American Industrial Hygiene Association Journal*; 58: 667-671.

World Health Organisation. 2007. Extremely Low Frequency Fields. Environmental Health Criteria Monograph No. 238. Geneva.

Chapter 5

Assessing health and safety compliance in distribution substations and residential areas of Mangaung Metropolitan Municipality

Abstract

This study aimed to evaluate the compliance of distribution substations in Mangaung Metropolitan Municipality with health and safety national standards and guidelines. Distribution substations (n=30) and residential environments (n=30) were randomly selected in Bloemfontein, Botshabelo and Thaba Nchu areas. Two separate checklists were used to assess compliance to health and safety standards in distribution substations and residential environments. Thirteen substations in Bloemfontein scored a total compliance value that is < 75% on housekeeping. The substations in Botshabelo and Thaba Nchu did not comply with the set compliance value for housekeeping. Only eight substations, namely; BS2 (68%), BS6 (68%), BS7 (68%), BS8 (68%), BS9 (68%), BS13 (68%), BOS4 (68%), TNS3 (68%) and TNS6 (68%) did not comply with set compliance value for fencing. All substations scored a total compliance mean value of ≥80%. All residential areas in Bloemfontein, Botshabelo and Thaba Nchu scored risk values that are <1 in all health and safety features. With regard to electromagnetic field sources, TNRE6 scored a peak risk value of 0.6, while BRE1, BORE1, BORE2 and BORE4 scored 0.4 each. BRE1 and BRE7 scored a peak risk value of 0.5 each on maintenance while BRE3, BORE3, BORE5 and BORE6 scored risk peak values of 0.375 of maintenance. Furthermore, all residential environments comply with the set composite risk mean value of <0.5. All distribution substations complies with the electrical requirements stipulated in Occupational Health and Safety Act, Act 85 of 1993 and the safety design in terms of the Institute of Electrical and Electronic Engineering standard 80 of 2000.

Keywords: compliance, health and safety standards, risk value, electromagnetic field sources, checklist

5.1 Introduction

While the demand and use of electricity has been increasing, the impact associated with electrical production also increases. In Mangaung residential sites, substations are built in close proximity to the residents. When new substations are built, residents are invited to participate as affected parties and their participation is centered on health and safety issues that may arise during the construction process. A distribution substation is an enclosure in which medium or higher voltage switchgear is kept that may be used to energise or isolate power supplies to equipment or installations (OSHA, 1993). According to Ilonen (2008), if a substation is not well-constructed, has protruding underground power lines, open trenches and fading safety signs, it may result in increased health and safety accidents that include trip and fall as well as electrical shock. In Bristol, Preece, Hand, Clarke and Stewart (2000) indicated that substations must be well-fenced and warning signs posted indicating the amount of voltages produced. Substations do not only pose safety threats to electric-utility workers, they also generate EMFs at certain magnitudes that affect the health of residents and the environment at large (Urbinello and Röösli, 2013). In 2005, Moriyama and Yoshitomi indicated that EMFs are strongest when close to their source and are regarded as health hazards in occupational settings. The effects of EMF exposures in both workers and residents have been associated with cancer-related conditions (Szemersky, Koteles, Lihi and Bardos, 2010) and declined crop production in the agricultural sectors, particularly crops planted under high voltage transmission lines (HVTL) (Li and Héroux, 2014).

The Institute of Electrical and Electronics Engineers standard 80 of 2000 ensures that there are safe limits of potential differences that can exist in a substation under fault conditions between points that can come into contact with the human body. These guidelines also serve to ensure that substations are properly grounded and designed in a manner that is safe and cannot pose health and safety threat. The electrical machinery regulations (EMR) of 2011 as amended under OHS Act, Act 85 of 1993 stipulates that all substations must have fire prevention equipment, electrical asset register, maintenance schedule, sign posted and be demarcated by fences that are in good conditions. The act also specifies that housekeeping should be taken into account when substations are built.

Due to health and safety concerns, it is recommended that only trained and authorised personnel should be allowed to work inside or near capacitors, reactors and other fenced-in areas inside substations (Kovertz, 2000). Untrained individuals may not be aware that some of the substation structures are energised. Furthermore, Shun-Li, Ghin, Ching-Lien and Lu (1999) outlined that workers should be protected against the hazards of live or induced voltage, proper housekeeping should be practiced and hazard warnings regarding battery systems in the substation should also be observed. The current study aims to evaluate health and safety compliances in the substations and residential sites of Mangaung Metropolitan Municipality. The evaluation will be in accordance with recommendations stipulated in the Institution of Electronics and Electrical Engineering (IEEE) standards and South African electrical safety regulations.

5.2 Problem statement

Over the past decades, it became evident that the skills and competencies of workers in the electrical industries have diminished (Mild, Mattsso, Hadell, Bowman and Kundi, 2005). According to Yamaguchi-Sekino, Sekino and Ueno (2011), the high numbers of safety accidents reported on annual bases are mainly from construction sectors, followed by electric-utility works with occupational illnesses. The electric-utility workplaces have different to similar health and safety incidents. The health and safety accidents in the electrical industries depend highly on conditions of a particular workplace and the equipment utilised as well as the knowledge of workers on potential hazards (National Institute for Occupational Safety and Health, 1995). The exposure to EMFs has also been considered as a factor that increases the health and safety incidents in the electric work environments, particularly in electrical power plants and substations (Sekino, 2011).

In a study by Wenzl (1997) conducted in Philadelphia on rail maintenance workers, it was indicated that prolonged exposure of employees to ELF magnetic fields can cause fatigue. Fatigue in electric-utility workplaces can contribute to decreased performance and simultaneously increases health and safety accidents (Cohen and Ellwein, 1990). The common health and safety accidents in the substations include trip and fall, electric shock, slip and fall and contact with hazardous substances from leaking transformers and conservator tanks (Ilonen, 2008). Furthermore, the improper housekeeping, lack of maintenance of electric equipment, unsafe acts and conditions by employees can contribute to increased health and safety accidents (Broadwell, 1986). Due to lack of maintenance of substations and training of workers on potential health and safety hazards, this study aimed to evaluate health and safety compliance in electrical substations and residential environments of Mangaung metropolitan municipality using a checklist.

5.3 Materials and methods

5.3.1 Study design

A cross-sectional study was conducted to determine compliance for substations and risk factors for residential environments. Two separate checklists were used. The first checklist was used to determine compliance with regard to health and safety in the substations. The second checklist was used to determine the external residential factors that can be affected by positioning of substations in the residential environments.

Both checklists were developed based on different health and safety aspects in 132 kV distribution substations (n=30) and residential areas (n=30) near selected substations in Mangaung Metropolitan Municipality. The distribution substations and residential sites were selected using simple random sampling method. The purpose of simple random selection was to ensure adequate representation of all residential sites and substations for health and safety concerns. Due to unequal geographical proportions within Mangaung Metropolitan region, 15 distribution substations and residential sites for each were randomly selected in Bloemfontein. Nine distribution substations and residential sites for each in Botshabelo area, as well as six distribution substations and residential sites for each in Thaba Nchu area were selected. A total number of 60 checklists were administered for distribution substations and residential sites. Furthermore, the development of health and safety checklist was in accordance with the specific requirements of the electrical regulations as mentioned in the OHS Act, Act 85 of 1993 and the IEEE standards. The main focus was on the general housekeeping around the substations, installations, which amongst them include posted warning signs, fencing, indicated voltage limits, conditions of a particular substation, maintenance schedule and functioning of electronic devices. The surrounding influences in relation to substation position and EMF sources were also observed in the residential sites. A systematic walk-through survey and induction was conducted on-site to observe the equipment and determine compliance with regard to the requirements of electrical safety regulations and IEEE standards. The distribution substations in Bloemfontein were coded as BS1 to BS15 and BRE1 to BRE15 for residential sites. In Botshabelo, coding was BOS1 to BOS9 for distribution substations and BORE1 to BORE9 for residential sites, as well as TNRE1 to TNRE6 for residential sites and TNS1 to TNS6 for distribution substations in Thaba Nchu. The main intent for coding was to minimise false and inaccurate allocation of data.

5.3.2 Sampling

Initially, a systematic walk-through survey was conducted to observe all electrical processes and faults that can cause health and safety accidents. After the walk-through survey at distribution substations, both distribution substations and residential sites were allocated checklists. Two types of health and safety checklist were allotted, one for substations and another one for residential sites. The first health and safety checklist developed comprise of health and safety aspects within the distribution substations and another checklist was for health and safety aspects in the residential sites located near substations. A health and safety checklist for distribution substations was used to assess aspects such as housekeeping and general maintenance, electrical asserts registers, fencing, signage, record keeping, devices in the control room and conditions of electrical equipment. The residential sites checklist was also used to observe the surrounding influences, EMF external sources, maintenance and general tidiness as well as type of a particular environment. Furthermore, all health and safety aspects for both distribution substations and residential sites were observed and recorded on a checklist. Compliance percentages were assigned to distribution substations health and safety features and the residential environment health and safety were assigned risk values.

5.3.3 Compliance percentages for distribution substations

The checklist consisted of six different health and safety features allocated different compliance percentage values. The allocation of compliance percentage per health and safety feature was based on the requirement and what has been deemed to be important by the OHS Act, Act 85 of 1993. The features were housekeeping, control rooms, warning and access control, register, fencing and record keeping. Of 12 sub features of health and safety on housekeeping, nine were regarded as important as they are stipulated in the act as requirements. Housekeeping was then allocated compliance of ≥75%. This was based on having nine or more sub features complying with the Act. Warning and access control consist of four sub features. Out of four, three sub features were deemed to be the requirements in terms of the act. Warning signs and access control were then allocated compliance of ≥75%.

Control rooms were allocated a compliance of ≥67%. Control rooms consist of nine sub features of which some of them are not covered in the Act. Only six sub features were deemed to be important in terms of the Electrical Machinery Regulations. Register, record keeping and fencing were allocated a compliance value of 100% as all of them consist of sub features which are covered and deemed important by OHS act. Any value below the set compliance values were referred to as non-compliance. The individual distribution substation compliances were also observed and therefore a total compliance mean value of ≥80% was allocated.

5.3.4 Compliance percentages for residential sites

The residential environment checklists consist of four features, namely, type of residential area, surrounding infrastructure, EMF sources and maintenance. Of the four health and safety features, surrounding infrastructure, EMF sources and maintenance were allocated risk compliance values. The values were allocated to each feature looking at the position of distribution substations from the surrounding factors. All features were allocated a risk value that is <1. A value of ≥1 was an indication that there is an influencing factor within a vicinity of 9 m from the distribution substation. The value that is above or equivalent to one was also an indication that there is an environment within proximity of 9 m that can be influenced by the electrical processes in the distribution substations. An individual compliance of residential environment was evaluated and therefore a composite risk mean value that is <0.5 was allocated.

5.3.5 Data analysis

The data was analysed using Excel programme (Microsoft 2010) to obtain the mean values for both risks and compliance percentages. Descriptive statistics was also performed to analyse the health and safety data from the distribution substation and residential environment checklists. The mean values for all features were calculated towards a total compliance mean value. The compliance status was also given to any distribution substation with a mean percentage value of ≥80%. All health and safety features in the residential environments were assigned risk values of less than one. The mean values for all features were calculated and a total composite risk mean value per residential environment was also calculated. All residential environments were given a compliance status based on obtaining a compliance risk value of < 0.5.

5.4 Results

5.4.1 Compliance of distribution substations

The measured data was assigned compliance percentage values on all six features to ensure that there is effective evaluation of health and safety on the distribution substations. In Bloemfontein, 13 substations scored a health and safety percentage value that is below the compliance value of 75% on housekeeping. The mentioned substations include BS3 (50%), BS6 (50%), BS7 (50%), BS12 (50%), BS14 (50%), BS8 (58%), BS1 (67%), BS4 (67%), BS5 (67%), BS9 (50%), BS11 (67%), BS13 (67%) and BS15 (67%) respectively. In terms of fencing, only six substations scored a health and safety percentage value that is below a compliance value of 100%. This include substation BS2 (68%), BS6

(68%), BS7 (68%), BS8 (68%), BS9 (68%) and BS13 (68%). Furthermore, all substations in Bloemfontein scored a total mean compliance value that is ≥80%.

All distribution substations in Botshabelo did not comply with the set compliance value of ≥75% on housekeeping. Only one substation, namely BOS4 (68%) scored a percentage value that is below 100% on fencing. Also in substation BOS3 (68%) it was observed that the scored value is below the compliance value of 100% on record keeping. All substations in Botshabelo scored a total mean compliance value of ≥80%. Moreover, all substations in Thaba Nchu scored a compliance percentage value of less than 75% on housekeeping. Substation TNS3 (68%) and TNS6 (68%) scored a poor compliance percentage value on fencing that is below 100%. In addition, it was observed that the total mean compliance value for substations in Thaba Nchu is ≥80%.

Table 5.1 below indicates all health and safety features that were measured in the substations of Bloemfontein, Botshabelo and Thaba Nchu. The table also includes the compliance percentages that were assigned to all features and the compliance percentage value per substation, named total compliance mean value.

Table 5.1: Compliance percentages of distribution substations to health and safety standards

Substations	Housekeeping ≥75%	Warning and access control ≥75%	Control rooms ≥67%	Register (100%)	Fencing (100%)	Record keeping (100%)	Total compliance mean value ≥80%
BS1	67	75	100	100	100	100	88
BS2	75	75	100	100	68	100	86
BS3	50	75	100	100	100	100	88
BS4	67	75	89	100	100	100	89
BS5	67	75	100	100	100	100	90
BS6	50	75	89	100	68	100	80
BS7	50	75	89	100	68	100	80
BS8	58	75	100	100	68	100	84
BS9	50	75	100	100	68	100	82
BS10	75	75	100	100	100	100	92
BS11	67	75	100	100	100	100	90
BS12	50	75	89	100	100	100	86
BS13	67	75	100	100	68	100	85
BS14	50	75	100	100	100	100	88
BS15	67	75	100	100	100	100	90
BOS1	33	75	100	100	100	100	85
BOS2	67	75	89	100	100	100	89
BOS3	50	75	89	100	100	68	80
BOS4	67	75	89	100	68	100	83
BOS5	67	75	100	100	100	100	90
BOS6	67	75	100	100	100	100	90
BOS7	67	75	100	100	100	100	90
BOS8	50	75	89	100	100	100	86
BOS9	58	75	100	100	100	100	89
TNS1	67	75	100	100	100	100	90
TNS2	58	75	100	100	100	100	89
TNS3	67	75	100	100	68	100	85
TNS4	67	75	100	100	100	100	90
TNS5	67	75	100	100	100	100	90
TNS6	58	75	100	100	68	100	84

The results from the table indicate the good health and safety practices in the substations. All distribution substations in Bloemfontein, Botshabelo and Thaba Nchu have a total compliance value that is ≥80%.

5.4.2 Compliance of residential environments

Table 5.2 below indicates the type of residential environments where the measured residential environments are situated. It also stipulates the risk values for all health and safety features, including the composite risk mean value per residential environment. All residential features in the checklist were assigned a risk value that is <1. This was based on the positioning of substations from surrounding infrastructures, general tidiness and EMF sources. The BRE1 is located in the urban area of Bloemfontein and it indicates a peak risk value of 0.5, while BRE7 is located in the rural area of Bloemfontein with a peak risk value of 0.5 on maintenance and general tidiness. TNRE6 is located in the urban area of Thaba Nchu and it indicates a peak value of 0.6 on EMF sources followed by an equal risk values in BORE1 (0.4), BORE2 (0.4), BORE4 (0.4) in Botshabelo and BRE1 (0.4) in Bloemfontein. Furthermore, BRE3 is located in the rural area of Bloemfontein and it has a peak risk value of 0.375, followed by three residential areas, namely BORE5 (0.375) which is located in the urban area as well as BORE3 (0.375) and BORE6 (0.375), situated in the rural areas of Botshabelo. The results on the table indicate that all residential environments in Bloemfontein, Botshabelo and Thaba Nchu are below the set risk value in all health and safety features. Furthermore, the total composite risk mean value for every residential environment is < 0.5.

Table 5.2: Compliance risk values of residential environments to health and safety standards

Type of residential environment	Residential environment	Positioning of substations-surrounding infrastructure (Risk value<1)	EMF sources (Risk value<1)	Maintenance/ General tidiness (Risk value<1)	Composite risk mean value (Risk value <0.5)
Urban	BRE1	0.125	0.4	0.5	0.34
Urban	BRE2	0.125	0.2	0	0.11
Rural	BRE3	0.375	0.2	0	0.19
Rural	BRE4	0.125	0.2	0	0.11
Urban	BRE5	0.125	0.2	0	0.11
Rural	BRE6	0.25	0.2	0	0.15
Rural	BRE7	0.125	0.2	0.5	0.28
Rural	BRE8	0.125	0.2	0	0.11
Urban	BRE9	0.25	0.2	0	0.15
Urban	BRE10	0.125	0.2	0	0.11
Rural	BRE11	0.125	0.2	0	0.11
Rural	BRE12	0.125	0.2	0	0.11
Rural	BRE13	0.125	0.2	0	0.11
Urban	BRE14	0.125	0.2	0	0.11
Rural	BRE15	0.125	0.2	0	0.11
Rural	BORE1	0.125	0.4	0	0.18
Rural	BORE2	0.25	0.4	0	0.22
Rural	BORE3	0.375	0.2	0	0.19
Urban	BORE4	0.25	0.4	0	0.22
Urban	BORE5	0.375	0.2	0	0.19
Rural	BORE6	0.375	0.2	0	0.19
Rural	BORE7	0.125	0.2	0	0.11
Rural	BORE8	0.125	0.2	0	0.11
Rural	BORE9	0.25	0.2	0	0.15
Rural	TNRE1	0.25	0.2	0	0.15
Rural	TNRE2	0.25	0.2	0	0.15
Urban	TNRE3	0.25	0.2	0	0.15
Rural	TNRE4	0.25	0.2	0	0.15
Rural	TNRE5	0.25	0.2	0	0.15
Urban	TNRE6	0.125	0.6	0	0.24

The results from the table indicate that the composite risk values of all health and safety features in all residential environments are below the set composite risk mean value of 0.5.

5.5 Discussion

5.5.1 Distribution substation compliance

The findings from this study indicate that only substation BS2 (75%) and BS10 (75%) complied with the set compliance value on housekeeping. The results also indicate that the non-compliant substations on housekeeping were as a result of outdated fire prevention equipment, vegetation inside substations, dirt and oil leaking transformers. According to section 6 of the Electrical Machinery Regulations (2011), transformers, as far as reasonably practicable, should be constructed in a way that is leakage and seepage proof. The same regulation stipulates that all fire extinguishers should be maintained and be in a good working order.

The Environmental Regulations for Workplaces, section 6, stipulates that the work environment should be free from tools or other materials that are not necessary for the work that is done in that particular workplace. On fencing, substation BS2 (68%), BS6 (68%), BS7 (68%), BS8 (68%), BS9 (68%), BS13 (68%), BOS4 (68%), TNS3 (68%) and TNS6 (68%) did not comply with the set compliance value. The major factor that contributed to non-conformance is the fading safety signs on the fence. According to Hygiene‟s normative (2000), factors that causes safety signs to fade include maintenance, age, exposure conditions, atmospheric conditions and surface deposits. Section 7, subsection 4 of the Electrical Machinery Regulations states that all employers in the electrical industries shall ensure that all electrical apparatus are labeled or marked (sign posted) in order to be identified, to minimise health and safety accidents and to comply with Occupational Health and Safety Act, Act 85 of 1993. Furthermore, BOS3 did not comply with the set compliance value for record keeping. The electrical apparatus service logbook was not in place during an inspection at substation BOS3. The OHS Act also requires that all records must be kept as to ensure, as far as reasonably practicable, good health and safety practices as well as compliance with this act. Apart from the observed non-compliances on health and safety features, all substations scored a total compliance mean value that is equal to and > 80%.

In a substation health and safety inspection survey by Authority for Electric Regulations, Omna (2006) it was observed that all distribution substations in Bidbid (Fanja), Samail, Izki, Ibra, Al-Qabil Bidiya, Al-Mudhaibi areas complied with condition seven of the License (MEW Operational & Safety Manual and OES). The condition seven of the license stipulates that all distribution substations must have secured fencing, oil and seepage proof transformers, prevention of unauthorised entry and danger warning signs to promote public awareness. According to the Oman‟s survey, out of 94 substations that were inspected, 35% had no adequate fencing, 19% had no caution or danger notice, 12% had switchgear damage and oil leakage was observed from 23% of the substations. The overall compliance percentage for all inspected substations was 100%. Even though the guidelines for inspection on this study were not according to condition seven of the license, but it is indicated that the major problems in the substations is fencing and oil leakage from transformers (housekeeping). The results from this study indicate an overall compliance of 100% with the requirements from the Act and IEEE standard. The non-compliances on sub features that include housekeeping and fencing were also observed as in the above mentioned survey.

5.5.2 Residential environments health and safety

The possible risks on the health and safety features were allocated compliance risk values looking at the position of substations from surrounding infrastructures at proximity of 9 m, EMF sources within proximity of 9 m and the general tidiness outside substations. BRE1 is located in the urban area of Bloemfontein and it indicates a peak risk value of 0.5 for maintenance. Also in BRE7, which is located in the rural area of Bloemfontein, a peak risk value of 0.5 was observed in terms of maintenance. The possible factor that led to high peak values on both residential environments is the visibility of trees below overhead power lines. According to Gene and Frederick (1978), when trees and power lines share space too closely, they can result in power outages and fire, which in turn will lead to air pollution.

McPherson (2006) stated that overhead power lines were responsible for 3% of ignition in CAL FIRE jurisdiction and has contributed four out of 20 large fires in the history of California. TNRE6 is located in the urban area of Thaba Nchu and it demonstrated a high risk value of 0.6 on EMF sources. BRE1 and BORE4 which are located in the urban areas, showed a high risk value of 0.4, similar to BORE1 and BORE2 in rural areas of Botshabelo. The peak risk values were as a result of the presence of 11 kV overhead power lines and electrical junction box within a distance 15 m from TNRE6 and 25 m from BORE1 and BORE2. The presence of overhead power lines and electrical junction boxes in close proximity to substations increases the magnitude of EMFs (Farag, Dawoud, Cheng and Cheng, 1999). A study by Thuróczy (2008) indicated that the strength of EMFs decreases quit rapidly with an increase distance from the source. With reference from Thuróczy (2008), the closer the EMF source to the substation the higher the probability or risk of increased EMF strength.

Furthermore, BRE3 which is located in the rural area of Bloemfontein, demonstrated a peak risk value of 0.375 on surrounding influences, and was similar to that of BORE3, BORE5 and BORE6 in the rural areas of Botshabelo. BRE3, BORE5 and BORE6 are located within proximity of 15 m from school properties. The major sources of EMFs at schools are electronic printing machines and computer devices (NOISH, 1994). According to Breysse, Lees, McDiarmid and Curbow (1994), where video display units (VDU) and photocopy machines are present, the total exposure of magnetic fields can be 0.13 μT. This was also revealed by a study conducted by Skotte (1994) in 55 office spaces of utility companies in Denmark. The study revealed that office workers can be exposed to an average magnetic field of 0.09 μT from electronic devices in the offices. BORE5 is located 30 m from fuel station. In Australia, a study by Tell and Sias (2013) demonstrated that vehicles can emit magnetic fields 150 m away from fuel station to residential environments; an average of 0.051 μT of ELF magnetic fields can be emitted by four gasoline powered vehicles.

There was no significant difference between urban and rural residential environments in terms of compliance risk values. All residential environments scored a composite risk mean value that is <0.5. The residential environments in Bloemfontein, Botshabelo and Thaba Nchu complied with all electrical health and safety features stipulated on the checklist.

This implies that all external residential factors are not within the proximity of 9 m from the substations. This includes the manufacturing factories, fuel stations, water sources, EMF sources and other surrounding infrastructures. Sakurazawa, Iwasaki, Higashi, Nakayama and Kusaka (2003) indicated that all distribution substations should be constructed 15 to 20 m away from apartments to avoid the risks of EMF emanating from the substations. The low risk values in residential environments may be due to an increased distance from the distribution substations.

Furthermore, in 1989, Coleman, Bell, Taylor and Primic-Zakelj looked at the health risks of residents in close proximity to distribution substations. In the said study, the population involved residents living in proximity of 25 m, 50 m and 100 m away from the substation. Residents in proximity of 50 m and 100 m showed no association with health effects while residents within 25 m had a small risk peak value of 1.3 µT. Large numbers of residents were classified as exposed but there was no significant trend in risk with distance from the nearest substation. There was again no significant trend when the control population was used. This indicates that the risk emanating from substations to residential areas can be determined by the distance. The closer residential areas are to substations the higher the risks of EMF exposure.

5.6 Conclusion

The findings from this study indicate that the health and safety aspects in the substations of Bloemfontein, Botshabelo and Thaba Nchu is in accordance with the requirements of the Electrical Machinery Regulations, stipulated under OHS Act, Act 85 of 1993. It was also observed that the design and safety of the electrical machineries in the substations is according to the requirements of IEEE standard 80 of 2000. The total compliance mean values on all substations in Bloemfontein, Botshabelo and Thaba Nchu indicates a good health and safety practices in the substations and also compliances in terms of the requirements of OHS act, act 85 of 1993 and IEEE standard 80 of 2000.

The OHS Act, Act 85 of 1993, highlights the health and safety requirements in the substations and other electric-utility workplaces, is it suggested that all fire prevention equipment should be maintained when required and the health and safety signs be replaced on regular basis. The substations should also be demarcated with a fence or wall that is in good conditions to avoid unauthorised entries. The oil seals of all transformers should be cleaned and replaced at least every six months to avoid oil leakage and grease accumulation. Furthermore, it is also recommended that the vegetation should be removed to avoid rodents‟ infestation and fire during electrical faults.

Moreover, there is lack of data on the health and safety compliance of distribution substations in South Africa. The results from this study will provide preliminary data on the state of compliance on health and safety in the substations of Mangaung region. Although the results indicate compliance and non-compliance with certain health and safety features of the OHS Act, the data will also provide the public and Mangaung substations custodian with the state of health and safety in the substations and the influence from external residential external sites.

5.7 Reference

Breysse, P., Lees, P.S.J., McDiarmid, M.A and Curbow, B. 1994. ELF magnetic field exposures in an office environment. *American Journal of Industrial Medicine*; 25: 177-185.

Broadwell, M.M. 1986. The Supervisor and On-The Job Training. Reading, Mass: Addison-Wesley Publishing Company.

Cohen, S.M and Ellwein, L.B. 1990. Cell proliferation in carcinogenesis. *Science*; 249: 1007-1011.

Coleman, M.P., Bell, C.M.J., Taylor, H.L and Primic-Zakelj, M. 1989. Leukaemia and residence near electricity transmission equipment: a case -control study. *Br. J Cancer*; 60: 793-798.

Farag, A, S., Dawoud, M, M., Cheng, T, C. and Cheng, J, S. 1999. Occupational exposure assessment for power frequency electromagnetic fields. Electrical Power System. *Scand Journal of Work Environmental Health*; 48: 151–175.

Gene, G.W and Frederick, D.J. 1978. Urban Forestry. John Wiley & Sons, Inc. P. 45.

Hygiene's normative (HN). 2000. Public Protection from Electric Fields caused by Electricity Lines. *Ministry of Health Care of Republic Lithuania*, Vilnius.

Ilonen, K. 2008. Indoor transformer stations as predictors of residential ELF magnetic field exposure. *Bioelectromagnetics*; 29 (3): 218.

Institute for Electrical and Electronic Engineer (IEEE). 2000. Standard 80, the guide for safety in AC substation grounding. New York, USA. ISBN 0-7381-1927-X.

Kovetz, A. 2000. Electromagnetic Theory. New York: Oxford University Press.

Li, Y and Héroux, P. 2014. Extra-low-frequency magnetic fields alter cancer cells through metabolic restriction. *Electromagnetic Biol Med*; 33 (4): 264-275.

McPherson, G.E. 2006. Urban Forestry in North America. *Renewable Resources Journal,* Autumn, at p. 9.

Mild, K., Mattsso, M., Hadell, L., Bowman, J and Kundi, M. 2005. Occupational carcinogens; ELF MFs. *Environmental Health Perspective*; 113 (11): 726-727.

Moriyama, K. and Yoshitomi, K. 2005. Apartment electrical wiring: a cause of extremely low frequency magnetic field exposure in residential areas. *Bioelectromagnetics*; 26: 238-241.

National Institute for Occupational Safety and Health (NIOSH). 1994. Hazard Evaluation and Technical Assistance Report: Akron General Medical Center, Akron, OH. Report No. HETA 93-1120-2429. *National Institute for Occupational Safety and Health*, Cincinnati.

National Institute for Occupational Safety and Health (NIOSH). 1995. EMF in the workplace. National Institute of Environmental Health Sciences, U.S. Department of Energy.

OMNA. 2006. Authority for electric regulations: Health & Safety Inspections at Mazoon Electricity Company SAOC Distribution. Report no. TD/HS/D/3-2006. Available at http://www.authorityforelectricregulations/MEC/SAOCdistribution.com.

Preece, A, W., Hand, J, W., Clarke, R, N. and Stewart, A. 2000. Power frequency electromagnetic fields and health. Where‟s the evidence?. *Physics Medical Biology*; 45: 139-154.

Sakurazawa, H., Iwasaki, A., Higashi, T., Nakayama, T. and Kusaka, Y. 2003. Assessment of exposure to magnetic fields in occupational settings. *Journal of Occupational Health*; 45: 104-110.

Shun-Li, L., Ghin, L, E., Ching-Lien, L, E. and Lu, H, T. 1999. "Power substation magnetic field measurement using digital signal processing techniques. *IEEE Transport. Power Delivery*; 14: 1221-1227.

Skotte, J.H. 1994. Exposure to power-frequency electromagnetic fields in Denmark. *Scandinavian Journal of Work, Environment and Health*; 20: 132-138.

South Africa. 1993. Electrical Machinery Regulations of 2011. Pretoria: Government Printer.

South Africa. 1993. Environmental Regulations for Workplaces. Pretoria: Government Printer.

South Africa. 1993. Occupational Health and Safety Act (OSHA). Act 85 of 1993. Pretoria: Government Printer.

Stewart, J. 2003. Occupational hygiene: control of exposures through intervention. *Encyclopedia of Occupational Health and Safety, ILO (Ed.)*. Available at: http://www.ilo.org/safework_bookshelf/english/.

Szemersky, R., Koteles, F., Lihi, R and Bardos, G. 2010. Polluted places of polluted minds? An experimental sham-exposure study on background psychological factors of symptom formation in „idiopathic environmental intolerance attributed to electromagnetic fields." *International Journal of Hygiene and Environmental Health*; 213 (5): 387-394.

Tell, R.A and Sias G. 2013. ELF magnetic fields in electric and gasoline-powered vehicles. *Bioelectromagnetics;* 34 (2): 156-161.

Thuróczy, G. 2008. Exposure to 50 Hz magnetic field in apartment buildings with built-in transformer stations in Hungary. *Radiation Protection Dosimetry*; 131 (4): 469-473.

Urbinello, D and Röösli, M. 2013. Impact of one's own mobile phone in stand-by mode on personal radiofrequency electromagnetic field exposure. *Journal of Exposure Science and Environmental Epidemiology*; 23 (5): 545-548.

Wenzl, T.B. 1997. Estimating magnetic field exposure of rail maintenance workers. *American Industrial Hygiene Association Journal*; 58: 667-671.

Yamaguchi-Sekino, S., Sekino, M and Ueno, S. 2011. Biological effects of electromagnetic fields and recently updated safety guidelines for strong static magnetic fields. *Magnetic Reson Medical Sciences*; 10 (1): 1-10.

Chapter 6

Conclusion and Recommendations

6.1 Introduction

It is very hard to imagine a world without electricity and yet whenever electricity is generated, ELF magnetic fields are produced. Occupational and residential exposure to magnetic fields has been an ongoing epidemiological research with no evident results that such exposure can be associated with occupational illnesses. Residents are continuously exposed to magnetic fields from electrical equipment at home, work and most importantly from electrical substations. The major source of occupational exposure to magnetic fields in distribution substations is transformers (Hubbard, 2008).

Furthermore, such exposures are regulated by exposure limits stipulated under the guidelines developed by the ICNIRP in 2010 and the health and safety conditions of substations are regulated by OHS act. The good health and safety conditions in electrical substations play a vital role in ensuring compliance with OHS Act and IEEE guidelines. The improper positioning of substations may also be observed as an important factor when assessing the risks emanating from substations that can potentially affect the surroundings of residential areas. The recommendations presented in this chapter address the findings presented in chapter 3, 4 and 5.

This chapter outlines the important control measures that can be taken to reduce high exposure levels of ELF magnetic fields in the substations and residential environments. It also seeks to recommend on the actions that can be taken to resolve some of the health and safety non-compliances that were observed in the distribution substations.

6.2 General discussions

The overview of this study was outlined in Chapter 1. The study aim and objectives as well as a brief review of ELF magnetic field literature with specific allusion to distribution substations and residential environments were also described in Chapter 1. The broad review of literature on ELF magnetic fields in the distribution substations and residential environments was presented in Chapter 2. The literature indicates that there is a high exposure level of ELF magnetic fields in the residential environments where electrical sources are present. It is also described in the literature that the major source of ELF magnetic field emission in the distribution substations is a transformer and the magnitude of exposure depends on the distance from the source. In Chapter 3, the results with regard to residential and environmental exposure to ELF magnetic fields were presented. There was a statistical significant difference when the exposure levels between different distance interims were compared. Significant and non-significant differences were also observed when residential environments were compared to one another.

Furthermore, Chapter 4 outlines the results on occupational exposure to ELF magnetic fields in electrical substations. The results indicated that the exposure of employees in all distribution substations is the same and there was a non-significant difference observed. The results on health and safety conditions of distribution substations and residential risk factors were presented in Chapter 5. There were some non-compliance observed on health and safety sub-features, but the overall health and safety conditions of distribution substations was compliant. The external residential factors were regarded to be non-threat to the health and safety of distribution substations.

6.3 Recommendations

The results from chapter 3 indicates that exposure of residents from ELF magnetic fields is below the recommended limits by ICNIRP of 2010, under general public exposure (200 μT). It is also indicated in chapter 4 that exposure levels are below 1000 μT as recommended by ICNIRP, under occupational exposure. The findings in chapter 5 indicate compliance with OHS Act and IEEE 80 of 2000 as well as accurate positioning of substations in the residential environments. Furthermore, it is recommended that a programme should be developed to incessantly evaluate the ELF magnetic field levels when there is new equipment in the substations, after maintenance and electrical power cut-off.

This study has demonstrated a strong correlation between distance from the source of exposure and magnetic field strength. It is therefore suggested that, for safe exposure, distribution substations should be built at least 500 m away from EMF sources, residential houses, manufacturing factories, industrial businesses and other surrounding infrastructure to reduce the intensity of EMF exposures and emissions. To regulate peak exposure levels, a risk management programme should be developed and be implemented in all distribution substations of Mangaung. All maintenance personnel should be advised to spend no more than two hours near transformers. Furthermore, all distribution substations should have a demarcated sign indicating the levels of magnetic field emissions of all electronic equipment. This will create EMFs emission awareness. Suitable protective clothing is also recommended to all personnel entering the distribution substations.

In all distribution substations, it is recommended that a proper maintenance schedule must be developed for all electronic equipment and be monitored. All fire extinguishers must be maintained when required and fences / walls must also be in good conditions to prohibit unauthorised entry into substations. Oil seals for all transformers must be replaced, at least every six months to avoid grease accumulation on the transformers. Vegetation must be removed on regular basis to avoid rodents" infestation and fire ignitions during electrical faults.

6.4 Future research

Future research will necessitate the actual implementation of risk management for health and safety conditions at the distribution substations. The EMFs awareness promotion starting from Mangaung residential environments will also be launched to make the general public aware of the exposure levels. This awareness campaign will be extended to the entire South Africa of which it will also create the responsiveness in electrical industries. Furthermore, future research will also include the recommendation of precise protective clothing for maintenance workers and suggestion on the fencing structure of distribution substations.

A proper maintenance schedule which will reduce the exposure time will be suggested for distribution substations. The measurements and mitigation of exposure to EMFs will be implemented and be extended to power lines, mini substations, electrical junction boxes as well as the signal towers.

6.5 Conclusion

This study suggests the need for the development of legislation that will regulate exposure levels in different distribution substations of South Africa and also to protect the general public. Since the exposure levels in the distribution substations of Managung and immediate residential environments are known, it is proposed that the health implications and mitigation measure of such magnetic fields should be investigated.

This study serves as a platform for additional research to be conducted on different distribution substations across South Africa. It also provides preliminary data on the exposure levels of ELF magnetic fields in the South African distribution substations and immediate residential environments. All objectives were addressed in this study and the data will be available for the purpose of knowledge advancement in the discipline of occupational hygiene and environmental health.

6.6 References

Hubbard, K. R. 2008. Electric and Magnetic Field (EMF) Exposure Assessment – Measurements Conducted at Hydra 765 kV Substation. *Eskom Technical Note to Transmission*.

ANNEXURES

ANNEXURE A: Substation Checklist

Region ____________________________

Substation no. ________________________

Substation			
	Yes	No	Comments
132 kV distribution substation			
Housekeeping			
Maintenance equipment lying around			
Any visible dirt in transformers			
Any leaking oil from transformers			
All silica gel containers in place			
Vegetation inside substation			
Open trenches in a substation yard			
Earth wires on steel pylons are regularly replaced			
Fire prevention equipment is maintained			
Security fencing is well maintained			
Any obsolete equipment around			
Backup battery terminals regularly cleaned and replaced			

	Yes	No	Comments
Maintenance plan is available			
Warning signs and access control			
Electrical shock signs are available			
Entrance is well- demarcated			
Substation is patrolled by security guards			
Access to unauthorized persons prohibited			
Control rooms			
Indication of incoming power is available			
Indication of outgoing power is available			
All switches are functioning			
Meter reading functions well			
All control rooms clearly indicated			
All conservator tanks are clean			
All conservator tanks are not leaking			
Control rooms in good conditions			
Indoor switch gears in good conditions			
Register			
Electrical assets register is available			
Fencing			

	Yes	No	Comments
The substation is well- fenced			
Safety signs on fences are not faded			
Lockable gate			
Record keeping			
All electrical faults are recorded			
All machinery service logbooks are in place			
All replacements are recorded			

ANNEXURE B: Residential Environments Checklist

Region ______________________________

Residential site no. ______________________________

Residential section			
	Yes	**No**	**Comments**
Type of residential environment			
Rural environment			
Urban environment			
Position of substation- surrounding infrastructure			
Schools within 9 m from substation			
Homes within 9 m from substation			
Playground within 9 m form substation			
Shopping center within 9 m from substation			
Fuel station within 9 m from substation			
Manufacturing factories, including other industrial businesses within 9 m from substation			
Animal kraals within 9 m from substation			
Water sources within 9 m from substation			
EMF sources			
Protruding underground cables outside substation			

	Yes	No	Comments
Overheard power lines within 9 m from substation			
Presence of live faulty electrical wires within 9 m from substation			
Junction/distribution box within 9 m from substation			
Street light control boxes within 9 m from substation			
Maintenance			
Trees under power lines			
A rusted junction/distribution box visible			

ANNEXURE C 1: Data collection sheet for residential sites

Region ______________________________

Residential site no.__________________________

Distances	ELF magnetic fields (uT)
3m	
6m	
9m	
3m	
6m	
9m	
3m	
6m	
9m	
3m	
6m	
9m	

ANNEXURE C 2: Data collection sheet for substations

Region ______________________________

Substation no. ______________________________

Angles (corners)	**ELF magnetic fields (uT)**
Corner 1 (front right)	
Corner 2 (front left)	
Corner 3 (rear left)	
Corner 4 (rear right)	