An Assessment of Electrical Deaths in the Western Cape Province from 2011 to 2020

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DECLARATION

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Abstract

Electrical injury is a significant cause of morbidity and mortality worldwide. When an individual comes into contact with an electrical current, the resulting injury can range from minor burns to cardiac arrest and death. Electrical deaths are particularly concerning due to their sudden, unexpected nature, and the fact that they often occur in otherwise healthy individuals. This study aimed to explore the pathophysiology of electrical injury and its effects on regions of the human body. Two sets of data were examined to ascertain the prevalence and patterns of electrical deaths in the Western Cape Province of South Africa between 1 January 2011 and 31 December 2020.The first data set contained the variables of age, date of death, sex, suburb and blood alcohol concentration. The second data set was a retrospective review of autopsy reports from Salt River Mortuary, to provide an in-depth analysis of injury patterns and the circumstances surrounding these deaths. The medicolegal data from the Western Cape Province, South Africa were reviewed and the demographics analysed. A total of 401 cases of fatal electrocutions were identified, where the City of Cape Town was identified as a hotspot, reporting over 64% of these deaths. Males aged 21 to 30 years old were identified to be most vulnerable to electrical deaths. Medicolegal case files were reviewed retrospectively to obtain the demographics, circumstances and electrical sources of the electrocution fatalities at Salt River Mortuary (SRM) in Cape Town. A total of 102 cases were reviewed from SRM, where 370 joule burns were recorded in the electrical deaths. Electrical injury was primarily seen in the extremities and upper regions of the bodies. A variety of injuries were recorded including minor burns, deep burns and charring. The intensity and prevalence of injury was compared between males and females. Vulnerable demographics and prevalent circumstances surrounding electrical deaths were identified. The main electrical sources were live wires from exposure to illegal connections and cable theft. Ultimately, a better understanding of electrical injury can help to improve prevention and management strategies, leading to better outcomes for those affected by this devastating type of injury.

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Glossary of terms

AC: Alternating current

Circuit: A closed loop or path through which electric current flows.

Current: The flow of electric charge through a conductor, measured in amperes (A).

CoCT: City of Cape Town

Electrical Conductor: A material or substance that allows the flow of electric current.

Electrical Contact: Direct physical contact between a person or object and an electrical conductor or source.

Electrical death/electrocution: Exposure to electrical current such that injury or tissue damage is inflicted significantly enough to result in a fatality.

Electrical Hazard: A situation or condition that poses a risk of electric shock or injury.

Electrical Injuries: Harm or damage caused by electrical accidents, including burns, muscle contractions, and nerve damage.

Electric Shock: The physiological response to the passage of an electric current through the body, which can range from mild discomfort to severe injury or death.

ESKOM: Electricity Supply Commission

Voltage: The electric potential difference between two points, measured in volts (V).

Resistance: The opposition to the flow of electric current in a circuit, measured in ohms (Ω).

FPS: Forensic Pathology Service

Informal housing: A settlement with housing consisting of corrugated iron, commonly referred to as shacks.

Insulator: A material that inhibits the flow of electric current.

Ohm's Law: A fundamental equation in electrical engineering that relates voltage, current, and resistance: $V = I \times R$.

SRM: Salt River Mortuary

WC: Western Cape Province

Chapter 1: Introduction

Electrical deaths are a significant problem worldwide. According to data from the World Health Organization (WHO), approximately 80,000 people die each year from electrocution, and more are injured (WHO, 2023). These deaths and injuries are often caused by exposure to high voltage power lines, faulty electrical wiring, and the use of defective or poorly maintained electrical equipment. The effect of electricity on and within the body is determined by a multitude of factors that determine the extent of injury and contribute towards the incidence of fatality. In addition, several injuries and fatalities occur in low- and middle-income countries, where there is a lack of electrical infrastructure and regulations may not be strictly enforced or substantially established (Essex and de Groot, 2019). A notable increase in electrical fatalities displays the necessity of the determination of the electrical sources or causes. To prevent future electrical deaths, it is essential to diagnose electrocutions using autopsies, witness reports and evidence analysis (Alqassim, Ewiss and Al-Ali, 2023). The majority of these deaths are preventable. Therefore, to reduce the number of electrical deaths and injuries, it is important to improve electrical infrastructure, enforce safety regulations, and educate people on the proper use, maintenance and risks of electrical equipment. Electrical deaths are a significant problem in South Africa, with numerous studies and reports highlighting the issue (Blumenthal, 2009; Awath-Behari, 2023).

This thesis will encompass a detailed examination of fatal electrocution incidents, considering various contexts and factors that influence their occurrence. By exploring the causes, consequences, and prevention of electrocution, this study contributes valuable insights that can inform safety protocols, policy development, and public awareness initiatives.

In this thesis, I provide a literature review in Chapter 2, focussing on the theory of electrical conduction and the pathophysiology of electrical current in the body. The chapter highlights gaps in knowledge and areas of focus for this study. The previous studies on electrical deaths are reported according to trends and geographical regions. This chapter highlights the lack of literature on electrical deaths in Africa.

Chapter 3 provides details regarding the study sample in the thesis. The chapter outlines the methodology utilised throughout the retrospective, longitudinal study. This includes data collection, analysis techniques, and ethical considerations.

Chapter 4 includes the representation of the findings and outcomes of the study, relating to the prevalence of electrical deaths in the Western Cape Province. Further analysis is conducted on a subsection of data, where patterns of electrical injury and circumstance are explored.

Chapter 5 discusses the primary findings of this study. The significance and relevance of the results are expanded with relation to previous literature. Various causes and mechanisms underlying fatal electrocution incidents are explored, offering insights into the physics, injuries and circumstances involved. The resulting electrical injuries are related to the circumstances to provide patterns of injury in the fatal electrocutions studied.

Chapter 6 reiterates the aims and objectives, reporting the primary outcomes of the study. Based on the results and discussion, this chapter summarizes the key findings, implications, and contributions of this thesis, as well as outlining avenues for future research in the field of electrocution prevention.

Through this research, I aim to contribute to the growing body of knowledge surrounding electrocution, ultimately striving for a safer and more informed society against potential electrical hazards.

Chapter 2: Literature Review

2.1 Theory of Electrical Conduction

Electricity is the flow of an electric charge through a material (Spies and Trohman, 2006). This movement or flow of electricity is caused by the movement of negatively charged particles, electrons, which is known as electrical current, measured in amperes (A). Electrons can be made to move by applying a voltage across a material. The voltage, measured in volts (V), is the difference in electric potential between two points in a material. Therefore, when a voltage is applied to a material, the electrons move from a region of lower electric potential to a region of higher electric potential. It is a form of energy that can be harnessed to power a wide range of devices and systems (Lee, 1997).

Ohm's law states that the current flowing through a conductor is directly proportional to the voltage applied across it, and inversely proportional to the resistance of the conductor. This relationship is often represented as:

$$I = V/R$$

where R is the resistance, I is the current and V is the voltage (Chen *et al.*, 2021). The current is calculated as the voltage divided by the resistance.

Once generated, electricity is typically transmitted over long distances through power lines, and then distributed to homes and businesses through a network of smaller power lines. In South Africa, the supply of electricity of electrification constitutes networks on a low voltage grid, typically defined as below 1000V, that is terminated through a distribution transformer (Louw and Bokoro, 2019). This electricity is supplied within bundled insulated, concentric cables which minimizes the risk of electrical exposure to people. The resultant voltage in households is typically 230V. The aspects of electrical supply such as current strength and voltage can have a diverse effect on the human body due to the interactions of the biological components and the nature of electricity (Bikson, 2004; Michiue *et al.*, 2009).

2.2 Electrochemical Physiology

The electric current can affect any organ in the body, however, the magnitude of injury depends on the composition of the tissue and resistance of the cellular components (Jellinek, 1936). Within tissues such as cortical bone and the epidermis where water content is lower, the resistance to electrical activity is higher (Lee, 1997).

Once the energized charge enters the body, it will attempt to find the closest exit site at a different potential or typically referred to as 'ground' (Bikson, 2004). When exposed to an electrical source, the body becomes part of the circuit allowing the current to pass through and reach ground. For an electrical fatality to occur, the ionization of molecules serves as the mechanism of injury of electrical current. The electrons in outer shells may be rearranged and this causes the production of free radicals which facilitate cell damage. The amount of current that an individual is exposed to is regarded as a major determinant of tissue damage inflicted by the electricity (Lee, 1997). The body becomes depolarized by the influx of electrical current such that the nervous system is overwhelmed, consequently the internal organs of the individual can become damaged (NIOSH, 1998). The cause of electrical death is electrical shock, and this can be classified according to the injuries presented either at a superficial or microscopic level. There is typically a primary electrical injury which includes joule burns and sparks. Electrical marks can be linear or round, depending on the conductor and contact point of the electrical source with the body (Saukko and Knight, 2015: 332). Electrical lesions can be described as comprising of central craters with surrounding raised edges as seen in Figure 2.1 (Mondello *et al.*, 2018). A joule burn is defined as the direct burn resulting from direct contact of the body with the conductor or electrical source. The injury may be small in size and is typically described with a central crater and surrounding burning of the tissue (Byard, 2022). While a spark burn or lesion is an injury that does not require direct contact of the skin with the conductor. Spark injuries are also referred to as arc burns (Path, 1988). Arc injuries are caused by high voltage electrical conduct which results in charred skin craters at the point of contact and inflamed, oedematous skin surrounding the primary injury (Fish, 1999). This occurs when the electric field of the electrical source creates a hot gas of ions that become a better conductor of electrical charge, therefore, are able to penetrate the body and initiate damage to the tissues (Lee, 1997). Due to the high temperatures associated with an electric arc, flash burns and charring are often associated with this type of injury (Fish, 1999). The drastic rise in temperature caused by the arc can also induce an explosive effect that causes the individual to be propelled from the electrical source (Fish and Geddes, 2009).

The secondary injury refers to damage to the body as an indirect result of the electrical shock such as the fractures caused by a fall from height (Fish and Geddes, 2009). Shock occurs when the energized charge passes through cell membranes through depolarization of the membrane components (Bikson, 2004).

Figure 2.1: Post-mortem electrical lesions with central craters and surrounding charring. Image obtained from Mondello et al, 2018.

The amount of damage is determined by the pathway through which the electricity travels. The resistance of the organs, electrical source and contact time with the electrical source determine the extent of injury and potential fatality (Teodoreanu, Popescu and Lascar, 2014). The entry point of electricity into the body is a critical factor in the damage due to electrical shock. Electricity entering through the left side of the body is potentially more dangerous than electricity entering the right side of the body (Saukko and Knight, 2015: 332). The reason is that there is a greater risk that cardiac injury can result in a fatality as the heart is located on the left side of the body. There are four paths of electricity that are considered to be the most dangerous and likely to result in death (Al-Alousi, 1990). The pathways of head-to-hand; hand-to-hand; hand-to-foot and head-to-foot are likely to result in extensive electrical trauma. The current thresholds that result in cardiac and pulmonary failure for different pathways in the body have not been ascertained. The present information indicates that as current passes from hand to hand, the magnitude of current that is the minimum required to disturb the respiratory muscle and cardiac rhythm is more than in skeletal muscle contraction in the limbs and extremities (Fish and Geddes, 2009). The reasons for this are that in the thoracic region, the current density, therefore, the electric field strength, is less than in the upper limbs and digits. It is also due to the fact that cardiac muscle cells are smaller in proportions than the cells of skeletal muscle (Lee, 1997). The extent of the tissue damage is caused by the magnitude of current of the electricity, which can lead to burns as the electricity passes through the body. The physical properties of electricity tend to follow the path with the least resistance, as it travels through nerves and blood vessels in the body attempting to reach a ground point (Waldmann *et al.*, 2017).

2.3 Electrical Injury and Death

The magnitude of damage depends on a variety of factors such as the characteristics of the electrical source. These factors include the point of contact between the body and electrical source, current strength, and the duration time of the electrical exposure (Michiue *et al.*, 2009). Spies and Trohman (2006) describe four mechanisms of injury with regards to electrocution. The first is the tissue damage associated with direct exposure to current such as cardiac fibrillation or apnoea. The second is mechanical injury from lightning strikes that leads to muscle contraction or falling. Thirdly, the burns associated with the conversion of electrical energy into thermal energy and lastly electroporation, which is the disruption of cellular membranes that result in cell death (Spies and Trohman, 2006). In cases of electrocution, the typical injuries seen at an autopsy include burn wounds and abrasions (von Caues, Herbst and Wadee, 2018). The cutaneous electrical mark is a valuable indicator of electrocution and is usually associated with an entrance or exit site of the electrical exposure (Al-Alousi, 1990).

Throughout the process of electrical current transfer, thermal injury and nonthermal injury can potentially damage the body. Electrothermal injury can lead to burns at the point(s) where electricity contacts the body. Subcutaneous tissue, bone, muscle, and internal organs can potentially be injured thereafter (Lee, Zhang and Hannig, 2000).

There are many frequency-dependent mechanisms of pathophysiology linked to damage which are caused by the strength of electrical current (Lee, 1997). These interactions do not depend on heat to inflict injury or change biological tissue. When human tissue has been in direct contact with electric current, the electrical mark is known as a joule burn (Ateriya *et al.*, 2020). Joule's law quantifies the amount of energy created from extended exposure to current in the form of the equation:

$$\text{Energy} = I^2 \times R \times T$$

Where "I" represents the current, measured in amperes; "R" is the resistance measured in ohms and "T" is the time, measured in seconds.

Electrical current can damage the body in multiple ways including the activation of nerves, electroporation and heat that causes burns (Bikson, 2004). This depiction indicates that the amount of current and resistance is proportional to the amount of energy generated from the electricity hence proportional to the tissue damage. Certain tissues of the body such as skin, fat and bone have a higher resistance to electricity, therefore, will increase in temperature and coagulate when exposed to high levels of electrical current (Spies and Trohman, 2006). Different skin thickness on the body has variable resistances to electricity. It was reported that approximately 150V is required to break the skin barrier in most areas on the body. However, areas with notably thicker skin such as the palms of the hands and soles of the feet, can require 400V of electricity to break the skin (Lee, 1997).

Depending on whether the skin is dry or moist plays a role in the damage seen (Giri, Waghmode and Tumram, 2019). The environmental and bodily conditions dictate the magnitude of damage from electrical shocks. Dry skin located on the palms of the hand can be sites of higher resistance to electricity while sweating is likely to reduce the resistance to electric current (Blumenthal, 2009). Moist skin will often dampen superficial damage, however, it will facilitate the path of electricity into the body that can result in significantly more damage to internal organs that result in severe congestion, while dry skin is likely to create severe superficial damage to the point of contact with the electricity but prevent deeper damage by limiting the amount of current into the body (Spies and Trohman, 2006).

The mechanism of injury of electricity in the body is caused by its interaction with the cell structures including proteins, membranes or the generation of heat (Lee, 2006). Another common mechanism of injury is the polarizing of cell membranes and denaturing of associated cellular proteins (Lee, Zhang and Hannig, 2000).

The permeability of the plasma membrane is the main structure of the human cell that determines the magnitude of injury in an electrical shock (Lee, Zhang and Hannig, 2000). With prolonged contact of the electrical source, the extent of damage is likely to increase substantially. Initially the electroporation will cause disruption of the regulation of the cell permeability, then the heat produced by the electricity will denature the proteins and lyse the membrane leading to cell death (Lee, 2006).

Although high voltages of electricity cause burns and tissue damage, it is shown that alternating current of a low voltage is more likely to result in fatalities (Dzhokic, Jovchevska and Dika, 2008). The properties of alternating current mean that it is three times more harmful to the human body than direct current, irrespective of the voltage. It has been found that 70 to 80 milliamps (mA) of alternating current or 200 to 250 mA of direct current is potentially harmful to the human body.

Ventricular fibrillation is the most common cause of death in low voltage electrocutions and can occur between 75 and 100 mA (Al-Alousi, 1990; Hardjanto, Nzilibili and Yudianto, 2019). Ventricular fibrillation is described as the asynchronous pumping of the heart that contributes to a poor distribution of oxygen to the brain which is fatal (NIOSH, 1998).

Within cardiac tissue, the incidence of myofibre break-up is considered to be a definitive indication of antemortem electrocution in the human body. This is especially useful when superficial injuries cannot be identified (Fineschi *et al.*, 2006). There is a possibility of fatality when there is no macroscopic evidence of electrical marks or burns (Bailey, Forget and Gaudreault, 2001). This was seen in 8% of the cases where the primary focus of the investigation was the prevalence of cardiac failure in electrical deaths. Microscopically, the cardiac tissue can be identified using immunohistochemical staining to identify the electrical damage (Kathum and Al-Khateeb, 2019).

The extent of injury on the human body when exposed to electricity is primarily based on the current. A minimal current strength has the potential to inflict for bodily harm than the magnitude of voltage. The ways in which the voltage of the electrical source can inflict damage are through breakages in the skin via burn wounds and electroporation (Fish and Geddes, 2009). Electroporation is the mechanism of electrical injury whereby the cell membrane becomes permeable to the electrical source hence the result is cellular damage or cell death (Lee, 2006). The electrical lesions are characterized by the separation of layers of skin such as the intraepidermal and subepidermal separation (Üzün, Akyildiz and Inanici, 2008). When looking at cutaneous marks under the microscope, the mark can look like the separation of the cells of the lower epidermis and can be described as sharp slits (Al-Alousi, 1990).

2.4 Global electrical death trends

To gain an understanding of the prevalence of electrical deaths globally, a literature review was conducted using Google Scholar. Key words including “electrocution”, “electrical injuries” and “accidental electrical death” were utilised. All relevant English language, original research articles were included.

2.4.1 Prevalence

The prevalence of electrical deaths varies based on the socioeconomic state of the country. In developed nations these accidental deaths are reportedly uncommon compared to other causes of death (Lindström, Bylund and Eriksson, 2006). Developing nations report higher prevalence of accidental and preventable electrical deaths (Shawon *et al.*, 2019; Awath-Behari, 2023). Suicide by electrocution is reportedly rare, however, the occurrence of suicidal electrocutions is more common in countries of the West (Gupta, Mehta and Trangadia, 2012). Rarely electrocution may be used as a method to mislead the manner of death, by trying to make a homicide appear as a suicide (Jambure, Tandle and Zine, 2012; Byard, 2022).

The increased use of electrical appliances in the home may have resulted in more home-related electrocutions compared to the past (Giri, Waghmode and Tumram, 2019). The dangers and necessary precautions surrounding the use of electricity are not well-communicated to the general public which leads to many, otherwise avoidable fatalities in developing countries (Shawon *et al.*, 2019). Global electrical deaths vary from region to region and are almost all accidental in nature (Blumenthal, 2009). Prevalence has been reported as deaths per 100 000 population or number of cases observed (Figure 2.2). A large amount of data has been gathered throughout Asia, North America and Europe compared to the continents of South America and Africa. There is a clear lack of literature, which reiterates the need for further research of electrical deaths in an African context.

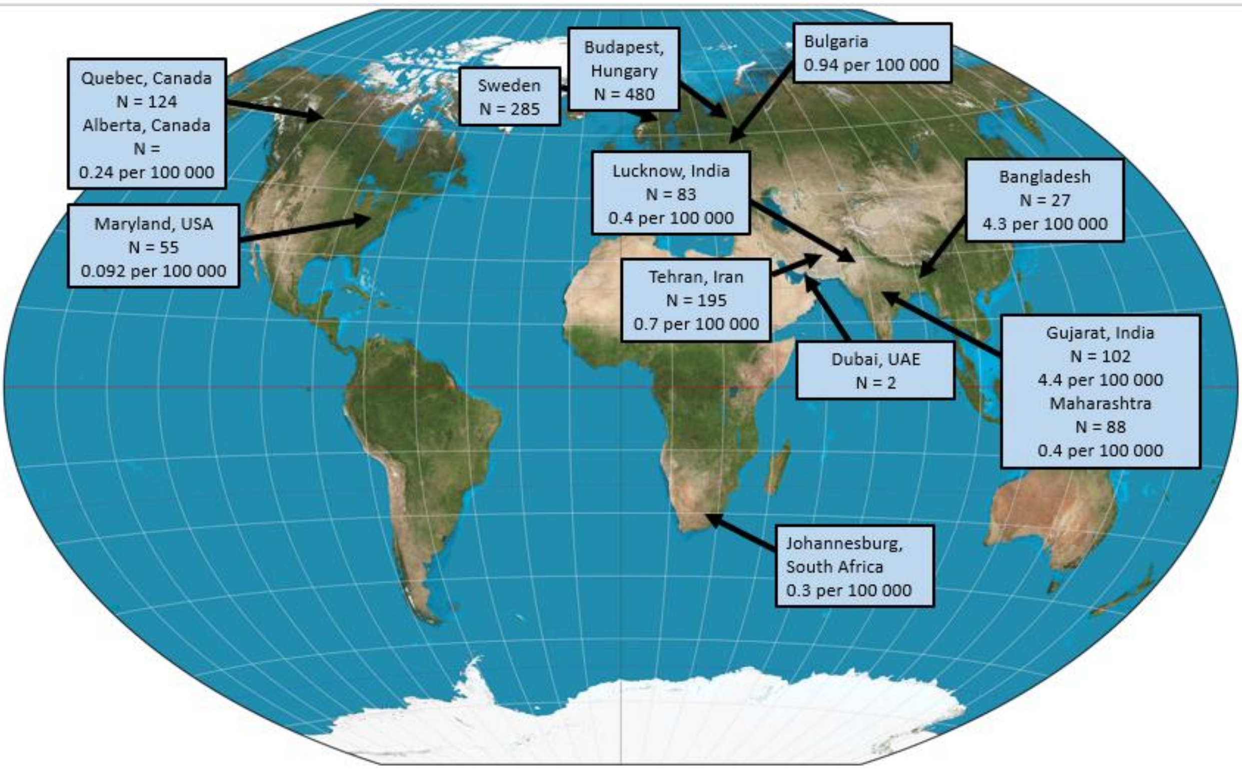

Figure 2.2: World Map showing the mortality rates from previous studies on electrical deaths.

Data derived from various studies: Bailey, Forget and Gaudreault, 2001; Lindström, Bylund and Eriksson, 2006; Shawon *et al.*, 2019; Giri, Waghmode and Tumram, 2019; Massey *et al.*, 2018; Gupta, Mehta and Trangadia, 2012; Sheikhazadi, Kiani and Ghadyani, 2010; Pilecky *et al.*, 2019; Alqassim, Ewiss and Al-Ali, 2023.

From 1980 to 1992, electrical deaths were the fifth leading cause of death accounting for approximately 7% of deaths in the United States of America (USA) (NIOSH, 1998). In Maryland USA, deaths by electrocution from 2005 to 2015 were reviewed (Massey *et al.*, 2018). Over this period, 55 electrical deaths occurred which affirms that electrocution is considered an uncommon cause of death in developed regions. It should be noted that the true number of occurrences of electrical accidents cannot be accurately measured due to the underreporting of these accidents (Waldmann et al., 2017).

Identification of the risk factors associated with electrical shock fatalities was investigated in Canada between 1987 and 1992 using medicolegal case files at the Quebec coroner's office (Bailey, Forget and Gaudreault, 2001). The demographics, circumstances and time of death were compared to assess the prevalence of such deaths. The group most susceptible to electrical deaths were typically young males that were incorrectly using electrical equipment during the summer, when humidity produces moisture on the skin and increases electrical conductivity.

In Sweden from 1975 to 2000, common sources of electrocution were aerial powerlines, railways lines and electrical appliances within households (Lindström, Bylund and Eriksson, 2006). Throughout the study, the incidence of electrical deaths had decreased despite the more apparent use of electricity in later years which displayed improved safety measures.

In Maharashtra, India electrical deaths from 2012 to 2016 were analysed (Giri, Waghmode and Tumram, 2019). Each case was studied extensively according to manner of death, temporal patterns, electrical source and autopsy reports. The demographic analysis reported that 80% of the individuals were male and few female deaths by electrocution occurred. A five-year retrospective study on electrocutions in Lucknow, India revealed 83 deaths due to electrocution (Kumar, Verma and Singh, 2014). Most of which occurred in July to September which is typically the rainy season in the region. There were 102 electrocutions from 2004 to 2008 studied at Shah Medical College in Gujarat, India (Gupta, Mehta and Trangadia, 2012). A study conducted in Bangladesh looked at the prevalence of electrical deaths in 2002 compared to 2015 and found a significant increase (Shawon *et al.*, 2019). The incidence of such deaths went from 1.7 per 100 000 to 4.3 per 100 000. The study notably compared parameters such as age and sex but further classified the prevalence of electrocutions seen in the rural and urban populations of Bangladesh. A limitation is that this study involved a cluster survey using recall from the previous year. The rural incidence of electrical deaths in 2015 was more than twice the recorded ratio in 2002, reported as 6.2 per 100 000 and 2.5 per 100 000 respectively, while that of the urban population remained fairly similar at 0.9 per 100 000 and 0.8 per 100 000, respectively. The authors suggest that the increase in electrocutions was due to increased access to electricity over the years. This was compounded by insufficient educational awareness around the dangers of electricity.

2.4.2 High and Low voltages

The strength of current is difficult to determine, therefore, electrical injuries are typically categorized by voltage in order to measure the magnitude of electricity that caused the damage (Waldmann *et al.*, 2017). The general distinction between high and low voltage is that high voltage is considered to be over 1000V whereas low voltage refers to any electrical source below 1000V (Chen *et al.*, 2021). Electrical deaths can occur due to contact with both low voltage and high voltage electrical systems. The distinction between high voltage and low voltage electrical shocks has been clinically placed at 1000V but the magnitude of the voltage is not proportional to the severity of the injuries observed (Duff and McCaffrey, 1999).

A common misconception is that fatality can only occur when exposed to high voltage, however, exposure to low voltage seen in household appliances can be lethal (Dzhokic, Jovchevska and Dika, 2008; Giri, Waghmode and Tumram, 2019). It is possible that electrical sources with a voltage lower than 80V can inflict injury to the human body and potentially cause fatalities (Peng and Shikuib, 1995). A common characteristic of low-voltage electrocutions can be seen in very humid environments. Such conditions encourage the presence of sweat on the body which can reduce the resistance of the body to electric current and increase the risk of electrical injury (Bikson, 2004). Low voltage electrical marks are typically described as small, elliptical, grey or black central craters with surrounded charring (Al-Alousi, 1990). There can be the presence of grey or white discolouration when necrosis is involved in the lesion. During prolonged contact with an electrical source, it is possible for coagulation necrosis to occur (Peng and Shikuib, 1995).

Electrical deaths that are seen in households and workplaces are commonly associated with exposure to voltages between 110 and 380V (Hardjanto, Nzilibili and Yudianto, 2019). It is reported that a current strength of over 16mA is enough to initiate the 'Let go' phenomenon where tetany induces the contraction of the extensor and flexor muscles in the forearm. Hence, there is an involuntary contraction whereby the individual cannot actively release the electrical source, therefore, there is a prolonged contact time (NIOSH, 1998; Bailey, Forget and Gaudreault, 2001). The mechanism of injury in low voltage deaths can be due to this forced contraction of the muscles and secondary asphyxia which would be facilitated through prolonged contact with the electrical source (Peng and Shikuib, 1995). The prolonged interaction of the hand to the conductive material in this phenomenon, can sometimes depend on how tightly the material was held by an individual

(Fish and Geddes, 2008). Metallization (deposition of metallic ions) of the entry wound may also occur due to prolonged contact (Ateriya *et al.*, 2020).

High-voltage electrical accidents can result in severe injury with potential damage to many organs and possibly death (Teodoreanu, Popescu and Lascar, 2014). High voltage injuries are typically caused by power lines and are usually associated with occupational accidents (Dzhokic, Jovchevska and Dika, 2008). In deaths due to high voltage electrocution, the superficial injuries seen are electric marks and burn wounds (de Donno *et al.*, 2019). The injuries are associated with charring of the skin, severe burns and possibly mechanical injuries, depending on the circumstances surrounding the death (Al-Alousi, 1990). Oedema and congestion of the organs is typically observed after a high voltage electrocution (Karger et al., 2002). This was exemplified in a case of high voltage electrocution case that had no external electrical injuries, however, cerebellar haemorrhage and pulmonary infiltrates were observed using computed tomography (CT) (Nizhu, Hasan and Rabbani, 2020).

Lightning strikes may also be considered as high current electrocutions, measuring from approximately 30 000 to 110 000A (Sleiwah *et al.,* 2018. The mechanisms of injury in lightning strikes include direct strikes, contact injuries, side splash or flash, ground current, and blunt injury (Cooper, Holle and Andrews, 2017; Blumenthal, 2021). This mechanism of injury occurs when lightning encounters the resistance of the Earth's surface and the area around the strike becomes energized. EPR results in a generation of electricity between an individual's feet, from which current flows up through the legs. Resulting injuries on the lower regions of the body are attributed to this mechanism of electrocution. This electrical shock is, however, less likely to cause death (Cooper, Holle and Andrews, 2017).

These studies provide evidence that high voltage electrocution is more likely to result in death than low voltage electrocution. Yet, death by low voltage electrocution does occur. It is important for governments and stakeholders to invest in improving electrical infrastructure and enforcing safety regulations to reduce the number of electrical deaths globally.

2.4.3 Occupational prevalence

A study conducted by the National Traumatic Occupational Fatalities (NTOF) in the United States (USA) identified a mean electrical death rate of 0.4 per 100 000 workers from 1980 to 1992. It was noted that the number of electrocutions decreased over the period of study (NIOSH, 1998). Using the information gathered from the US Labor Department's Bureau of Labor Statistics, an analysis by the Centre for Disease Control and Prevention (CDC) was carried out for a ten- year period, between 1992 and 2002. In their finding, 42% of electrical deaths were caused by overhead power lines which occurred during maintenance, repair and installation that aligned with the tasks of the occupation (Cawley and Hornee, 2006).

Electrical deaths were examined in Tehran, Iran from 2002 to 2006 and reported that 63.7% were work-related (Sheikhazadi, Kiani and Ghadyani, 2010). The study indicated that many employees were not aware of the potential risks associated with their environment, therefore, the safety training received was inadequate.

In Hungary, accidental electrical injuries were investigated from 2011 to 2016 to assess the biomarkers of cardiac arrhythmias. The occupational incidence of the electrical accidents was reported as 38.3% (Pilecky *et al.*, 2019).

The place, where most of the electrocutions occurred in Bangladesh, was in the workplace or while working in open land (Shawon *et al.*, 2019). Between the 13 years of the two study cohorts, workplace electrocutions increased from 35.7% in 2002 to 40.2% in 2015. All the workplace deaths in the study occurred in fields of agriculture.

A study in Dubai incorporated trace evidence analyses, medicolegal investigations, and the expert opinion of an electrical engineer to investigate occupational electrocution cases (Alqassim, Ewiss and Al-Ali, 2023). One of the cases involved a worker who did not wear the required personal protective equipment (PPE), which would have served as a safety measure against electrical injury (Alqassim, Ewiss and Al-Ali, 2023). Failure to correctly use the required PPE was also seen in 55% of workplace electrocutions in the US (NIOSH, 1998).

2.5 South African perspective

2.5.1 Prevalence

Compared to the literature in other countries, South Africa has a greater prevalence of electrical deaths (Blumenthal, 2021). This proves to be a serious mode of fatality, that is otherwise preventable. Unfortunately, limited research has been conducting investigating fatal electrical deaths at a regional scale in South Africa.

In Mpumalanga 304 burn-related deaths between 2007 and 2008 were retrospectively investigated, of which 33 deaths involved electrocution (Blom, Van Niekerk and Laflamme, 2011). A comparison of electrical and thermal burn fatalities was conducted utilising data gathered from

Johannesburg, Pretoria, Mpumalanga and Cape Town between 2010 and 2014 (Keyes and Liphoko, 2021). However, only in Johannesburg were electrical deaths reported as a distinct category. There were 28 electrocutions and one fatal lightning strike reported from the Johannesburg Forensic Pathology Service. The most recent South African study analysed electrical deaths in KwaZulu Natal from 2006 to 2016 (Awath-Behari, 2023). This study analysed the trends in fatal electrocutions across three mortuaries in the province. Almost half of the fatal electrocutions studied were due to illegal connections. In many cases of illegal connections, the cables will be laid out irregularly and cross the informal houses, due to the lack of regulated infrastructure (Gaunt *et al*., 2012). Often such illegal connections result in exposed live wires, which are in reach of children and are in such a position that accidental contact is likely. This is a common trend throughout the country and emphasizes the need for intervention to prevent such deaths.

2.5.2 High and Low voltages

A study at Tygerberg Forensic Pathology Service, Cape Town from 2008-2012 described the incidences of low and high voltage deaths in 39 cases. It was reported that 79.5% of the electrical deaths were due to low voltages while the remaining were high voltage deaths. High voltage deaths were commonly attributed to cable theft and illegal connections (von Caues, Herbst and Wadee, 2018). Although over 12% of cases in the study were due to illegal connections, this may have been an underrepresentation due to many case circumstances being unknown. Over the period 2001-2004, 126 electrical deaths were investigated in Gauteng, the majority of which were caused by low voltage sources (Blumenthal, 2021). The study indicated that deeper burn wounds were seen in deaths by high voltages compared to the burn wounds seen in low voltage deaths.

Further research in the East Metropole of the City of Cape Town, Western Cape investigated railway-associated deaths at Tygerberg Forensic Pathology Laboratory between 2016 and 2017 (von Caues, Herbst and Wadee, 2018). Approximately six cases (5.8%) were attributed to electrical deaths in a study on railway-associated deaths in this region from 2016 to 2017 (Okkers, 2021). Three of the cases were allegedly due to train surfing and the other three involved the discovery of the decedents hanging from the train. The circumstances surrounding electrical deaths can highlight areas of concerns and where measures of prevention need to be implemented.

2.5.3 Access to Electricity

The energy crisis in South Africa is a pertinent issue that affects the whole country. The rising price of electricity has contributed decreased economic growth (Khobai and Le Roux, 2017). The government does not regularly provide basic services of electricity to areas of informal housing, therefore, illegal connections are established (Shokoya and Raji, 2019). In informal settlements, many occupants cannot afford to pay for electricity (Mbanjwa et al., 2023). This is an attempt by these communities to gain access to the electrical supply, however, these practices are unsafe and increase the risk of electrical injury or death (Louw and Bokoro, 2019). According to a publication by the Western Cape Government (2019), it was reported by the South Africa Police Services, that the country loses an estimated R2 billion to R5 billion annually, due to power outages caused by illegal connections and cable theft. This is through the replacement of such resources and the necessary interventions to secure the copper (Nkwana and Mpuru, 2019). This supply of electricity is not regulated nor well-maintained, therefore, illegal connections are a significant contributor to electrical deaths in South Africa.

Even though the establishment of illegal connections is a criminal offence, the problem is a systemic issue (Geyevu and Mbandlwa, 2022). The lack of access to a regulated electrical supply has many contributing factors. Namely, the increasing price of electricity and the increasing unemployment rate. With regular disruptions to the electrical supply or loadshedding by ESKOM, it is crucial that areas and activities with high risk of electrocutions be identified. The rise of electrical prices can explain the trends of electrocution seen in the study (Bowman, 2021). This is due to the establishment of illegal connections in order for informal settlements to gain access to this energy supply (Gaunt *et al.*, 2012). Despite community knowledge of the dangers of illegal connections in certain informal regions in KwaZulu Natal, the lack of service delivery to electrify these areas results in electricity theft and the establishment of more illegal connections (Geyevu and Mbandlwa, 2022).

Access to electricity has become a larger, nationwide challenge with the implementation of regular rolling blackouts, also known as loadshedding (Bowman, 2021). Loadshedding and restricted access to electricity are likely contributing factors to the incidence of electrical deaths. It was reported that in March 2014 was the first occurrence of loadshedding in South Africa since 2008 (Niselow, 2019). Throughout 2015, loadshedding was implemented for 99 days and this was primarily from January to September. More notable power cuts took place in June, November and December 2018. In 2019 the stages of loadshedding had increased and occurred mostly in February and March.

2.6 Conclusion

The literature suggests that electrical deaths in South Africa are a significant problem, with the majority of deaths occurring due to contact with high voltage power lines and faulty electrical wiring. Although electrical fatalities are not common in comparison with other pathological fatalities in the country, these deaths are preventable. Hence, the reporting of such cases will provide information to potentially avoid such tragedies (Spies and Trohman, 2006; Keyes and

Liphoko, 2021). With the advancement of technology and the increase in electrical appliances, the risk of electrical shocks and injuries have increased (Duff and McCaffrey, 1999). There is vast number of variable circumstances of accidental electrical deaths, therefore, it is difficult to predict the extent of bodily damage (Lee, 1997). It is, therefore, imperative to prevent such deaths from occurring by identifying the electrical sources and groups most susceptible. Reflecting on the main source of electrical supply in the country and reporting the challenges faced, such as loadshedding, could indicate the reasons for trends in electrical deaths in the region. It is important for the government and stakeholders to invest in improving electrical infrastructure and enforcing safety regulations to reduce the number of electrical deaths in South Africa.

2.7 Aims and Objectives

The overarching aim of this study was to investigate the prevalence and patterns of electrical death in the Western Cape Province. This was achieved through the following objectives:

1. Identify the prevalence of electrical deaths across the Western Cape between 1 January 2011 and 31 December 2020.
2. Determine the age group and sex most vulnerable to electrical deaths.
3. Document the presence and anatomical location of trauma.
4. Assess the risk of individuals typically vulnerable to electrical deaths.

Chapter 3: Methodology

3.1 Study Design

This study was a retrospective, longitudinal investigation of electrical deaths within the Western Cape Province of South Africa. The study investigated all cases between 1 January 2011 and 31 December 2020, where the external cause of death was related to electrocution. Here electrocution was defined as damage caused by generated electric current passing through the body. This included death due to electric shock, burn injuries caused by arc light, and injuries caused by falls from height due to electric shock. Part of the mandatory criteria was a cause of death, determined by a forensic pathologist, that is related to electrical trauma. Data from all mortuaries in the Western Cape (Table 3.1) were included in the study and analysed according to the designated health districts.

The study was broadly broken up into two components. The first component assessed all data from the Western Cape Province to ascertain provincial patterns. The second component was an in-depth analysis of cases from Salt River mortuary to obtain higher level resolution, particularly surrounding associated injuries.

Ethical clearance to conduct this study was obtained from the University of Cape Town Human Research Ethics Committee (HREC ref: 516/2022) (Appendix A) and the Western Cape Department of Health via application WC_202209_001 (Appendix B).

3.2 Western Cape data

From the Western Cape Government data, the health districts were assigned according to the towns/suburbs given for each case.

3.2.1 Data collection

The data from the Western Cape Government was collected from the Forensic Pathology Services (FPS) Business Information Management System (BIMS) database. Variables associated with this data included: manner of death, external cause of death, sex, date of death scene, injury, age and blood alcohol concentration results. These were used to ascertain the prevalence of electrical deaths per health district per year.

Table 3.1: The health districts of the Western Cape, associated mortuaries and the approximate number of cases per year.

Health District	**Mortuaries**	**Cases per year***
Cape Winelands	Stellenbosch	500-999
	Paarl	500-999
Central Karoo	Beaufort West	0-249
	Laingsburg	0-249
City of Cape Town	Salt River Academic Centre	>2000
	Tygerberg Academic centre	>2000
Eden	George	500-999
	Knysna	250-499
	Mossel Bay	250-499
	Outshoorn	500-999
	Riversdale	0-249
Overberg	Hermanus	250-499
	Swellendam	0-249
West Coast	Malmesbury	0-249
	Vredenburg	0-249
	Vredendal	0-249
	Wolseley	0-249

*Mortuary intake estimates obtained from www.westerncape.gov.za

3.3 Salt River Mortuary data

3.3.1 Data collection

For the period from 1 January 2011 to 31 December 2020, cases pertaining to electrical deaths at Salt River Mortuary were retrospectively reviewed. Relevant cases were obtained from the Office Autopsy Database (HREC: R036/2014). Once identified, the relevant data was extracted, anonymised and analysed according to age (years), sex, injury, extent of injury, alcohol concentration and temporal trends to ascertain the prevalence in the Western Metropole of Cape Town. Following this, hard-copy medico-legal case files, which include a post-mortem report and death scene documentation, were reviewed for each electrical death. The overview information surrounding the death and hospital admittance was located in additional notes within the FPS002 form. The data recorded from the post-mortem reports included circumstances surrounding death, suburb, death scene, blood alcohol concentration and the cause of death declared by the forensic pathologist. Extracted information was password-protected and stored in Excel 2016. The electrical voltage was determined based on postmortem findings or the electrical source that caused the electrocution. The voltage was then listed as high, low or unknown, depending on the circumstances. This information was inferred based on the standard voltages associated with the various electrical sources. Low voltage was listed for electrical sources below 1000V, hence high voltage was stated for electrical sources over 1000V.

The extent of injury was attained by reviewing the postmortem reports, where the bodily region, injury type and size of injury (cm) were reported. The report contained the overall findings, detailed descriptions and the primary cause of death. The electrical injuries in each of the cases were documented according to the classification given in the postmortem report, by the forensic pathologist performing the autopsy. The injury type and location on the body were recorded to quantify the extent of electrical injury seen in each electrical death. The incidence of electrical injury was sorted in body region categories and displayed using a diagram made on QGIS 3.30.3 software, Open Source Geospatial Foundation (OSGeo). For the purpose of this study, the appendages were not analysed according to anterior and posterior classifications on the body.

3.3.2 Inclusion and exclusion criteria

Data from the FPS 002 form was used to ascertain circumstance and form FPS 007 indicated the medicolegal autopsy findings by the official pathologist. Electrical trauma is here defined as exposure to electrical current such that injury or tissue damage is inflicted significantly enough to result in a fatality. Individuals of any age were analysed in the study. Deaths with electrical trauma present but where the primary cause of death is related to another mechanism (eg; blunt force trauma due to falling) were included. Cases where the cause of death was still under investigation or could not be determined were excluded. Although cases where death was due to burning associated with the initiation of a fire from an electrical source/electrical malfunction are considered electrical deaths, these were excluded as the cause of death was associated with the fire and not exposure to an electrical current.

3.3.3 Data Analysis

All statistical analysis was conducted using SPSS Ver 28 (IBM Corp, Armonk, NY). Statistical significance was determined based on a p-value <0.05. All data were analysed descriptively, and frequency distributions were generated using the population data from the latest census (2011) of South Africa. Each electrical death was categorized according to the Western Cape health districts (Table 3.1), using the towns and suburbs given. Prevalence was reported as percentage of total cases and per 100 000 population, where possible. Categorical data was descriptively assessed as frequency distributions. Association between categorical variables was determined using Pearson's Chi square tests. The mean age between groups was assessed using one-way Analysis of Variance (ANOVA) and presented as box plots.

Chapter 4: Results

Within this study two data sets of the electrocution cases from 2011 to 2020 were analysed. An aggregated data set for the whole Western Cape Province and a more detailed data set encompassing cases investigated at Salt River Mortuary. The data set for the Western Cape was analysed to assess the prevalence of electrical deaths throughout the province and highlight health districts of potential concern. Following this, data from Salt River Mortuary (SRM) was analysed to provide further information regarding the circumstances and injuries surrounding fatal electrocutions.

The analysis of data at a provincial level provides insight into areas of concern for policy makers. This provides further insight into the electrical deaths and allows informed decision making. Gathering the data from many years ensures that targeting interventions are based on trends and not rare occurrences. Therefore, resources to prevent such deaths can be allocated based on the regional needs in the province. The identification of vulnerable populations is crucial to prevent fatalities and understand this impact on the population.

4.1 Western Cape

Over the period of study, the Western Cape recorded 67 072 unnatural deaths. There were 401 (0.6%) electrical deaths recorded in the Western Cape from 2011 to 2020. The relative distribution of cases saw sporadic fluctuation between 2011 and 2018. However, the proportion of electrical deaths increased in 2019 and 2019. Compared to the 2011 cases, the prevalence of electrical deaths was more than double by the end of the study period (Figure 4.1). According to the latest published census (2011), the total population of the Western Cape (WC) was 5 822 734. Therefore, the prevalence of electrical deaths during this period was 0.69 per 100 000 population per year.

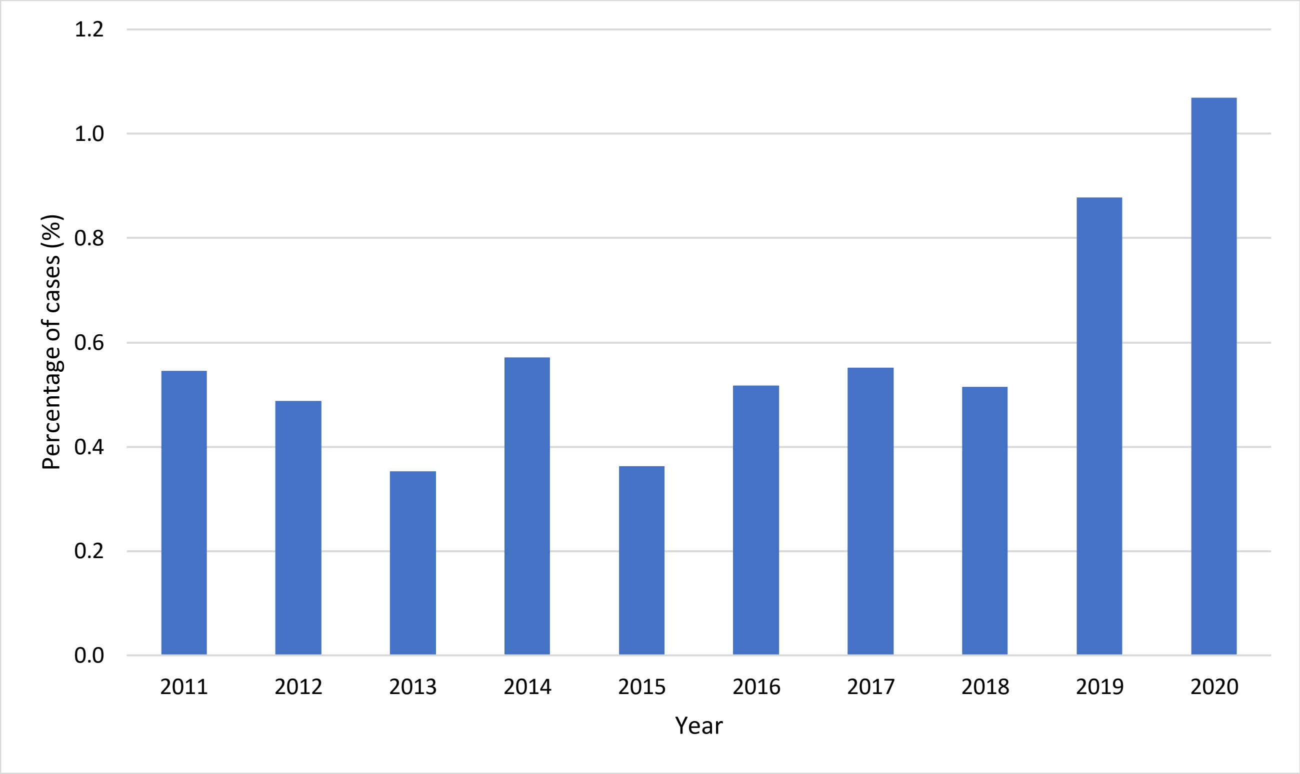

Figure 4.1: The percentage of electrical deaths compared to unnatural deaths reported in the Western Cape Province from 2011 to 2020

4.1.1 Age

The ages of the deceased individuals were recorded for 99.8% of the cases (n = 400). There were six cases, where individuals were aged between 8 to 11 months, that were rounded off to one year old for the purpose of analysis. The oldest individual was 83 years old. The mean age was 25.9 years old, and the median age was 26 years old. Most of electrical deaths (133; 34.4%) occurred in the age group 21 to 30 years (Figure 4.2). The youngest age group, 0 to 10 years old, had the next highest prevalence with 21.2% of cases (n= 85), followed by 31 to 40 years with 20.7% (n= 83) of the cases. Differences in the proportion of cases in each age group were not significantly different (p = 0.38).

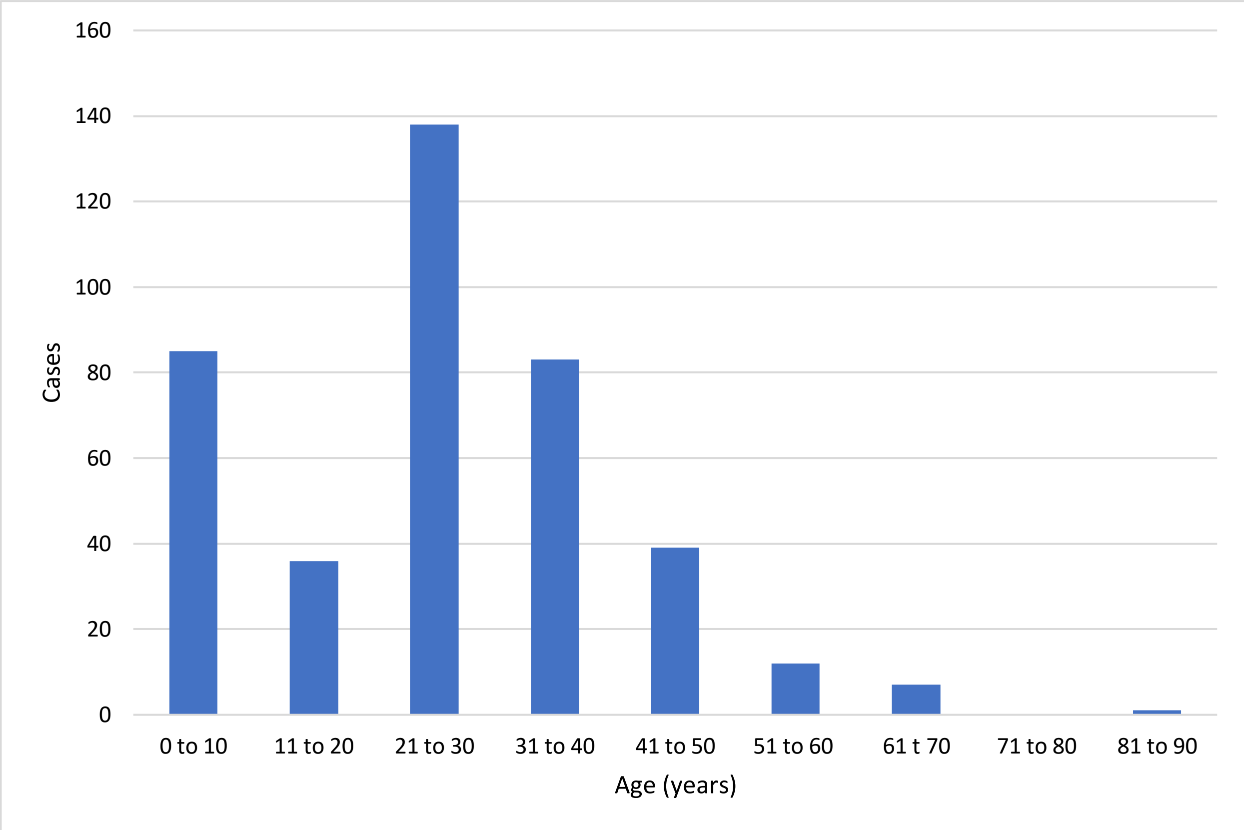

Figure 4.2: Bar graph indicating the age distribution seen in the Western Cape Province data over the period of study.

4.1.2 Sex

A significantly greater proportion of males (340; 84.8%) were involved in electrical deaths compared to females (61; 15.2%) ($p = 0.53$). This pattern was consistent across all age groups. The prevalence of electrical death was 1.2 per 100 000 population per year in males and 0.2 per 100 000 per year in females.

In 98.8% (n= 396) of the cases, the manner of death was classified as accidental. Within the accidental electrocutions (n=396), 84.8% (n =336) were male and 15.2% (n= 60) were female. Homicides made up 0.7% (n= 3) of cases and suicides were seen in 0.5% (n= 2) of cases. Both the suicides were male individuals in 2011, they were 61 years old and 26 years old, respectively. From the homicide cases, one was a 47-year-old female. The other two homicides were a 32-year-old male and a 9-year-old male. No statistical association between manner of death and sex was observed ($p = 0.53$). Most females were aged between 0-10, however, this was not statistically different from the distribution observed in males ($p = 0.61$)

Table 4.1: The ages, grouped into categories, associated with each sex across the study.

	Sex	
Years	**Male**	**Female**
0 to 10	60	24
11 to 20	29	7
21 to 30	127	11
31 to 40	72	12
41 to 50	34	5
51 to 60	10	2
61 t 70	7	0
71 to 80	0	0
81 to 90	1	0
Total	340	61

4.1.3 Health District

From 2011 to 2020, 64.6% (n= 259) of electrical deaths were reported in the City of Cape Town (CoCT), followed by 15% (n=61) reported in the Cape Winelands (Table 4.2). The rest of the health districts reported smaller proportions of electrical deaths [Eden (9.0%), West Coast (6.2%), Overberg (3.0%) and the Central Karoo (1.7%)]. The prevalence of electrical deaths per health district per year revealed that districts ranged from 0.44 to 0.99 per 100 000 per year (Table 4.2). When looking at the population size per health district, Central Karoo had the highest prevalence with 0.99 per 100 000 per year. Approximately 18.2% of death scenes were reported to have occurred in informal housing (Figure 4.3). With the next prevalent scene being the railway track (16%).

Table 4.2: The number of electrical deaths, prevalence per 100 000 per year, average age and male-to-female ratio of electrical decedents in each Health District.

	Cape Winelands	Central Karoo	City of Cape Town	Eden	Overberg	West Coast	Total
Number of cases	61	7	259	36	12	26	401
Prevalence per 100 000	0.76	0.99	0.69	0.63	0.46	0.64	0.69
Average Age (years)	28.2	11.0	26.0	23.9	28.3	32.1	28.2
Male: Female	7.7:1	2.5:1	5.5:1	5:1	3:1	7.7:1	5.5:1

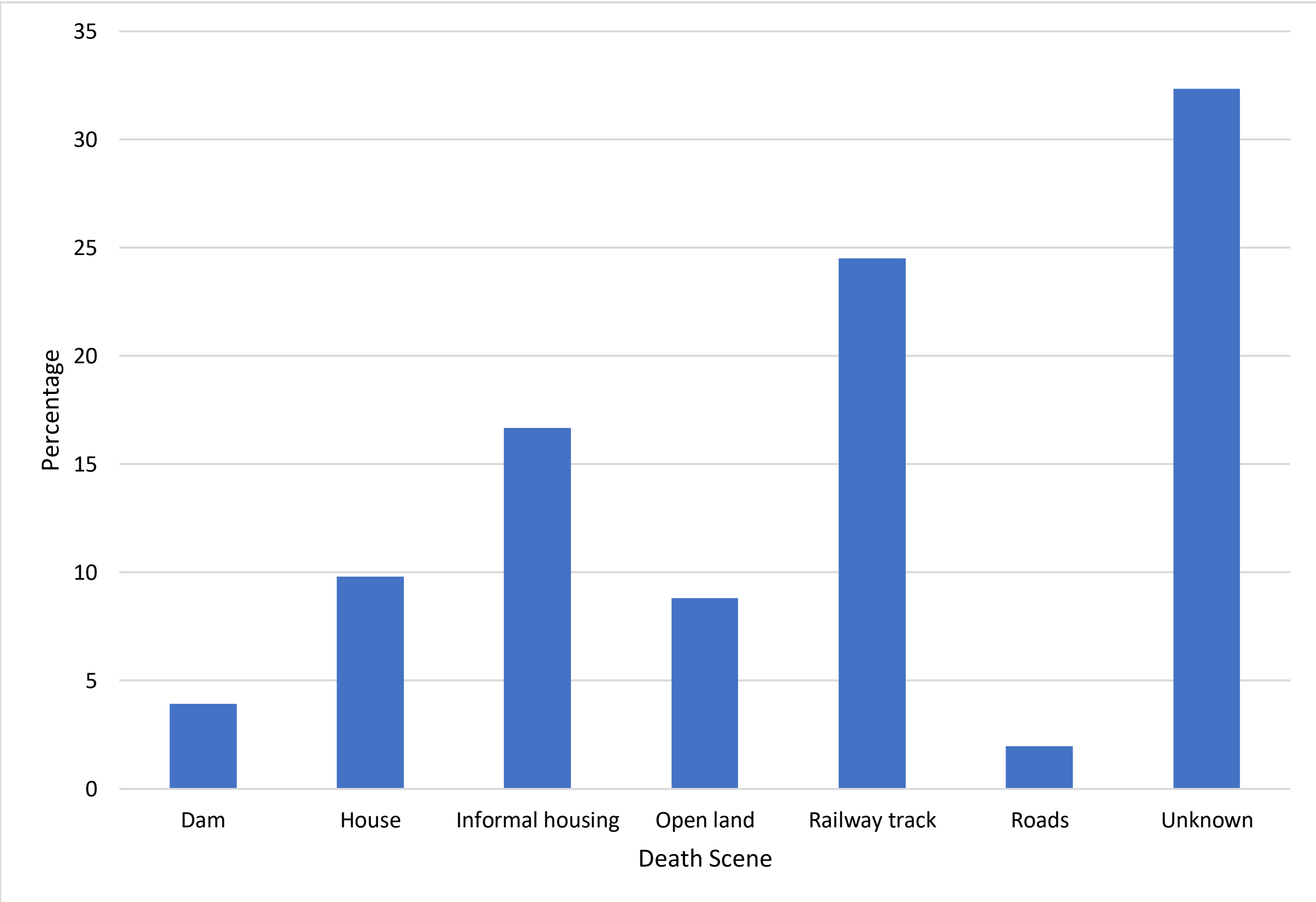

Figure 4.3: The percentage of deaths and associated death scenes in the Western Cape.

4.1.4 Temporal patterns

The months of the year were analysed with the largest proportion of electrical deaths, 11.5% of cases, occurring in January throughout the study period. December had the next highest electrocutions with 11% of the total cases (Figure 4.4). The months with the lowest percentage of electrical deaths were June and April, 5% and 6% respectively. An analysis into the days of the week associated with the electrocutions revealed that 16.2% of the deaths occurred on a Sunday, followed by 16% of cases on Saturdays and 15.7% on Thursdays (Figure 4.5).

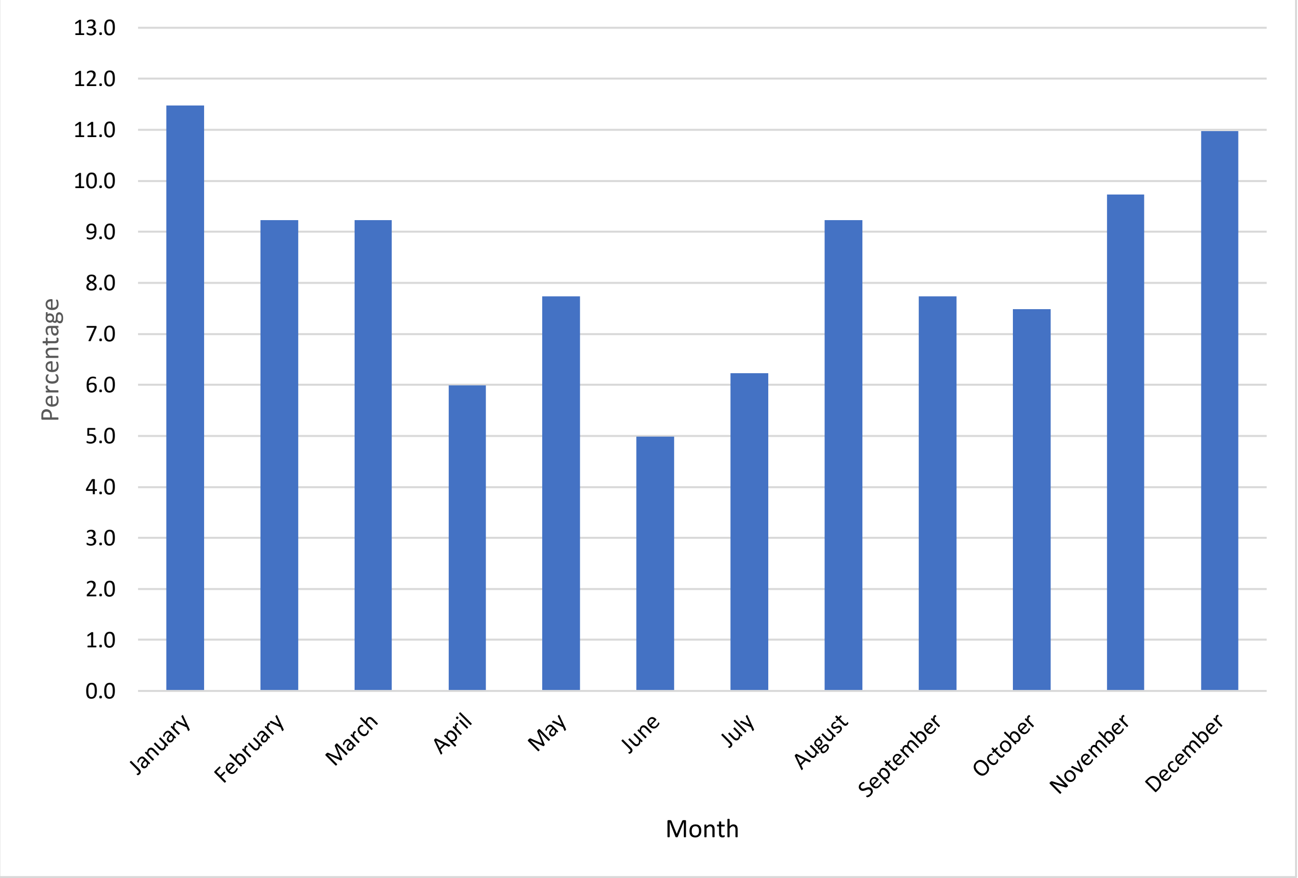

Figure 4.4: The percentage of electrical deaths reported in each month from 2011 to 2020.

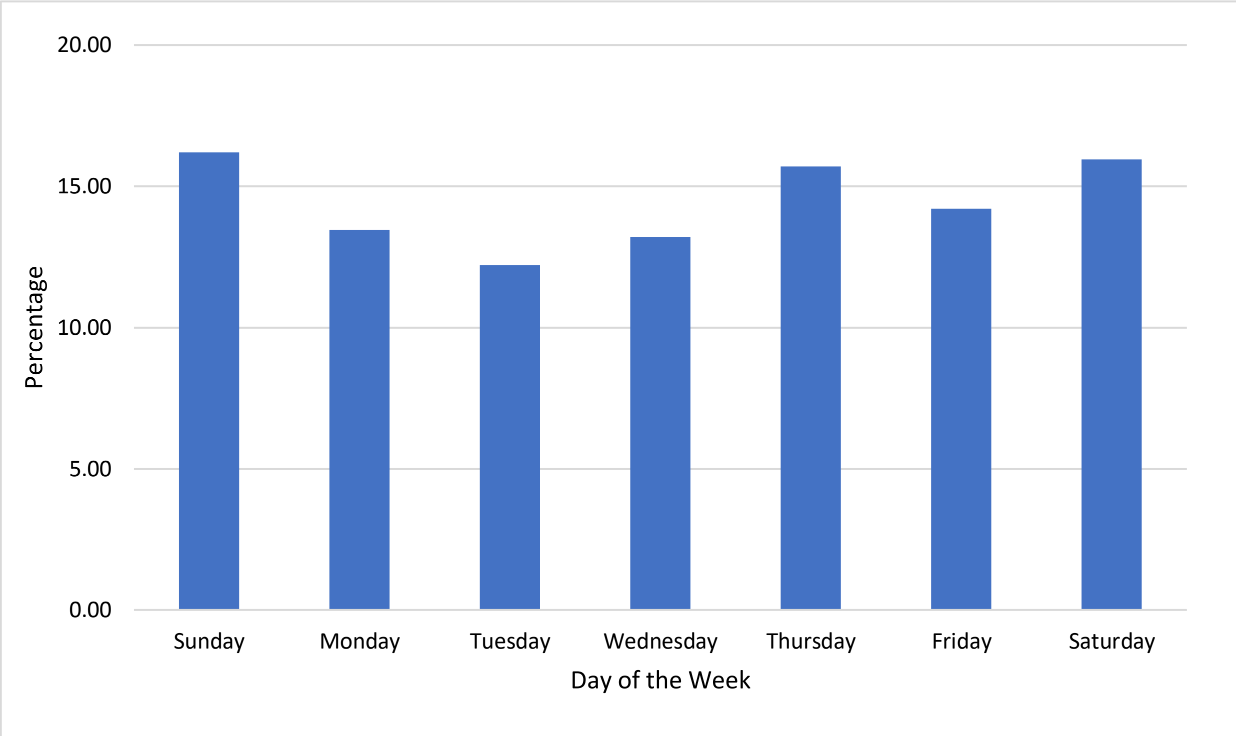

Figure 4.5: Percentage of electrical deaths that occurred on each day of the week over the ten-year period.

4.1.5 Blood Alcohol Concentration

From the Western Cape data set, samples for blood alcohol analysis were retained in 62.8% (n= 252) of cases. No sample was retained in 37.2% (n= 149) of the cases. In the cases with a positive blood alcohol, the range of concentrations varied from 0.01g/100ml to 0.47g/100ml. In majority of the cases (53%), the concentration was less than 0.05g/100ml (Figure 4.6). Within 8.98% of all cases, the individuals had recorded blood alcohol concentration of 0.05g/100ml and higher. The majority of individuals with BAC > 0.05g/100ml were males.

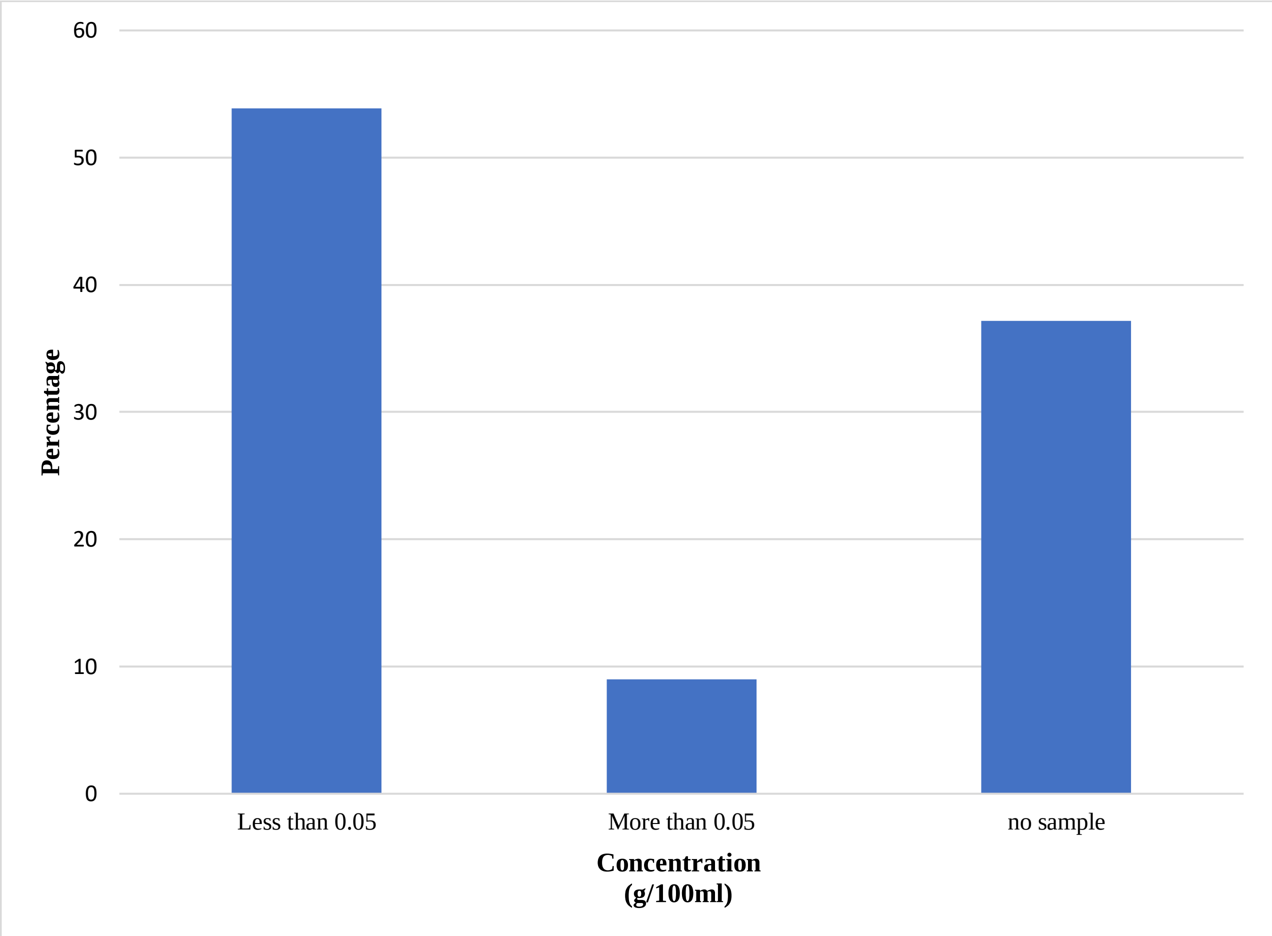

Figure 4.6: The blood alcohol concentration (g/100ml) recorded as percentages of the electrical deaths in the Western Cape.

Table 4.3: Summary of the Western Cape Province data and prevalence per year.

	Male (84.8%)	**Female (15.2%)**	**Total**
Total prevalence	1.2 per 100 000	0.2 per 100 000	0.69 per 100 000
Age			
0-10	60	24	84
11-20	29	7	36
21-30	127	11	138
31-40	72	12	84
41-50	34	5	39
51-60	10	2	12
61-70	7	0	7
71-80	0	0	0
81-90	1	0	1
Health district			
Cape Winelands	55	5	60
Central Karoo	5	2	7
City of Cape Town	219	40	259
Eden	30	6	36
Overberg	9	3	12
West Coast	23	2	25
BAC			
>0.01g/100ml	37	7	44
>0.05g/100ml	29	7	36

4.2 Salt River Mortuary

4.2.1 Data Analysis

Between 2011 and 2020, there were 35 738 autopsies conducted at Salt River Mortuary in Cape Town. Of these deaths, 102 (0.29%) cases were included in this study as electrical deaths.

4.2.2 Number of Deaths per year

The number of electrical deaths increases from 2013 to 2015 then experiences a decline in 2016 (Figure 4.7). Thereafter, the percentage of electrical deaths steadily increased until the highest percentage was reached in 2019 and 2020, with 17.7% (n= 17) of the total electrical deaths reported in the study. In the last two years of the period of study, 35.4% of the cases studied were reported.

In this study, most electrical deaths were recorded in Philippi (n = 15) followed by Gugulethu (n = 13), Mitchell's Plein (n = 9), Langa (n = 7), Nyanga (n = 6) and Pinelands (n = 6) (Figure 4.8). There were suburbs that recorded one electrical death in the ten-year period in suburbs such as Camps Bay, Maitland, and Woodstock. A list of the number of cases per suburb can be found in Appendix C. According to the latest published census in 2011, there were 3 740 026 people reported in Cape Town. Therefore, the prevalence for Salt River Mortuary was 0.27 per 100 000 per year.

Only one suicide by electrocution was reported during the study period, a prisoner found with an electrical cord wrapped around his neck, had died due to the injuries from the direct electrical exposure. There was one case where the manner was allegedly homicide by community assault, however, this was inconclusive according to the case file. All other electrocutions in the study were accidental.

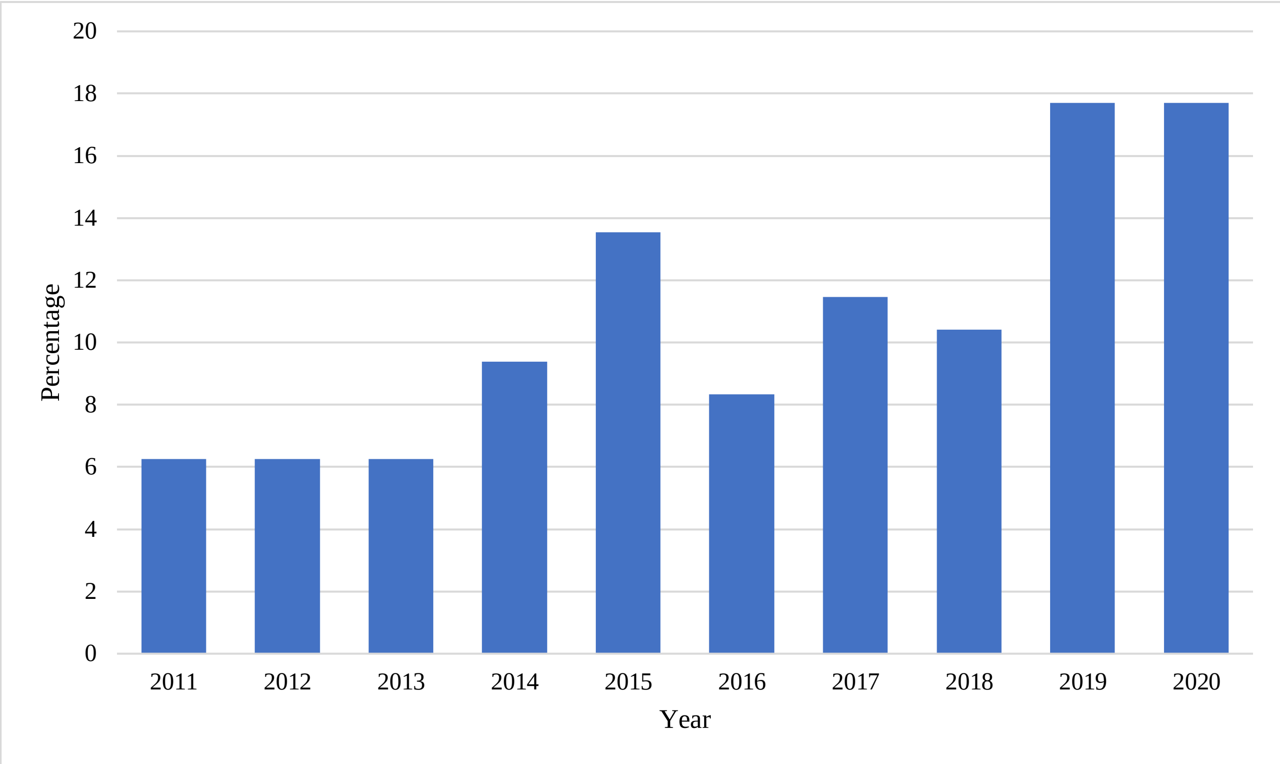

Figure 4.7: The percentage of electrical death cases observed at the Salt River Mortuary, each year from 2011 to 2020.

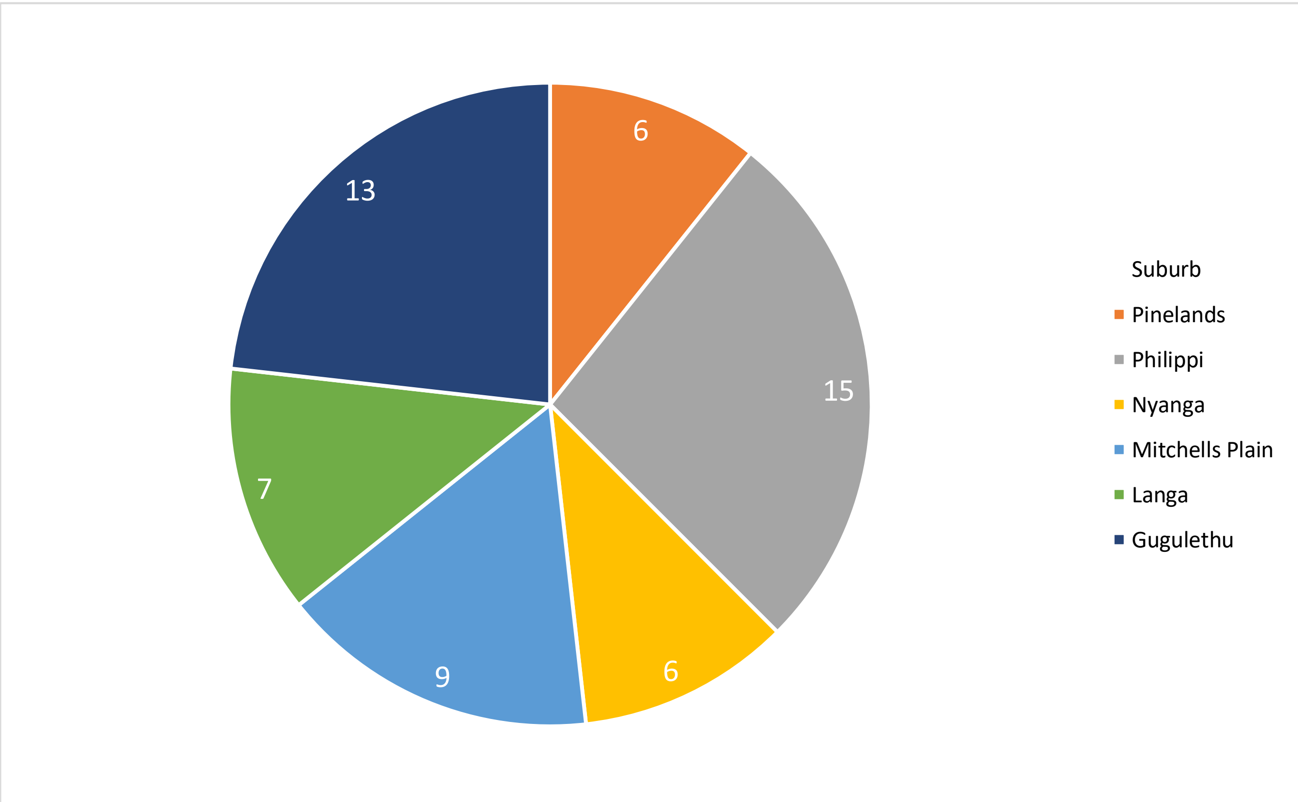

Figure 4.8: Pie chart of the suburbs where the most electrical deaths occurred.

4.2.3 Age and Sex

Within the SRM data, the youngest individual involved in an electrical death was recorded as 1 year old and the oldest individual was 65 years old. The mean age of the decedents was 24.2 years old. The median of the data was 25.5 years old. From 2011 to 2020, the data consistently reported that the most susceptible ages to electrical fatalities, were that of individuals below 35 years old (Figure 4.9). It was reported that 54.9% of adults aged 18-40 years old, were the most prevalent age range (n= 56) in this study. Furthermore, in 27.4% (n= 28) of cases the decedents were minors.

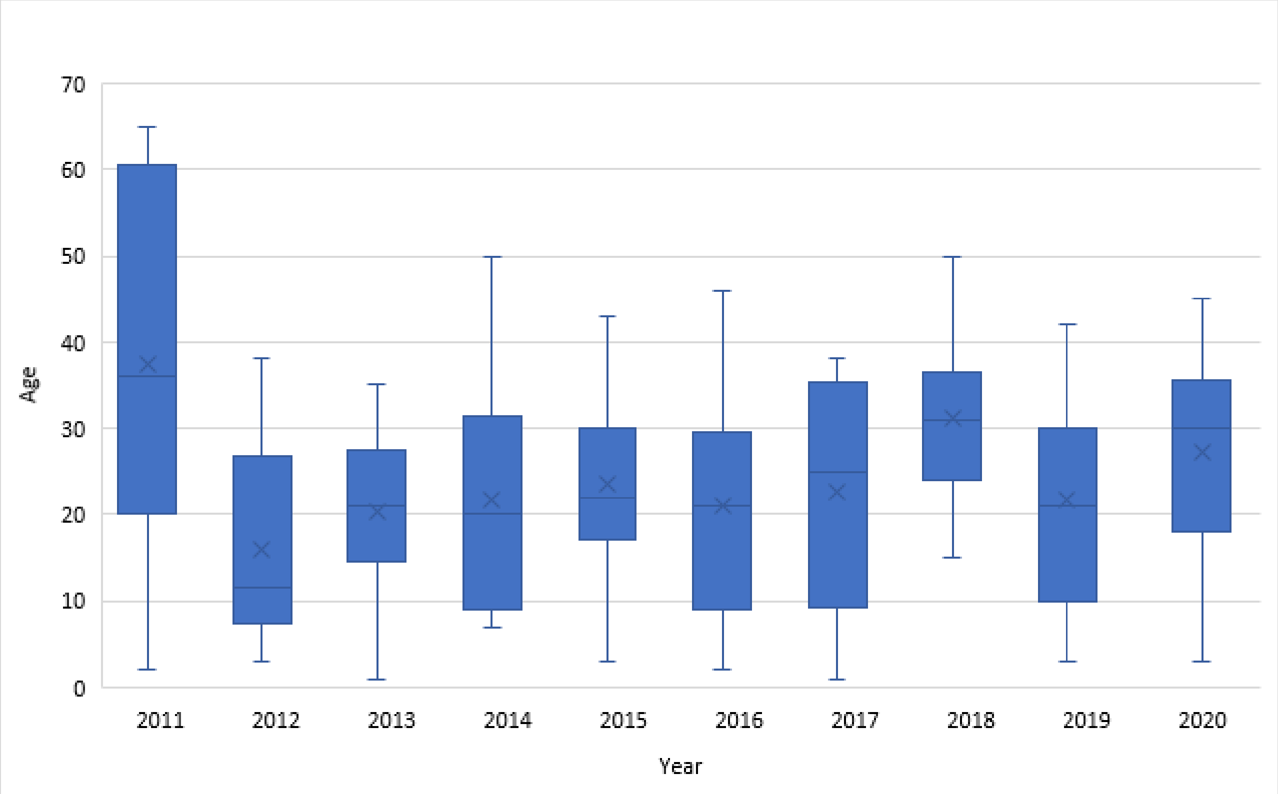

Figure 4.9: Box-and-whisker plots displaying the age ranges of the decedents of electrical deaths from 2011 to 2020.

A total of 83 males (81.4%) and 19 females (18.6%) were involved in electrical deaths over the ten-year period. In no cases was the sex of the individual not determined. The prevalence for electrocution for males was 0.49 per 100 000 per year and for females 0.1 per 100 000 per year.

4.2.5 Circumstances of death

The source of electrocution was known in 93.1% (n = 95) of the cases. The electrical sources in these electrical deaths were primarily associated with live wires (n= 52; 51%), railways lines (n= 29; 28.4%),) and appliances (n= 7; 6.9%),). The electrical source was unknown in 6.9% of the cases. In 36.4% (n= 35) of cases the circumstance surrounding the electrocution was allegedly related to illegal connections. In all of those cases, the electrical source was contact with a live wire. Additionally, contact with a live wire through cable theft was reported in 21.6% (n=22) of cases.

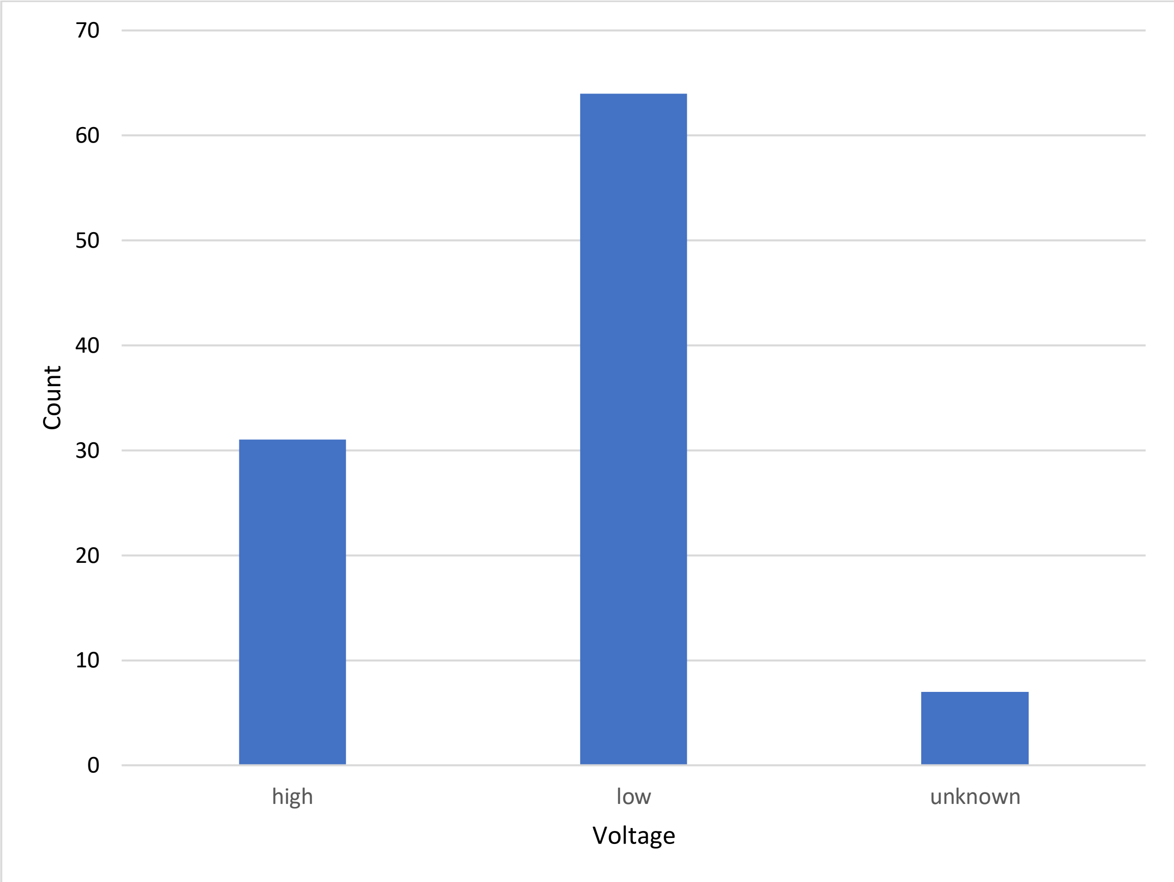

Figure 4.10: Graphical representation of the number of alleged high, low or unknown voltages recorded in each electrical death investigation.

The suspected voltage associated with electrocution was obtained from the case file in 95 cases (93.1%) based on the circumstances and reports. There were 7 cases where the electrical source was unknown (Figure 4.10). The alleged low voltage electrical deaths accounted for 67.4% (n = 64) of the cases and suspected high voltage electrical deaths in 23.5% of cases (n = 24).

All deaths associated with high voltage occurred in males. It was found that in low voltage deaths, 24.3% (n= 17) of cases involved females, whereas 75.7% (n= 53) of low voltage deaths involved males (Figure 4.11)

The scene of the death was reported in majority of the cases and it was found that most decedants died in hospitals, on the railway track and in informal settlements (Figure 4.12). Circumstances surrounding deaths were analysed in terms of electrical current and source of electrocution. There were 13.7% of SRM cases reported as freak accidents. Double the amount of workplace electrical deaths occurred compared to home fatalities (Figure 4.12). Although death by lightning is regarded as electrocution, there were no deaths due to lightning strikes reported. Some of the decedents (n =

22, 21.6%) succumbed to their injuries while being treated in hospital. Where death occurred at the scene, 25% occurred at railway tracks and 17% in or near informal housing.

There were a variety of circumstances surrounding male electrocutions compared to the female electrocutions (Figure 4.13). The predominant females circumstances of electrocution included freak accidents and illegal connections, while the male circumstances included cable theft (21.6%), illegal connections (19.6%) and train surfing (13.7%).

During the period of study, the majority of the electrical deaths due to alleged exposure to illegal electrical connections resulted in the deaths of individuals (63.9%) below the age of 20 years old (Figure 4.14). Further analysis reports that 40% (n = 14) of these deaths involved children below the age of 10 years old. More than half of all electrical deaths in children younger than 5 years old were associated with illegal connections. In most of these cases, the children were playing and were accidentally exposed to the fatal electrical sources.

One such case was a 20-month-old female that allegedly touched barbed wires, in an informal settlement, that resulted in a fatal electrocution. The body appeared damp at autopsy, which enhanced the intensity of electrocution, resulting in congested organs and oedema. In this case, the mother was also electrically shocked but survived.

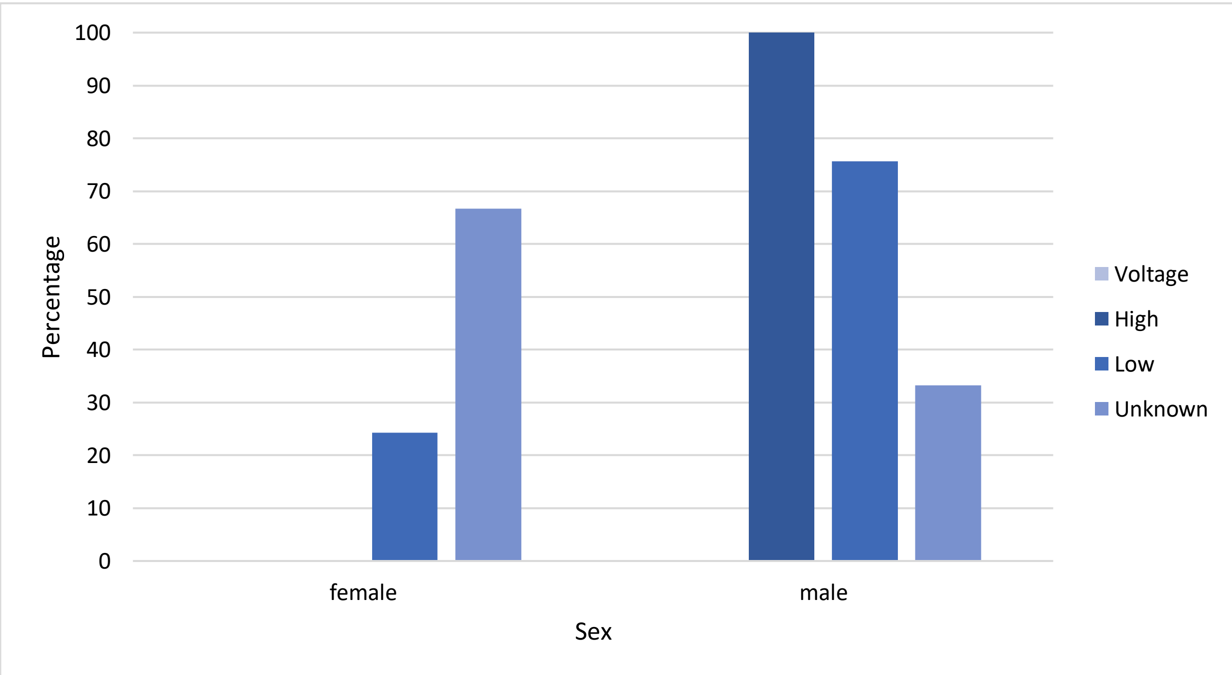

Figure 4.11: The percentage of cases with high, low or unknown voltages and the associated sex in each electrical death at the Salt River Mortuary.

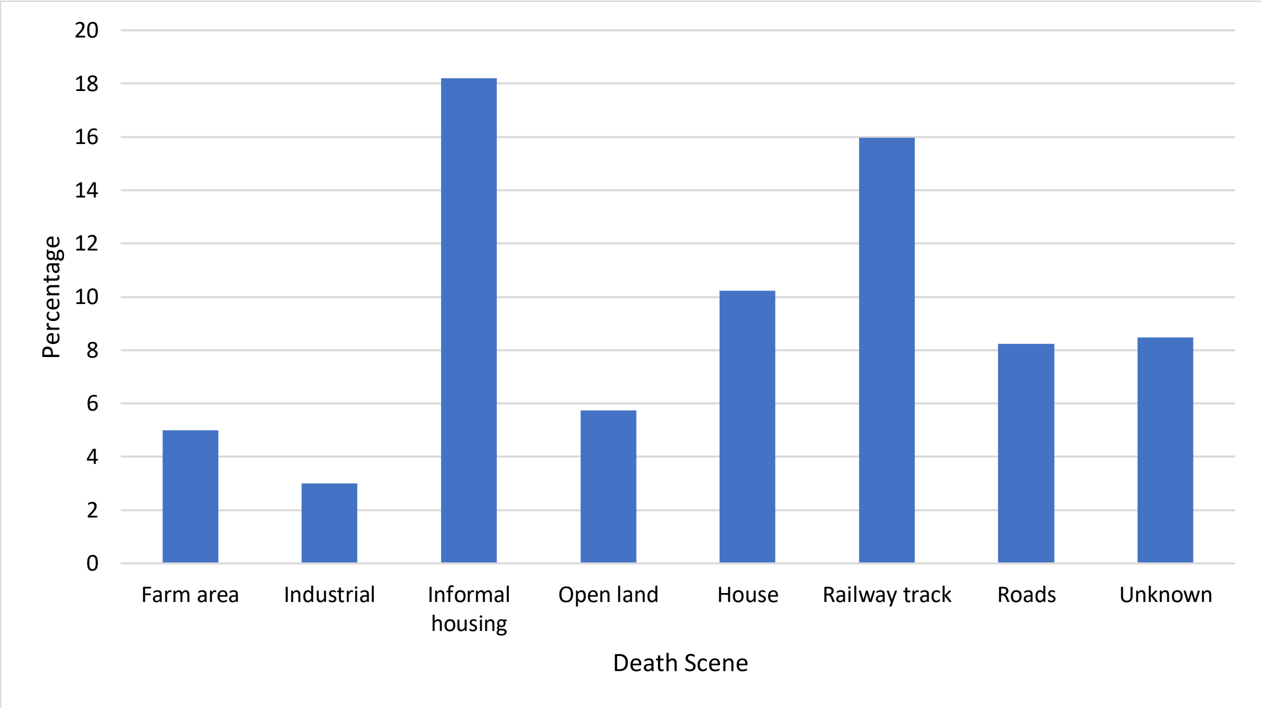

Figure 4.12: The percentage of deaths and associated death scenes.

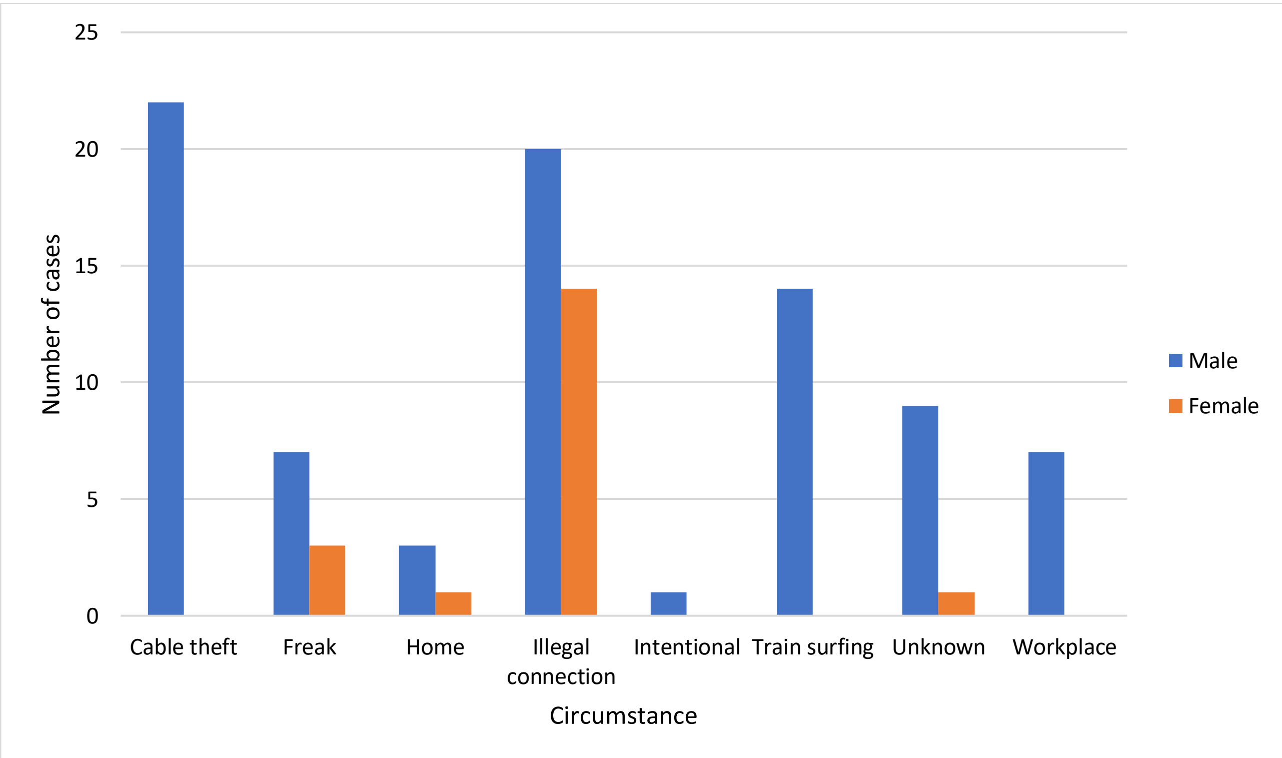

Figure 4.13: The circumstances associated with male and female electrical deaths at Salt River Mortuary from 2011 to 2020.

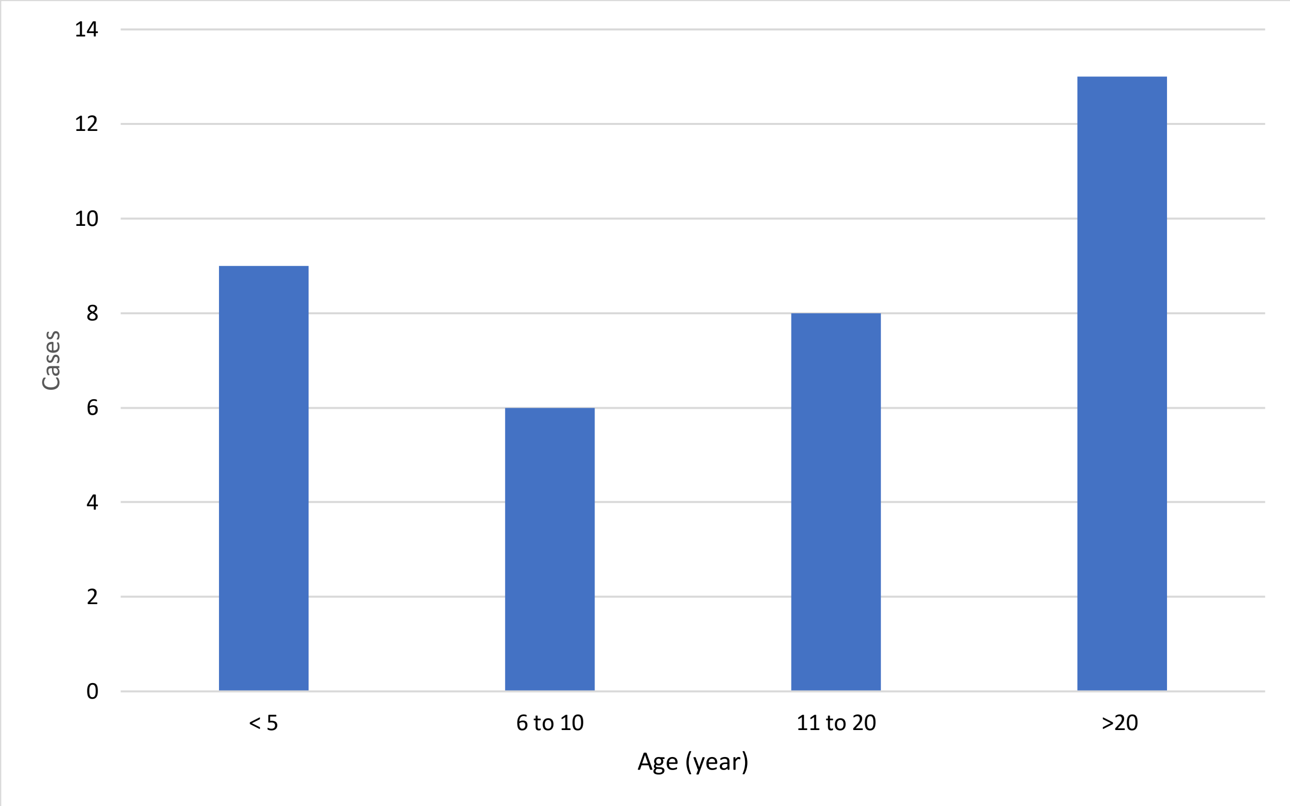

Figure 4.14: Bar graph representing the ages of deceased individuals involved in electrocutions allegedly due to illegal connections.

4.2.6 Blood Alcohol Concentration

There were 24 cases, where the toxicology report was not present at the time of data collection. From the SRM data, 45.1% of the cases (n = 46) had blood collected for alcohol analysis. Of these cases, 80.4% (n = 37) had no blood alcohol detected (Figure 4.15). There was a positive alcohol concentration in 19.6% (n= 7) of cases submitted for BAC analysis. The lowest recorded BAC was 0.01 g/100ml and the highest was 0.34g/100ml.

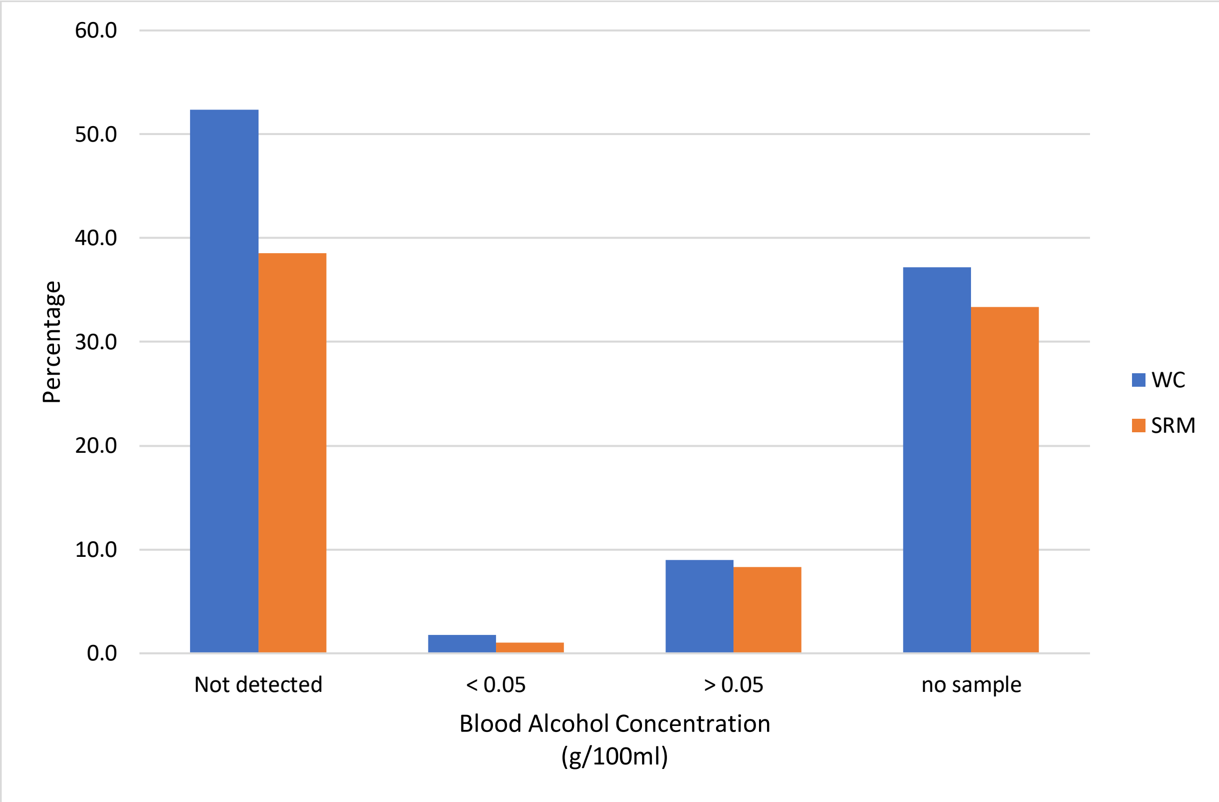

Figure 4.15: The blood alcohol concentration (g/100ml) recorded as percentages of the electrical deaths in the Western Cape (blue) and Salt River Mortuary (orange).

4.2.7 Injury

A total of 370 injuries were recorded, equating to a mean of 3.6 injuries per person. In 94.1% (n= 96) of cases, at least one electrical-related injury was present. A total of 324 joule burns were observed in 82 individuals. Some association was observed between the electrical source and type of injury. Exposure to a live wire of illegal connections contributed to injuries in 34.3% of cases, with a linear electrical lesion in at the point of contact in 20% of cases.

Electrical injuries were typically described as having a central crater with raised edges, pale collapsed blisters, melted epidermis and charring of the skin. In a few cases, necrosis, de-epithelization and charring was observed. Charring was reported in 32.4% (n = 33) of the cases, with an even distribution between high and low voltage electrocutions. The low voltage charring injuries occurred with exposure to illegal connections, therefore, no insulation was likely present. The charring was predominantly seen in the forearms and fingers. However, some cases reported charring in the upper and lower legs.

A representation of the anatomical distribution of injuries can be seen in Figure 4.16. Most injuries were observed on the hands (137 injuries), followed by the head (18) and abdomen (22). There were

21 electrical injuries observed on the right foot. No significant difference in the proportion of injuries to the right (188 injuries) or left side (186 injuries) of the body were observed ($p = 0.093$).

Exit wounds were observed primarily on the feet or hands (62.5%) of individuals. However, in some cases the exit wound was located elsewhere on the body due to contact with a secondary object which grounded the electrical current. One individual had electrical burns on the right palm (entrance wound) and two parallel lines of blisters on the lower abdomen (exit wounds) that corresponded to a metal belt buckle worn at the time of death. The youngest was an 11-month-old male that touched an exposed wire of a television set, the electrical injury was seen on the right hand and foot. The exit wound was a ruptured, blackened blister at the base of the right big toe. Another individual had an exit wound located on the shoulder.

Electrical injuries often presented with associated abrasions, lacerations and fractures. From these non-electrical injuries, abrasions were observed in approximately 30.1% of non-electrical injuries (n= 31). Necrosis was observed in two of the cases allegedly surrounding circumstances of cable theft. There were 6 cases (5.9%) with no external injury, however, congestion in organs including the lungs, kidneys and brain were observed at autopsy. Organ congestion was reported in 68 (66.7%) cases, most commonly of the lungs (n=71; 69.6%). Petechial haemorrhage was recorded in three (2.9%) cases, two involving alleged cable theft and the third 7-year-old involved in a freak accident with an appliance.

An analysis of the male and female patterns of injury found that males were reported to sustain more injuries than females, with an average of 3.7 and 2.9 per body, respectively (Figure 4.16). The most prominent body region of electrical injury was hands seen in males (78.4%) and females (28.9%). Body regions of other injuries were primarily on the left forearm, right lower leg and the left foot in females. The chest and back region had the next highest injury count for the males in the study. However, there were up to 20 injuries seen on the forearms, arms, abdomen, lower legs, upper left leg and right foot.

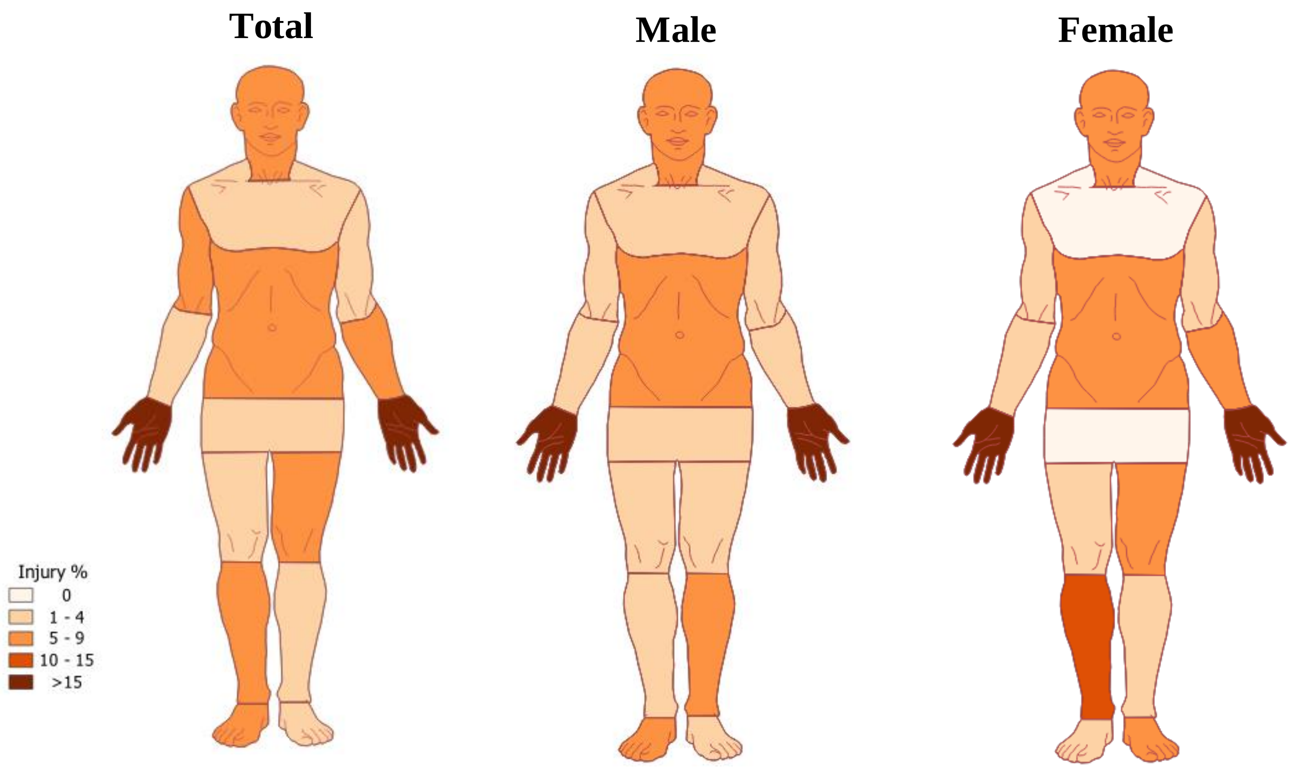

Figure 4.16: Anatomical distribution of electrical injury prevalence in male and female cases. The anterior and posterior regions of the appendages and extremities were not considered separately.

Different bodily regions contained injuries according to the age groups. In decedents 10 years old and younger made up 20% of SRM cases. The injuries were primarily seen on the hands and feet in approximately 50% of the cases in this age group. These injuries often occurred while the children played and accidentally touched or stepped on electrical sources such as live wires.

In the teenagers, aged 11 to 17 years old, 50% of the electrocutions were due to exposure to illegal connections. One case involved a decent who drank water from a tap that was near electrical wires, which led to electrical injuries on both hands and the left big toe. In the individuals that were considered late teens, the resulting injuries were predominantly located on the lower limbs, as opposed to the extremities. The circumstances revolved around train surfing, where extensive burns were seen in the upper and lower limbs. The burns were described as charred with central blisters and hypopigmentation.

Chapter 5: Discussion

This study investigated electrical deaths within the Western Cape Province of South Africa between 2011 and 2020. A multicentre study of electrocutions over a ten-year period has not previously been conducted in the Western Cape Province of South Africa. Over the period of study, there was an increasing trend in electrical deaths, with the number of electrical fatalities doubling by the end of the period of study. A considerable increase in electrical fatalities displays the necessity of the determination of the electrical sources or causes. To prevent future electrical deaths, it is essential to diagnose electrocutions using autopsies, witness reports and evidence analysis (Alqassim, Ewiss and Al-Ali, 2023). Research on patterns of injury contributes to the understanding of areas where interventions need to be targeted.

5.1 Prevalence

In this study, the majority of deaths were accidental (98.8%), which differs from electrical fatalities in developed nations, where suicides are reported in higher proportions (Karger, Süggeler and Brinkmann, 2002; Wick *et al.*, 2006). In total, there were 401 (0.6%) cases across the 17 facilities in the province, equating to a prevalence of 0.69 per 100 000 population per year. This prevalence is larger than many of the reported rates seen in Europe, North America and parts of the Middle East (Lindström, Bylund and Eriksson, 2006; Sheikhazadi, Kiani and Ghadyani, 2010; Masseyet al., 2018), but is low in comparison to developing nations (Dokov and Dokova, 2011; Kumar, Verma and Singh, 2014; Shawon *et al.*, 2019). The reasons for these differences can be behavioural, economic disparities or possibly social in nature. Perpetrators of train surfing are mostly the youth, hence the social factors that encourage this activity include poverty, unemployment and peer pressure (Madzivhandila, Mofokeng and Motsepe, 2022).

To identify the circumstances that lead to fatal electrocutions, an understanding of the region and people within is imperative. Even within individual countries, regional differences in prevalence are reported, as highlighted in India for example (Gupta, Mehta and Trangadia, 2012; Kumar, Verma and Singh, 2014; Giri, Waghmode and Tumram, 2019). While limited research has investigated fatal electrocutions in South Africa, the reported prevalence for the Western Cape is lower than that reported for Kwa-Zulu Natal (1.35 per 100 000 population per year; 2006 – 2016) and greater than that observed in Johannesburg (0.3 per 100 000 per year; 2010 – 2014) (Keyes and Liphoko, 2021; Awath-Behari, 2023).

Within the Western Cape Province, regional differences were also apparent. The prevalence of electrical deaths per health district per year revealed that districts ranged from 0.44 to 0.99 per 100

000. This was based on the population sizes of each health district and highlights the need for intervention to prevent such deaths in the Western Cape. Over 64% of the fatal electrocutions in the province took place in the City of Cape Town (CoCT), with a prevalence of 0.69 per 100 000 per year. Some health districts in the Western Cape have a higher percentage of unnatural deaths than others (Statistics South Africa, 2017). These include Central Karoo, CoCT and Overberg with 15.3%, 14% and 12.2%, respectively. This suggests these health districts are areas where public safety is threatened, and safety measures need to be focused.

To gain an understanding of injury patterns observed in fatal electrocutions, an in-depth analysis of data from Salt River Mortuary (SRM) was also conducted. This facility is regarded as one of the busiest of the 17 facilities in the province (Auckloo and Davies, 2019). The information from the medicolegal case files that contained postmortem investigations, witness statements, police reports and hospital records were collated to determine the sources of electrocution and suspected circumstances surrounding the deaths. The in-depth analysis of Salt River Mortuary data revealed that even within a city, differences may exist at the suburb level. The highest prevalence of fatal electrocution was observed in Philippi, a large area comprising primarily of dense urban regions in the East and semi-urban farm regions in the West. Scenes of death in this area included open land, informal housing, and railway tracks. In most cases, electrocution was associated with exposure to live wires due to illegal connections, while electrocutions by railway lines were due to train surfing or cable theft.

5.2 Age

In the WC, fatal electrocutions appeared to affect a wide range of ages. The age group with the most electrocutions was 21 to 30 years old, which consisted of 34.4% of the cases. This aligns with previous studies where this was the most common age group reported in electrical deaths (Sheikhazadi, Kiani and Ghadyani, 2010). The age groups with the next highest prevalence of electrocutions were 0 to 10 years old (21.2%). Children have also been found to be the most exposed in KwaZulu Natal, South Africa and Adelaide, Australia with most of the electrocutions occurring in this age group (Awath-Behari, 2023 Wick et al., 2006). In Gauteng individuals in the age group of 30-39 years, were reported to have the greatest risk of fatal electrocution (Keyes and Liphoko, 2021). It is interesting to note that the prevalence amongst middle aged adults, few injuries occurred in the workplace, therefore, electrocutions were not as a result of occupational hazards. Rather the prevalence may be associated with electricity in the household, through illegal or accidental exposure to electricity.

The high prevalence of children (21.2%) differs from previous studies as children are rarely the most prevalent age group to have been fatally electrocuted in countries such as Iran, India and USA (Sheikhazadi, Kiani and Ghadyani, 2010; Kumar, Verma and Singh, 2014; Giri, Waghmode and Tumram, 2019). In contrast, in Bangladesh, 33.7% of reported fatal electrocutions occurred in those aged below 17 years (Shawon *et al.*, 2019). The group most at risk of electrocution were young males at the age of 15–20 years old (Kathum and Al-Khateeb, 2019; Shawon *et al.*, 2019).

The current study indicates, most individuals below 20 years old were electrocuted in circumstances surrounding illegal connections. Often children are electrocuted when playing near exposed live wires. Illegal connections are discussed further in 5.6 Circumstances.

5.3 <u>Sex</u>

In this study, there were almost six times more males involved in electrical deaths than females This aligns with the cases being predominantly male in Iran, Iraq and Northern India (Kumar, Verma and Singh, 2014; Sheikhazadi, Kiani and Ghadyani, 2010; Kathum and Al-Khateeb, 2019). In a previous study, no females were involved in electrical fatalities within or near informal housing (Giri, Waghmode and Tumram, 2019). However, in the present study, 42% of females died within or near informal housing. This outlines the need for intervention strategies in such areas to prevent electrical deaths.

The SRM male and female prevalence, 0.49 per 100 000 and 0.1 per 100 000 respectively, was similar to the provincial prevalence. Males were more likely to be electrocuted in a variety of scenarios, while females were only fatally electrocuted during accidental exposure to electrical conductors or live wires. This alludes to the activities involving the risk of electrical deaths being predominantly male (Peng and Shikuib, 1995; Bailey, Forget and Gaudreault, 2001; Wick *et al.*, 2006; Sheikhazadi, Kiani and Ghadyani, 2010; Gupta, Mehta and Trangadia, 2012; Kumar, Verma and Singh, 2014; Massey *et al.*, 2018; Shawon *et al.*, 2019; Keyes and Liphoko, 2021; Awath-Behari, 2023). Activities such as train surfing and cable theft are often conducted in social settings (Hesselink, 2008). From the findings of this study, only males were reportedly participating in such activities.

There were more injuries per body in males than females in the study. Differences in the location of injuries were noted between sexes. Males had more injuries located in similar body regions compared to the females, who displayed a wider variety of injury locations. The activities that the decedents were involved with, at the time of electrocution, could have contributed to these findings. Train surfing and cable theft, activities that only involved males in this study, that expose individuals to high voltage electrical sources that result in more extensive injuries (Sokhal *et al.*, 2017).

5.4 Temporal trends

The highest incidences of electrical deaths occurred in the summer months, November to January which correlates with previous studies (Bikson, 2004; Laupland *et al.*, 2005; Wick *et al.*, 2006; Awath-Behari, 2023). The potential reason for the increased prevalence can be attributed to the higher probability of sweating and moisture found on the body. Moisture serves to increase conduction of electrical current that could influence the extent of injury and potentially increase the risk of fatality (Blumenthal, 2009; Massey *et al.*, 2018). In contrast, a study in Johannesburg reported the majority of the deaths due to electrical burns occurred in the months of winter (Keyes and Liphoko, 2021). That study primarily focused on deaths due to burns, therefore, their temporal findings of electrical deaths reflected the need for warmth from heaters. However, a summer month in 2013 contained more electrical deaths than the other noted months, which aligns with the prevalence in this study.

Electrical deaths that happened on the weekend (Saturday or Sunday) made up approximately 32.2% of the cases in the WC. Majority of the decedents with positive blood alcohol concentrations (BAC) died on the weekend. Since weekdays are typically associated with work and school, this trend explains the accidental exposure of individuals to electricity within unregulated environments.

BAC determination is typically routinely requested in majority of the unnatural cases at SRM (Auckloo and Davies, 2019). This can be used to determine the possible state of the person at the time of death. According to Jung and Namkoong (2014), certain symptoms of alcohol ingestion can present when BAC is up to 0.05 g/100ml, such as slowed motor performance (Table 5.1). A BAC greater than 0.05 g/100ml can result in impaired sensation and incoordination. Hence, these symptoms can contribute to the risk of electrical death through prolonged contact with electrical sources. Most of the cases in this study reported no detected alcohol present in the blood. Within 8.98% of the provincial cases, the individuals had recorded blood alcohol concentration of 0.05g/100ml and higher. According to The National Road Traffic Act 93 of 1996, these values are over the legal limit and the individual would have been considered under the influence of alcohol (Republic of South Africa, 1996). Clinically, an individual with a BAC over the legal limit is associated with more risky behaviour (Neal and Fromme, 2007). This behaviour can lead to injury and even result in fatality. From the SRM data, it was evident that the 7 cases with positive BAC were not more than the legal limit.

Table 5.1: Clinical manifestations associated with different blood alcohol concentrations (BAC).

BAC (g/100ml)	Approximate alcohol consumption*	Clinical manifestation
< 0.05	1-2 drinks	Mild euphoria, slowed motor performance, prolonged reaction time
> 0.05	3-5 drinks	Impaired sensation, incoordination
> 0.1	6-10 drinks	Mood lability, cognitive and memory difficulties, marked incoordination, ataxia
> 0.2	>10 drinks	Nausea, vomiting, nystagmus, alcoholic blackouts, marked slurring of speech, aspiration risk
> 0.3		Hypoventilation, hypothermia, cardiac arrhythmia
> 0.4		Coma, respiratory arrest, death

*A standard single drink contains about 0.010–0.012 g of ethanol, which is estimated to increase the blood alcohol concentration of a 70-kg man by 0.015–0.020 g/100ml.

Therefore, it can be inferred that alcohol consumption was not the primary contributor to the incidence of electrocution in these circumstances. However, alcohol consumption cannot be excluded as a contributing factor to the risk of electrocution. Perhaps further research is necessary to determine this association (Awath-Behari, 2023). It should be noted that there was a nationwide ban on alcohol that spanned from 27 March to 1 June 2020 and 12 July to 17 August 2020, therefore, this could have affected the results significantly (Moultrie *et al.*, 2021).

Many electrical fatalities occur as a result of people attempting to steal copper cables from live power lines (Western Cape Goverment, 2019). These cables are a commodity used in a variety of industries, therefore, this provides a source of income to those involved in theft of electrical utilities. Taylor et al. (2003) reported that the majority of the electrocutions due to cable theft included intoxicated decedents. However, this study reported no cases where the individuals BAC was higher than 0.05g/100ml during alleged cable theft. This can be explained by the intention behind such activities. Although cable theft poses a high risk of injury, it is motivated by the need to source income off the copper (Nkwana and Mpuru, 2019).

5.5 Voltage

For the purpose of this study, high voltage electrocutions were defined as those occurring with a voltage above 1000V (von Caues, Herbst and Wadee, 2018; Nizhu, Hasan and Rabbani, 2020).

There were twice as many suspected low voltage electrical deaths compared to high voltage deaths in this study. This is consistent with previous research where electrical accidental deaths were primarily due to contact with low-voltage household alternating current (AC) sources (Laupland *et al.*, 2005; von Caues, Herbst and Wadee, 2018; Kathum and Al-Khateeb, 2019). However, the circumstances surrounding the accidental deaths in this study were primarily due to exposure to illegal connections, which are classified as a low voltage electrical supply (Louw and Bokoro, 2019). Hence cable theft and illegal connections are a fatal risk to the thieves as well as the community that is exposed to the established illegal connections (von Caues, Herbst and Wadee, 2018; Nkwana and Mpuru, 2019; Madzivhandila, Mofokeng and Motsepe, 2022).

The state of the infrastructure of electrical supply in South Africa remains underdeveloped (Essex and de Groot, 2019). Therefore, the electrocutions could have been prevented if the basic need of regulated electricity supply was satisfied in these areas and more awareness of the dangers of electricity are spread. This is a common trend throughout the country and emphasizes the need for intervention to prevent such deaths (Awath-Behari, 2023). Not only is the risk of direct electrocution increased, but so is the devastation from the destruction of homes and deaths resulting from fires that are caused by electrical malfunctions (Kahanji, Walls and Cicione, 2019).

Deaths that occurred in households were seen in almost 10% of the cases, which corresponds to the minority of electrical deaths of 22.9% seen in a study in North India (Kumar, Verma and Singh, 2014). The mechanism of injury in low voltage deaths can be due to forced contraction of the muscles and secondary asphyxia, which would be facilitated through prolonged contact with the electrical source (Peng and Shikuib, 1995).

The prevalence of lightning deaths is considered to be region-specific and differs throughout the world (Sleiwah *et al.*, 2018). Although lightning deaths are more prevalent in other regions of the country, such as Gauteng, no lightning deaths were recorded in this study (Blumenthal, 2021). There is a lack of literature documenting the injuries associated with high voltage electrical deaths from the theft of cables (Blumenthal, 2009). This study reported the circumstances and electrical sources associated with some of the high voltage electrocution cases. There were several railway lines reported to be the electrical sources in the cases of suspected cable theft and train surfing. The injuries associated with these cases were typically charring of the upper regions of the body. Train surfing was reported in 13.7% (n =14) of the cases seen in the Western Metropole of Cape Town primarily from 2013 to 2020. A smaller study of the Eastern Metropole of Cape Town revealed three fatalities from train surfing during a similar period (Okkers, 2021). More than double the prevalence of charring was reported in this study compared to the Eastern metropole of Cape Town with 32.4% of the cases compared to 5.9%, most of which were from suspected high voltage electrocutions in train surfing and cable theft. Charring, brown scorching and black contact marks, with the electrical source, were observed primarily on the forearms and hands. The social activity of train surfing is encouraged by peer involvement and lack of barriers or security at railway stations (Hesselink, 2008). The popularity of the social activity of train surfing is a pressing challenge as it is governed by motives of defiance and financial need (Sedite, Bowman and Clowes, 2010). The accidental exposure to high voltage electricity can result in severe injury with potential damage to many organs and possibly death (Nizhu, Hasan and Rabbani, 2020). A greater awareness of the dangers of high-voltage electricity needs to be communicated to the vulnerable populations.

5.6 Circumstances

Cable theft and illegal connections were major contributors to death in this study, accounting for 21.6% and 19.6% of electrical deaths respectively. Cable theft is a major issue, as this activity contributes toward damage of infrastructure and hinders economic development (Nkwana and Mpuru, 2019). Seeing that the copper from cables is used widely in industries, such as construction, there is a demand for theft of these electrical utilities (Taylor *et al.*, 2003). As loadshedding becomes more frequent, cable theft is more accessible as there is no risk of electrocution during power cuts.

More electrical deaths took place in areas of informal housing than formal housing. This is further supported by the fact that areas of higher socioeconomic status, such as Camps Bay, recorded the least electrical deaths in this study. The main circumstances surrounding these electrocutions were likely to have been freak accidents. Further research would need to be conducted to determine if there was an association. Areas of poor socioeconomic status in the Western Metropole of Cape Town including Philippi and Gugulethu, had higher numbers of electrical deaths. This corresponds with the notion that the reasoning behind accidental electrical deaths may be associated with lack of access to resources (Taylor *et al.*, 2003). Hence, people seek to obtain unregulated supplies of electricity through the establishment of illegal connections (Depuru, Wang and Devabhaktuni, 2011). The layout of illegal electrification in informal settlements involves a maypole (typically 9 metres long) that can supply up to 27 households (Gaunt *et al*., 2012). Hence, there are many overhead cables connected to various shacks, which prove to be a hazard when the maypole length is reduced (7 metres). In many informal settlements, shacks are often constructed out of corrugated iron, which serves as a strong conductor of electricity when in contact with live wires. The hazard illegal connections can range from flimsy wires near conductors to live cables across roads or near water. Consequently, there is a higher risk of injury with these exposed live wires, therefore, greater chances of fatal electrocutions in these communities. As mentioned, children playing are likely to accidentally be exposed to these wires and risk being fatally electrocuted.

Workplace fatalities made up less than 5% of the cases seen in this study. This differs from previous research in other countries, where over 50% of cases are occupational deaths (Kumar, Verma and Singh, 2014; Massey *et al.*, 2018; Shawon *et al.*, 2019; Alqassim, Ewiss and Al-Ali, 2023). The construction industry has the most electrical fatalities in North America, followed by maintenance, installation and repairs (Bureau of Labor Statistics, 2019). Recorded as occupational deaths in USA, 71% of these electrocutions occurred due to contact with a powerline (Massey *et al.*, 2018). Conversely, the findings of the current study revealed that 21,6% of the electrocutions due to contact with powerlines were associated with alleged cable theft. It is plausible that males have been more likely to operate electrical equipment, therefore, more susceptible to electrical deaths of this nature (Wick *et al.*, 2006). The occupational electrical deaths accounted for majority of the high voltage cases reviewed in Sweden, the authors revealed that shielding dangerous areas at railway stations and constructing structures such as carriages to reduce climbing, would be suitable strategies to prevent further electrical occupational deaths (Lindström, Bylund and Eriksson, 2006).

5.7 Patterns of injury

Electrothermal injury can lead to burns at the points where electricity makes contact with the body. Subcutaneous tissue, bone, muscle, and internal organs can potentially be injured thereafter (Chen *et al.*, 2021). An electrical lesion is classified according to the characteristics associated with the injury type. A lesion is more likely to lead to necrosis of the tissue, hence this is reported within the medicolegal autopsy report (Jellinek, 1936). Electrical lesions were observed in 94.1% (n =96) of cases in the Salt River Mortuary data over the ten-year period. The injuries were described as having a pale central crater with raised edges, pale collapsed blisters, melted epidermis and charring of the skin. Similar descriptions were observed in previous studies as collapsed blisters surrounded by pale areola without charring (Michiue *et al.*, 2009). More than one burn wound per body was seen in many cases in this study. Direct contact with electricity occurred in 80% of the cases in a study conducted in India (Giri, Waghmode and Tumram, 2019). Only an entry wound was observed in more than half of the cases while an entry and exit wound was only seen in 10.2% of the cases (Giri, Waghmode and Tumran, 2019).

In 62.7% of electrocution cases at SRM, the electrical injuries were observed on the hands and/or fingers of the deceased. This was likely to have been the point of contact with the electrical sources (Dzhokic, Jovchevska and Dika, 2008). This aligns with an Indian and American study that reported majority of cases with upper extremity injuries (Massey *et al.*, 2018; Giri, Waghmode and Tumram, 2019). Almost all burns were located in the upper regions of the body in low voltage electrocutions (Peng and Shikuib, 1995). This differed from the current study which showed multiple electrical injuries located on the lower regions of the body. The reason for joule burns on the lower regions of the body can be explained by the evidence of exit wounds, as the pathway of electricity through the body is not predictable. Another reason could be accidental exposure to electricity at the lower bodily regions, the presence of conductors and body posture at the time of the electrocution (Hardjanto, Nzilibili and Yudianto, 2019). This explains the difference in patterns of injury between the children and teenagers in this study. Especially where the circumstance of electrocution was exposure to live wires, the children typically presented with injuries on the hands and feet. While the teenagers had injuries associated with the lower regions of the body, such as the legs.

The largest joule burn in a previous study was located on the abdomen and included features of necrosis in a low voltage death, whereas this study observed necrosis in two cases of high voltage electrocutions (Peng and Shikuib, 1995; Giri, Waghmode and Tumram, 2019). This can indicate that the occurrence of necrosis is possibly not dependent on the voltage type. Less injuries were seen in the feet than the hands, this could have been attributed to the activities surrounding exposure to the electrical source. Electrocutions by direct contact with live wires were seen in 26% of the cases studied in USA (Cawley and Hornee, 2006). Conversely this study demonstrated almost double that figure with 50% of cases, where there was exposure to a live wire. The pathway of the current determined the extent of injury in the individuals with the prevalence of electrical injury in the feet occurring in 9% of the injuries recorded. This aligns with the likelihood of these injuries being associated with exit wounds, depending on the posture of the individual during the electrical shock (Dzhokic, Jovchevska and Dika, 2008; Hardjanto, Nzilibili and Yudianto, 2019).

The presence of metal materials enhances the body’s susceptibility to electrical injury (Blumenthal, 2009; Massey *et al.*, 2018). In one case of alleged cable theft, an individual was found still clasping a metal saw against their body at the post-mortem investigation. The patterns of injury recorded in this case were extensive as the left head, forearm, lower leg, hip, hand and abdomen had electrical injuries.

The low voltage electrocutions that led to charring injuries occurred with exposure to illegal connections, therefore, no insulation was likely present. In many cases, particularly in low voltage electrocutions, death is not immediate (Bailey, Forget and Gaudreault, 2001). Often individuals will succumb to their injuries while being treated in hospital. Typically, death is associated with complications including haemorrhagic shock, head injury, sepsis, multi systemic complications or anoxic encephalopathy (Bailey, Forget and Gaudreault, 2001). In the current study 90 (20%)

individuals died while undergoing medical treatment in hospital in the province. Of the 24 hospital admissions at SRM, most of these cases exhibited haemorrhage and multi-organ congestion.

It is possible for no external injuries to be present in cases of fatal electrocution. In the SRM data, there were 5.9% of cases with no external injury, however, congestion in organs including the lungs, kidneys and brain were observed at the autopsy stage of the medicolegal investigation. The internal damage to organs included oedema and haemorrhage (Peng and Shikuib, 1995). There was severe congestion in vital organs such as the blood vessels in the brain, both kidneys, conjunctivae, both lungs had interalveolar haemorrhage and the liver was dark. The organ associated with majority congestion according to the reports was the lung seen in 69.6% (n=71) of cases, which can be considered as an effect of exposure to electrical current. This corresponds with a main pathology being pulmonary congestion and oedema in other studies (Karger, Süggeler and Brinkmann, 2002; Michiue *et al.*, 2009). Congestion of the internal organs was observed in 92.1% of the cases in the Eastern metropole of Cape Town (von Caues, Herbst and Wadee, 2018).

The non-electrical injuries reported included abrasions, bruises, lacerations and fractures. These are secondary injuries that result from the effect of electrical exposure, such as fall from height. This was commonly seen in previous studies conducted in the country (Blumenthal, 2009; von Caues, Herbst and Wadee, 2018; Keyes and Liphoko, 2021; Awath-Behari, 2023). There were petechial haemorrhages observed in three cases, two suspected high voltage deaths and one alleged low-voltage death (Karger, Süggeler and Brinkmann, 2002). The pathophysiology of petechial haemorrhages in electrical deaths is explained by the forced muscle contractions of the muscles involved in respiration (Karger, Süggeler and Brinkmann, 2002). This would typically be an indication that the electrical contact was low in voltage.

Electrical injury and subsequent fatalities place a burden on society (Sokhal *et al.*, 2017). Previous research has demonstrated that voltage does not always relate to injury. This should be considered at autopsy as the identification of electrocution as the cause of death, may be obscured by the presence of extensive burns and tissue damage.

5.8 Study limitations and recommendations

The study was retrospective in nature, therefore, limited by the secondary data collection. Due to the nature of the data collection and the evidence of underreporting of deaths, it must be noted that these findings could be an underrepresentation of electrical deaths in the suburbs allocated to Salt River Mortuary. Accommodations for spelling errors were made to ensure that cases were not missed in the data collection. Double entry validation was performed to prevent human error and ensure accurate collection of the data. The descriptions of the death scenes were vague in majority of the cases. This hindered a clear depiction of the events before and during the electrocutions. The statements by South African Police Service officers could only allege the circumstances such as cable theft or train surfing, in majority of the cases. However, compiling the available data gave an indication of the common circumstances surrounding electrocutions in the region.

The latest official census data available was from 2011. For calculations of prevalence rates, this study used this data as the population size for the entire study duration. While the study incorporated data from 2011, the population is assumed to have increased over the years. Thus, prevalence rates may be slightly skewed. To overcome this, prevalence was also reported as a proportion of unnatural death cases. Nevertheless, the reported prevalence rates provide a good indication of burden of fatal electrocutions in the region. A larger study across many provinces may provide a deeper understanding of the prevalence of electrocutions in South Africa. This will increase the sample size substantially to draw more accurate conclusions from the data.

A limitation in this study was that the injury patterns were not assessed according to the anterior and posterior prevalence. However, the analysis of the gathered data provided a depiction of the patterns of injury of various body regions in different circumstances of electrocutions. A recommendation would be to report the size of the injury in relation to the circumstances to ascertain the danger of electrical exposure.

Chapter 6: Conclusion and Recommendations

This study aimed to investigate the prevalence and patterns of electrical death in the Western Cape Province. There is a lack of substantial research on the demographical aspect of electrical deaths in South Africa, therefore, this research addressed this issue. Research using autopsy reports contribute to the crucial awareness surrounding fatal electrocution, ultimately striving for a safer and more informed society against potential electrical hazards.

The City of Cape Town was found to be the health district in the Western Cape with the highest risk of fatal electrocutions, making up over 64% of cases in the study. The population group most vulnerable to fatal electrocutions were males aged 21 to 30 years old. However, the study highlighted that the youth below 20 years old made up over 20% of the cases and remain vulnerable to electrocutions, especially by the presence of illegal connections. The prevalence of electrical death was 1.2 per 100 000 in males and 0.2 per 100 000 in females.

An extensive analysis into a subset of the data found that deaths due to electrocution at Salt River Mortuary made up approximately 25% of the cases seen in the province. Hence, the Western Metropole of Cape Town can be considered a hotspot for fatal electrocutions. The main electrical sources were exposed live wires and railway lines. It is recommended that policy makers implement the safety measures needed to prevent electrocutions should be aimed at these sources. The injuries seen were primarily joule burns on the hands, which were likely to be direct points of contact with the electrical source. Majority of the circumstances surrounding the deaths ranged from accidentally stepping on live wires to train surfing and cable theft. A recommendation would be the implementation of physical barriers or security at railway stations to deter train surfing and prevent these accidents. In the present study, it was also found that the majority of these deaths occurred in low-income communities, where electrical infrastructure may not be up to code and maintenance is often lacking. Another recommended safety measure would be raising awareness about the dangers of exposure to electrical sources in the vulnerable communities identified. The influence of loadshedding implemented by ESKOM during the period of study could have contributed to the increased prevalence of cable theft and illegal connections (Awath-Behari, 2023).

A notable increase in electrical fatalities displays the necessity of the determination of the electrical sources or causes (Alqassim, Ewiss and Al-Ali, 2023). To prevent future electrical deaths, it is essential to diagnose electrocutions using autopsies, witness reports and evidence analysis. Research on patterns of injury contributes to the understanding of areas where interventions need to be targeted.

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Appendix A: Ethical clearance documents from University of Cape Town Human Research Ethics Committee.

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room 45 E-52-E-Floor- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

25 August 2022

HREC REF:516/2022

Mr C Mole
Division of Forensic Medicine & Toxicology
Entrance 2, Level 5, Rm 5.10 FHS
Email: Calvin.mole@uct.ac.za
Student: Chtans001@myuct.ac.za

Dear Mr Mole

PROJECT TITLE : AN ASSESSMENT OF ELECTRICAL DEATHS IN THE WESTERN CAPE PROVINCE FROM 2011 TO 2020-SUB-STUDY LINKED TO R36/2014 – (MASTERS CANDIDATE-MISS ANSUYA CHETTY)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 August 2023.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Miss Ansuya Chetty will also be involved in this study.

Please quote the HREC REF 516/2022 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

HREC.REF516.2022

Appendix B: Ethical approval from the Western Cape Government.

Annexure A APPLICATION FOR ACCESS TO

HEALTH DATASETS

The following application form is to be completed by all person/persons/organisations/groups who wish to access to health-related datasets from Western Cape Department of Health and is to be completed in accordance with the Departments. Guidelines on requests for access to patient datasets from the Department of Health. Please note that application for use of data does not guarantee that the data request will be approved. If the intended purpose for data access is altered or extended in anyway, a new agreement must be entered into.

Applicant details: (Refers to the detail of the person requesting the change.)

Name: Calvin

Surname: Mole

Designation / Rank: Lecturer

Date: 15/02/2023

Organisation: University of Cape Town

Email: Calvin.mole@uct.ac.za

Tel/Cell: 0825848670

Please supply the contact detail of the person to whom the processed application must be returned.

Details of Data Request: (please append any additional information where necessary)

Type of Data Requested : (please tick appropriate option)	Aggregated data	Non-identified individualised data X	Identified individualised data
Please provide a short description of the data requested. Please attach a list/attach a list of the variables required. All electrical deaths in the Western Cape from 1 January 2011 to 31 December 2020. The variables of date of death, age, sex, death scene, cause of death, circumstance of death.			
Do you have a National Health Research Database ref no.?	Yes X No	Number: WC_202209_001	
Time period the data should cover:	Start date: 31/08/2022/mm/yyyy	End date: 31/08/2023 dd/mm/yyyy	
Frequency of Access: (please tick appropriate option)	Once-off X	Periodically	
If periodically, please specify time frames for access:			
Is the data to be used for research purposes?	Yes X	No	

Please provide a brief motivation for this request, highlighting the purpose for which the data will be used The data will be used in a retrospective study to identify population groups most vulnerable to electrocutions in the Western Cape by examining the prevalence of electrocutions over a ten-year period. Accidental electrical deaths are a pressing problem, therefore the incidence of such deaths must be investigated to establish risk and possible implementation of safety measures to prevent such deaths. Study not funded/funded by: not funded		
Do you have a security protocol for handling the data (attach detail if necessary)?	Yes X	No

PHDC Manager- Technical assessment and comments:		☑ Feasible Where relevant: ☑ Protocol cover ☑ Ethics ☑ Consent docs
Assigned PHDC analyst: Assigned Time:	PHDC Manager Signature: Michael Vismer Digitally signed by Michael Vismer Date: 2023.02.15 10:23:08 +02'00'	Date: 2023/02/15

Outcome of Application: (To be completed by the Designated Health Authority)

Name:	Vonita	Surname:	Thompson
Designation / Rank:	Director	Signed:	Vonita Thompson.
Application Approved:	Yes X | No	Date:	2023/03/08

5th Floor, 8 Riebeek Street, Cape Town, 8001, PO Box 2060, Cape Town, 8000 Tel: +27 21 483 9366 fax: +27 21 483 6058

TERMS OF AGREEMENT FOR ACCESS TO HEALTH DATASETS

The Western Cape Department of Health is committed to ensuring availability of data that supports the provision of health care and other essential services to authorised Users. This agreement aims to ensure the authorisation, maintenance of confidentiality and appropriate use of datasets provided to Users.

This agreement is between:

The Western Cape Government: Department of Health, hereafter "the Department"

AND

……………………Calvin Mole………………………………………………………., hereafter "the User"

1. Application for use of data must be made through the channels identified in the "Guidelines on requests for access to patient data and patient information systems" document.
2. This agreement sets forth the terms and conditions to which the Department will disclose certain confidential health information in the form of a Dataset(s).
3. The User agrees that the Department is the owner of the Dataset(s).
4. Permitted Uses and Disclosures:

4.1. Except as otherwise specified herein, the User may make all uses and disclosures of the Western Cape Forensic autopsy data Dataset(s) necessary to conduct An assessment of electrical deaths in the Western Cape Province from 2011 to 2020. for the period starting 31/08/2022 and ending 31/08/2023.

4.2. The User will receive the Dataset(s) once-off, from the designated Department official.

4.3. In addition to the User, the individuals, or classes of individuals, who are permitted to use or receive the Dataset(s) for purposes of the Identified Project include: Calvin Mole and Ansuya Chetty

5. User Responsibilities:

5.1. The User will not use or disclose the Dataset(s) for any purpose other than permitted by this Agreement pertaining to An assessment of electrical deaths in the Western Cape Province from 2011 to 2020 for which written approval was granted.

5.2. The User agrees that the Dataset(s) provided will not be released to any third party that is not included by the provisions of the agreement between the primary parties, without the written permission of the Department. A third party will be required to complete an agreement as well.

5.3. The User agrees that the Department will be provided with an opportunity to comment and give feedback prior to the finalisation of any report/publication derived from the Dataset(s) according to the following conditions:

5.3.1. The data will be used to compile a report thesis and journal article for publication and to report on electrical deaths in the Western Cape.

5.3.2. The report will be sent to the Department for perusal prior to finalisation. The latter should respond or react within 31 working days on the report being issued. If this period lapses it will be interpreted as a confirmation that the Department acknowledges the presentation and interpretation of data as correct and factual in the report.

5.4. The User will ensure that the Department is acknowledged in any output resulting from the use of the data including.

5.5. The User will communicate any data quality issues identified to the Department, to improve the dataset.

5.6. The User agrees that any use of the Dataset(s) or reliance by the User on any of the Dataset(s) is at the User. s own risk and that Department shall not be held liable for any loss or damage howsoever arising as a result of such use.

5.7. The User agrees that he/she will make no statement nor permit others to make statements indicating or suggesting that interpretations/views drawn from the findings are those of the Department.

5.8. The User agrees that he/she will maintain confidentiality in accordance with item 6. Below.

6. Data Security and Confidentiality:

All Dataset(s) from the Western Cape Department of Health are to be treated as confidential and used in accordance with the following security standards:

6.1. Database storage: At a minimum the database must have user-level security, may not be housed on laptops or external media unless these are encrypted. Ideally the data should be stored on a central server with restricted access and not be stored on portable computer equipment like memory sticks, external hard drives and laptops.

6.2. The Data Sets(s) must be password protected and such passwords are not to be shared with anyone other than the principle user.

6.3. Data may not be linked to personally identifiable records from any other source unless prior approval has been explicitly granted.

6.4. File storage: At a minimum files will be stored with AES encryption e.g. 7-zip, and 15 character passwords which include numbers, special characters and letters.

6.5. Passwords and files may not be provided together but using two different methods of communication e.g. data zipped and e-mailed while password is SMS. ed to User.

6.6. When the timeframe for the agreed utilisation of the data expires (see item 4.1. above) the data must be destroyed in all its forms.

7. In making information available, the Department of Health reserves the right to set conditions in which its staff (including academic staff in joint provincial posts) should be invited to participate in any research undertaken that uses the data they have generated with a view to co-authorship of the final report/s.

8. The User accepts that this data is routinely collected as part of service delivery and therefore the data quality may not be of the highest quality.

9. Failure to adhere to the written agreement can and may be sanctioned

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Signatories:

CALVIN MOLE | | 15 February 2023

User's Name (Print) | Signature | Date

V Thompson | | 2023/03/08

Department of Health (Designated authority) | Signature | Date chtans001:Report_Turnitin.docx

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