THE SPATIAL DISTRIBUTION OF ASBESTOS AND THE COMMUNITY AWARENESS AND PERCEPTION OF ASBESTOSIS RISK IN GA-MATHABATHA, LIMPOPO PROVINCE, SOUTH AFRICA

by

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DISSERTATION

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DEDICATION

I dedicate this study to my parents, Mr. Morwamakoti Phineas Thobejane and Mrs. Eva Mantwampe Thobejane.

DECLARATION

I declare that this study "**THE SPATIAL DISTRIBUTION OF ASBESTOS AND THE COMMUNITY AWARENESS AND PERCEPTION OF ASBESTOSIS RISK IN GA-MATHABATHA, LIMPOPO PROVINCE, SOUTH AFRICA**" is my own work and all the sources used or quoted have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

Manuel Teleki Thobejane	18 March 2025
Full names	**Date**

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ABSTRACT

Asbestos dust exposure poses a significant public health concern, particularly in areas characterised by unrehabilitated asbestos mines. As such, this study aims to evaluate the spatial distribution of asbestos and the community awareness and perception of the risk of asbestosis in Ga-Mathabatha. Remote sensing analysis techniques were adopted to predict areas containing different types of minerals associated with asbestos. Meanwhile, field observations were carried out to validate the presence of asbestos in such areas. Patterns and trends in wind speed and direction - factors critical to asbestos minerals distribution - were analyzed and their potential influence was described. Furthermore, 18 in-depth interviews and 250 survey questionnaires were administered as part of a mixed-methods design for evaluating the community's awareness and perception of asbestosis risk. Remote sensing analysis results predicted that chrysotile asbestos was highly concentrated in the eastern part of the community, meanwhile tremolite asbestos dominated the southern part, and a few of the serpentine in the eastern part. Evidence from field observations concurs with these findings, revealing that asbestos deposits are present in the surrounding villages and along riverbanks. Meteorological data has shown that the asbestos dumping sites lie within the path of dominant winds, suggesting a potential risk of windborne asbestos fiber dispersion into surrounding areas. Conversely, survey results revealed that 66% of participants were aware of the danger of exposure to asbestos dust, while 40.8% (32.8% + 8%) perceived asbestosis as deadly and incurable. The results underscore the importance of education and awareness programs targeting individuals with limited knowledge and negative perceptions, and those engaging in activities that increase their exposure.

Keywords: Asbestos dust exposure; Asbestosis; Distribution; Ga-Mathabatha community; knowledge; awareness; practice; perception

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1. INTRODUCTION

This chapter begins by providing a comprehensive account of the study's context, then outlines the research problem, rationale, intended aim and objectives, research questions, and definition of operational concepts. Furthermore, it offers a concise overview of the structure of the chapters included in this research.

1.2. BACKGROUND TO THE STUDY

The mining industry is one of the most significant sectors that generate substantial revenues for national economies, provide employment opportunities, and boast foreign exchange earnings (Karakaya and Nuur, 2018; Fernandez, 2020; Lin and Zhu, 2021). Asbestos was once mined in countries such as Canada, China, Russia, Kazakhstan, and South Africa, however, due to health concerns and subsequent bans, production declined in the late 1980s (Jacques and Pienitz, 2022). Countries such as Russia and Kazakhstan continue to produce the largest volume of asbestos, with over 700,000 matrices tons mined in 2022 (Chen et al., 2022; Kurzhunbaeva, 2024). Before 2007, South Africa mined over 10 million tons of asbestos, making it the first country in Southern Africa to produce such a large amount (Selby, 2023). However, asbestos mining rights were terminated in South Africa in 2008, and asbestos mines were subsequently banned in the same year due to health-related complications regulated by the Department of Labour Asbestos Regulations Act no (115 of 2002) (Ndlovu, teWater Naude and Murray, 2013; Mashalane et al., 2018). The act prohibited any person from taking part in any asbestos-related project that might pose a significant health hazard, however, despite the ban, there is still an alarming rise in asbestos-related diseases, particularly in areas closer to unrehabilitated asbestos shafts in South Africa, precisely in the Limpopo Province, Mpumalanga, and North-West Province (Petja et al., 2009; Petja et al., 2010; Kwata, Moja and Chadi 2018; Freemantle et al., 2022).

Asbestos is the collective term for a family of naturally occurring fibrous silicate minerals (Campbell et al., 2020). The term asbestos is derived from the Greek term for

“*unquenchable*” or “*indestructible*” (Campbell et al., 2020; Airoldi et al., 2021; Avataneo et al., 2021; Chen et al., 2022; Bolan et al., 2023). Due to its remarkable properties such as tensile strength, extreme resistance to thermal and chemical breakdown, and fibrous habit, asbestos has been exploited in various commercial and industrial applications (Silas et al., 2017). This fibrous silicate mineral is found in various geological settings in countries not limited to Canada, China, Russia, Kazakhstan, Brazil, India, Zimbabwe, South Africa, and others whose continents are hosted within metamorphic, altered mafic, or ultramafic rock (Sporn, 2014; Mazzeo, 2018; Cornelissen et al., 2019). Asbestos minerals are broadly classified into the serpentine (chrysotile) and amphibole (crocidolite, amosite, tremolite, anthophyllite, and actinolite) series, both of which share the common features of occurrence such as long fiber length, flexible poly filamentous bundles and small fiber diameter (Sporn, 2014; Huh et al., 2022; Vorster et al., 2022; Kusiorowski et al., 2024).

Despite its commercial benefits, asbestos poses significant harm to both environmental and human health. Its negative environmental impact includes air, water and soil pollution caused by the transportation of asbestos rocks, soils and fibers into the atmosphere and water bodies (Peña-Castro, 2023; Curti et al., 2024; Paustenbach et al., 2024). The effects of asbestos dust exposure on human health include an increased risk of respiratory diseases such as asbestosis, mesothelioma (pleural, peritoneal, and pericardial), ovarian and lung cancer (Furuya, 2018; Yamamoto et al., 2021; Huh et al., 2022; Kwak et al., 2022) as well as other chronic health complications resulting from prolonged inhalation of asbestos fibers. Statistics reveal that over 90,000 people die every year from these asbestos-related diseases, globally (Reid et al., 2018; Dalsgaard et al., 2019; Arachi et al., 2021; Bolan et al., 2023; Jerie, Shabani, and Shabani, 2024; Whitmer, 2024). Emmett (2021) highlights that there is unquantifiable additional death from communities residing near areas of high asbestos concentration. Commonly recognised symptoms of asbestos-related illnesses include dyspnoea, chronic non-productive cough, chest constriction or angina, weight reduction resulting from decreased appetite and deviation from the usual width and roundness of fingertips and toes (clubbing) (Kwata, Moja, and Chadi 2018; Karimi, Ahmadi, and Partabian, 2020). Once these symptoms

manifest, there is no cure or prevention, and the only viable option is death.

The widespread exposure to asbestos is often exacerbated by a limited understanding of its health risks, transmission pathways, and safe handling practices (Ripabelli et al., 2021) Meanwhile, attitudes towards asbestos exposure are often shaped by social and economic factors, and risk perception, influencing whether individuals take exposure risks seriously or dismiss them as insignificant. Conversely, perceptions of asbestos hazards vary widely, with some communities recognizing it as a dangerous environmental contaminant, while others remain unaware of its long-term health effects, particularly in areas where asbestos is naturally occurring or was historically mined. In light of this background, this study sought to assess the spatial distribution of asbestos and the community awareness and perception of asbestosis risks.

1.3. PROBLEM STATEMENT

Un-rehabilitated asbestos mines remain a significant public health concern (Kwata, Moja, and Chadi 2018; Avataneo et al., 2021; Huh et al., 2022; Malinconico et al., 2022; Bolan et al., 2023; Lisco et al., 2023). Despite the implementation of regulatory measures in numerous countries including Canada, China, Russia, South Korea, Kuwait, Norway, Australia, Japan, and South Africa, asbestos continues to present substantial health and environmental hazards, particularly in areas in closer proximity to un-rehabilitated mines and asbestos mining disposal sites (Van Zandwijk, Reid, and Frank, 2020; Thives et al., 2022; Chen et al., 2022; Jacques, and Pienitz, 2022). Whitmer (2022) highlighted that more than 230,000 people die every year from asbestos dust exposure, of which 60% of the fatalities result from communities near asbestos mines, open shafts, tailings, and cement production industries. This problem is also evident in agricultural activities such as crop farming, animal farming, and fishing, especially in developing countries of Africa and Asia where un-rehabilitated asbestos mines are prominent (Ayenimo et al., 2006; Obmiński, 2022; Thives et al., 2022). More than 19,000 farmers die every year, while 15,000 suffer from pulmonary lung diseases in Mali, Ghana, Nigeria, Angola, and Burkina Faso (Frank and Joshi, 2014; Silas et al., 2017; Arachi et al., 2021; Mensi et al., 2021). When herds grace in asbestos contaminated land hills, the asbestos fibers accumulate in

their fur, resulting in potential exposure to humans in contact with the animals (Mensi et al., 2021; Jung et al., 2021). Furthermore, Georgina et al., (2018) mentioned that there were asbestos fibers inside the lungs of domestic animals plowing and grazing in highly concentrated areas of asbestos.

Meteorological factors such as rainfall, wind speed, and direction influence asbestos fiber exposure and distribution (Kwata, Moja and Chadi 2018; Malinconico et al., 2022; Obmiński, 2022; Avataneo et al., 2023; Peña-Castro et al., 2023). Excessive rainfall causes floods, which lead to the weathering and erosion of asbestos soils and materials into the watercourses exposing everyone depending on contaminated wells, dams, water catchments, streams, and tributaries (Mizan, Phillips, and Nthoke 2018; Cornelissen et al., 2019; Obmiński, 2022; Thives et al., 2022). Contract MTK (2018) further added that asbestos can be leached from houses made of asbestos roofs by rainfall, and fibers contaminate soils and runoff below the roof, which contributes to a high potential risk of exposure. For example, more than 180,000 shacks and RDP houses made of asbestos in South Africa, Gauteng province townships such as Soweto, Mamelodi, and Alexandra expose approximately 35% of individuals who harvest rainfall water from roofing and water leaking from the roofs (Petja 2009; Petja et al., 2010; Campbell et al., 2020; Freemantle et al., 2022). Furthermore, wind also contributes to the exposure; for example, the gust of prevailing winds from the direction of open-cast asbestos mines, asbestos dumping sites, and asbestos industry dust to the communities nearby exposes people to asbestos dust (Campbell et al., 2020).

Unrehabilitated asbestos mines and dumps are prevalent in communities of Mpumalanga, Northwest, Northern Cape, and Limpopo province. For example, Kwata, Moja, and Chadi (2018) highlighted that there were five unrehabilitated asbestos dumps located in Mpumalanga province near communities around Mbombela (formerly known as Nelspruit), Malelane, and Badplaas. Meanwhile, Petja et al., (2010) highlighted that there was evidence of asbestos mines and dumps in Limpopo province, near the communities of Penge, Mafefe, and Ga-Mathabatha. Three community members residing in Ga-Mathabatha community, Makapeng village, informed SABC News (2022) that they lost

their loved ones due to exposure and that they were also suffering from asbestos-related diseases. Considering this problem, this study sought to investigate the asbestos distribution in Ga-Mathabatha and the community's awareness, as well as perceptions towards asbestosis risk.

1.4. RATIONALE

More than 55 countries, including South Korea, Kuwait, Norway, Zimbabwe, Swaziland, and South Africa have implemented strict policies to control asbestos usage and minimize exposure (Aryal, and Morley, 2020; Thives et al., 2022). In South Africa, regulations prohibiting asbestos were implemented on March 28, 2008 (Haynes, 2010; Phillips, Rees, and Swanepoel 2016). However, despite over a decade of mining discourse, asbestos-related diseases and deaths continue to wreak havoc. This ongoing crisis is largely attributed to the presence of unrehabilitated asbestos mines.

Studies have been conducted, particularly in South Africa, to investigate the impact of asbestos mines, rehabilitation statuses, and the mineralogical content of rocks and soil debris (White, Nelson, and Murray 2008; Petja et al., 2010; Jones 2011; Georgina et al., 2018; Rapholo 2018). For example, Petja et al., (2010) employed geospatial technologies such as Geographical Information Systems (GIS) and Remote Sensing (RS) to monitor asbestos mine rehabilitation in the post-mining environments of Limpopo Province. Meanwhile, White, Nelson, and Murray (2008); Jones (2011); Georgina et al., (2018); Rapholo (2018) and Freemantle et al., (2022) analyzed mineralogical content, evaluated the environmental impact of asbestos, and monitored the asbestos mines rehabilitation. Conversely, Georgina et al., (2018) determined the geochemical and morphological characteristics of asbestos from dust samples collected near former asbestos mining in Limpopo Province (e.g. Malemang, Mafefe, Mathabatha, Penge, and Taung Village). These studies validated a new research gap that integrates both the observational analysis of asbestos earth materials debris and the communities' awareness and perception of health risks. As such, an empirical study was undertaken to assess the spatial distribution of asbestos in the geographical location and extent of Ga-Mathabatha, and to further explore the community's awareness and perception of asbestosis risk.

1.4.1. Aim and objectives of the study

This study aimed to assess the spatial distribution of asbestos and the community awareness and perception of the risk of asbestosis in the Ga-Mathabatha, Limpopo Province, South Africa.

The objectives of this research were to:

i. Assess the spatial distribution of asbestos in Ga-Mathabatha.
ii. Analyze the patterns and trends in wind speed and direction, and describe their potential influence on asbestos exposure in Ga-Mathabatha.
iii. Evaluate Ga-Mathabatha community's awareness and perception of asbestosis risk.

1.4.2. Research questions

The research sought to answer the following questions:

i. How is the asbestos mineral distributed in Ga-Mathabatha?
ii. What are the observed patterns and trends in wind speed and direction, and how do they influence potential asbestos exposure in Ga-Mathabatha?
iii. What is the Ga-Mathabatha community's level of awareness and perception of risk of asbestosis?

1.5 DEFINITION OF OPERATIONAL CONCEPTS

Spatial distribution

Shaker, (2015) defines distribution as spreading or arranging something over an area. In this study, spatial distribution is referred to as the physical arrangement or array of naturally occurring minerals on the earth's surface.

Community

Miller et al., (2003) define a community as a human group sharing territory and involved in different but related aspects of livelihood. In this study chapter, a community is defined as a group of people residing in the same area and sharing natural resources such as water, air, minerals and others at a given time.

Community risks

Granger et al., (1999) and Bhattamishra, and Barrett, (2010) define community risk as the outcome of the interaction between hazard phenomena and the vulnerability elements at risk within the community. For this study, community risk is defined as individuals who are living or residing near asbestos dumping and have the potential of being exposed to asbestos dust daily.

Asbestos fibres

Boulanger et al., (2014) and Moteallemi et al., (2020) define asbestos fibres as naturally occurring silicates used in construction and manufacturing factories such as cement plants and insulations. In this study, asbestos fibres are tiny naturally occurring minerals present in rocks and soils and are harmful to respiratory organs when inhaled.

Prevailing winds

Duchscher and Myrick, (2008) define prevailing winds as winds that blow from a single direction over a specific area of the Earth. Accordingly, the definition of prevailing winds in this study is winds that blow constantly in one direction over a given region.

Airborne disease

Olatunji et al., (2024) study addresses airborne diseases as diseases transmitted through the air and affect the respiratory system, including the lungs. In this study, respiratory droplets and dust particles suspended in the air that people inhale can cause illnesses known as airborne diseases.

Water-borne disease

The National Institute of Environmental Health Science notes that water-borne diseases result from run-off contamination with fertilisers or pesticides (Olatunji et al., 2024). This study's definition of water-borne diseases is consistent with these studies, defining them as diseases caused by asbestos dust or fibers in water.

Community perception

Green (1999) refers to perception as how communities observe, understand, interpret,

and assess certain behaviours, diseases, aspects, and phenomena. According to this study, community perception is an individual's subjective viewpoint shaped by their experiences, exposure to their environment, cultural background, social development, limited resources, attitude, and knowledge.

Asbestos

Asbestos is a group of naturally occurring fibrous minerals, namely, actinolite, amosite, anthophyllite, crocidolite, tremolite (amphibole minerals), and chrysotile (serpentine mineral) (Van Gosen, 2007; Furuya et al., 2018; Yamamoto et al., 2021). The definition same definition was adopted for this study.

1.6 ORGANISATION OF CHAPTERS

This study was organised into the following five chapters:

Chapter 1 provides context to the study by outlining the background information, problem statement, rationale, aim, objectives, research questions, and operational concepts.

Chapter 2 examines the existing literature on the global spatial distribution of asbestos mines, meteorological factors influencing asbestos distribution, and the assessment of community awareness and perception of asbestosis risk and asbestos dust exposure. Prior to its conclusion, the chapter also discusses the theoretical framework that underpins the study.

Chapter 3 describes the study area and outlines the methodology, including the research design, data sources and collection methods, sampling techniques and analytical procedures.

Chapter 4 presents and discusses findings on the spatial distribution of asbestos in Ga-Mathabatha, wind speed and direction and their potential influence on potential asbestos distribution as well as the community's awareness and perception of asbestosis risk.

Chapter 5 delivers the summary of the major results as well as the conclusions and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

This chapter examines the existing literature related to the spatial distribution of asbestos and community awareness and perception of asbestosis risk. The focal points are: (i) naturally occurring asbestos and its negative impacts (ii) spatial distribution of operational and closed asbestos mines; (ii) geological mapping of asbestos (iii) Meteorological factors and their potential influence on asbestos distribution; (iv) community practices, knowledge, awareness, attitude and perception of asbestosis risk; and (v) the theoretical framework that underpins this study.

2.2. NATURALLY OCCURRING ASBESTOS AND ITS NEGATIVE IMPACT

Naturally Occurring Asbestos (NOA) is a fibrous mineral that occurs naturally in rocks, soil, and sediments (Gualtieri, 2020). This type of mineral is mostly found in ultramafic, specifically in serpentine rock formations. It is broadly classified into the serpentine (chrysotile) and amphibole (crocidolite, amosite, tremolite, anthophyllite, and actinolite) series, both of which share the common features of occurrence such as long fiber length, flexible poly filamentous bundles and small fiber diameter (Sporn, 2014; Huh et al., 2022; Vorster et al., 2022; 2023; Kusiorowski et al., 2024). Due to its properties, these minerals were extensively mined.

The NOA was discovered and mined to create Asbestos Containing Material Materials (ACMs) for commercial uses. Due to its remarkable properties such as tensile strength, extreme resistance to thermal and chemical breakdown, high resistance to water, asbestos has been exploited in various construction, manufacturing, and infrastructural development industries (Silas et al., 2017). Compared to other fireproofing and insulation materials, asbestos was relatively inexpensive and widely available for the production of brake pads, cement and plaster, roofing, floor and ceiling tiles, wall panels and underground pipes (McCulloch, 2003; Giacobbe et al., 2010; Govorko et al., 2017; Mazzeo, 2018; Kim et al., 2018; Musk et al., 2008; Bolan et al., 2023). Industries such as automotive, aerospace, and military have benefited greatly from the mining of asbestos

in the past (McDonald et al., 1984). The asbestos industry also contributed to economic growth and infrastructure development, particularly in resource-rich regions. For example, Roro mine in India produced 0.4 – 0.5 million tons of asbestos annually, and imported about 100,000 tons, creating around 1,500 jobs and increasing the economy by 46% in the 1970s (Szeszenia-Dąbrowska et al., 2015; Yadav, 2016). Conversely, the asbestos mining and manufacturing industry once provided thousands of jobs in countries such as Canada, China, Russia, Brazil, and South Africa (McCulloch, 2003). For instance, the ten active chrysotile asbestos mines in Canada, Quebec province, employed more than 620 workers, producing 900,000 metric tons of asbestos annually, of which 97% of the stockpile was exported to Asia, contributing 1.35 billion US dollars to the country's GDP in the 1950s (Jacques, and Pienitz, 2022). Despite its historic economic, developmental, and societal benefits, this mineral has tremendous negative impacts on the physical and social environment.

Effects of asbestos mining have been noted to range from contamination of the natural environmental systems (including soils, water, and atmosphere), disruption of biodiversity and ecosystems, human health risks, and land abandonment (V, 2007; Musk et al., 2008; Swayze et al., 2009). Asbestos fibers persist in the environment indefinitely, contaminating soil, water, and air long after mines and industrial sites have shut down (Swayze et al., 2009). Georgina et al. (2018) cited that asbestos fibers weigh less than 1 gram, can be easily suspended in the air, contaminate watercourses and sand, and further pose a potential threat to the people nearby. Agents such as wind and water can transport asbestos fibers over long distances, spreading contamination beyond mining sites and affecting nearby communities (Jacques, and Pienitz, 2022). For example, over 20% of residents in Libby, a city in Montana, United States, were exposed to asbestos and asbestos fiber from an unrehabilitated asbestos mine in the area. These asbestos fibers were highly embedded in the tree barks and leaves, creating a significant health hazard for wood harvesters (Luus, 2007). Conversely, Wittenoom, in Western Australia, was the well-known contaminated village where polluted drinking water, soils, and the environment, were contaminated from poorly controlled crocidolite asbestos mining operations in 1966 (Musk et al., 2008).

Beyond its physical environmental hazards, asbestos exposure has significant social environmental consequences, particularly in communities near former asbestos mines, asbestos dumping and industrial sites, and areas with naturally occurring asbestos (NOA). These impacts affect public health, livelihoods, socio-economic stability, and community well-being, often leaving long-term burdens on affected populations. For instance, more than 200,000 people die annually from asbestos-related diseases such as asbestosis, mesothelioma, and cancer, worldwide (Selby, 2023). These diseases have long latency periods (10–50 years), meaning that symptoms often appear decades after exposure, making early detection and prevention difficult (Bhandari, Thada, and Sedhai, 2020). Meanwhile, former asbestos mining towns and industrial areas are often abandoned due to high levels of contamination, leading to the displacement of entire communities (Bhandari, Thada, and Sedhai, 2020). For example, an abandoned Turner Brother asbestos factory in Spodden Valley, Rockdale, in England, was left without proper environmental inspections and rehabilitation procedures. In 2004, over 650 houses were built in an asbestos-contaminated environment after the area was sold to a building consortium; to this day, the community is still trying to remediate the area (Hellawell and Hughes, 2021). Meanwhile, in Amagasaki, Hyogo Prefecture, Japan, the Kubota Corporation industry, which produces asbestos cement, relocated to Kakogawa in 1973, leaving the area unrehabilitated. A large accumulation of asbestos-contaminated soil, resulting from the leakage of asbestos-laden water from the abandoned factory, has contaminated the area, placing over 800 inhabitants at high risk of exposure (Kitamura et al., 2022). Sometimes, people living near asbestos mines or dumpsites may be forced to relocate, disrupting social networks, cultural heritage, and economic activities. In some cases, asbestos-contaminated land remains uninhabitable. For example, in March 2022, the Western Australian government permanently closed the asbestos-contaminated town of Wittenoom, relocating more than 7,800 residents, demolishing structures, and burying the downside to prevent further possible exposure (Watson, 2024).

Asbestos was banned in many countries due to its severe health risks, environmental contamination, and long-term socio-economic consequences. Scientific research and public health studies have conclusively linked asbestos exposure to fatal diseases,

occupational hazards, and widespread pollution, prompting governments to impose strict regulations and, in most cases, a complete ban on its use, production, and trade (Kurumatani, and Kumagai, 2011). International organizations, including the World Health Organization (WHO), International Labour Organization (ILO), and Collegium Ramazzini, have called for a worldwide asbestos ban (WHO, 2022). Over 60 countries, including Canada, Brazil, Australia, and South Africa, have completely banned asbestos mining, production, and use (Van Gosen 2007). Despite its ban, asbestos is still mined and exported in countries such as Russia, China, India, and Kazakhstan (Emmett, 2021; Thives et al., 2022; Weerarathne et al., 2024).

2.3. The spatial distribution of asbestos and asbestos mines globally

Figure 2.1 shows the spatial distribution of active and closed asbestos mines, worldwide. The map reveals that asbestos was mostly mined in the Northern Hemisphere, particularly in continents such as North America, Europe, and Asia. This distribution could be attributed to the geologic distribution of ultramafic and serpentinized rock formations in those regions, which host naturally occurring asbestos (Arachi et al., 2021; Qu et al., 2023). Meanwhile, the distribution map further illustrates that chrysotile was the most mined type of asbestos. Studies reveal that this type of asbestos is easy to mine and process, and it has a unique fibrous structure that makes it ideal for use in various applications such as insulation, cement, and textile (Sporn, 2014; Mazzeo, 2018; Jacques, and Pienitz, 2022). In North America, asbestos was mined in provinces of Canada, including British Columbia, Newfoundland and Labrador, Ontario, and Quebec, as well as Yukon Territory (Slavik et al., 2023). Thirteen asbestos mines were located in Quebec Province, which include a small open-pit mine at Puturniq in Nunavik and the largest open-pit asbestos mine, Jeffrey Mine (Kuyek, 2003). A similar trend can be observed in Asian (China, India, and Kazakhstan) and European (Finland, Italy, France, Germany, the United Kingdom, South Korea and Russia) countries. China, India, Kazakhstan, and Russia are among the countries in the world, up to today, are still mining and exporting asbestos due to high industrial demand, less strict regulation, and fewer asbestos bans. Russia, for instance, is the largest producer of asbestos globally, with an

annual production of 700,000 million metric tons in 2022 (Selby, 2023). This country is also home to the largest open-pit chrysotile asbestos mine, located at Mountains in Asbest township (Chen et al., 2022). India is also characterized by open-pit chrysotile asbestos chrysotile, particularly in Pulivendla tehsil, Cuddapah, and Andhra Pradesh. In France, asbestos was mined for almost half a century (from 1920 to 1965) in the Alps (the Val de Peas mining tremolite-asbestos) and in Corsica (the Canari mine extracting chrysolite) (Ross and Nolan 2003). Following the ban on asbestos in 1997, there is no longer any extraction, transformation, or primary use of asbestos in France. Before its ban in 2009, Korea's largest mines were located in South Chungnam province, with twenty-nine mines located in the Hongseong area (Kang et al., 2016).

The map also shows that as compared to the Northern Hemisphere, the Southern Hemisphere had very few numbers of asbestos mines with countries such as South Africa, Botswana, Zimbabwe, Australia, Brazil, and New Zealand having a demonstrated history of extraction of asbestos minerals. The map further reveals that among all 6 types of asbestos, crocidolite was predominant in the Southern Hemisphere and mined in countries such as Bolivia, South Africa, Botswana, and Australia. In Africa, the southern Africa region was the cornerstone of asbestos mining and export. The region includes countries such as South Africa, Botswana, Swaziland, Zimbabwe, with South Africa producing all three commercial types (chrysotile, crocidolite, and amosite). Zimbabwe's major asbestos mine, Shabanie-Mashava, was located near the town of Zvishavane and was once a significant producer of chrysotile asbestos before its closure in 2008 (Mutetwa, Moyo, and Brouwer, 2022; Runganga, 2024; Jerie, Shabani, and Shabani, 2024). The mine used to employ around 3,000 workers and produced about 200,000 tons of asbestos annually before its closure (Mutetwa, Moyo, Brouwer, 2022; Runganga, 2024; Shabani, and Shabani, 2024). In Swaziland, Havelock asbestos mine was the largest source of employment in the country, where 148 Europeans and 1,555 Africans were employed. The mine generated over 42,000 tons of chrysotile asbestos in 1976 (McCulloch, 2005). It was officially closed in 2002, and the area was left unrehabilitated, leaving 300 people in Bulembu exposed to asbestos (McCulloch, 2005).

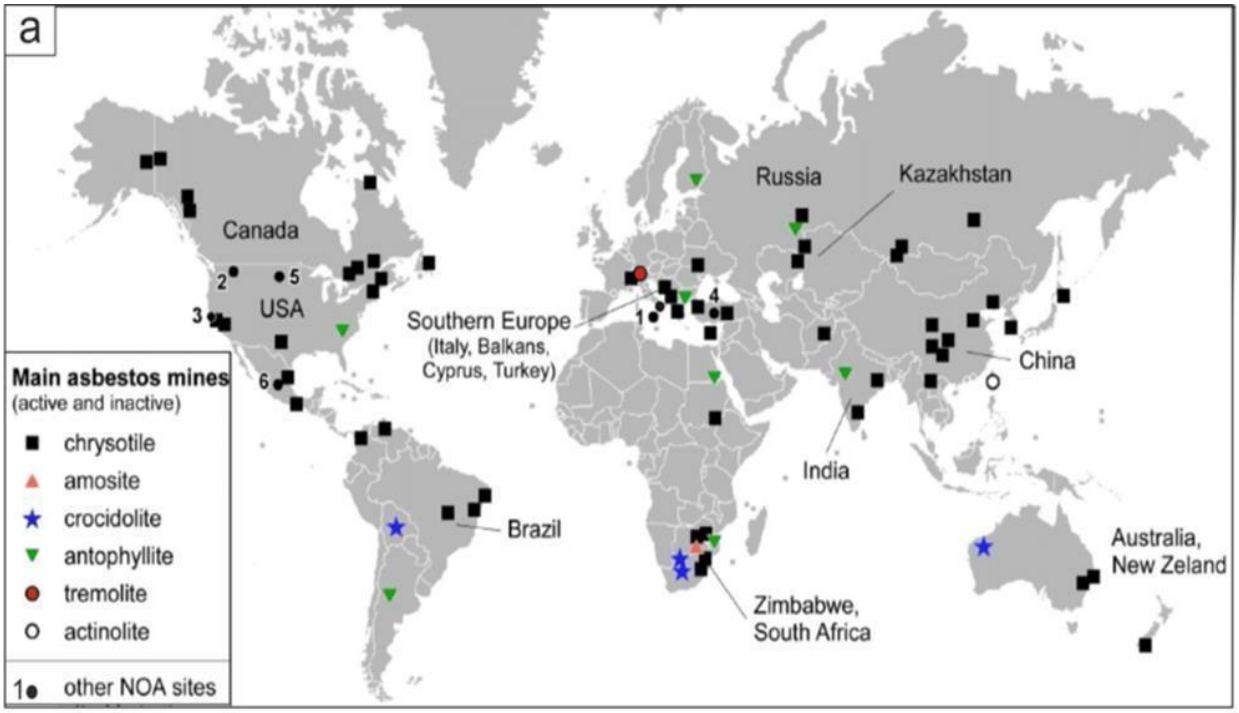

Figure 2.1: The distribution of asbestos mines globally (Source: Ricchiuti, Bloise and Punturo, 2020)

Figure 2.2 reveals that naturally occurring asbestos such as chrysolite, amosite, actinolite, crocidolite, anthophyllite, and tremolite were mined in South Africa. Chrysolite was mostly mined in Northern Cape, Mpumalanga, Limpopo, Gauteng, and Kwa-Zulu Natal Province (Nelson 2013). South Africa mined more than 10 million tons of asbestos between 1910 and 2000, and the amount of chrysotile exported peaked in 1977 at 380,000 tons (McCulloch, 2003; Abratt, Vorobiof, and White, 2004; Nelson, Murray, and Phillips, 2011; Cornelissen et al., 2019). In Mpumalanga province, chrysotile asbestos was mined at African Chrysotile Asbestos (ACA) mine, Badplaas asbestos and Malelane asbestos mine in Mbombela (Kwata, Chadi, and Moja, 2018; Cornelissen et al., 2019). Meanwhile, Kuruman and Priska in the Northern Cape Province host rehabilitated and un-rehabilitated asbestos mines (Mashalane et al., 2018)

Limpopo is the only province where 4 of 6 asbestos types were mined at larger scale, especially around the North and South East regions of the province. Anthophyllite and chrysolite, for example, were mined at the northernmost part of the province at Island

North Claims and Kromellenboog asbestos mines. According to records, 30% of the 60,389 tons produced in the nation in 1960 came from these mines (Mzwethu 2010). Meanwhile, Weltevreden and Penge mine, in the southeast quadrant, were well known for the amosite (brown asbestos), and crocidolite (blue asbestos) asbestos extraction. These mines are found closer to villages such as Ga-Malemang, Ga-Mathabatha, Mafefe, and Penge (Petja 2009; Petja et al., 2010; Kwata and Moja 2017; Freemantle et al., 2022). Due to the public health risks and widespread pollution, among others, the South African government was prompted to ban the mining of asbestos in the country in 2008.

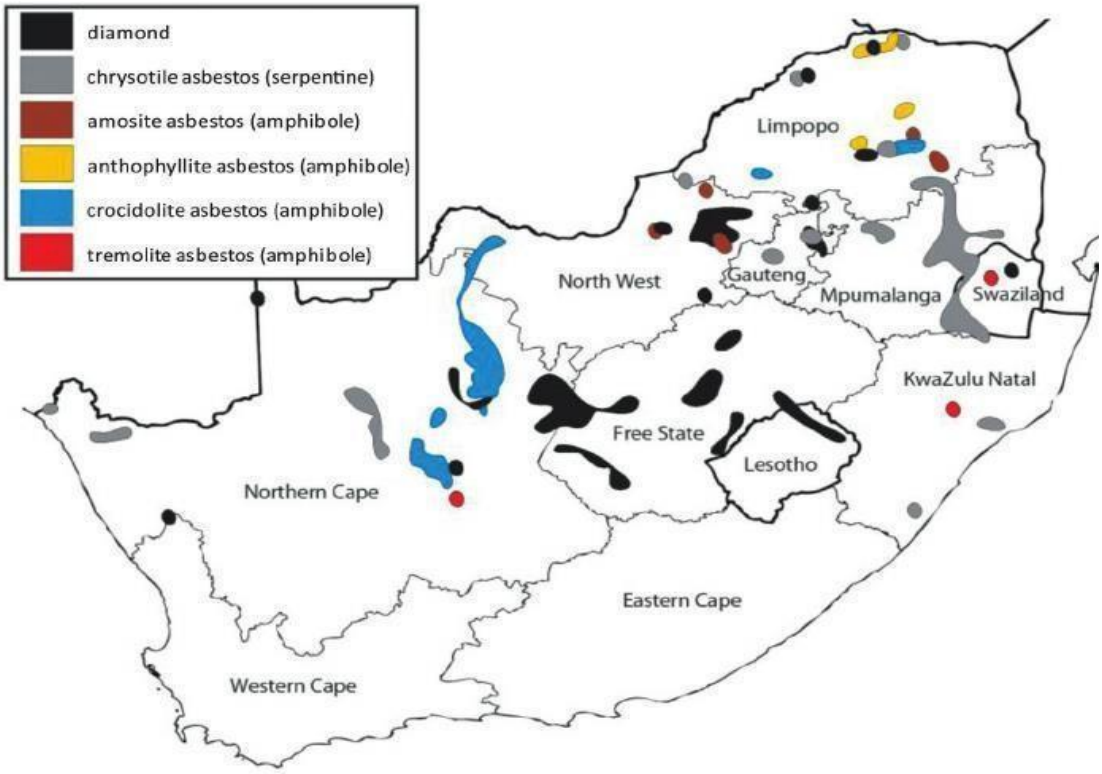

Figure 2.2: The distribution of asbestos mines in South Africa (Source: Nelson, 2013)

2.4. Geologic mapping of asbestos

Historically, mineral exploration and geological mapping have relied on field-based methods, geochemical analysis, and geophysical surveys to identify and classify mineral deposits (Kurumatani, and Kumagai, 2008; Wei et al., 2012; Ugolini et al., 2015). Conventional techniques such as rock sampling, petrographic analysis, and X-ray

diffraction (XRD) have been widely used to determine the mineral composition of geological formations (Hwang et al., 2011; Kusiorowski et al., 2013; Dichicco et al., 2017; Malinconico et al., 2022; Lee, Mischler, and Wolfe, 2024). For example, X-ray diffraction was used to analyse thirteen serpentinite rock samples from the Pollino area (Southern Apennines) in Italy. The results showed that the earthy portion of the region was dominated by serpentine and amphibole-like minerals (tremolite, d = 2.94 Å; actinolite, d = 8.31 Å) (Dichicco et al., 2017). Additionally, geophysical methods, including magnetic, gravity, and electromagnetic surveys, have been instrumental in detecting subsurface mineral deposits by analyzing variations in the Earth's magnetic and gravitational fields (Liu et al., 2017; Kermani et al., 2021; Hinojosa et al., 2022). In the Durango mining site of Mexico, Hinojosa et al., (2022) utilised 2D electrical resistivity imaging (ERI) to detect abandoned and undocumented historic silver mining infrastructure. Meanwhile, in the Iranian city of Karaj, for instance, Kermani et al., (2021) study successfully employed a phase-contrast microscope and magnetic survey to investigate the airborne asbestos fiber concentration, which was 1.84 f/L PCM and 18.16 f/L SEM, which was much higher than the normal asbestos fiber concentration. Spatial geological mapping, which involves the interpretation of topographic maps, geological surveys, and aerial photography, has been the foundation of mineral exploration, allowing geologists to delineate rock formations and identify potential mineralized zones (Petja et al., 2009; Krówczyńska, Wilk, and Zagajewski, 2014; Wilk, 2021; Lysaniuk et al., 2021). However, these conventional approaches are often time-consuming, labour-intensive, and limited in their spatial coverage, particularly in remote or inaccessible regions (Jacobsen, 1993; Petja et al., 2010; Shay et al., 2016).

To complement these conventional methods, remote sensing has emerged as a reliable, non-invasive and cost-effective technology for the mapping and continuous monitoring of areas characterized by minerals at different scales. It has increasingly been lauded globally as more efficient alternatives for mineral discrimination, identification, and mapping. Currently, there are numerous ground-based, airborne, and space-borne multispectral (e.g. ASTER, Landsat 5 TM, Landsat 7 ETM+, Landsat 8/9 OLI & TIRS, Sentinel-2, WorldView-3) and hyperspectral remote sensors (e.g. AVIRIS, AISA, HyMap,

PRISM and CHRI) that enable the detection of specific mineral spectral signatures, allowing for the differentiation of mineral types based on their unique reflectance and emissivity properties (Clark et al., 2003). The applications of remote sensing technologies in geological mapping is based on the assumption that different minerals exhibit unique spectral signatures due to their interaction with electromagnetic radiation. These interactions occur in various portions of the electromagnetic spectrum, particularly in the visible (VIS), near-infrared (NIR), shortwave infrared (SWIR), and thermal infrared (TIR) regions. So, each mineral has a characteristic way of absorbing, reflecting, and emitting electromagnetic energy at specific wavelengths (Sankaran and Nasir, 2024; Clark et al., 2003; Swayze et al., 2009). For example, asbestos minerals, particularly chrysotile, tremolite, and actinolite, have distinct absorption features in the SWIR (2.1–2.4 µm) and TIR (8–12 µm) regions due to their molecular composition (Clark et al., 2003; Swayze et al., 2009), allowing for their identification using multispectral and hyperspectral remote sensing techniques (Clark et al., 2003; Swayze et al., 2009). In particular, the shortwave infrared (SWIR) region (2.1–2.4 µm) has been found effective in distinguishing asbestos from non-asbestos-bearing silicate minerals due to its characteristic hydroxyl (-OH) absorption features (Sankaran and Nasir, 2014; Swayze et al., 2018).

Globally, the capabilities of multispectral sensors such as ASTER, Landsat, Sentinel-2 MSI, WorldView-3, MODIS, and SPOT were tested in detecting minerals such Ni-magnesioferrite, magnetite, awaruite, talc, arnothite, kaolinite, soapstone, kaosmec, montmorillonite, chrysotile, serpentinite and quartz, sericite, and pyrite-clay has been tested (Gillespie et al., 1998; Han, and Nelson, 2015: Abrams et al., 2015; Pour et al., 2019; Ninomiya, and Fu, 2019; Khaleghi et al., 2020; Soliman et al., 2021; Jeong et al., 2022; Qasim et al., 2022; Sankaran and Nasir., 2024). For instance, ASTER's SWIR and TIR bands have been successfully applied in mapping geological formations (Gillespie et al., 1998; Abrams et al., 2015; Pour et al., 2019; Soliman et al., 2021; Sankaran and Nasir, 2024). Similarly, Qasim et al., (2022) tested the utility of ASTER and Sentinel - 2B in detecting epidote, epidote + chlorite, serpentine, and anorthite, meanwhile, Khaleghi et al., (2020) compared the performance of Landsat-8 (OLI), Sentinel-2, and ASTER in mapping hydrothermal alteration and iron oxide minerals. Their results revealed that

Sentinel-2 data proved remarkably better mapping for iron oxide minerals than the OLI and ASTER data. Although these studies have demonstrated the utility of remote sensing technologies in mapping minerals, little research has been done in South Africa (e.g. Muavhi and Tessema, 2021; Muavhi Mavhungu and Ndivhudzannyi, 2021; Petja et al., 2009)

Traditional statistical and classification methods such as principal component analysis (PCA), spectral angle mapper (SAM), spectral information divergence (SID), and minimum distance classifier (MDC) and machine learning algorithms such as support vector machine (SVM) have been instrumental in large-scale mineral detection. For instance, Pour et al., (2019) used SVM to detect autochthonous development. The SVM obtained an accuracy of 98%. It is universally acceptable that the accuracy of mineral detection relies on correcting for atmospheric interference, such as water vapor and aerosols, which can alter spectral reflectance (Jeong et al., 2022). As such, preprocessing techniques like atmospheric FLAASH (Pour et al., 2019) and QUAC (Zalaky, 2019) are often employed to improve data quality and model accuracy. For example, Zalaky (2019) used Quick Atmospheric Correction (QUAC) to perform atmospheric correction on ASTER and Landsat 8 satellite imageries in mapping SiO2, opal, chalcedony and cristobalite. Additionally, another study show that the accuracy of mineral detection also relies on comparing remote sensing spectra with spectral libraries measured from spectrometer instruments (Sankaran and Nasir, 2024) or extracted from the USGS (Higgins et al., 2003; Beiranvand Pour et al., 2019). These libraries contain known spectral profiles for minerals, enabling automated mineral classification using spectral matching algorithms.

Abbasi et al., (2022), Malinconico et al., (2022) and Torres et al., (2023) argue that remote sensing technologies are most effective when mineral-bearing rocks and soils are exposed and not covered by vegetation, water, or thick soil layers. Leaf vegetation is present, spectral mixing can occur, requiring spectral unmixing algorithms to separate the asbestos signal from other land cover types (Torres et al., 2023). The integration of remote sensing, machine learning algorithms, and geophysical data further enhances

mineral detection accuracy, making it an essential complement to conventional geological methods in modern mineral exploration. Advancements in spectral unmixing algorithms have further enhanced the accuracy of asbestos mineral identification, enabling the differentiation of asbestos fibers from other silicate minerals in complex geological settings (Farrand and Harsanyi, 2020). As remote sensing technology continues to evolve, its integration with ground-based validation techniques such as X-ray diffraction (XRD) and laboratory spectral analysis is improving the reliability of asbestos mapping, ensuring better geologic mapping and monitoring.

2.5. Meteorological events on potential asbestos distribution and exposure

Meteorological factors, particularly wind, rainfall, and temperature variations significantly influence the distribution and dispersion of asbestos (Compton et al., 2010; Boulanger et al., 2014; Parwada, and Van Tol, 2016; Cornelissen et al., 2019; Campbell et al., 2020; Malinconico et al., 2022; Chapungu et al., 2023). These environmental variables have been reported to play a vital role in determining how asbestos fibers are released, transported, and deposited in the environment, thereby influencing human exposure and risks (Obmiński, 2022; Malinconico et al., 2022; Avataneo et al., 2023; Peña-Castro et al., 2023). NOA is commonly found in ultramafic and serpentinized rock formations, and when these rocks are naturally weathered or disturbed through human activities such as mining, construction, and agriculture, asbestos fibers become environmentally mobile (Gunter, 2010; Buck et al., 2013; Van Gosen et al., 2016; Gualtieri, 2020; Bloise et al., 2017; Obmiński, 2022). However, natural forces, particularly wind, rainfall, and temperature variations, play a fundamental role in controlling the movement and dispersion of these hazardous fibers, determining the extent to which asbestos can spread beyond its source areas and affect surrounding communities.

2.5.1. Role of rainfall on asbestos distribution

Rainfall has the potential to distribute asbestos, and asbestos dust through weathering, erosion, and wet deposition (Obmiński, 2022; Malinconico et al., 2022; Avataneo et al., 2023; Peña-Castro et al., 2023). Swayze et al., (2009) argue that heavy rainfall and flooding can erode asbestos-bearing soils and transport fibers into rivers, lakes, and

groundwater systems, increasing the risk of waterborne asbestos contamination. Meanwhile, runoff from mining waste sites or naturally exposed asbestos deposits can further spread asbestos-containing sediments into agricultural fields and residential areas. Conversely, light to moderate rainfall can help suppress airborne asbestos by wetting the surface, thereby reducing fiber suspension in the atmosphere. However, during prolonged dry periods following rainfall events, evaporation can expose previously settled asbestos fibers, making them susceptible to wind-driven transport once again (Kwata, Moja and Chadi 2018; Malinconico et al., 2022; Obmiński, 2022; Avataneo et al., 2023).

Research has been undertaken in the recent past to demonstrate the influence of rainfall to asbestos. For instance, Avataneo et al., (2022) verified the possible correlation between asbestos concentration and precipitation pattern over the four seasons in Balangero, northwestern Italy. The results indicated that the quantity of fibers found in water samples was strongly dependent on the precipitation (average waterborne asbestos concentration was 106 f/L and peaked up to 20·106 f/L after intense precipitation). On the other hand, Ervik, Eriksen Hammer, and Graff (2021) conducted a study in Southern Norway to examine the relationship between rainfall data and the improper destruction of asbestos-laden structures. The findings indicated that while rainfall decreased airborne asbestos concentrations, the resuspension of asbestos-contaminated dust from previously wet surfaces during subsequent dry periods increased airborne asbestos levels. In contrast, historical precipitation data was integrated with asbestos fiber concentration measurements in urban areas such as the city of Iran (Karaj), where asbestos-containing structures were undergoing demolition (Singh et al., 2019; Neitzel et al., 2020; Obmiński, 2021; Kyriakidis et al., 2024). The findings indicated that whereas rainfall initially reduced airborne fiber concentrations, subsequent dry periods after rain resulted in elevated asbestos levels in the air due to the resuspension of asbestos-laden dust particles from previously moist surfaces. Attempts have also been made in Africa to investigate the influence of rainfall on asbestos distribution. For instance, Kyriakidis et al., (2024) tested the relationship between materials made of asbestos, such as house roofing, ceiling, floor tiles, and cement, with rainfall, and drinking

water in Mati and Kineta (Athens, Greece). In Zimbabwe, two major factories manufacturing chrysotile asbestos cement in Harare and Bulawayo were selected to determine the trends in the concentration of waterborne chrysotile asbestos fibers (Mutetwa et al., 2021). Their results detected 57% and 50% of asbestos dust exposure, indicating an increase in the concentration of chrysotile asbestos fibers in the Harare and Bulawayo water bodies near the factories, respectively (Mutetwa et al., 2021). In South Africa, Limpopo, Mpumalanga, and North West provinces, other studies focused on the impacts of heavy rainfall adjacent to decommissioned asbestos mines (Petja et al., 2010; Jones et al., 2018; Kwata, Moja, and Chadi, 2018; Freemantle et al., 2022). For example, Petja et al. (2010) described post-asbestos mines in Mafefe and Penge as major contributors to waterborne asbestos that contaminates rivers nearby. Kwata, Moja, and Chadi (2018) used wind rose diagrams to show that rainfall, wind speed, and direction were the main reasons why asbestos fibers got into the communities of Mbombela, Malelane, and Carolina in Mpumalanga. In summary, these investigations demonstrated that significant precipitation resulted in the deterioration of tailings, facilitating the downstream migration of asbestos fibers into adjacent water sources, along riverbanks, and on gravel roads inside urban areas. Upon desiccation, these areas transform into repositories of airborne asbestos fibers, especially in low humidity and wind conditions.

2.5.2. Wind speed and direction

Wind affects the dispersion of airborne asbestos fibers. Asbestos fibers are often diminutive and weigh less than 1 gram individually, facilitating their airborne dispersion at elevated wind velocities (Mashalane et al., 2018; Krówczyńska, and Wilk, 2019; Mutetwa, Moyo, and Brouwer, 2022; Peña- Castro et al., 2023). In regions with exposed asbestos-bearing rocks, abandoned mine sites, or contaminated soils (Peña- Castro et al., 2023), intense winds can disturb, lift, and transport asbestos fibers across considerable distances, with the prevailing direction influencing their dissemination trajectory (Frank and Joshi, 2014; Omanga et al., 2014; Neff and Bertler, 2015; Furuya et al., 2018; Xu et al., 2020). The extent of fiber dispersion depends on wind speed, direction, and atmospheric stability, with higher wind speeds increasing the potential for asbestos

inhalation exposure in downwind communities. Seasonal wind variations further impact asbestos movement, with stronger winds in dry seasons increasing the likelihood of fiber suspension and dispersal (Pastuszka, 2009; Pawełczyk, and Božek, 2015; Kim et al., 2020; Compton, and Underwood, 2021).

To date, several studies have ascertained the effects of wind on asbestos distribution by highlighting the significance of wind speed, wind direction, and atmospheric stability in influencing fiber dispersion (Abakay et al., 2016; Thives et al., 2022; Jayakumari et al., 2024). For example, Awadh (2023) found that the wind in Mosul, Iraq, was blowing from the west and northwest toward the rehabilitated asbestos landfill, potentially increasing the risk of asbestos dispersion into the city. The wind contained 72.7% sand, 25.1% sediment, chrysotile 60%, actinolite 23%, and 2.19% clay. Other studies have effectively predicted and identified areas of storm dust exposure by incorporating wind speed and direction (Joshi 2021; Hamzeh et al., 2021; Chaichan et al., 2023). For example, Moteallemi et al., (2020) studied Mashhad city, Iran, classifying asbestos dust in the area as an airborne and further highlighted that the contaminated air surrounding the city was a result of improper handling of asbestos waste. According to these investigations, wind is a significant factor in the transportation of aerosols, asbestos, quads, and contaminants from the desert to major cities. Studies by Yang et al. (2019) and Suhartono et al., (2020) have demonstrated that strong winds and dry conditions exacerbate airborne asbestos mobility, increasing exposure risks for surrounding populations. For example, Yang et al., (2029) further demonstrated that the asbestos dumplings and tailings located at the windward side of the community correlate with the wind patterns, as during windy seasons, the dust from the tailings accumulates in the villages, exposing everyone to asbestos. Meanwhile, Suhartono et al. (2020) found a mutual relationship between meteorological variables (such as wind speed and direction) and unrehabilitated asbestos sites. Their study emphasizes that the most effective solution is to rehabilitate these areas and raise awareness about the dangers of inhaling asbestos dust.

In South Africa, only a limited number of studies have connected wind speed and direction with asbestos distribution and asbestos dust exposure. For example, Kwata, Moja, and

Chadi (2018) quantified and characterised dust fall samples captured using a 5.0-liter cylindrical bucket in Mbombela, Malelane and Badplaas - towns adjacent to a former asbestos mine (Kwata, Moja, and Chadi 2018). The results revealed that the measured dust rates were below a concerning residential limit of 600 mg/m2/day. Similarly, Kwata and Moja (2017) and Malatji et al., (2021) highlighted that the presence of asbestos dust, rocks, and soils at people's homes, soccer grounds, schools, churches, and on the streets were as a result of climatic conditions such as strong winds and rainfall eroding asbestos debris from unrehabilitated shafts into the communities.

2.5.3. Atmospheric predictive modelling and trajectories

The study of airborne pollutant dispersion has increasingly relied on atmospheric transport modeling, particularly in assessing the movement of hazardous particles such as asbestos dust (Sami et al., 2012). Several studies have demonstrated that wind-driven dispersion plays a crucial role in transporting airborne fibers over long distances, affecting communities far from the contamination source (e.g. Li et al., 2021; Xiao et al., 2024). NOAH HYSPLIT model, satellite imagery, ground base sensors and trajectories (backwards backward and forward trajectories) are fundamental component of atmospheric modeling and has been widely used to trace the pathways of airborne pollutants (Penny, Zeidman, and Burgess, 2013; Notaro et al., 2015; Lei et al., 2019; Xiao et al., 2024). For example, Neitzel et al., (2020) determined the concentration of asbestos present during the demolition of abandoned residential dwellings in the city of Detroit, United States using an empirical model (NIOSH 7402 method). While effective for localised predictions, the model's accuracy diminishes when applied to different geographic regions or environmental conditions. Meanwhile, Li et al., (2021) monitored the concentration of total suspended particulates (TSP) in the Anjialing open-pit coal mine in Pingshuo. Similarly, Cherrie, McElvenny, and Blyth, (2018) applied TSP concentration hybrid model based on a long short-term memory (LSTM) network and the attention mechanism (LSTM-Attention). Their results indicated that both the autoregressive integrated moving average (ARIMA) and LSTM- Attention models can be used to predict the TSP concentration, and both give reasonable results.

Modeling approaches using trajectories have been successfully applied in several studies on industrial emissions, dust storms, and volcanic ash dispersion, providing critical insights into the spatial distribution of hazardous aerosols (Zhao et al., 2015; Seibert et al., 1994; Draxler & Hess, 1997). For example, Zhao et al., (2015) successfully used backward trajectories to identify the sources of dust based on CALIPSO and MODIS satellite data. The dust sources were accurately identified using the HYSPLIT (Hybrid-Single Particle Lagrangian Integrated Trajectory) trajectory model and multiple satellite data. The majority of studies have focused more on finding the origins of the dust and investigating the moving pathway of contaminated dust, including that of asbestos (Briceño-Zuluaga et al., 2017; Al-Dousari, Doronzo, and Ahmed, 2017; Aili et al., 2021; Awadh, 2023). Limited studies have focused on identifying the long-range transport pathway of the air parcel from the source to other potential areas of exposure. Those that have attempted focused on other dust particles (Briceño-Zuluaga et al., 2017; Aili et al., 2021; Awadh, 2023). For instance, Alli et al., (2021) used a cluster analysis of forward trajectory to identify the transport pathway of dust particles from the dried bottom of the Aral Sea, Central Asia. The results indicated that air parcel trajectories originating from the dried bottom of the Aral Sea can affect regions thousands of kilometers away in a relatively short period. This dust storm has a high potential of transporting dust and other aerosols to other areas, such as the Siberian Plain and southern regions, such as the Iran Plateau. Studies incorporating these forward trajectory analyses with asbestos dust exposure from unrehabilitated asbestos mines and dumping are scarce, specifically in South Africa, where closed asbestos mines are prevalent. While extensive research has examined the transport of industrial pollutants, limited studies have focused specifically on asbestos trajectories in rural environments, where informal settlements may be exposed to airborne contamination without adequate mitigation measures.

2.6. COMMUNITY AWARENESS AND PERCEPTION OF ASBESTOSIS RISK

Asbestosis is a chronic lung disease caused by long-term inhalation of asbestos fibers (Järvholm, and Burdorf, 2024). This disease leads to lung scarring (fibrosis) and respiratory complications (Kang et al., 2018; Keskitalo et al., 2019; Yang et al., 2020;

Ferrante, 2021; Kim et al., 2022). It develops over years or decades following prolonged asbestos exposure, particularly in occupational settings, mining areas, and communities near asbestos deposits (Keskitalo et al., 2019; DeBono et al., 2021; Ou et al., 2023). According to WHO (2022), more than 90,000 people die every year globally from asbestos-related diseases such as lung, cancer, mesothelioma, and asbestosis. Additionally, Raeis-Abdollahi et al., (2019) recorded more than 2,000 fatalities from the chrysotile asbestos mine Hajat in Nehbandan, eastern Iran. Meanwhile, Miller et al., (2022) highlighted that in the United States of America, 12,000 to 15,000 Americans die every year from asbestosis. In Asia, countries such as Japan, Korea, and Singapore record more than 15,000 cases of asbestosis death from inhalation of asbestos fiber in the manufacturing industries (Gariazzo et al., 2023). In South Africa, more than 200 asbestosis and mesothelioma cases are reported annually, of which 20% of the cases come from people residing in unrehabilitated asbestos mines (WHO, 2022). Since the closure of asbestos mines in 2008, South Africa has spent approximately R416 970 823 on 4 700 claimants in asbestos relief funds to compensate asbestosis victims (Cornelissen et al., 2019). However, records revealed that, to this date, only 40 out of 249 asbestos mines were rehabilitated by South African state owned Mintek Consulting company through the Department of Mineral Resources (DMR) for over 800 million (Cornelissen et al., 2019), leaving thousands of communities exposed to dilapidated closed mine shafts and disposal sites. The scientific community, however, argues that community knowledge, awareness, attitude, perceptions, and practices play a significant role in reducing asbestos fiber exposure and preventing subsequent risk of asbestosis.

2.6.1. Practices that exposes communities to asbestos

Activities that individuals as well as the community at large engage in influence the likelihood of asbestos exposure (LaMontagne, and Walker, 2005). These include unsafe handling of asbestos-containing materials, improper waste disposal, and living in close proximity to abandoned mines or asbestos waste dumps, which increase exposure to asbestosis and the risk of developing asbestosis and other asbestos-related illnesses (Singh, and Mahato, 2019; Mbah, 2019). In some communities, people continue to use

asbestos-based materials in construction and household applications due to their accessibility, availability, affordability, and durability, often without understanding the long-term consequences.

Various studies have contributed to the understanding of practices that exposes communities to asbestos (LaMontagne, and Walker, 2005; Culley, Zorland, and Freire, 2010; Marsili et al., 2019; Emmett, 2021; Khamhing, McArdle, and Ross, 2023; Frangioudakis et al., 2023). A growing body of literature revealed that individuals who engage in occupations such as asbestos mining, asbestos plant work, boiler making, building, insulating, asbestos cement work, and textile mill work were at high risk of being exposed to asbestos dust (Caleo et al., 2018; Singh, Singh, and Mahato, 2019; Mbah, 2019; Lee, and Kim, 2021). Lee, and Kim, (2021), for example, revealed that 1228 corrugated asbestos cement and roofing workers were diagnosed with asbestosis while working at Korean asbestos-cement slate in Korea. Similarly, Kitamura et al., 2023 reported that the highest proportion (65.5%) of male respondents working at large-scale asbestos-cement (AC) plant in Amagasaki, Japa were victims of the asbestos-related diseases. Meanwhile, Airoldi, (2023), highlighted that asbestosis cases in Italy emerge from residences that are environmentally exposed to the dust every day.

Domestic activities, including, leading herds to pass near asbestos dumping, collecting water from asbestos-contaminated areas, passing near asbestos dumpings, not handling asbestos waste properly, drinking rainwater harvested from asbestos roofs, playing on asbestos dumpings, were identifies as major practices that increased communities' risk to asbestosis (Furuya et al., 2018; Yamamoto et al., 2021; Huh et al., 2022; Kwak et al., 2022; Zhang, Hong, and Kim, 2022). For instance, Petja et al., (2010) found out that women and children collect firewood and rock from mountain-mined asbestos. This domestic activity exposes them to asbestos and subsequent asbestosis. This was confirmed by Freemantle et al., (2022), in which respondents admitted to harvesting wood near asbestos shafts, drinking contaminated water harvested from rivers, passing near asbestos dumplings, and not properly disposing off asbestos waste at their homes. Meanwhile, household activities such as sweeping the yard, cleaning the windows and

irrigating with asbestos-contaminated waters, installing a home ceiling made of asbestos, building a house using asbestos rocks and soils are identified as the primary source of secondary exposure (Petja et al., 2010; Freemantle et al., 2022; Obmiński, 2022; Durczak et al., 2024). Additionally, one of the risky practices that perpetuates the risk of asbestosis in communities residing in asbestos-rich areas is agriculture. Agricultural practices such as cattle herding and grazing expose both the herder and the herd to asbestos dust exposure. Goat, sheep, and cattle farmers who pasture their herds in the mountains are also more vulnerable to being exposed to asbestos dust. Maja et al. (2020) indicated that walking in closer proximity to asbestos disposal sites may result in asbestos fibers adhering to clothing, exposing individuals and their families to dust at home. Unsafe occupational, domestic, and agricultural practices continue to increase asbestos exposure risks in affected communities, often due to a lack of awareness and alternative resources. Addressing these high-risk activities through education, regulation, and proper waste management is crucial in reducing asbestosis cases and other asbestos-related illnesses.

2.6.2. Knowledge and awareness related to asbestos and asbestosis risks

Knowledge and awareness are crucial in determining how individuals and communities recognize asbestos-related hazards, including sources of exposure, associated health risks, and appropriate protective measures (Marsili et al., 2015; Marsili et al., 2019; Bertolotti et al., 2025). It is widely accepted that a lack of knowledge and awareness leads to unintentional exposure, as community members may unknowingly use asbestos-containing materials in construction, farming, and household activities in many asbestos-affected regions (LaMontagne, and Walker, 2005; Goodall, and Ahmed; 2015; Hernández, Pereira, and Bloise, 2024; Bertolotti et al., 2025). Several studies have explored the occupational mineworkers knowledge and awareness related to asbestosis (Hughes, Weill, and Hammad, 1987; Li et al., 2014; Metintas et al., 2017; Tuncer and Gomleksiz, 2025; Bertolotti et al., 2025). For example, Hughes, Weill, and Hammad, (1987) revealed that over 54% of employees at two chrysotile asbestos cement plants were not aware of the exposure to crocidolite and chrysotile asbestos. Similarly, Tuncer

and Gomleksiz, (2025) revealed that nearly half of the respondents (49.4%) were unaware of the potential danger of inhaling asbestos dust while demolishing household material made of asbestos. In contrast, Bertolotti et al., (2025) revealed that 62% of 280 participants (general practitioners of Territorial Assistance Equipes (EATs) in the Piedmont region) were highly aware of the risk of asbestos exposure from asbestos cement, roofing, and ceiling in their workplace. Other related asbestosis cases and mortality rates experienced in asbestos cement plants highlighted the similar trend of lack of awareness of workers experiencing asbestos-related symptoms in Italy, Brazil, Japen, China, and Russia (Hughes, Weill, and Hammad, 1987; LaMontagne, and Walker, 2005; Culley, Zorland, and Freire, 2010; Bertolotti et al., 2025).

A growing body of research has shifted focus towards the knowledge and awareness of broader populations, particularly those residing close to asbestos-rich areas. For instance, Metintas et al., (2018) revealed that the knowledge and awareness level of asbestos was low among rural and urban communities that were at risk of environmental asbestos exposure in the central region of Anatolia, Turkey. Freemantle et al., (2022) added that knowledge of asbestos also contributes to the risk of the exposure. For example, lack of knowledge about the danger of exposure to asbestos results in individuals participating in activities that put them at higher risk of being exposed. Such activities include, coming home wearing the same PPE as the one worn at the asbestos construction sites, performing rituals and cleansing in rivers contaminated with asbestos fibers, and hunting wild animals that live in the trenches of asbestos. Furthermore, lack of knowledge on asbestosis and asbestos dust exposure has resulted in primary school children of less than 15 years of age playing in asbestos dumping sites, putting themselves at high risk of exposure (Reid et al., 2018; Consonni et al., 2019; Prunetti, and Stransky, 2020). Meanwhile, the unemployed locals of Mafefe, and Penge who had little to no knowledge about the danger of asbestos dust exposure , used to extract asbestos minerals from the rock by crushing the rocks of asbestos and pile them in the containers to trade them in exchange for money to support their family (Petja 2009; Petja 2010). (WHO; 2022). The level of knowledge and awareness regarding asbestos exposure plays a critical role in shaping individuals' behaviors and risk perception.

Studies consistently highlight that low awareness contributes to unintentional exposure, placing both workers and community members at higher risk of asbestosis.

2.6.3. Attitudes and perception regarding asbestosis

Community attitude and perception also play a significant role in the rise of asbestos-related diseases in workplace and contaminated areas (Verger et al., 2008). Lee, and Kim, (2021) argues that although there were enough inductions about asbestos management at work, ignorance, and attitude of not wearing PPE in a correct way have contributed to the exposure. This was confirmed in a South African study, in which 60% respondents admitted to not taking proper precautions when exposed to asbestos dust (Wagner et al., 1960) and taking PPE to their homes while it was not permitted was the major contributor to secondary exposure (Petja 2009). Individuals who perceive asbestosis as a severe and incurable disease are more likely to adopt preventive behaviors, reducing their risk of exposure. Conversely, those with low risk perception may engage in unsafe practices, increasing their likelihood of asbestos dust exposure. Additionally, shifts in awareness and behavioral responses over time can influence asbestos exposure trends, potentially impacting the incidence of asbestosis cases. For instance, Bond, and Cook, (2004) recorded that more than 1,900 residents of Otara Ward of Manukau City in South Auckland, refused to relocate to other areas of less asbestos exposure as they perceive asbestosis as less deadly and mentioned that people were killed by fear rather than the disease. Menwhile, Matei et al., (2015) reported that 45% of 500 respondents in Darabani town, Botoşani County, admitted to drinking the contaminated water collected from their asbestos roofed houses despite being fully aware of the risk associated with asbestos. On the other hand, In South Africa, the Mintek consulting company was stopped from continuing with rehabilitation processes (Minek, 2018) as a result of a lack of job opportunities in the area. These findings highlight the critical role of community attitudes and perceptions in influencing asbestos exposure risks. Misinformation, complacency, and economic priorities often outweigh health concerns, leading individuals to engage in unsafe practices despite awareness of the dangers.

2.7. Theoretical framework

Various conceptual frameworks have been developed and implemented to address community awareness and perception of specific environmental issues (Scalia, 2017). For this study, the modified conceptual framework by Baba-Nalikant et al., (2023) has been adopted. The main purpose of adapting and modifying this conceptual framework was to correlate demographic variables with awareness and perception, as well as to align with the aim of the work on community awareness and perception. The new modified conceptual framework aims to conceptualize the community of Ga-Mathabatha's level of awareness and perception of asbestosis risks. This study defines community awareness as the inquiry or consciousness that stems from perceived knowledge about asbestosis. Additionally, this investigation categorized community perceptions of asbestosis into knowledge, attitude, and practices. The framework also illustrates the socioeconomic characteristics, hazards, vulnerability, and demographic characteristics of households located within the Ga-Mathabatha community.

Figure 2.3 below demonstrates asbestos mines, dump sites, and waste rocks as major sources of asbestos exposure that affects community members about their demographic, socioeconomic variables, approximate to the source, and years of residence. Figure 2.3 further demonstrates that the community perception of asbestos dust exposure and asbestosis disease is structured upon three major factors, namely, knowledge, attitude, and practice. This study was built upon the Raphael et al., (2009), Scalia, (2017), Green (1999), and Rapholo, (2018) studies that portray perception as a dynamic variable that is influenced by knowledge, which influences practices and attitudes. These three factors that are influenced by community perception of asbestosis and asbestos dust contain three aspects (physical location, demographic driver, and socio-economic driver) that contribute to the exposure.

Knowledge in this study was interpreted as the mutual understanding and proper interpretation of certain environmental concepts of interest. The drivers of community knowledge include aspects of socio-economic characteristics such as age, level of education, occupational level, and the number of years a person has stayed in a village.

Scalia, (2017) study indicated that some knowledge about the surrounding environment is acquired at some stage, and the older the person, the more knowledge they acquire due to the experience they gain with time. Scalia, (2017) further detailed that young people of 19 years and below are less knowledgeable about certain environmental pollutants aspects as compared to older people of more than 30 years and above. Level education is also a greater aspect of knowledge, as studies indicate that people with tertiary qualifications tend to have adequate knowledge about certain environmental factors (Scalia, 2017). Although it is an opinion and contradictory to Olofsson and Rashid, (2011). It is said that people who work at asbestos factories and asbestos construction companies have adequate knowledge as they are being alerted about it during induction processes. People who stayed in a certain village for a period have indigenous knowledge about the events that happened and that are still happening at that time (Scalia, 2017; Bullock, 2020; Afzal et al., 2021).

Community practices in this study are defined as activities that people engage in that expose them to asbestos dust. It is important to evaluate the activities that people engage in, as they play a major role in distributing asbestos fibers and exposing others to asbestos dust (Petja et al., 2010). For example, Culley, Zorland, and Freire, (2010), Petja et al., (2010), studies have expressed those practices such as playing with asbestos dumping, cleaning the contaminated yard without wearing a face mask, swimming in asbestos-contaminated water, and heading livestock to contaminated land hills are major practices contributing to the exposure. The socio-economic factor that influences practice is age. For instance, children under the age of 15 were found playing in asbestos-dumping sites, exposing themselves to the dust (Geogina et al., 2018). Adults over the age of 30 years engage in illegal asbestos mining without proper personal protective gear, exposing them to asbestos dust. Gender and educational attainment have an impact on practices as well (Scalia, 2017). For instance, in areas that are near unrehabilitated asbestos mines and dumping sites, the females who engage in chores at home without wearing face masks may be exposed to the dust. This aspect directly affects the asbestosis risk, as people who engage in activities that may lead to exposure are at high risk of being exposed to asbestos dust and being diagnosed with asbestosis.

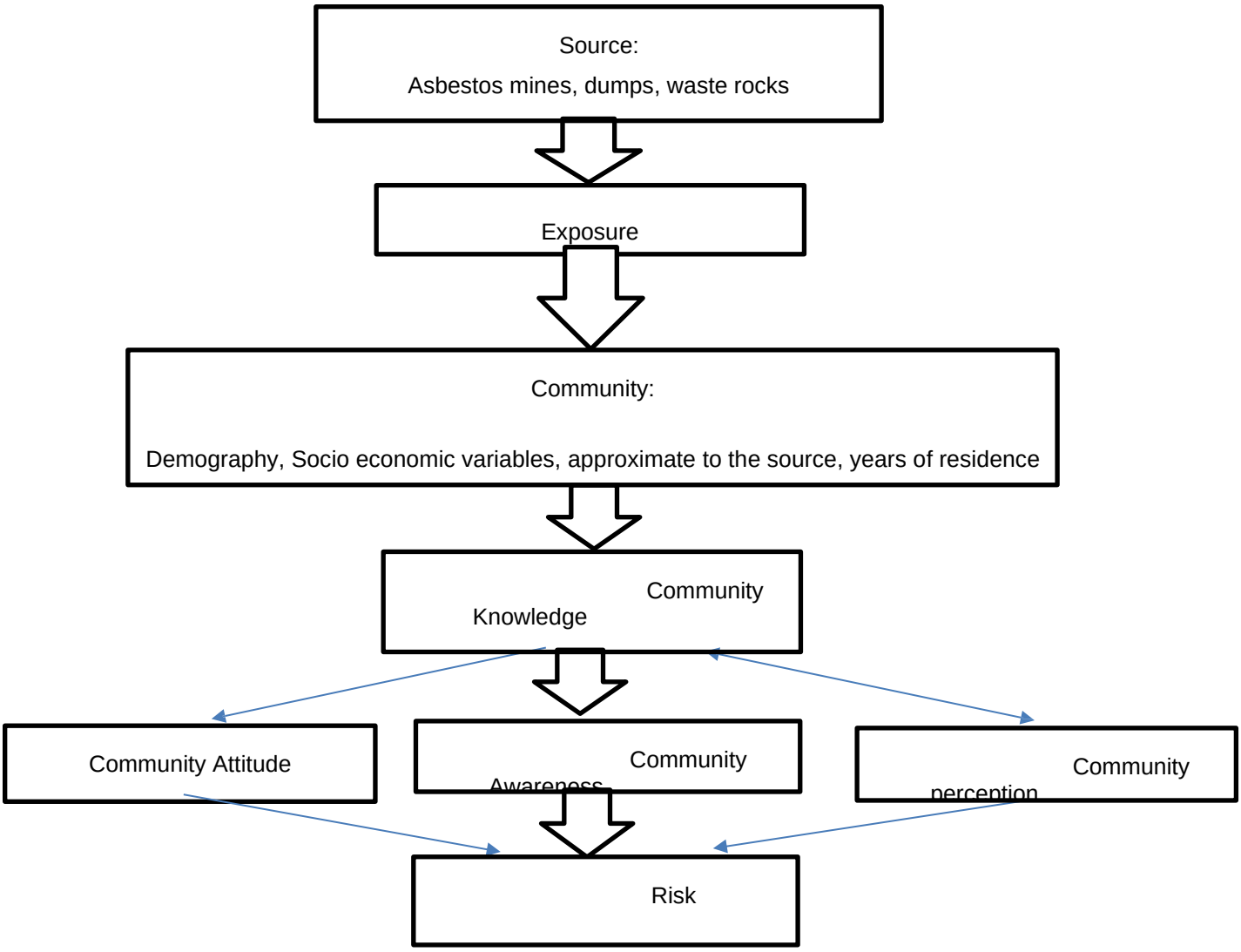

Figure 2.3: Conceptual framework (Adopted from Baba-Nalikant et al., 2023)

CHAPTER 3: METHODOLOGY AND ANALYTICAL PROCEDURE

3.1. Introduction

This chapter describes methods and material used to assess the spatial distribution of asbestos and community awareness and perception of asbestosis risk in Ga-Mathabatha. It presents the description of the study area, research design, and methods used to collect, analyze, and present the data, as well as the ethical considerations for data collection and the validity and reliability of the results.

3.2. Description of the study area

3.2.1. Locality of the study area

This study was conducted in Ga-Mathabatha, a rural area in the Capricorn District of Limpopo Province, South Africa. Ga-Mathabatha is located at 24.2197° S, 29.8251° E, and is divided into the following villages: Maseleseleng, Makapeng, Mphaneng, Masioneng, Madikelong, Success, Shushumela, Mmashadi, Makgoba, Lekgwareng, Phasweng, Mahlaokeng, and Roma (see Figure 3.1). Households in these villages have access to basic services such as electricity, schools, and primary healthcare facilities (Statistics SA, 2011). Access to community water supply is still an ongoing crisis, and community members depend on boreholes, water from local rivers, and water harvested from rooftops (Statistics SA, 2011). For instance, water from the Olifants River is used by community members for domestic purposes and subsistence crop and livestock farming (Petja, 2009). Rainfed subsistence farming, hunting, fishing, small-scale brick manufacturing, and spaza shops are the main sources of livelihood in the area. Community members still collect firewood, rocks, and cow dung in the open fields, as well as sand and water from the local rivers nearby (Statistics SA, 2011; Contract MTK, 2018; SABC News, 2022).

The Ga-Mathabatha area is characterized by summer rainfall with an annual rainfall of 497 mm and an annual average temperature of 24 °C (www.weathersa.co.za, n.d.). It is situated or surrounded by mountains locally known as Lebating, Lekgotse, Kholla, Lebanyaneng, and Bollatshwene with the main rivers such as Olifants River, Mphogodima

River, and Tongwane River passing through the village (see Figure 3.1).

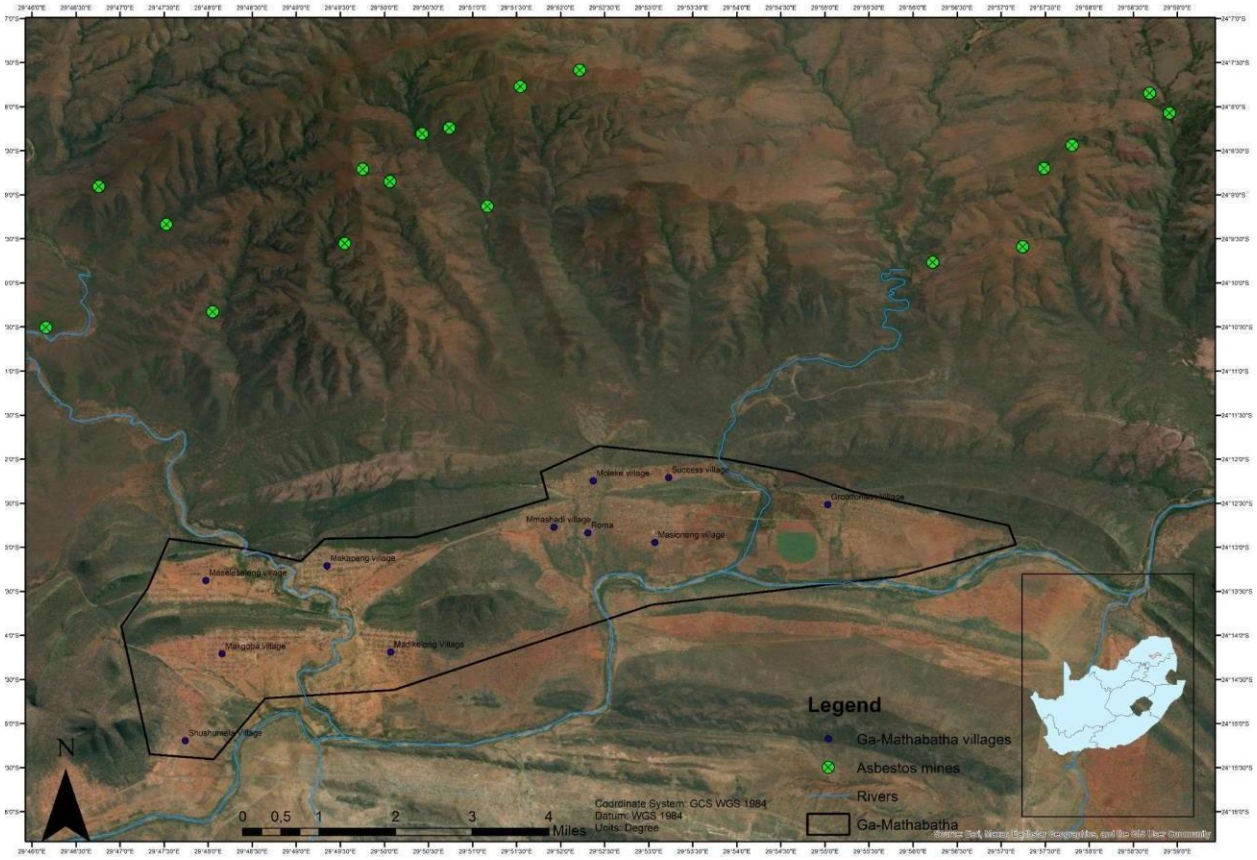

Figure 3.1: The geographic setting of the study area (Source: Author's creation)

3.2.2. Geological setting of the study area

Regionally, the study area falls within the Kaapvaal craton, which is one of the few regions on Earth where many relatively pristine Mid-Late Archaean rocks have been preserved (Van Reenen, and Smit, 1996; Uken, 1998; Baglow and Brandl, 2009). The craton covers an area of about 1.2×106 km² and predominantly comprises granitoid with interspersed greenstone belts, covered by a variety of Late Archaean to Meso-proterozoic sedimentary and volcano-sedimentary basins. The craton has been intruded by the world's largest mafic layered intrusion and traversed by several significant swarms of mafic dykes (Van Reenen, and Smit, 1996; Uken, 1998; Baglow and Brandl, 2009).

The Pietersburg Greenstone Belt occurs in the northern margin of the "low-grade" granite-

greenstone terrain of the craton (Van Reenen, and Smit, 1996; Uken, 1998; Baglow and Brandl, 2009). It is a narrow, elongated northeast-trending feature with an exposed strike length of 125 km and a maximum width of 20 km (Baglow and Brandl, 2009). The sequence is dominated by mafic-ultramafic igneous rocks and is overlain by terrigenous sediments. The Late Archaean/Early Proterozoic Transvaal basin comprises approximately 15 km of low-grade metamorphosed clastic and chemical sediments interbedded with volcanic. The Transvaal Supergroup has been further subdivided into the Wolkberg, Chuniespoort, and Pretoria Groups. Around 2.06 Ga ago, these rocks were subjected to thermal metamorphism resulting from the Bushveld Complex intrusion in the center of the Transvaal basin, which caused the recrystallization of the sandstones into quartzites, generated hornfels, and resulted in the partial melting and plastic flow of mudstones (Van Reenen, and Smit, 1996; Uken, 1998; Baglow and Brandl, 2009).

The Chuniespoort Group comprises the chemical and clastic sediments of the Malmani Subgroup dolomites, the Penge-banded iron formation, and the Duitschland Formation. The Malmani Subgroup can be further subdivided into five formations, a classification largely dependent on the amount of chert and the nature of the stromatolites (Baglow and Brandl, 2009). Meanwhile, The Chuniespoort Group has been reported to be the primary host of various types of asbestos minerals (Baglow and Brandl, 2009) that has led to the exploitation of the land around Ga-Mathabatha in the extraction of these minerals from earlier until 2008. Different types of asbestos mines were observed in Figure 3.1, and the majority of the streets were contaminated with asbestos fibers, and rocks.

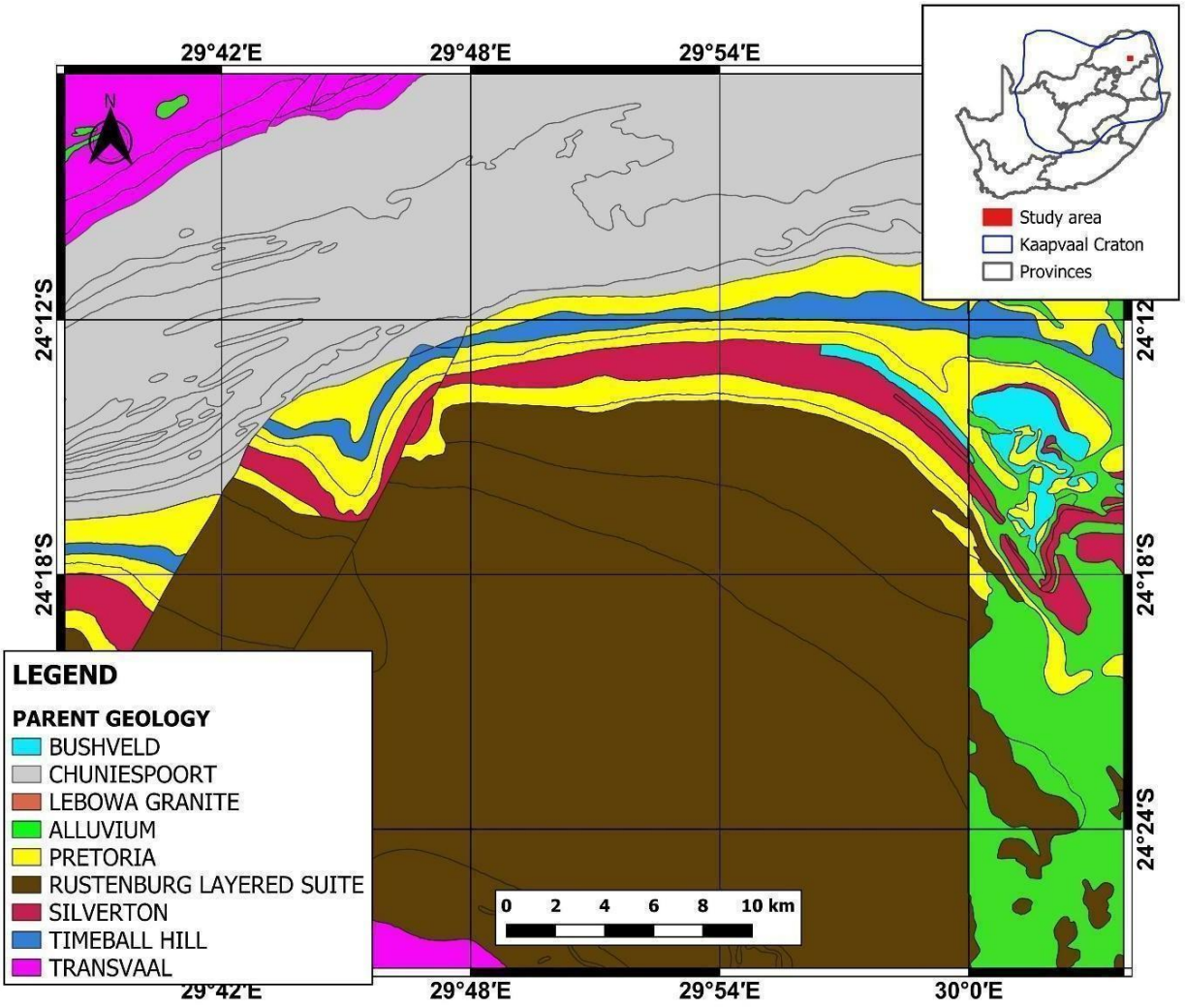

Figure 3.2: Parent geology of the study area (Source: Authors' creation)

3.3. Research design

This study employs a case study approach to investigate the spatial distribution of asbestos and community awareness of asbestosis risk in Ga-Mathabatha. A case study was chosen as it allows for an in-depth, localized spatial analysis of distribution and human awareness, attitude and perceptions within a specific geographical context of Ga-Mathabatha. To achieve a comprehensive understanding, the study adopted a mixed-method approach to assess the spatial distribution of asbestos and community. According to Creswell and Plano Clark (2018) a mixed-method design collects and analyses both

the qualitative and quantitative data in order to gain the depth and breadth of the research problem. As such, quantitative methods such as remote sensing, meteorological analysis and household survey analysis were integrated with qualitative methods like in-depth interviews and field observations in order to investigate the spatial distribution of asbestos and community awareness of asbestosis risk in the study area. Furthermore, triangulation was applied by cross-validating multiple data sources - remote sensing maps with field observations and household survey responses with in-depth interviews - to enhance credibility, and reliability and ensure a holistic perspective on asbestos distribution and exposure. Patton, (1999) defines triangulation as the use of multiple methods or data sources to develop a comprehensive understanding of phenomena.

3.4. Data collection and analysis

3.4.1. Spatial distribution of asbestos in the Ga-Mathabatha community

3.4.1.1. Asbestos mapping using remote sensing techniques

3.4.1.1.1. Satellite imagery data acquisition

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery was used to map the location and distribution of the asbestos mineral in the study area. ASTER is an advanced multispectral remote imaging instrument that covers a wide spectral region with 14 bands ranging from the visible to the thermal infrared region with high spatial, spectral, and radiometric resolutions (Table 3.1). The resolution varies with the spectral region: 15 m in the visible and near-infrared (VNIR), 30 m in the short - wavelength infrared (SWIR), and 90 m in the thermal infrared (TIR). These three spectral regions have three, six, and five bands, respectively. Each ASTER scene has a swath width of 60 km. ASTER has been widely used to discriminate different Earth materials based on the dissimilarity that exists among their spectral properties (Gillespie et al., 1998; Abrams et al., 2015; Soliman et al., 2021).

The ASTER imagery selected for this study includes one ASTER L1T cloud-free scene acquired in August 2005 from the US Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). This winter scene was relatively less vegetated

compared to other scenes collected during the summer season. Torres Gil et al., (2023) argue that vegetation density negatively affects the amount of mineralogical information that can be retrieved from the processing of remote sensing data. In addition to this, ASTER data collected in 2005 carry all fourteen bands, unlike data collected post-2009, which lack SWIR bands due to the failure of the SWIR instrument in 2008 (Clark et al., 2017). Minerals associated with asbestos, such as chrysotile, tremolite, serpentine, and actinolite, have diagnostic spectral features in the VNIR and SWIR regions, thus making these spectral regions the most significant regions for mapping minerals of interest (Clark et al., 2017). Therefore, ASTER bands are considered appropriate for the accurate mapping of minerals of interest in this study.

Table 3.1: Wavelength ranges, and spatial and radiometric resolutions of ASTER bands

Spectral	Band number	Wavelength range (µm)	Central wavelength	Spatial resolution (m)	Radiometric resolution (Bit)
VNIR	1	0.52 - 0.60	0.556	15	8
	2	0.63 - 0.69	0.661		
	3	0.78 - 0.86	0.807		
SWIR	4	1.60 - 1.70	1.656	30	8
	5	2.145 - 2.185	2.167		
	6	2.185 - 2.225	2.209		
	7	2.235 - 2.285	2.262		
	8	2.295 - 2.365	2.336		
	9	2.360 - 2.430	2.400		
TIR	10	8.125 - 8.475	8.291	90	12
	11	8.475 - 8.825	8.634		
	12	8.925 - 9.275	9.075		
	13	10.25 - 10.95	10.657		
	14	10.95 - 11.65	11.318		

3.4.1.1.2 Processing of ASTER satellite data

The processing of ASTER satellite imagery was carried out using ENVI software (version 5.1). Out of fourteen ASTER bands, only nine bands from VNIR and SWIR spectral regions were used for mineral mapping due to their relatively high spatial resolution and spectral wavelengths favourable for mapping minerals of interest (Muavhi and Tessema, 2021; Muavhi, 2022). The VNIR and SWIR bands were stacked together to form a single multiband layer. During band stacking, the SWIR bands with 30 m by 30 m resolution were resampled using the nearest neighbour resampling method to match the spatial resolution (15 m by 15 m) of VNIR bands. This was done so that all nine bands could have the same spatial resolution, which is a prerequisite for further spatial analysis.

Log residuals atmospheric correction technique was then applied to VNIR-SWIR multiband layer to remove atmospheric effects and to convert ASTER L1T radiance data to surface reflectance data. Conversion from radiance to surface reflectance is essential for multispectral image processing when detecting the presence of surface targets using a reference mineral spectral library, as spectral libraries are signatures of surface reflectance (Muavhi and Tessema, 2021).

3.4.1.1.3 Mapping of asbestos minerals

Mapping minerals of interest requires reference mineral spectra. These could be acquired from spectral libraries like the USGS or image extraction. In this study, the USGS spectral libraries of asbestos minerals were used to map chrysotile, tremolite, serpentine, and actinolite (Figure 3.3). The spectral libraries were resampled to match the VNIR-SWIR ASTER bands. Firstly, central wavelengths of the VNIR-SWIR bands were provided, and then ENVI assumed critical sampling and used a Gaussian model with a FWHM equal to the band spacings.

The ASTER resampled asbestos mineral libraries (Figure 3.4) were used to generate areas with potential to host asbestos minerals based on the spectral mapping process which is discussed in the following section.

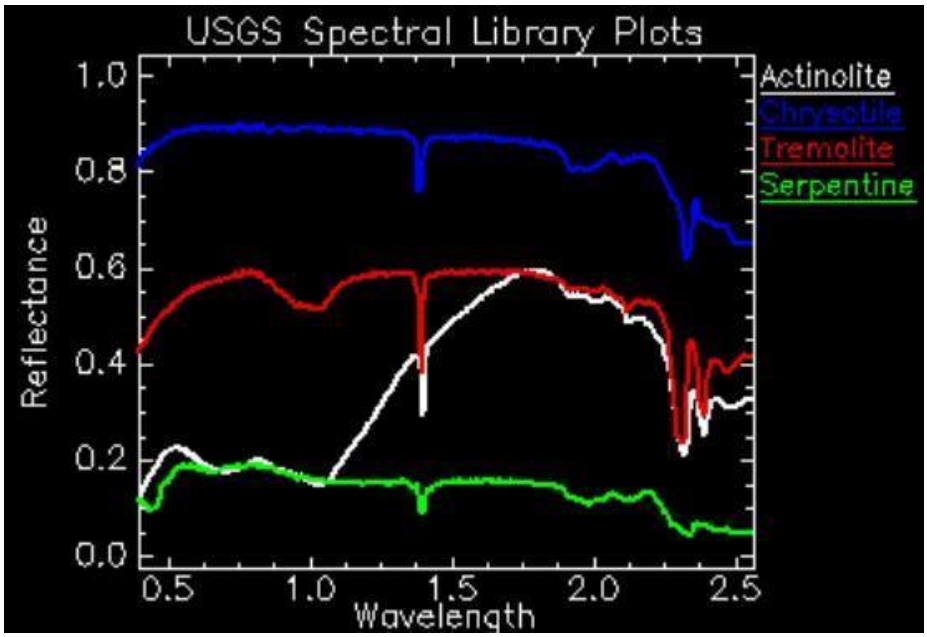

Figure 3.3: USGS spectral library of asbestos associated minerals (Source: Author's creation)

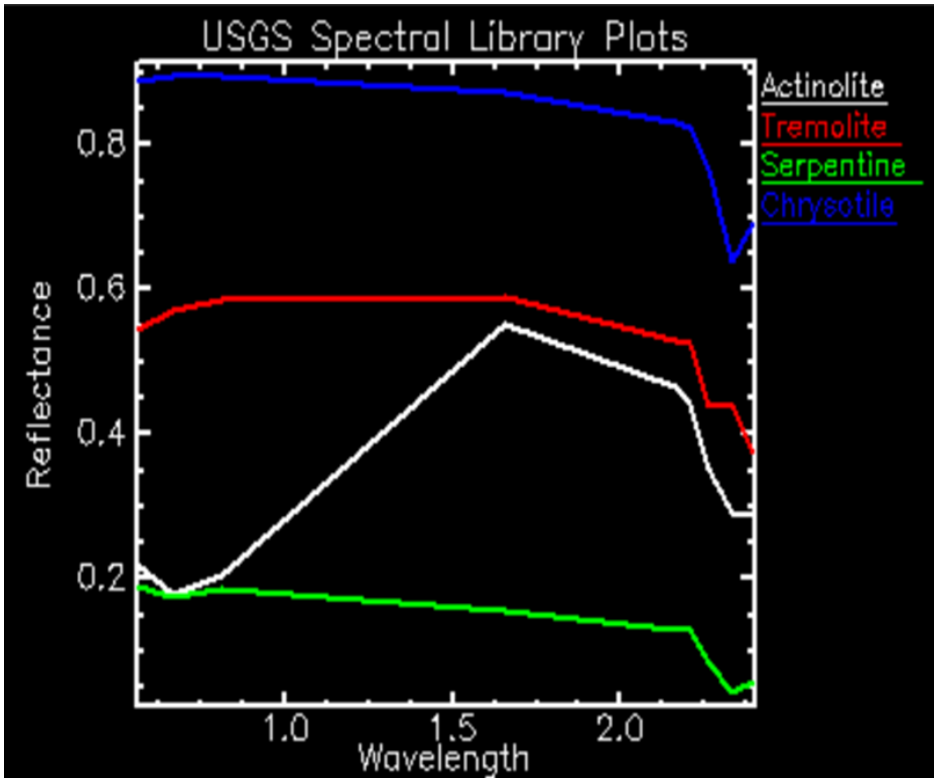

Figure 3.4: Resampled USGS spectral library of asbestos-associated minerals (Source: Author's creation)

3.4.1.1.5 Spectral matching

To perform spectral matching, the spectral Information Divergence (SID) mapping algorithm was employed. A spectral matching process was performed in order to compare the image spectra to known mineral spectral libraries from USGS- databases (Figures 3 and 4). In this case, SID uses divergence measures to match the pixels of an image (under question) to known reference mineral spectral libraries. The smaller the divergence value, the more likely the pixels and reference spectra are similar (Du et al., 2004). The divergence between unknown r_i and r_j reference spectra can be defined as:

$$SID\ (r_i, r_j) = ((r_i||r_j) + ((r_j||r_i) \quad (1)$$

Where:

$SID\ (r_i, r_j)$ represents the symmetrised divergence between two signals or distributions r_i and r_j

$((r_i||r_j)$ is the Itakura-Saito Divergence between r_i and r_j and

$((r_j||r_i)$ is the Itakura-Saito Divergence between r_j and r_i, but reversed.

SID results in a classified image showing the best fit between each pixel and input mineral reference spectra depending on the divergence measure. Additionally, rule images are provided showing the divergence measure values between each pixel and each reference spectrum (Muavhi et al., 2021).

Finally, the ASTER resampled spectral libraries of asbestos minerals (Figure 4) were used to produce asbestos mineral maps of the study area.

3.4.2 Asbestos field observations

This study adopted field observation methods to validate areas that were predicted to have high asbestos minerals by remote sensing spectral and imagery analysis described in 3.4.1. Field observations refer to the act of directly observing and recording data about people, behaviors, or phenomena in their natural environment, rather than in a controlled setting (Wilczyńska et al., 2005; Famiglietti et al., 2008; Gold, 2017). The purpose of using

field observation was to document and capture concrete verifiable evidence of different types of asbestos rocks present in different locations within Ga-Mathabatha. Physical properties such as fibre morphology, colour and texture were observed to identify asbestos and distinguish them from one another. Areas of observation were purposely selected, and photographs were used to capture and record the evidence of asbestos concerning the environment. The purpose of utilizing this method was motivated by different studies that successfully used field observational methods to observe and capture asbestos rocks and soils in different areas (Wilczyńska et al., 2005; Bhunia, Kumar, and Pourghasemi 2019; Marengo et al., 2023; Lisco et al., 2023; Somma et al., 2024).

Angle of observation refers to the perspective from which the researcher views the subject (Gibbons, and Adrian 1997). The choice of angle can impact the accuracy, completeness, and interpretation of the data (Leung et al., 2012). Types of angles of observation include direct angle, side angle, top-down angle, bottom-up angle, and distance-based observation (Makovsky et al., 1996; Gibbons, and Adrian 1997; Leung et al., 2012). In this study, side angle observation was used to view the asbestos fibers were exposed alongside rock fractures in the mountains of Ga-Mathabatha, top-down angle observation was adopted to identify the asbestos distribution and areas where the mineral was highly concentrated, bottom-up angle was used to observe weathered asbestos rocks, soils, and outcrops. Safety boots, overall, safety glasses, hard hand gloves, face mask, ear plugs, safety cap or heart hat were used to conduct field observations. This was guided by the Department of Water Affairs policy on the handling and disposal of asbestos and asbestos-containing waste section 20 of the Environmental Conservation Act, 1989 (Act of 1989). Field observations were conducted from February 3rd to March 31st, 2024, between 08:00 am and 04:00 pm, and on days when the wind was moderate to avoid extreme exposure to asbestos fibers.

3.4.3. Patterns and trends in wind speed and direction

Wind speed and direction were used to establish patterns and trends and to further describe their potential influence on asbestos exposure in Ga-Mathabatha. Wind speed

and direction data were sourced from the South African Weather Service (SAWS). The data utilized to generate average yearly cycles and trajectories (shown in figures 4.5, 5.6, and 4.15) were sourced from the NOAA website. The wind speed and direction from SAWS were validated with data from ERA5 reanalysis and were presented using wind roses to show the general wind direction and wind speed in knots (1 knot = 1.15 mph) monthly.

3.4.4. Community's level of awareness and perceptions of asbestosis risk

Two methods of data collection and analysis, namely, in-depth interviews and household surveys were blended to assess the community's level of awareness and perceptions of the risk of asbestosis. Initially, a semi-structured interview guide (see Appendix 1) was used in an exploratory phase to elicit information and reveal variations in perspective, experiences, and opinions of the specific target population that revealed potential themes and variables that were important in informing the development and design of more focused and valid final questions for the survey questionnaire. As such, the respondents for the in-depth interviews were selected using purposive sampling were the Ga-Mathabatha households were selected due to their closer proximity to unrehabilitated mines. Furthermore, the data collection process continued until a saturation point was reached, with 18 respondents, and where no new information was being presented by the respondents. The results from the interviews were used to provide depth to the interpretation of statistical analysis results from the questionnaire (Grasmück and Scholz, 2005; Oyebamiji et al., 2018). The plan was to triangulate findings from both types of data; hence, the preliminary survey instrument that aligns with the qualitative research was created during the proposal stage but was modified to create a context-specific questionnaire (see Appendix 2) as new data from interviews were recorded.

The open-ended indepth interviews were recorded using tape-recorder, transcribed into Microsoft Excel 2016 and analysed using six stages of thematic analysis. Thematic analysis is a method of identifying, analysing, and reporting patterns within data (Braun and Clarck 2006). These stages include familiarizing with data, generating initial codes, generating initial themes, potential themes, naming themes, and producing a report

(Braun and Clarck 2006). Additionally, direct quotations from participants were used to represent their views, ensuring that the findings accurately reflect the perspectives and lived experiences of respondents.

Meanwhile, the household survey was conducted using a structured questionnaire with closed-ended questions to elicit information on the demographic and socio-economic characteristics, knowledge, attitudes, perceptions, and practices (KPP) of the participants. The actual total number of households in Ga-Mathabatha for the year 2023 was unknown to the researcher, as such, 271 households were selected for the purpose of this study using the Cochran (1963:75) formula below at a 90% confidence level with *p* = 0.5 and a confidence interval of +/- 5% to ensure representativeness. Cochran's formula is a well-established statistical method for determining sample sizes in survey studies that seek to ensure representativeness, particularly when the study population is larger or unknown.

$$n_0 = \frac{Z^2 pq}{e^2} \quad (2)$$

Where:

n_0 = the required sample size;
Z = the z-value corresponding to the desired confidence level (1.645 for 90% confidence level);
p = the estimated proportion of the population; and
e = the desired level of precision (also called margin of error).

A such:

$$n_0 = \frac{(1.645)^2(0.5)(0.5)}{(0.5)} = 217 \text{ households}$$

These 271 households were selected using simple random sampling, and within each selected household, the head of the household was purposely selected to complete the survey. If the household head was not available, anyone between the ages of 18 and above was allowed to participate. Out of 271 questionnaires that were administered, only

250 were completed and finally used for further analysis. Raw data from survey questionnaires was coded using Microsoft Excel 2016 Version and imported into Statistical Package for Social Sciences (SPSS) Version 27 for analysis. Descriptive statistical analysis was used to summarise demographic characteristics (e.g. gender and age) and socio-economic characteristics (e.g., occupation, level of education, marital status) variables. Additionally, the Chi-square (χ^2) statistical tests were performed to establish the possible association between independent and dependent variables. Specifically, Pearson's Chi-square analysis tool in SPSS was adopted to analyse the relationship between age and asbestosis risk, level of education and community awareness of asbestosis, and several years spent in the community with awareness and perception of asbestosis risk. The significance level (α) was set at 0.05, and the results were reported using *p*-values derived from the Chi-square test. A *p*-value less than 0.05 indicated a statistically significant association between the variables, with smaller p-values (e.g., $p < 0.0001$) providing stronger evidence of association between them.

3.5. Ethical consideration

This study involves human subjects, and therefore it was conducted following professional ethics and moral principles, not only to safeguard the researcher's interests but also the respondents' interests. The studies that involve human subjects are subjected to ethical clearance; as such, the clearance was applied for and approved by the Turfloop Research Ethics Committee (see Appendix 6).

3.5.1. Informed consent

Permission to conduct the study in the Ga-Mathabatha community was obtained from the tribal authority (see Appendix 5). The researcher explained every detail about the research, including that the participation in the survey is voluntary and anonymous, and they could withdraw anytime they feel like doing so. The consent form was also explained in detail before the commencement of the survey.

3.5.2. Confidentiality and anonymity

Respondents were informed of confidentiality and anonymity about the collected data and the results of the final report. As such, none of the acquired data is displayed in a manner that allows for the identification of the specific source of the data. Moreover, the researcher refrained from sharing the material with anybody beyond the research team or gathering any personally identifiable information about the participants.

3.5.3. Avoidance of harm

The researcher exerted every effort to prevent any form of psychological and physical injury to the participants. The investigator refrained from using any derogatory stereotypes, assumptions, or remarks that were deemed unkind towards the participants.

3.5.4. Respect

During the data collection operation, the researcher showed appropriate regard for the cultural background of the participants and refrained from approaching them with any judgment.

3.6. Validity and reliability

The triangulation of multiple methods of data collection and analysis as well as the collection of data from different sources strengthened the validity and reliability of the results in this study. This is supported by Cohen, Manion, and Morrison (2017), who argue that cross-verifying the consistency and accuracy of findings from different approaches enhances the validity of the results while reducing biases, to some extent. For this study, the selection of random sites for observations was informed by the remote sensing-derived asbestos maps. Meteorological variables, such as wind speed and direction, were analysed to describe events that contributed to asbestos exposure and distribution in the study area. Despite the preconceived knowledge that the research had on asbestosis. The study's survey questionnaire variables and themes were fully informed by the responses from the key in-depth interviews. Furthermore, the statistical findings were corroborated with those of the in-depth interviews. This, in a nutshell, ensures the validity

and reliability of the results.

CHAPTER 4: RESULTS PRESENTATION AND DISCUSSION

4.1. INTRODUCTION

This chapter presents and synthesizes the findings regarding the spatial distribution of asbestos, wind speed and direction trends and patterns and their potential influence on asbestos dust exposure and distribution as well as the community's awareness and perception of asbestosis risk. It interprets and discusses (a) maps that depict the spatial distribution of asbestos in the study area; (b) photographs captured during field observations; (c) wind roses and trajectories for wind speed and direction, respectively; and (d) frequency tables and Chi-square *p*-values for the surveys as well as quotes for the in-depth interviews on the community's awareness and perceptions of asbestosis risks.

4.2. SPATIAL DISTRIBUTION OF ASBESTOS

4.2.1. Asbestos mineral mapping using remote sensing techniques

Figure 5 shows asbestos minerals in the study area. Four types of asbestos minerals were detected by ASTER imagery mapping. These include chrysolite, tremolite, serpentine, and actinolite. In some areas in the study area, the asbestos minerals appear together, forming at least two mineral clusters. Chrysotile appears to be the most dominant mineral, followed by tremolite. Actinolite dominates the northern part with some lenses of tremolite. Serpentine appears to be the least dominant mineral among the four asbestos minerals. These results align with a geological map produced by Bloise et al., (2019) study on assessment of naturally occurring asbestos in Episcopia, Italy. Their study highlighted that Serpentinite rocks are widely outcropped in the Lucania region while tremolite/actinolite and/or chrysotile were detected in serpentinite outcrops of several urban centres of the region. This clearly demonstrates that different asbestos types could be detected in the same region.

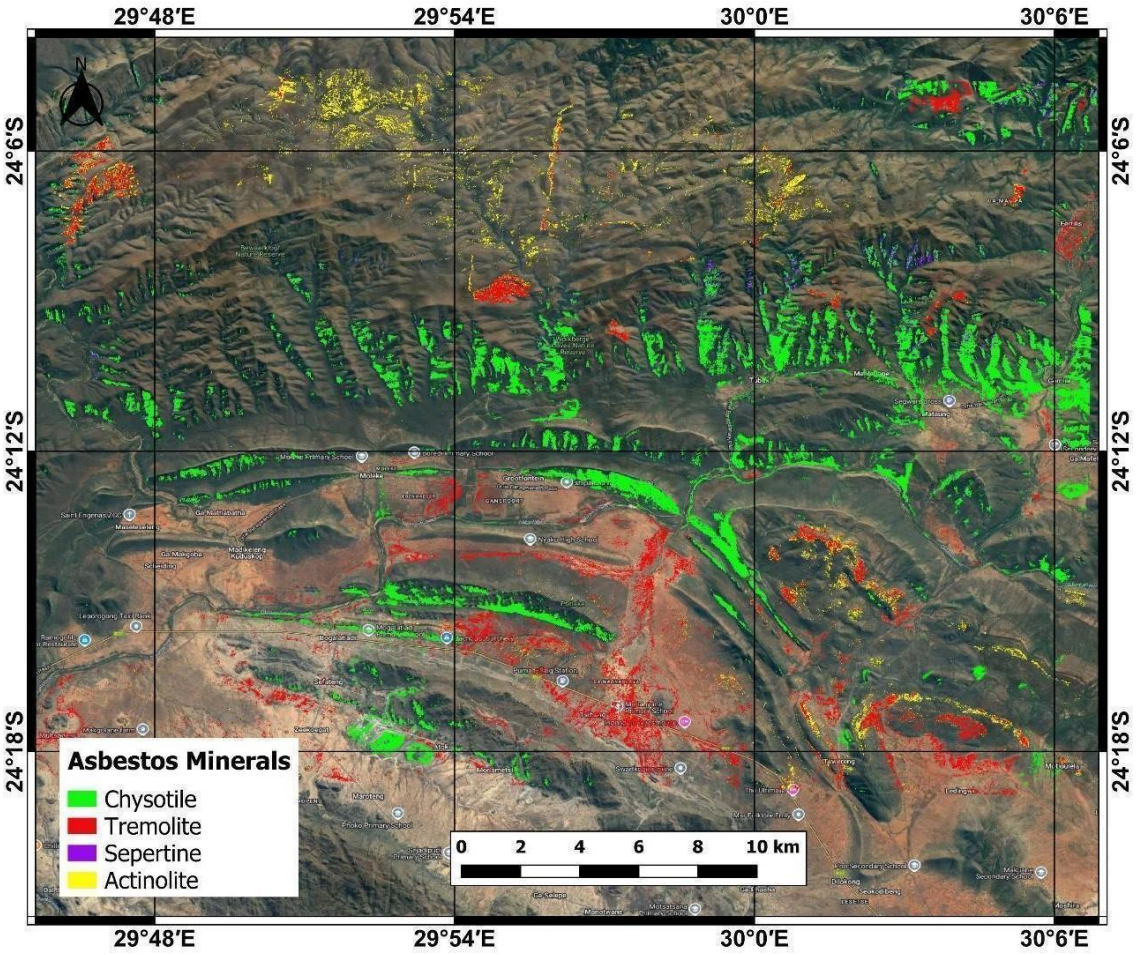

Figure 4.1: Asbestos minerals mapped with SID algorithm (Source: Author's creation

In Figure 4.1, the asbestos minerals are superimposed on the geology of the study area. As it can be observed, Chuniespoort Group appears to be the major host of asbestos minerals, which supports what has been previously reported (Peacock, 1928; Dreyer, 1968; Bezuidenhout et al., 2013). Chuniespoort Group is followed by Rustenburg Layered Suite, while Pretoria Group comes third as one of the major hosts of minerals of interest. It is important to note that both Chuniespoort Group and Pretoria Group belong to the Transvaal Supergroup.

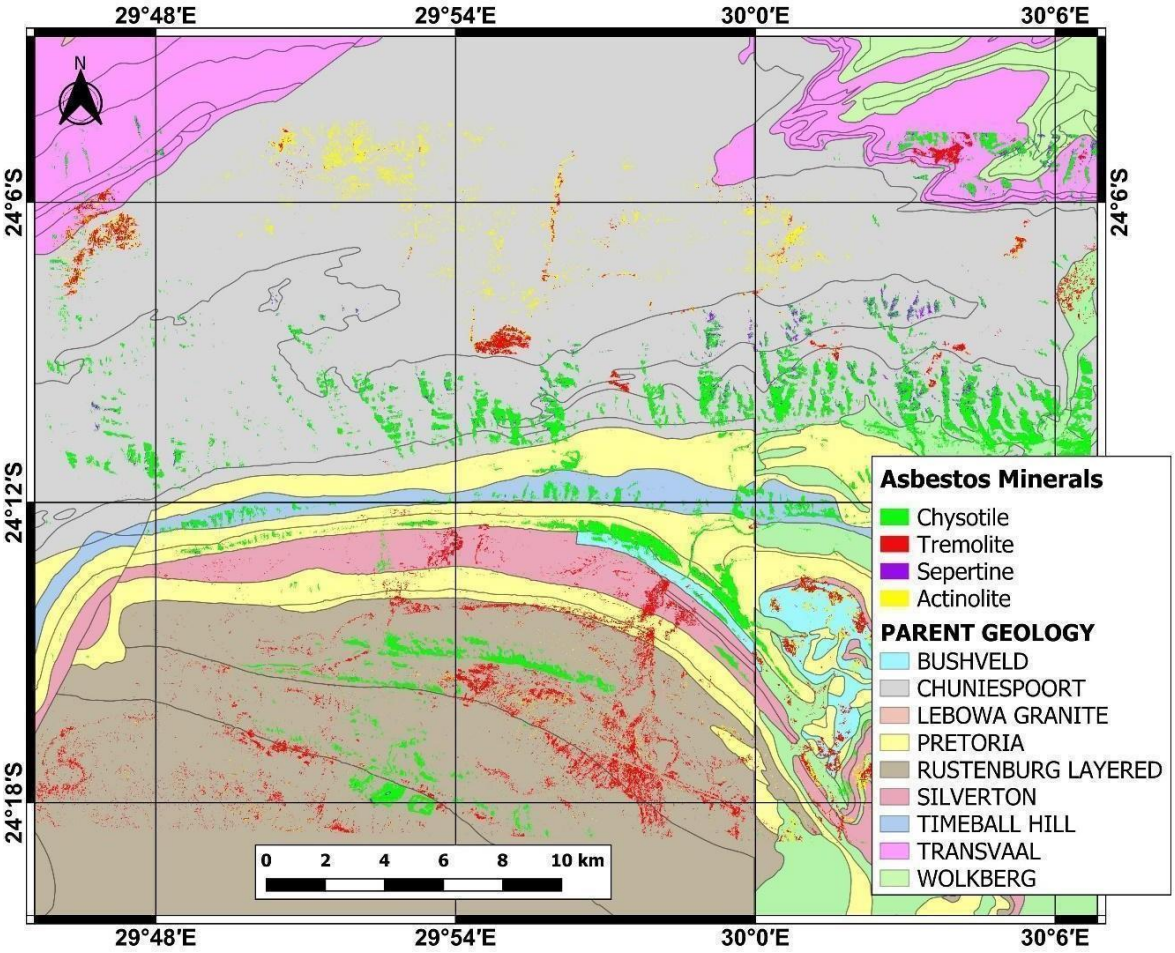

Figure 4.2: The asbestos mineral and parent geology structure (Source: Author's creation)

4.2.2. Field observations in Ga-Mathabatha

Field observations were made to validate the findings made in Figure 4.1 about the spatial distribution of different asbestos types in the study area. The initial observations were conducted in the Success village forest, where piles of asbestos mining waste was found stacked near the gravel road, a location frequently used by pedestrians, vehicles, and livestock (see Appendix 3.1). Chrysotile asbestos was the predominant type found in the dumps, with fibers observed on the tree leaves and branches, as well as asbestos waste rocks scattered along the gravel road. This type of asbestos is characterized by white colour, with a thin long curly figures. These physical properties concur with those described by Whitmer, (2023). They described this type of asbestos as white in colour.

The second observation was conducted at the Tongwane River, which flows near the asbestos dumping site. Asbestos fibers were seen suspended on the river's surface, while chrysotile asbestos rocks and contaminated soil were found within the water (see Appendix 3.2). Locals were observed sourcing water from this river, which serves as the primary water source for the community due to a lack of reliable and consistent municipal water supply. Chrysolite asbestos was also predominant at Moleke village, particularly along the street road and within the residents' yard (see Appendix 3.6). These findings and field observations align with predictions in Figure 4.2, which indicated the presence of chrysotile asbestos in the northern part of the study area, encompassing Success Village, Success bushes, Moleke Village, and Tongwane River.

Tremolite asbestos was observed to be dominant in Masioneng village (see Appendix 3.5) and Olifants River (see Figure 3.5 and Appendix 3.7). In Masioneng Village, this type of asbestos was seen on the gravel road, inside gullies and on residential properties. Tremolite asbestos is characterised by its white to grey colour and sharp needle like fibers, distinguishing it from other asbestos types based on its physical properties (Whitmer, 2023). These observed properties are similar to those described by Singh et al., (2019), who also identified tremolite asbestos in waste sites where houses had been demolished. At Olifants River, a mixture of tremolite, chrysotile, and actinolite asbestos were identified (see Appendix 3.6). This mixture of asbestos rocks and soils was observed within the river water, along the river banks and on the roadway leading to the river. Fibers were also seen floating on its surface. This Olifants River is the second largest permanent river in Limpopo province, serving as a vital water source for both humans and livestock in surrounding communities. Its tributaries, the Tongwane and Mphogodima rivers, collect rainwater from the upper mountains of Ga-Mathabatha where asbestos was historically mined, before merging into the Olifants River Domestic animals such as goats, sheep, cows, and donkeys, were observed drinking from the river.

High runoff accompanied by weathering, mass wasting, and erosion could potentially be attributed to the accumulation of asbestos fibers, rock, and soils from the unrehabilitated shafts in the mountains of Ga-Mathabatha to the rivers and low-lying areas. These results

concur with the findings made in Figure 4.1, where these asbestos types were predicted to be present. Conversely, observations revealed that rocks that are used to construct man-made features like bridges are made out of asbestos. Specifically, piles of rocks (chrysotile asbestos, tremolite asbestos, and actinolite asbestos) were observed stacked alongside the Mphogodima River, which acts as a bridge, allowing people to pass from Maseleseleng village to the main international R37 road (Appendix 3.2). These asbestos rocks and soils observed along the river channels and near the gravel road could potentially place the community members that pass the river using the gravel road at high risk of asbestos exposure. For instance, Mashianyane Secondary School is located near the river where samples and observations were made. This renders both the teachers and learners highly exposed to these minerals.

Field observation methods made in this study align with the findings of Kwate et al., (2018), who similarly detected types of asbestos in Mbombela (formerly Nelspruit), Malelane, and Badplaas in the Mpumalanga province of South Africa. Global studies also concur in using observational maps to validate predictions; for example, Lucci et al. (2018) also observed and captured Amphibole in the Isadalu magmatic complex in Ogliastra (central Sardinia) between the towns of Villagrande Strisaili and Talan.

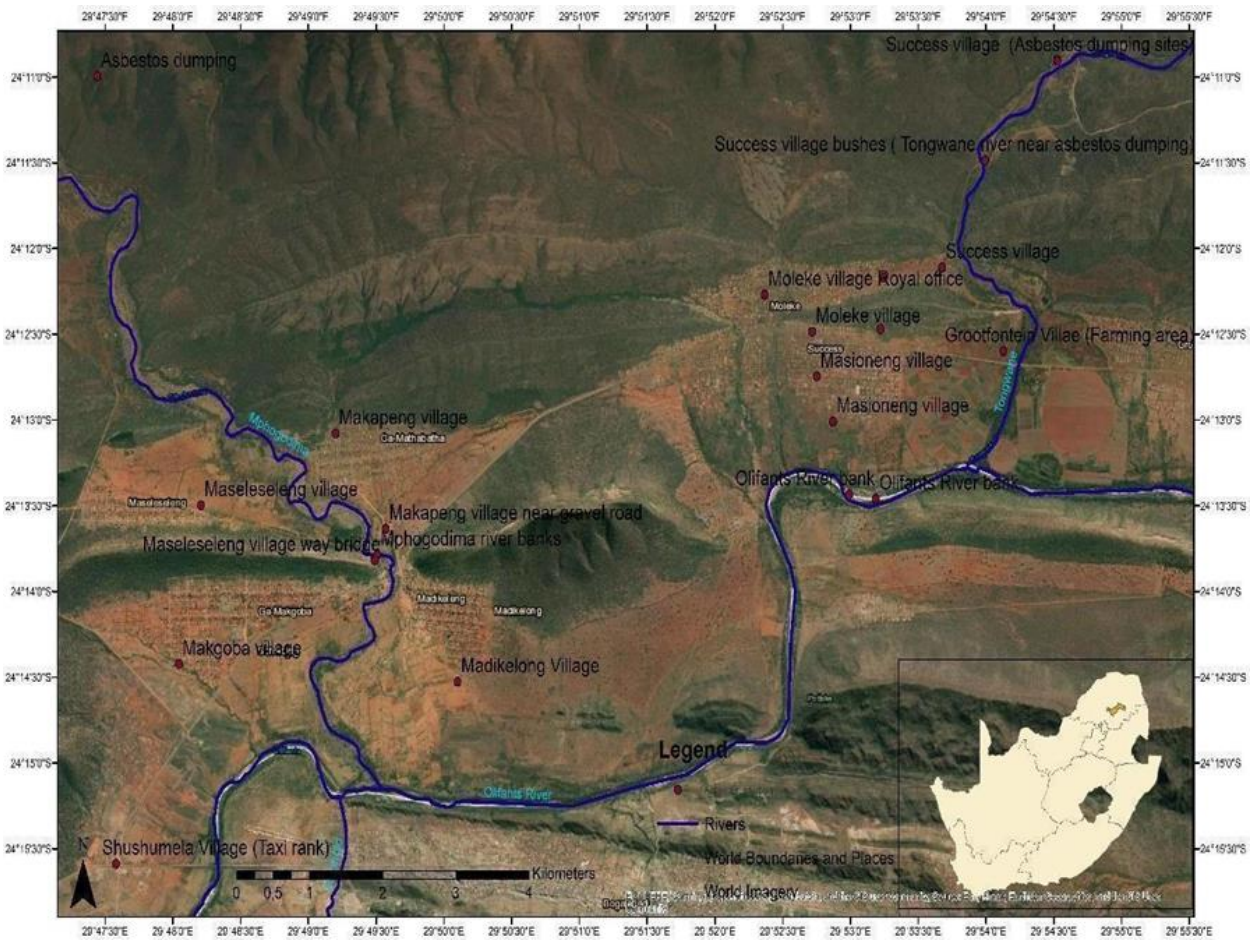

Figure 4.3: The field observation map of Ga-Mathabatha (Source: Author's creation)

4.3. Wind speed and direction and their potential effect on the dispersion of asbestos

4.3.1. Annual average wind rose

Figure 4.4 illustrates the 30-year average annual wind patterns from 1991 to 2020. The findings reveal that the wind in Ga-Mathabatha was blowing from the ENE and E directions, where asbestos dumping is located (Figure 4.1). This aligns with regional climatic data provided by the South African Weather Service (2024), which indicates that the Limpopo Province, including Ga-Mathabatha generally experiences prevailing easterly winds. The location of asbestos dumping sites (Figure 4.1) relative to the prevailing wind directions suggests a potential risk of windborne asbestos fiber dispersion

toward downwind areas (Burkhanova, Kovtunov, and Azarov 2019). This insinuation aligns with observations made by Le, Kim, and Kil, 2020 in China. Their results highlighted that most of the wind that disperse asbestos fiber comes from ENE direction, E direction and NE direction.

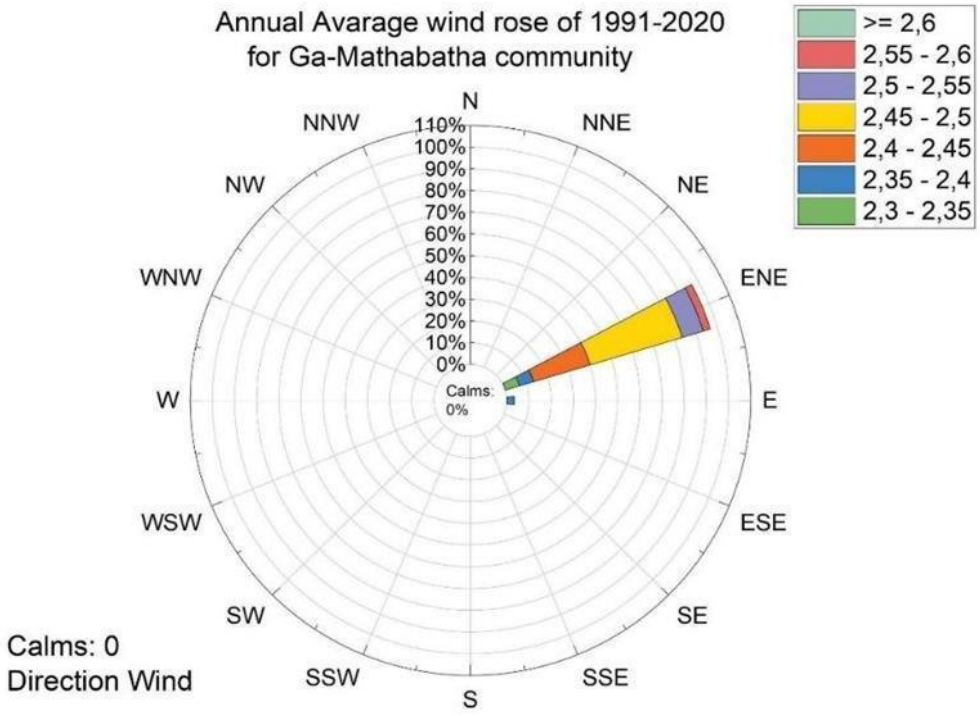

Figure 4.4: 30-year period (1991 to 2020) annual average wind speed and direction at Ga-Mathabatha (Source: author's creation

The monthly average wind rose analysis from 1991 to 2020 indicates that the winds predominantly blow from the east-northeast (ENE) and east (E) directions during spring, summer, and early winter (Figure 4.5 and 4.6), carrying air masses into Ga-Mathabatha. However, during May, June, July, and August, wind direction becomes more variable, blowing from multiple directions across the study area. Kwata, Moja, and Chadi (2018) has also observed that the wind was blowing from all directions from January to June in Mbombela (formerly Nelspruit), closer to mine dumps in Malelane, and Badplaas, Mpumalanga Province. Observations in the study area discovered that most asbestos

dumpling sites and open shafts were in the direction where these winds are blowing from (Figure 4.1., 4.3 and Appendix 3). Previous studies on chrysolite manufacturing factories in the South of California found that the dust sample collected using buckets contained chrysotile asbestos fibers during the summer and spring seasons (McDonald et al., 1984). While this study does not directly measure airborne asbestos fiber concentrations, the observed alignment between wind patterns and asbestos waste locations highlights the need for further air quality monitoring and health risk assessments to evaluate potential exposure pathways in Ga-Mathabatha.

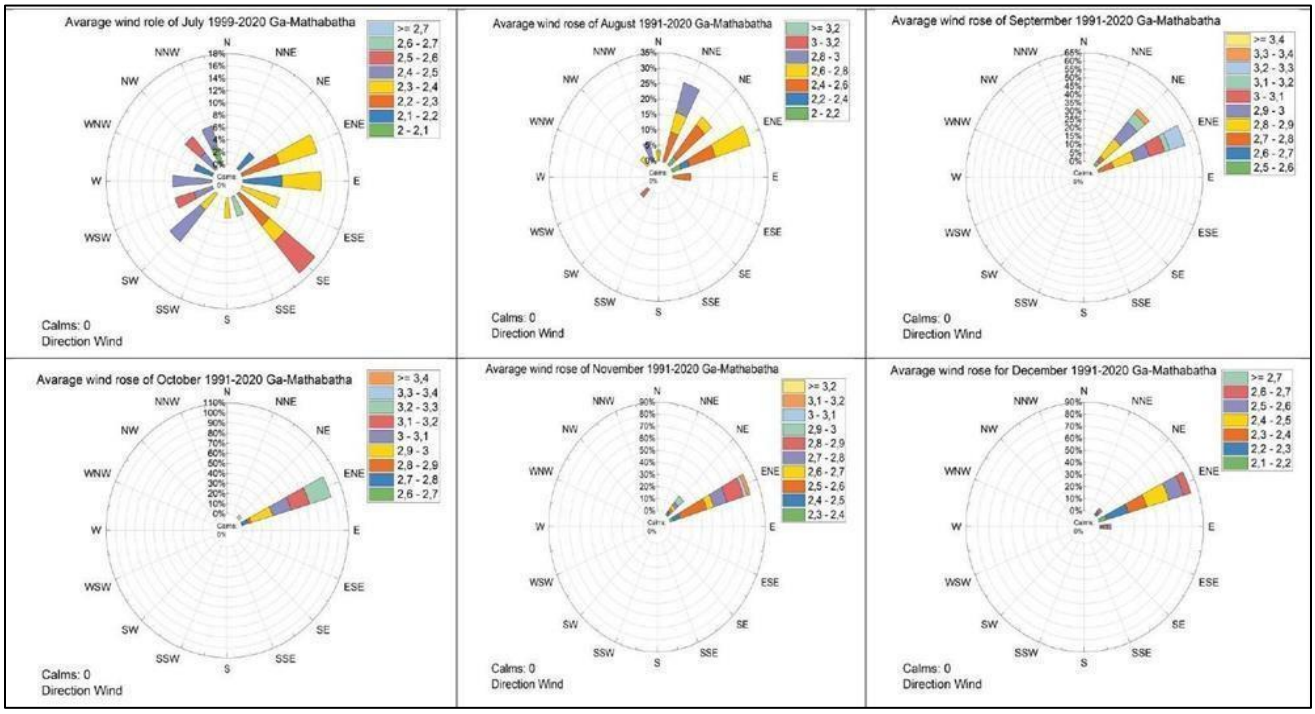

Figure 4.5: Monthly Wind Rose from January to June (Source: author's creation)

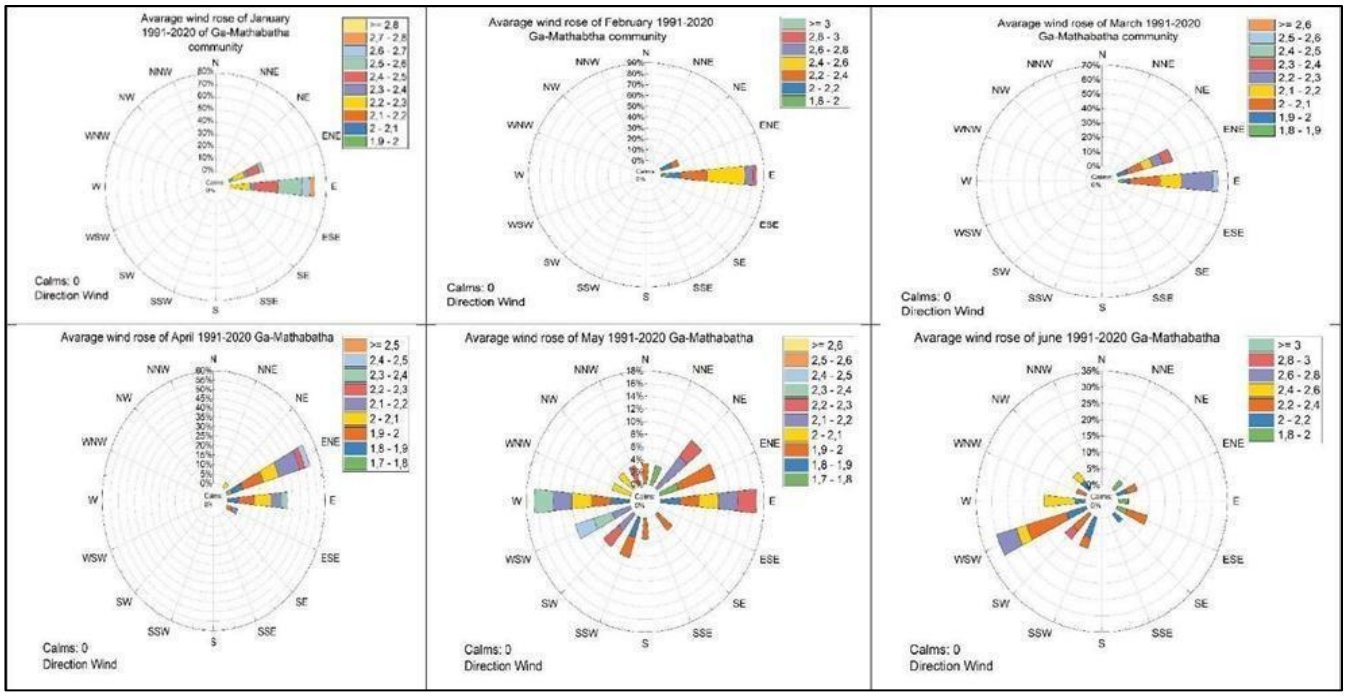

Figure 4.6: Monthly Wind Rose from July to December (Source: author's creation)

4.3.2. The forward trajectories of Ga-Mathabatha

The forward trajectories results demonstrate that wind that originates from Ga-Mathabatha travel across Burgersfort, Mpumalanga, Gauteng, and the Northwest, extending towards the western Indian Ocean (Figure 4.7). Given that asbestos fibers are lightweight and capable of becoming airborne, this trajectory raises concerns about the potential long-range transport of asbestos dust into downwind regions. Aili et al., (2021) employed the HYSPLIT model to identify the transport pathway of salt-dust particles from the desiccated bottom of the Aral Sea in Central Asia. Their results revealed that air parcel trajectories that originate from the desiccated bottom of the Aral Sea can have a significant impact on regions spanning many thousands of kilometres in a relatively short period. Other studies on forward trajectories of dirty desert dust reveal that people hundreds of kilometres from are exposed from dust (Li and Koutrakis, 2020; Wang et al., 2022). The alignment between forward air mass trajectories and the location of asbestos dumping sites in the study area suggests that regions along these pathways may be at risk of exposure, emphasizing the need for further air quality monitoring.

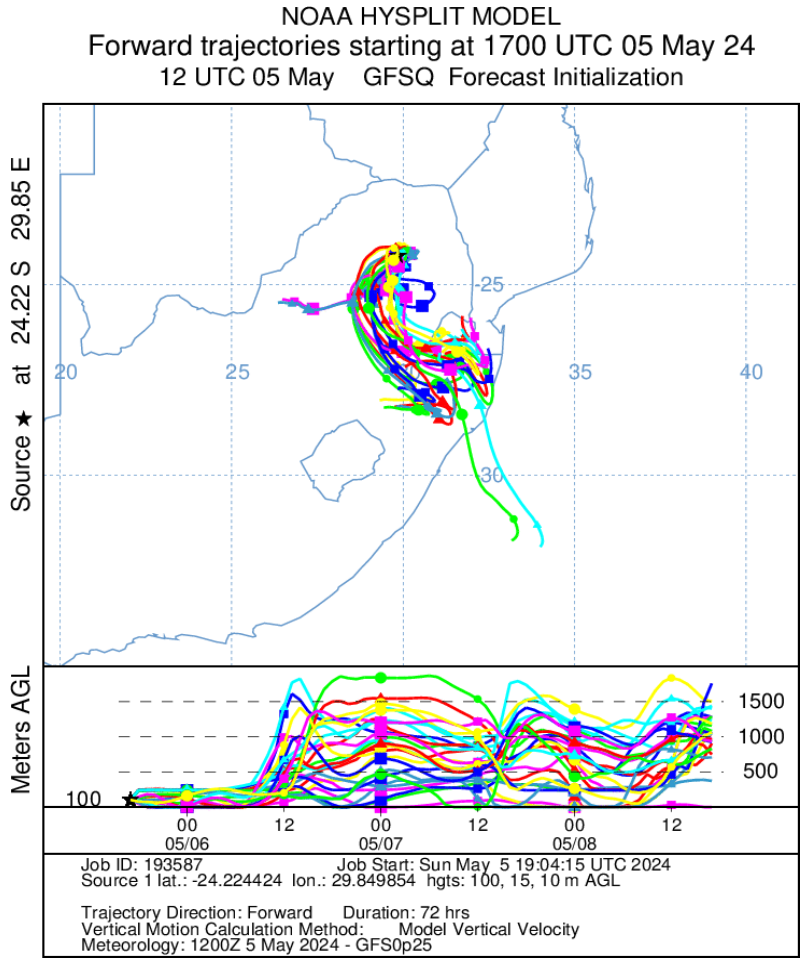

Figure 4.7: Forward trajectories of Mathabatha from the NOAA HYSPLIT model (Source: author's creation

4.4. COMMUNITY AWARENESS AND PERCEPTION OF ASBESTOSIS RISK

This section presents and discusses the results obtained through household surveys, while the themes generated from the interviews were utilised to supplement the surveys by quoting the respondents' views on asbestosis and asbestos dust exposure. The results initially present the demographic and socioeconomic characteristics of the respondents. This is followed by descriptive summaries on communities' awareness and perception of asbestos risk. The descriptive summaries are further enhanced by the presentation of the statistical association between demographic, socio-economic variables, and community awareness and perception. The results are displayed as tables and quotes from

interviews.

4.4.1. Demographic and socio-economic characteristics of the respondents

The results on the demographic and socioeconomic characteristics of the survey participants (Table 4.1) indicate that more females (60%) participated in this study than males (40%). On the other hand, 26% of the participants were those of 25–35 years, followed by elders of 65 years and above with 24%, and 45–64 years of 20%. The distribution of education levels revealed that 50.4% of participants had secondary school qualifications, 20% had Technikon College qualifications, and 3.6% had Adult Basic Education and Training (ABET). Marital status indicates that more (46%) participants were married or cohabitating as husband and wife, while 35% and 8% of participants were never married or divorced, respectively. The findings further demonstrate that 31.6% of participants were unemployed, while 19.6% were full-time employed, and 18.8% were self-employed. Those who lived in the community for more than 35 years were 39%, followed by 33% who lived for 10-15 years, and 21% who resided in the areas for 0-5 years. Most of the individuals (57.65%) sourced their water from the rivers for drinking and crop irrigation, while 22.8%, 18.4%, and 13.2% sourced their water from bought water, boreholes, and communal taps, respectively. Furthermore, 57.6% revealed that their domestic animals drink primarily from the river, while 22.8% and 18.4% use bought water, boreholes, and communal taps, to quench the thirst of their livestocks.

Table 4.1: Demographic and socio-economic characteristics of the survey participants

Variable	**Categories**	**Percentage (%)**
Gender	Male	40%
	Female	60%
	Total	100%
Age	15-24	9%
	25-34	26%
	35-44	21%
	45-64	20%
	65+	24%
	Total	100%

Educational level	Primary school	4.4%
	Secondary School	50.4%
	Technikon College	22%
	ABET	3.6%
	University	20%
	Total	100%
Marital status	Never married	35%
	Divorced or separated	8%
	Widow/widower	11%
	Married or living together as husband and wife	46%
	Total	100%
Employment Status	Full-time employment	19.6%
	Part-time employment	18.8%
	Self-employment	18%
	Retired	12%
	Unemployed	31.6
	Total	100%
Length of residence (years)	0–5	21%
	5–10	3%
	10–15	33%
	15–30	4%
	30+	39%
	Total	100%
Source of water for drinking and irrigation	Bought water	22,8%
	Borehole	18.4%
	Piped water from communal tap	13,2%
	River	57.65%
	Total	100%
Source of water for domestic animals	Bought water	22.8%
	Borehole	18.4%
	Piped water from communal tap	18.4%
	River	57.6%
	Total	100%

4.4.2. Respondents' knowledge and awareness on asbestosis risk in Ga-Mathabatha

4.4.2.1. Respondents' knowledge of asbestosis risk and exposure

4.4.2.1.1. General knowledge of asbestos

The findings on general knowledge about asbestosis and asbestos fibers (Table 4.2) highlight that 90% of respondents know what asbestosis (*Marela*) is, while 10% do not. Meanwhile, 85% of the respondents know that this disease is deadly and incurable, and 15% do not. Furthermore, 79% of the respondents know someone in the household, a relative, or in the community who has asbestosis, while 21% don't know anyone. These results concur with those of Konak, Tatlipinar, and Omurtag (2017). Their study revealed that 60% of over 125 workers had adequate knowledge of asbestos dust exposure in Istanbul, Turkey. Similarly, Mithanga, Gatebe, and Mburu (2023) highlighted that the majority of the maintenance workers at the university in Kenya only had general knowledge about asbestos and asbestos dust exposure. In this study, the disparities in knowledge were initially observed among the in-depth interviews participants, and here is what some of the respondents had to say about asbestos and asbestos fibres:

> *"A lot of people confuse this disease with TB; however, TB is curable and can be treated. But this one is like a poison. Once you inhale a single fiber, you will be gone within 5 years, it does not play. It eats you bit by bit. The doctors cannot perform operation because the hair will be stuck into the lungs, and they have to remove the lung fibers and take these tiny fibers out which will eventually kill you.. I can describe this disease as a lung disease, because it affects the lung mostly." (Respondent no.4, 16th February 2024, Success village)*

> *Asbestos fibers are like thongs that spike up your lungs bit by bit until you die, to me I saw them as small inhalable thongs that cannot be broken down, burned, nor destroyed easily because I have worked with them on several projects. Asbestos fibers look like human hair that can be carried away easily by wind, they stick easily on your clothes, they behave like your hair. (Respondent no. 5, 16th February 2024, Success Village)*

> *This disease is poisonous and if it penetrates your skin andcauses painful wounds that swell . The*

fibres can travel through your blood to other parts of your body and damage your brain,heart, liver and lungs. That is why people who have it, complain of stomach pain, heartburn, headache and all that you can think of. It's worse when you are smoking because lungs will be even more damaged. This is a disease that killed many of our people here in Ga-Mathabatha. (Respondent no. 8, 17th February 2024, Success Village)

"I worked with asbestos for over 10 years in Makapeng, and I am diagnosed with it as we speak. I know everything about asbestos, asbestosis, asbestos fibers, and how one can inhale the fibers as I am a victim of the disease." (Respondent no. 1, Moleke village, 10th February 2024)

"I know a lot about asbestos, and I have worked in construction before. Asbestos is not like any other mineral because the fibers can push through normal PPE and penetrate your skin. There are specific PPE's that are needed when one is in contact with or handling asbestos, and not every company can issue that to their employee as it is expensive." (Respondents no. 2, Moleke village, 10th February 2024)

"I don't know much about asbestos, but I am willing to share the little that I know. What I know is that Marela is a lung disease that is caused by the inhalation of asbestos fibers. They are wool-like structures that come out when you crush the asbestos rock; they are shiny like silver; some are white and grow. I have worked with asbestos before, and we were given masks to protect us from the inhaling asbestos dust." (Respondent no. 3, Moleke village, 11th February 2024).

Bickerstaff (2004) highlighted that people who lived in one area for longer have a higher level of knowledge, attitude, and perceived risk than those with shorter residency. This is also supported by Brody (2004), who revealed that men who lived in the area longer believed the creek river pollution to be more dangerous than those who lived for a shorter period.

As such, the association tests between general knowledge of asbestosis (Marela) and asbestos fiber with respondents' age, gender, and length of residence. The test revealed a statistically significant relationship ($p < 0.001$) between these demographic variables and general knowledge of asbestos. Females, adults (65 years+), and 30 years plus residency period participants had more general knowledge of asbestos than any demographic group. These results concur with those of Culley, Zorland, and Freire, 2010. The study focused on community response to naturally occurring asbestos, and the majority of respondents with general knowledge of naturally occurring asbestos were females who lived in the areas for more than 10 years (Culley, Zorland, and Freire, 2010).

Table 4.2: The basic knowledge about asbestosis and asbestos fiber

Knowledge of asbestos, asbestos fiber and asbestosis.	**Yes**	**No**	**Total**
Do you know what asbestosis (*Marela*) is?	90%	10%	100%
Do you know that asbestosis is deadly and incurable?	85%	15%	100%
Do you know what asbestos fibers are?	68%	32%	100%
Are asbestos fibers hairlike structures that can be inhaled easily?	58%	42%	100%
Are asbestos fibers wool-like structures that are found when you break down asbestos rock?	76%	24%	100%
Do you know anyone in the household or relative who was diagnosed with asbestosis?	79%	21%	100%

4.4.2.1.2. Community knowledge on symptoms of asbestosis

Roughly 60% (41.2% + 18.8%) of respondents strongly agree and/or agree that shortness of breath, persistent cough, chest pain, and swollen fingertips are among the symptoms associated with asbestosis (Table 4.3). Meanwhile, 18% were unsure, presenting a lack of knowledge of the symptoms, which might lead to failure to recognise asbestosis at an early stage and subsequent further respiratory damage. Additionally, 22% (16% + 6) disagreed and strongly disagreed that these were the correct symptoms of asbestosis. During interviews, respondents were asked to describe symptoms of asbestosis disease, and this is what they said.

> *"This disease of Marela (asbestosis) has killed our parents. I remember back in 2009 when my mother was sick, very sick, and we thought it was Tuberculosis because she was having shortness of breath*

and a dry cough. As days and weeks passed, she started coughing blue mucus mixed with blood; she would lose appetite and lose weight as well; she couldn't speak or eat well because her chest was painful. The doctor confirmed that she had the final stage of Marela. She was given medication, but she still passed on." (Respondent no. 13, 8th of March 2024, Makapeng Village)

"I am diagnosed with Marela, and I got it when we were still residing in Makapeng near those asbestos mines. We used to make mud, mixed with asbestos, to design objects, and the same with the sand and soil; we used to eat them and inhale them without being aware. It is just God's grace that I am still alive. I remember fainting in 1995, and before I fainted, I felt so weak, and my body was losing so much weight. I would cough colour mucus, and my chest was very painful." (Respondent no.18, 22 March 2024, Makapeng Village)

"What I have heard is that it shows TB-like symptoms, with constant coughing." (Respondent no. 14 of March 2024, Makapeng Village)

"A lot of people confuse this disease with TB; however, TB is curable and can be treated, but this one is venomous; it kills you." (Respondent 4, 16 February 2024, Success Village)

The results of most 60% of participants correctly identifying symptoms of this airborne disease (asbestosis) align with those of Tuncer, and Gomleksiz (2025) who highlighted that the majority of workers (66%) in asbestos cement plants were able to identify the symptoms of asbestosis. Werner, (2003), Albarqouni et al., (2016), and Ngwewondo et al., (2020) argue that the ability of participants to identify symptoms of diseases is vital in reducing panic and depression, seeking treatment early, motivating individuals to adopt preventive behaviours, and making them more likely to participate in routine health check-ups and seek medical advice.

Statistical tests between the symptoms (shortness of breath, persistent cough, chest pain, swollen fingertips of asbestos) and the age, gender, and period of residence. The findings show that there was a significant relationship ($p < 0.001$) between these variables with correct symptom identification. The majority of participants who identified with these symptoms were diagnosed with the disease or knew someone closely diagnosed with the disease. These results align with a study by Bickerstaff and Walker, (2001), who highlighted that people who were victims and/or treated those diagnosed with asbestos-related diseases have adequate knowledge, as well as well-informed views about

asbestos-related diseases. Furthermore, when an individual lives with an asbestosis patient, for example, they engage in more frequent and in-depth conversations with doctors and specialists who will explain the disease in detail, including its symptoms. Meanwhile, van Der Wal et al., (2006) highlighted that those who have obtained a higher level of education tend to be more knowledgeable about heart failure caused by asbestosis. Their findings align with this study, showing that the majority of individuals who were able to identify asbestosis symptoms had secondary school qualifications or higher.

Table 4.3: Knowledge about the symptoms of asbestosis

Symptoms	Strongly agree	Agree	Unsure	Strongly disagree	Disagree
Coughing out blood, chest pain, shortness of breath, urinating blood	64.8%	13.2%	9.2%	4.8%	8%
Short memory, short eyesight, stomach pain	20.8%	6.8%	21.6%	28%	22.8%
Fatigue, dry cough, eye blockage, nose blockage	16.4%	10%	46%	4.4%	7.2%
Nightmares, depression, loss of appetite	32%	20%	20.8%	11.6%	15.6%
Shortness of breath, persistent cough, chest pain, swollen fingertips	41.2%	18.8%	18%	16%	6%

4.4.2.1.3. Community knowledge on the causes of asbestosis, risk and exposure

A significant majority (193 respondents, or 77%) strongly agree or agree that inhaling contaminated air from Makapeng, Success, and Maseleseleng causes asbestosis and asbestos dust exposure (Table 4.4). In comparison, 23% were unsure, strongly disagreed, or disagreed. The majority of individuals (77%) in this study reflect a high level of awareness/knowledge of the danger of inhaling air blowing from these villages, and only a small portion (23%) do not. Although this is the case, more education could help clarify these risks for this group. Makapeng, Success, and Maseleseleng are villages of high potential asbestos concentration, as seen in Appendices 3.1, 3.3, and 3.4, respectively. These suggest that the majority of the participants were able to highlight that the asbestos might be coming from these contaminated areas. Similarly, Airoldi et al., (2021) reported that the majority (64.3%) of participants were able to highlight that the

contaminated air they are breathing comes from the asbestos cement plant nearby, which was the major source of exposure. Bullock, 2020) also Another study observed the same trend, where the majority (approximately 60%) of the workers suffering from early signs of asbestosis and mesothelioma, such as chest pain and difficulty, were unable to identify the asbestos mine as a major occupational exposure.

Table 4.4 also shows that 187 respondents (75%) strongly agree or agree that using contaminated water from the Tongwane River and Mphogodima for bathing or household chores increases the risk of asbestosis. Only a few of about 49 respondents (20%) are unsure, and 14 respondents (6%) strongly disagree with the idea that using contaminated water increases asbestos exposure risk and exposure. Most respondents are aware that contaminated water is a potential source of asbestos exposure, while the number of respondents who disagree is small. A deeper insight was provided by respondents who mentioned that:

> *"When you break down these asbestos rocks that you're seeing here (respondents pointing), there will be substances that will come out, and we call them Borela. If you dare to inhale this Borela, you will soon be dead because this disease has no cure, my friend!" (Respondent no. 17, March 2024, Makapeng Village)*

> *"I know a lot of people who have Marela because we grew up together, and we used to go hunting, swimming, and playing soccer with them. We got these diseases when we were still young, but because it takes time to show, you won't notice instantly. We used to play hide and seek around the asbestos dumping; we played a lot on those dumping, and we used to relax there and just observe trucks that would pass by the road loaded with minerals." (Respondent no. 15, 18th March 2024, Makapeng Village)*

A chi-square test of association reveals a strong association ($p < 0.001$) between causes of asbestos exposure (residing in areas concentrated on asbestos such as Success, Makapeng, and Mashikana villages) and age, gender, level of education, and period of residence . These results demonstrate that there is a strong association between females, secondary school qualification holders, and people who resided in the area for more than 30 years with areas of high asbestos concentration. Similarly, Mager, Knopick, and Oddy, (2022) established a strong relationship between people who attended the church for more than 10 years and with knowledge on asbestos contaminated drinking water at

church, in New Zealand. Individuals who attended church for more than 10 years and drank water from the church were more knowledgeable about the quality of the water they were drinking as compared to those who stayed for at least 5 years (Mager, Knopick, and Oddy, 2022).

Table 4.4: Views on the causes of asbestosis risk and exposure

What level of agreement do you know the following can cause high asbestosis risk and asbestos dust exposure?	**Strongly agree**	**Agree**	**Unsure**	**Strongly Disagree**	**Disagree**
Inhalation of contaminated air blowing from Makapeng, Ga-GG, Success, and Mphanama	60%	17%	16%	5%	1%
Using contaminated water from Tongwane River and Mphogodima for bathing and doing chores	48%	27%	20%	7%	0%
Residing in areas that are highly concentrated by asbestos (e.g. Success, Makapeng, and Mashikane villages	30%	54%	7%	8%	0%
Smoking cigarettes	10%	8%	22%	8%	27%

4.4.2.1.4. Community knowledge of areas with high asbestos concentration

Gallina & Williams, (2014) study highlighted that individuals who feel a strong connection to their home are more knowledgeable and aware of and concerned about the environmental risks associated with their location. This is due to a sense of place, or of feeling connected to the location and environment, and more awareness of the pollution and toxin issues (Gallina and Williams, 2014; Harclerode et al., 2016). The majority of the participants mentioned Makapeng Village as the most contaminated area of asbestos concentration, followed by Success, Maseleseleng, and Makgoba with 9.6%, 12.8%, and 18%, respectively. These results are valid as they align with observations made in these areas of high concentration, as seen in Appendix (3.1, 3.2, 3.3, 3.4), results from previous studies (Petja , 2009; Petja et al., 2010), and news reports (SABC News, 2022), who concentrated on closed asbestos mines of Ga-Mathabatha. Similarly, a study by Ramos-Bonilla et al., (2019) in Sibaté, Colombia, indicated that people residing in or adjacent to

areas of high environmental hazards, such as asbestos cement plants, are more knowledgeable and highly aware of their surroundings. Highlighting a similar theme, two in-depth interview respondents aged 66 and 30 years, respectively, and who have resided in Mathabatha for over 10 years remarked:

> *"Makapeng is the most asbestos-polluted and contaminated village as compared to others. The majority of asbestos dumping, open shafts, and old houses are found there. Most people who got diagnosed with asbestosis (Marela) got it there." (Respondent no. 11, 9th March 2024, Madikelong Village)*

> *"I know several villages with high concentration, including Makapeng obviously, then Success, and Maseleseleng. These are the villages where, even if you can go and observe now, you will find piles of asbestos dumping, asbestos soils everywhere." (Respondent no 15, 14th March 2024: Makapeng Village)*

The correlation between the identification of areas highly concentrated in asbestos and asbestos fibers was linked with gender and period of residence. The results highlighted that there was a strong significant relationship ($p < 0.001$) between gender, age, and participants who lived in the area for more than 30 years with correctly identifying areas of high asbestos contamination. These results are consistent with those of Ramos-Bonilla et al., (2019). The observation made relates that the residents near Sibaté, Colombia, state that the people who were able to identify that dust contains concentrated of actinolite asbestos lived in the area for more than 5 years.

Table 4.5: Perceived areas of high asbestos concentration

Name the villages of Ga-Mathabatha with the most asbestos concentration	**Percent (%)**
Makapeng	50%
Success	9.6%
Masioneng	1.6%
Madikeleng	1.2%
Ga-GG	12.8%
Makgoba	18%
Maseleseleng	6.8%
Total	**100%**

4.4.2.1.5. Community knowledge of meteorological factors and their impact on asbestos dust risk exposure

Table 4.6 presents the communities knowledge of meteorological factors that influences the communities' exposure to asbestos dust. 119 respondents (or 47.6%) identified high rainfall as a major variable factor that contributes to the risk factor of the exposure. Furthermore, 80 respondents (or 32% of the total) identified strong winds as a factor that increases asbestos exposure risk. Less respondents recognised drought and high temperature (6% and 14% as contributing factors). Respondents were asked to describe the meteorological variables that contribute to asbestos dust exposure some stated, during the in-depth interviews, that:

> *"I once worked in a construction company that was appointed to plant trees on top of those asbestos dumping sites on the escarpments to avoid them being easily washed away by wind and rainfall waters. We were told that the reason why our water in the rivers and catchment was contaminated because rainfall sweeps off the asbestos sand into the water." (Respondent no. 07, 17 March 2024, Success Village).*

> *"We have suffered from a lack of communal tap water for decades now, and our rivers have been the source of water. The reason why I am saying rainfall is the major concern is because, when we were collecting water from the Mphogodima River during its flowing seasons using buckets. We would find asbestos fibers inside the river, inside our buckets, and containers from the river. These come from the runoff from asbestos mines in the mountains of Makapeng village." (Respondent no. 14, 15 March, Makapeng village).*

Marino et al., (2001), Mizan, Phillips, and Nthoke, (2018), and Marengo et al., (2023) identified high rainfall and strong wind as major contributing factors to asbestos dust exposure and further classified this asbestosis as waterborne and airborne disease. These results concur with those of Kwata et al., (2028), who highlighted these variables as major contributors to asbestos exposure in Mpumalanga Province, South Africa. Studies on naturally occurring asbestos have also identified wind speed and direction as the major asbestos risk (Noonan, 2017; Cherrie, McElvenny, and Blyth, 2018; Ricchiuti, Bloise, and Punturo, 2020).

Table 4.6: Meteorological variables that are perceived to contribute to asbestosis risk and exposure

The following are examples of meteorological variables that put people at high risk of asbestos exposure.	**Percentage (%)**
High rainfall	47.6%
Strong winds	32%
High temperature	6%
Drought	14.4%
None of the above	0%
Total	100%

4.4.2.1.6. Community awareness of asbestosis risk

The majority of the respondents, 54.4%, are aware of asbestos concentration and areas of high risk in the community (see Table 4.7), while 45.6% are not. These results suggest that although 54.4% of respondents are aware of high-risk areas of potential asbestos exposure, nearly half are unaware. This entails that while awareness campaigns have reached the majority, there are still others who haven't heard anything about asbestos risk areas, and this highlights a significant gap. Jeffers and Lin, (2022) recorded that residents of St. Kitts and Nevi were aware of sources of asbestos dust; however, they had low awareness of the health-related effects of the exposure. Their results concur with those obtained in this study, where the majority are aware of areas of potential exposure. Participants of the in-depth interviews were asked about their opinion on areas of high-risk exposure, and this is what one of them had to say:

> *"I am fully aware of the asbestos dumping sites in this community, as I have seen them and played on top of them several times when I grew up. My late father was a goat and cattle farmer who used to camp them in the bushes next to this asbestosis dumping because there is good grazing grass there, and as a reminder of what took my late father's life, I have this asbestos rock here at home that I want you to see what I am talking about." (Respondents no. 18, 23 of March 2024, Makapeng Village)*

> *"I worked with the project that came here in 2019 to rehabilitate some areas. I am aware with no doubt*

that Makapeng is one of the areas of potential risk, as I have seen many asbestos shafts and dumping on that side." (Respondents no. 17, 02 March 2024; Makapeng Villages)

There is a significant 38% who are aware that asbestos can lend on clothes when a person passes by a highly concentrated area, while 62% are unaware. This suggests that although there are respondents about asbestos in the area, there are other individuals who still have this insight and knowledge about its distribution and exposure. Ferracini and Sahmel, (2024) study on taking home exposure and risk highlighted that the most asbestosis cases at home result from their spouse returning home from work while still wearing PPE for respiratory protection. These align with the results of this on high awareness in areas of high-risk potential. Conversely, the association between awareness in areas of high asbestos concentration was made with a demographic variable such as age, gender, level of education, and length of residence. It was discovered that there was a strong significant relationship between these variables ($p < 0.001$). This highlights that participants' demography affect the awareness, for example, a study conducted in Iran, on asbestos inhalation in the city highlights that the majority of participants who were aware were elderly, who lived in the area for more than 10 years (Awadh 2023).

Table 4.7: Community awareness of asbestosis risk

Awareness of asbestosis risks: Are you aware that:	**Yes**	**No**
Makapeng village, Success, Maseleseleng, including Tongwane River, and Mphogodima are highly concentrated asbestos rocks and are areas of high risk to asbestos dust exposure.	54.4%	45.6%
People and animals that pass, collect, or drink water from Tongwane, Mphogodima, are at high risk of being exposed to asbestos dust.	38%	62%
The asbestos dust that exposes the community to asbestos comes from post-asbestos shafts in the area.	85%	14.8%
Rainfall and wind play an important role in asbestos transportation.	98%	2%

4.4.3. Practices that expose the community to asbestos

4.4.3.1. Domestic activities that expose communities to asbestos dust

The findings reveal that the majority (139, or 55.6% of respondents) regularly use asbestos contaminated water from Mphogodima or the Tongwane River to do chores such as washing clothes, cars, mopping the floor, and cleaning. 65 respondents sometimes and 47 respondents often use these contaminated waters (Table 4.8). In essence, 100% of respondents rely on water from these rivers for daily chores, indicating that these rivers are a major water source for the community. This raises significant concerns as asbestos fibers were observed suspended on the surface of the river water and continuous exposure could lead to serious health complications.

The results further indicate that the majority (151, 60.4%) of participants highlighted that they sometimes drink water, indicating that while many do not rely on the rivers daily for drinking, they still use it periodically. Furthermore, only a smaller portion of 7 and 15 respondents often and rarely drink this water less frequently, while only 6 of them never drank the water. The fact that 71% (222 out of 250) of respondents either always or sometimes drink water from these rivers highlights the possible significance of water quality in this region. This could spiral out into a potential major public health crisis.

On using face masks when cleaning the yard, an overwhelming majority of respondents (71%) never wear a face mask during this activity. Only a small number of respondents use a face mask when cleaning their house or yard. A single respondent (always) and 70 respondents (sometimes). A portion of 71% of respondents never use face masks when cleaning, despite the potential risks of airborne asbestos fibers or other contaminants. This poses a serious concern, as cleaning activities, especially in environments with asbestos contamination, can disturb dust and fibers, increasing inhalation risks. Public health education is needed to encourage protective measures, such as wearing face masks during cleaning, particularly in contaminated areas.

Geophagia, or the consumption of soil, is another concerning practice in the study area. The results of this study highlight that a notable portion of respondents always consume

soil. While only 7 respondents (rarely) and 202 respondents (never) eat soil daily. Soil consumption (geophagy) is a relatively common practice in some communities (Vermeer, and Frate, 1979; George, and Ndip, 2011; Eberl et al., 2025). With 48 respondents (19%) reporting some level of soil consumption, there is a potential health risk if the soil is contaminated with asbestos fibers. This practice could lead to the ingestion of hazardous materials, posing a serious threat to health.

Table 4.8: Domestic practices that expose communities to asbestos

How often do you undertake the following practices:	**Always**	**Sometimes**	**Often**	**Rarely**	**Never**
Wash clothes, car, mop, and clean using water from Mphogodima or Tongwane river	55.6%	26%	18.8%	0%	0%
Drink water from the Mphogodima and Tongwane river	28.4%	60.4%	2.8%	6%	2.4%
Use a face mask when cleaning the house and yard	0.4%	28%	0%	0%	71.6%
Practice subsistence farming at home	37.6%	38.8%	18.8%	0%	4.8%
Clean your dog or cat at home	0%	3.6%	0%	0%	96.4%
Slaughter cows and goats at home	33.2%	23.2%	28.8%	0.4%	7.6%
eat soil	16.4%	0%	0%	2.8%	80.8%
Buy rocks, soil, concrete, sand, and bricks from local shops	40.8%	15.6%	20.8%	0%	22.8%
Close your windows during the windy season	69.2%	30.8%	0%	0%	0%
Harvest roof water into storage tanks to drink	53.2%	26.8%	20%	0%	0%

4.4.3.2. Outdoor activities that expose communities to asbestos dust

The majority of respondents (43%) report that they were always involved in small-scale brick manufacturing in the community, following that, 8% and 22% of respondents represent a relatively small portion of those who are sometimes and rarely involved in brick manufacturing, respectively. Given that brick manufacturing often involves using raw materials such as clay and soil, this could potentially expose the community to hazardous materials (like asbestos, if present in the environment). A respondent was asked about the source of sand used when manufacturing bricks; they mentioned that: *“They use river*

sand sourced from Olifants (see Appendix 3.6) because it is free and not far from their factory (Respondent No. 17, 02 March 2024, Madikane village). Hence, people working in small-scale brick manufacturing and those buying these bricks are more vulnerable and face higher levels of exposure. The results of 43% of respondents at high risk of exposure for participating as small-brick manufacturers align with the study of Mutetwa et al., (2021), who mentioned that more than 75% of asbestosis cases result from asbestos cement plants (ACP) in Zimbabwe and further highlighted that asbestos cement is made up of 20% asbestos and 80%.

Table 4.9 further reported that 3% of respondents are always passing by gravel near asbestos dumping sites at Success Village (see Appendix 3.1), where asbestos dumping was observed. Meanwhile, most respondents (60%) sometimes pass by these high-risk areas. A significant number (27%) report passing these areas often. While only a small number of respondents always pass by these hazardous sites, a large majority (96%) pass these areas at least sometimes or often. These results suggest that only 10% of the respondents are less exposed because they never pass near these dumping sides, whereas 90% of the participants are at high risk of exposure for passing near this area always, sometimes, and often. These results concur with those of Ramos-Bonilla et al., (2019), Cavallo, (2020), and Emmett, (2021), who mentioned that most cases of asbestosis result from individual passing and accumulating asbestos fibers on their clothes. Respondents were asked whether they passed near these asbestos dumps at success (see Appendix 3.1) and Makapeng (see Appendix 3.3), and this is what they said:

> *"I am an animal farmer, and yes, I pass by that gravel road of success villages coming from the forest heading my cattle every day, and I am used to it. I know there are asbestos dumps on that side, as I see them every day, and I don't care; I am not scared; I can't allow my cattle to starve because I am afraid to pass there." (Respondent no 5, 16 February 2024, Success Village)*

Emmett, (2021) study detailed that children and adolescents may experience distinctively high exposure from playing in asbestos waste sites and recreational activities in abandoned factory sites. Early and late adolescent stages range from 10–19 and 19–24,

respectively (Sawyer et al., 2018). As such, a test of association was conducted between age, gender, and people who passed by these asbestos sites. The p value of <0.001 reveals a significant relation between these variables with participants who pass near asbestos dumping at successes, Makapeng. The majority of people who pass these areas always, often, and sometimes were female and individual, with 65 years plus, followed by 25-35 years. Youth and adolescent individuals contributed as compared to any other age group. These results defeat claims made by Wortzel et al., (2021), Emmett, (2021), and Bolan et al., (2023), whose study mentioned that children of 23 years were more exposed by playing and/or passing near asbestos dumping. The findings also reveal that almost half of respondents (54.5%) sometimes collect firewood rocks and soil from local mountains predicted to have asbestos. Qualitative data further suggest this, as reflected in the interview comment:

> *"My brother, I am living with my grandparents, who are 89 and 75 years old. They prefer drinking tea and eating porridge that is made from firewood from the outside and not by electricity. I have to go there and collect firewood to cook for them daily. Obviously, I am being exposed, but what can I do or say because when you talk back, they say you are being disrespectful?" (Respondent no. 11, 17th February 2024, Madikelong Village).*

Studies related to the accumulation of asbestos fibers on the victim's clothes while passing near asbestos-dumping construction sites were conducted. The results of this study align with those of Leader et al., (2021) in the Mnyenzeni Village Kalumani area of Kilifi County, who mentioned that although this asbestos disposal site is 7 km away from Maji Ya Jumvi Town. People who pass near asbestos disposal sites have contributed to asbestos exposure in Maji Ya Jumvi Town (Leader et al., 2021).

Table 4.9: Outdoor activities that expose the residents to asbestos

How often are you involved in the following outdoor activities?	Always	Sometimes	Often	Rarely	Never
Small-scale brick manufacturer in the community	42.8%	8%	0.4%	21.6%	27.2%
Collect water at Tongwane river for other reasons	40.4%	18%	41%	19%	42%

Pass by gravel near asbestos dumping at success, Makgoba, and Maseleseleng villages?	3.2%	60.4%	26.8%	0%	9.6%
Allow domestic animals to drink water at Bollatswene, Tongwane, and Mphogodima rivers or pastures near the mountain	43.2%	26.8%	22.8%	0%	0%
hunt at Kholla, Lekgotse, and Lebeting local mountains	2.8%	18.4%	4.8%	62.4%	0%
Collect firewood, rocks, or soil near local mountain	8.8%	54.4%	28%	0%	8.8%
Participate in asbestos rehabilitation construction programme in the community	9.6%	26.8%	0%	8.4%	55.2%

4.4.4. Community perception on asbestosis and asbestos dust exposure

4.4.4.1. Community perception on the risk and prevalence of asbestos

The majority of participants, 40.8% (32.8%+8%), perceive asbestosis as deadly and incurable, while 23.8% are unsure, and 35.6% (11.6%+24%) are unsure (see Table 4.10). A study by Schlünssen, et al., (2023) indicated that there are 200,000 deaths globally annually from asbestosis, and a respondent from SABC News (2022) from Makapeng in the Ga-Mathabatha community highlighted, "*I have lost both of my parents and elder brother from asbestosis who were once worked at this asbestos mine in Makapeng villages*."

Meanwhile, 35.6% of respondents strongly disagree that this disease is incurable and fatal, raising concerns that they may be affected or spread false information to other community members about the disease. Comments made by some of the respondents align with those who do not perceive asbestos as deadly and incurable, and this is what was said:

> *"I strongly believe that asbestosis is like any other lung disease, such as TB, which can be treated with medication. I believe that people use "cham or spell" (also known as black magic) to assassinate other people and blame asbestosis, as they claim once you get it there is no way out of it." (Respondent no. 01, 10 February 2024, Moleke Village)*

> *"I know people who doctors confirmed that they have asbestosis and even claim compensation money*

from the government, but they are still living healthy and well. When is your time to go? Is your time to go with or without the disease? I mean, why are these people still alive because they are old and lived in this community for a long time if this asbestosis is really deadly and incurable?" (Respondent no. 14, 16 March 2024, Makapeng Village)

The association between the risk of asbestosis, areas of high asbestos exposure, and drinking water from contaminated rivers with demographic variables such as age, level of education, and period of residence was performed. It was discovered that there was a strong relationship between all these variables with $p < 0.001$. Female participants of 30 years plus and 60 years plus and who lived in Ga-Mathabatha for more than 30 years perceive asbestosis as deadly, areas of high asbestos exposure, and drinking water from contaminated rivers as sources of exposure. These results align with those of other studies on water pollution. Another study indicates that people who livedlonger in areas experiencing water or air pollution were once exposed to waterborne disease than those who lived in the area for less than a year (Harclerode et al., 2016).

The largest group 51.2% (42.8% + 8.4%) of respondents strongly agree that Makapeng, Success, and Maseleseleng are high-risk areas for asbestos dust exposure. Meanwhile, 13% were unsure, and 25.2% strongly disagreed. The observations made in this study strongly highlight that Makapeng is highly concentrated in asbestos rocks, asbestos fibers, asbestos dumping (see Appendix 3.3), and old asbestos mines. Success villages are highly concentrated on asbestos dumping, contaminated rivers near the dumping (see appendix 3.1) and Maseleseleng with asbestos rocks making a cross bridge (see appendix 3.2). Studies by Petja (2009), Petja et al., (2010), and Geogina et al., (2018) also concur with the findings that there is evidence of asbestos mines, especially in Makapeng villages, that people currently suffer from their exposure. With this evidence, including SABC News (2022) information, there were records of people living in Ga-Mathabatha strongly disagreed that these villages are highly concentrated in asbestos. This raises a big concern about the further increase in asbestos dust exposure and asbestosis fatality cases from people with negative perceptions.

Makapeng, Maselseleng, and Makgoba villages have no access to reliable clean

communal water, according to respondents from an interview made by SABC News (News 2023; SABC News 2024). Community members highlighted that they buy water, use boreholes, and collect from the Tongwane River and Olifants River for drinking and other uses. Community members were asked whether they perceive drinking water from these rivers as the main source of asbestosis and asbestos exposure (Table 4.10). Most participants, 54% (38+16) strongly perceive this activity as the major source of exposure, while 15% were unsure, and 31% (10%+21%) strongly disagree. Positive perception results (54%) of respondents in this study suggest many participants recognise these activities as hazardous in terms of asbestos dust exposure, as a study by Avataneo et al., (2022) highlighted that people collecting water contaminated with chrysotile were more vulnerable as this type of asbestos could be ingested when drinking water.

Table 4.10: Community perception on asbestosis

In your own opinion, do you perceive:	**Strongly agree**	**Agree**	**Unsure**	**Disagree**	**Strongly disagree**
Asbestosis as a deadly incurable disease	33%	8%	24%	12%	24%
Areas like Makapeng, Success and Maseleseleng have high areas of asbestos dust exposure	43%	8%	14%	10%	25%
contractors that helped in closing open shafts of asbestos helpful and reducing the exposure	15%	5%	35%	29%	26%
drinking water from Mphogodima and Tongwane as the main source of asbestosis	38%	16%	15%	10%	20.8%
Consulting professional doctor as helpful when experiencing asbestos symptoms	38%	14%	5%	20%	23%
Planting vegetation on top of asbestos dumping is effective in reducing the exposure	20%	9%	46%	24%	33%

4.4.4.2. Community perception on asbestos exposure activities

The majority of respondents, 73% (47%+26%) regard household cleaning without a respirator as a substantial risk of asbestos particulate exposure. The result suggests that individuals are cognizant of the potential for dust to transport asbestos particles, which is a legitimate concern in areas that have been contaminated. Nevertheless, 41% of respondents are still uncertain, while 13% do not perceive the importance of this practice, which may be attributed to the inconsistent information regarding the dangers of indoor exposure. These results, showing that respondents perceive the importance of wearing a face mask at home, are consistent with those of Kwata, Moja, and Chadi (2018), who collected dust samples at households near asbestos dumping and discovered asbestos fibers on tables, floors, and windows. The community believes this asbestos dust is hazardous and harmful to their health and well-being (Kwata, Moja, and Chadi 2018).

There were 48% (33%+15%) of respondents who perceive that passing near asbestos dumping sites poses a risk, while a substantial 24% are unsure and 28% (15%+13%) disagree**.** This varied response may be attributable to the variability in perceived exposure, which is determined by the frequency and proximity of crossing these sites. For example, 28% expressing negative perceptions may stem from insufficient information on exposure to asbestos clothing. A study by Maja et al. (2020) indicated that proximity to asbestos disposal sites may result in asbestos fibers adhering to clothing, exposing individuals and their families to dust at home. Which concurs with 48% of respondents having a positive perception of asbestos exposure. Respondents were asked to express their perception of passive near asbestos dumping, and this is what was said:

> *"The majority of people I know with asbestosis and who died from it were exposed because of working in the asbestos mine when they were still active. I have never heard someone who was diagnosed because they passed near that side; hence, I am saying that is not possible." (Respondent no. 12, 09 March Madikelong Village)*

> *"My spouse herds cattle for grassing at the mountains, but I am surprised every time when I wash clothes that he normally wears going that side. I found these unusual things that make the dirty water*

shine; they are like small pieces of wool." (Respondent no. 8, 23 February 2024, Makgoba Village)

There is a substantial level of concern regarding the ingestion of soil and rocks in asbestos-prone locations, as 60% of respondents perceive geophagia as a danger. A negative perception of 27% (20%+7%) of the risk of rock consumption in contaminated asbestos areas, as well as a concerning 13% uncertainty, is present. These reflect a high level of knowledge or awareness of the danger of ingestion of asbestos fibers.

A considerable number of participants (47%) perceived using river sand and rocks for building poses an asbestos exposure risk. However, 23% were unsure of the risk, and 30% did not perceive this activity as potential exposure. Berry et al., (2020), Guth et al., (2020) on asbestos exposure risk from ceiling, roofing, contaminated bricks, and sand align with 47% of participants perceiving using asbestos materials for buildings as major risk exposure. Petja et al., (2019) further detail that the exposure in the community results from using asbestos-contaminated sand, rock, and bricks, which also align with participants perceiving risk in using these materials.

During surveys, some participants presented asbestos rocks (see Appendix 3.5) kept in their houses as evidence that indeed this area is high in asbestos. This practice raised concerns about potential exposure to household members. A significant 21% (12%+9%) did not perceive this behaviour as a major risk, whereas a significant 55% raises uncertainty. This uncertainty may result from considering some materials to be less dangerous and more inert or historically significant.

Table 4.11: Community perception on asbestosis and asbestos dust exposure

In your own opinion, do you perceive the following activities as major asbestos dust exposure?	**Strongly agree**	**Agree**	**Unsure**	**Disagree**	**Strongly disagree**
Cleaning your house and sweeping the yard without wearing face mask	47%	26%	41%	3%	10%
Passing near asbestos dumping with or without herds	33%	15%	24%	15%	13%
Consuming rocks/soils (geophagia)	45%	15%	13%	20%	7%

Collecting river sand, rocks, sand, and stones from local mountains and rivers for building and renovations.	15%	32%	23%	16%	14%
Storing asbestos rocks and sand at home for historical purposes	20%	4%	55%	9%	12%
Doing chores, washing clothes, cars, and other items using water from Mphogodima	25.2%	23.6%	16%	0%	35.2%

4.4.4.3. Community attitude on asbestosis and asbestos dust exposure

The majority of respondents, 79.2% (52% + 27.2%), considered teaching and raising awareness on asbestos as "important" or "very important," while 10.8% were unsure, and 10% viewed it as a very unimportant aspest of community awareness. A substantial majority of the community recognises the significance of educating the public on this issue. This reflects a positive attitude toward public health education and suggests that initiatives to spread awareness would be well received. These results are consistent with those of Marsili et al., (2019), who further highlighted that raising awareness and networking with stakeholders in communities living in industrially contaminated areas is essential action to broaden knowledge, improve attitude, and reduce exposure. One of the interviewees who also believed in the importance of teaching and raising awareness on asbestos risk expressed that:

> *"It is very important to teach and raise awareness, especially to our children, about the danger and risk of exposure. I was diagnosed with asbestosis simply because I didn't take this disease seriously; I saw it as a good way of making quick money because of the compensation they were giving diagnosed people back when mine was still operational. Raising awareness will help reduce cases and asbestos deaths." (Respondent no. 15, 24 February 2024; Makapeng Village)*

> *I think attitude has an influence also on the rise of asbestosis cases, for example, people who were diagnosed with Marela (asbestosis) were going to list their name at the royal house and doctors used to come and check them up to confirm. After they checked you up, then they categorized you as low, medium, and high based on the level of asbestos fibers detected in your lungs. After that, there was a certain amount of money that compensated people based on their categories and I remember the medium was R110 430.00, because that's what my mother got. So based on jealousy that people are*

getting a lot of money from these diseases, most people went to the dumping sites and ate and inhaled those asbestos fibers in the hope of being compensated with this money." (Respondent no 18, 23 March 2024, Makapeng Village)

The majority of participants, 47.6% (10.4% + 37.2%), consider wearing face masks during windy seasons as "very important and important," while 20% are unsure, and 31.2% (13.2% + 18%) believe it is unimportant and very unimportant. This reflects that almost half of the respondents recognize wearing a mask as an effective practice to protect themselves against airborne asbestos dust, especially during windy seasons, The 47.6% and 31.2% of respondents with positive and negative attitudes towards domestic workers in Nigeria, and Uganda who were using asbestos cement to make brings without any personal protective equipment (Olasumbo et al., 2016; Moda, Sawyerr, and Clayson, 2018, Mutetwa, Moyo, and Brouwer, 2021). Some significant people contradicted and supported the motion that wearing a face mask is not important as it hinders them from breathing normally. Meanwhile, 40% had a positive attitude and believed in the following activities: avoid drinking water from contaminated rivers in the area, washing off domestic pets before they enter the house, and wearing protective gear when passing asbestos dumping. Meanwhile, less than 30% of the respondents were unsure and considered these activities unimportant or very unimportant. The majority of the participants are aware of the importance of avoiding activities that might expose them to contaminated asbestos dust. These results align with those of Turci et al., (2016) in Italy who highlighted that the majority of farmers avoid areas with naturally occurring asbestos because it has potential exposure. Another study conducted by Sacolo, Chimbari, and Kalinda (2018) supports participants with a negative attitude towards practices that expose them to waterborne diseases. Their study further highlighted that 60% of the respondents had a negative attitude due to misconceptions regarding asbestosis exposure and control. One of the interviews in this study also expressed a negative attitude towards activities that expose the community to asbestos dust and contaminated water and said:

"I don't believe in asbestos, and I don't believe that we have to avoid drinking this natural water because of this asbestos. I also don't believe that people who died in this community were killed by asbestos. They claim they died from the exposure. Many people are healthy and alive but still drink and breathe

this air that you claim to be contaminated, including myself. What kills people is fear and witchcraft. They just use this asbestos to shield the major cause, and I will continue drinking water from Success River without any fear of anything." (Respondent no. 14, 15 March 2024, Makapeng Village).

"I think attitude has an influence also on the rise of asbestosis cases; for example, people who were diagnosed with Marela (asbestosis) were going to list their name at the royal house, and doctors used to come and check them up to confirm. After they checked you up, they categorized you as low, medium, and high based on the level of asbestos fibers detected in your lungs. After that, there was a certain amount of money that they compensated people based on their categories, and I remember the medium was R110 430.00, because that's what my mother got. So based on jealousy that people are getting a lot of money from these diseases, most people went to the dumping sites and ate and inhaled those asbestos fibers in the hope of being compensated with this money." (Respondent no 18, 23 March2024, Makapeng Village) "There are specific PPE that a person uses when they are working in asbestos construction companies, and there was a project by Mintek that was here to rehabilitate the shafts and areas of asbestosis risk. They appointed local community members, and we were earning a lot of money. After we were appointed, we went through induction, where they taught you everything about asbestos exposure. We were told to change clothes and PPE after work, however, because several people wanted to be seen working in that area. You would see someone going home with that PPE. From there you can tell that these people were taught, and they know, yet they just chose to off-ramp and put themselves and everyone in danger of exposure." (Respondent No. 15, on 09 March2024, Makapeng Village).

A chi-square was performed to determine the association between age, gender, and period of residence with the importance of teaching and spreading awareness about the danger and risk of asbestosis and asbestos dust exposure, wearing a face mask during windy seasons, and avoiding drinking water from Mphogodima, Tongwane, and Olifants. It was discovered that there was a strong relationship $p < 0.001$. Males, those aged 25-34 and lived in the area for 10-15 years, represent the majority with negative attitudes towards activities that exposes communities to asbestos dust. These results align with other studies that interpret males for engaging less with health information or community health initiatives as they prioritise work and other responsibilities over accessing information that improves their knowledge, attitude, perception, and awareness of airborne diseases (Jain et al., 2010; Wilken et al., 2017; Nyakarahuka et al., 2017; Lee, Kim, and Cheong, 2021; Jalaluddin et al., 2023).

Table 4.12: The community attitude towards asbestosis and asbestos dust exposure

Community attitude towards asbestos and asbestosis: In your own opinion, is it important to:	**Important**	**Very important**	**Not sure**	**Very unimportant**	**Unimportant**
teach and spread awareness to people about the danger and risk of asbestos and the exposure	27.2%	52%	10.8%	10%	0%
wear a face mask during windy seasons	10.8%	37.2%	20.8%	13.2%	18%
avoid drinking water from the Mphogodima river and Tongwane	10.4%	31.6%	26.8%	12.8%	18.4%
relocate to other communities nearby, such as Atock, to avoid asbestosis	10.4%	36.8%	27.6	11.6%	16%
wash off your domestic animals before they can enter the house	12%	35.6%	25.2%	11.2%	16%
wear protective gear when going pass asbestos dumping sites	10%	35.6%	28.4%	10.4%	15.2%
avoid hunting wild animals in the mountains to avoid being exposed to asbestos	10.8%	6.8%	20.8%	12%	32.4%
wear your PPE when working under occupational activities that expose people to asbestos?	24.8%	18.8%	5.2%	12%	12.4%

CHAPTER 5: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1. INTRODUCTION

The study investigated the spatial distribution of asbestos and community awareness and perception of asbestosis risk in Ga-Mathabatha, Limpopo province, South Africa. This chapter summarizes the findings on (i) the distribution of asbestos in Ga-Mathabatha, (ii) the trends and patterns of wind speed, and direction on asbestos dust exposure, and their potential influence on asbestos exposure as well as (iii) community awareness and perception of asbestosis risk and further draws the conclusion and make recommendations based on the findings.

5.2. SUMMARY AND INTERPRETATION OF THE RESULTS

5.2.1. Spatial distribution of asbestos in the study area

The findings on the spatial distribution of asbestos in Ga-Mathabatha revealed a high concentration of chrysotile asbestos in the eastern part of the study area, followed by tremolite asbestos dominating the southern part, and actinolite asbestos in the northern parts. Meanwhile, serpentine was less concentrated in the northeast. The field observations carried out in the study area validate that villages located in the eastern part of the community were highly concentrated of chrysotile (white asbestos). Observations conducted in Tongwane , Mphogodima , and Olifants River exposed that asbestos fibers were seen floating on the water's surface, while rocks and soils were found on the riverbeds, along the riverbanks, and in surrounding areas.

5.2.2. Trends and patterns in meteorological variables and their potential influence on asbestos distribution

The monthly average wind roses from 1991 to 2020 indicate that the wind originates from the dual directions of NEN and E during the summer seasons and from all directions during the winter. The forward trajectories further revealed that the wind blowing from Ga-Mathabatha travel across Burgersfort, Mpumalanga, Gauteng, and the Northwest, extending towards the western Indian Ocean. As such, trajectories could potentially

suspend less dense asbestos fibers to the communities nearby, and potentially exposing the residence to the contaminated dust.

5.2.3. Community awareness and perception of asbestosis risks

The demographic and socio-economic profile of the participants indicates that more females participated in this study than males. Most of the respondents had secondary school qualifications and were highly unemployed individuals. The majority of the participants have general knowledge of asbestosis (90%), and asbestos fiber (68%), and know someone in the household diagnosed with the disease (79%). Meanwhile, the majority know the causes of the disease (76%), and its symptoms (33%). However, there is still a concerning number of participants who do not perceive it as deadly incurable, and one of the respondents highlighted that it's like any other disease, such as TB, which can be treated with the correct medication. Respondents engage in small-scale brick manufacturing, harvesting water from the river and collecting firewood, rocks and soils from the local mountain. These activities lead the residents to asbestos dust. Other participants still engage in practices such as eating soil, ignoring the possible exposure through asbestos ingestion. The Chi-square revealed that there was a significant relationship ($p < 0.001$) between community awareness on demographic variables such as age, gender, and level of education. Furthermore, the majority of participants who were knowledgeable about asbestosis and asbestos dust exposure were females older than 60 years, and lived in the area for more than 10 years.

5.3. CONCLUSION

The study assessed the spatial distribution of asbestos and community awareness and perception of asbestosis in Ga-Mathabatha. The spatial distribution analysis confirmed that asbestos contamination is widespread across different parts of Ga-Mathabatha, particularly in rivers and surrounding landscapes. The presence of asbestos fibers in water bodies such as Tongwane, Mphogodima, and Olifants River raises concerns about potential contamination of drinking water and agricultural irrigation, which could have long-term effects on the ecosystem. Additionally, the wind trajectory analysis suggests that asbestos dust could be transported to neighboring regions, extending the

environmental risks beyond the immediate study area. The findings revealed that the community members are at potential risk of asbestos exposure through everyday activities such as harvesting water, collecting firewood, and engaging in small-scale brick manufacturing. The inhalation and ingestion of asbestos fibers have been linked to severe respiratory diseases, including asbestosis, lung cancer, and mesothelioma. While most respondents acknowledged the risks associated with asbestos, misconceptions and negative attitudes persist, particularly among younger males. Meanwhile, the fact that some community members do not perceive asbestosis as a deadly or incurable disease suggests a critical gap in public health awareness.

5.4 RECOMMENDATIONS

The findings of the study provided an insight into the spatial distribution of asbestos, the meteorological factors and their impacts on dust exposure as well as the community's awareness and perception of the risk of asbestosis in the Ga-Mathabatha, Limpopo province. Based on the results, this study makes the following recommendations.

5.4.1. Rehabilitation of asbestos dumping, and loss asbestos rock and soils

The results on the distribution of asbestos and observations made in the community revealed that Ga-Mathabatha is highly contained in asbestos. Therefore, it is recommended that the South African Government through the Department of Mineral and Resources (DMR) and state owned Mintek resuscitate the efforts to rehabilitate closed asbestos mines and shafts.

5.4.2. Public awareness and education

The results on community awareness and perception of asbestos and asbestosis risk revealed that a concerning 45.6% of participants were unaware of the presence of asbestos in the community while 10% did not know what asbestosis is. indicating knowledge gap in awareness. It is therefore recommended that schools, hospitals, and tribal authorities designate specific days for Non-Governmental Organizations (NGOs), professional teachers, trained health care givers/professionals , and environmental

consultants (such as Mintek Consulting) to conduct community wide awareness campaigns and programs on asbestos risks. These awareness campaigns could be implemented through meetings, social media platforms, local radio stations, and posters strategically throughout the community to educate residents about asbestos and asbestosis risk.

5.4.3. Land use spatial planning

The spatial distribution analysis of asbestos in Ga-Mathabatha indicated that asbestos were predominantly concentrated in Maseleseleng, Makapeng, Success, and Madikane. As such, decision-makers including tribal authorities and ward councilors should refrain from allocating new residential or farming land in areas that are highly contaminated with asbestos rocks and soil to minimize the risk for further exposure.

5.5. FURTHER RESEARCH

The use of the Segment Information Dispersal (SID) algorithm for mapping the geographical distribution of asbestosis yielded positive results; however, future studies should consider utilizing advanced Machine Learning Algorithms (MLAs) such as Random Forest (RF) and Support Vector Machine (SVM) to predict the spatial distribution of asbestos in the study area and to further assess the accuracy of such algorithms in mapping this mineral. Meanwhile, the use of Unmanned Aerial Vehicles (UAVs) could offer data at a higher resolution for mineral detection purposes; as such, their application within this context should be considered.

Quantitative analysis has proven useful in describing the communities' perception and awareness; however, future studies could consider building comprehensive exposure, risk, or susceptibility indices. These indices could further be used to map varying degrees of exposure, risks, and/or susceptibility across various communities within the jurisdiction of Ga-Mathabatha for targeted interventions.

The research provided a descriptive analysis of the meteorological factors, specifically wind speed and direstion and further linked them, based on the literature, to their potential

effects on the distribution of asbestos dust. However, future research should aim to empirically validate these relationships by performing statistical significance tests. These tests should examine the association between wind speed and directionand proxies (e.g., dust particulate concentrations, fiber measurements) for asbestos fibers or dust concentrations, thus providing a more robust understanding of their interaction. Finally, a comprehensive study on testing the quality of water from the boreholes, dams, rivers, and harvested rooftop water should be conducted.

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APPENDIX 1: IN-DEPTH INTERVIEW GUIDE

My name is Thobejane Manuel, a master's student from the University of Limpopo, Department of Geography and Environmental Studies. I am conducting an interview on the spatial distribution of asbestos and community awareness and perception of asbestosis in in Ga-Mathabatha, Limpopo Province, South Africa. Your household has been randomly selected and we would like to discuss these issues with the head of the house. Your opinions will help me to get a better idea about asbestosis in Ga-Mathabatha. There are no right or wrong answers. The interview will take about 45 minutes and 50 minutes with an interpreter. Your answers will be confidential. I will not be recording your name, and it will be impossible to pick you out from what you say, so please feel free to tell me what you think. The data we collect from these interviews will always only be used for academic research. You have the right to terminate this interview at any time, and you have the right to refuse to answer any questions you might not want to respond to. However, your response to all the questions will be highly appreciated.

Would you like me to get started with the question?

Yes

No

Tick as appropriate.

SECTION A: DEMOGRAPHIC CHARACTERISTICS

1. What is your gender?

a. Male		b. Female	

2. Which age category do you fall under?

a. 15-24		d. 45-54	
b. 25-34		e. 55-64	
c. 35-44		f. 65+	

3. What is your present marital status?

a. Married or living together as husband and wife		c. Divorced or separated	
b. Widow/widower		d. Never married	

4. What is your highest level of education? *Include distance and correspondence education*

a. Primary school		d. University	
b. Secondary school		e. Adult basic education and training/literacy classes	
c Technikon College		f. Never went to school	
5. What is your work status			
a. Self-employment		d. Unemployed	
b. Part-time employment		e. Retired	
c. Full-time employment			
6. What is your main occupation? (*Write in full*) ----------			
7. How long (in years) have you been staying in Ga-Mathabatha? years			
8. Have you worked in asbestos mine before?			
a. Yes		b. No	
9. How long (in years) have you worked in the mine? Years			
10. Absolute location of the household with households' coordinates:			
10. Do you know that there is asbestos dust and asbestosis diseases in your area?			
a. Yes		b. No	
11. Do you know anyone in your household or relatives who was diagnosed with asbestos?			
a. Yes		b. No	
12. How far in km is your house located in relation to asbestos mine, asbestos dump sites, abundant asbestos house structures?			
13. What do you think about asbestos dust from mine in the community?			
14. What made you aware that there is asbestos dust and asbestosis in the community?			
15. What are the things that kids do/practice that might put them at high risk of the asbestos dust			
16. What do you know about the asbestos mines in the community?			
17. What is your opinion about the asbestos waste dump in Ga-Mathabatha?			
18. How do you think people get exposed to asbestos dust?			

19. Which activities do you think puts people at high risk of asbestos dust exposure?

20. What practices/activities do you think people do that exposes them to asbestosis?
21. Windy seasons set to expose people to asbestos dust, what is your opinion on that statement?
22. Asbestosis is a deadly disease, what do you think can cure it and why?
23. How do you think rainfall affect the asbestos dust exposure?
24. What do you do when you are exposed to asbestos dust?
25. Do you or anyone in the household sweep the yard with a broomstick?
26. What symptoms do you know that people with asbestosis have?
27. Which household chores does it expose people to asbestos?
28. How does livestock farming and crop farming impact asbestos dust exposure?
29. What do you do when you see kids playing in asbestos dump sites?
30. What do you know about asbestos?
31. What are the symptoms that people with asbestosis have?
32. Which seasons are most likely to spread asbestos dust and why?
33. What is your opinion on people who wear facemasks, and why?
34. What is your opinion on people that reside approximately near an asbestos mine/ dump site in relation to their exposure and contracting asbestosis?
35. What is your opinion on people that eat soil in Ga-Mathabatha?
35. What is climate change
36. Explain how rainfall affect the asbestos dust exposure
37. In your opinion, how do wind speed and direction affect asbestos dust exposure from the asbestos mine to the community?
38. What are the practices that you do that exposes you to asbestosis and asbestos dust exposure?
40. Animals that pasture on the mountain can also expose themselves and people to asbestos and asbestosis, how do you think they do exposes themselves and other people?

APPENDIX 2: HOUSEHOLD SURVEY QUESTIONNAIRE

I am Manuel Teleki Thobejane, a master's student from the University of Limpopo, Department of Geography and Environmental Studies. I am currently conducting a study on the spatial distribution of asbestos and community awareness and perception on asbestosis risk in Ga-Mathabatha. I have randomly selected your home, and we aim to discuss these issues with you as the family head. Your insights will enhance my understanding of asbestosis, a respiratory lung disease, in Ga-Mathabatha. There are no correct or incorrect responses. The questionnaire will take you around 30 minutes to complete. Your responses will remain secret. I will not record any personal information, including your name or income, making it difficult to identify you based on your statements. Therefore, please feel free to participate candidly. We will exclusively use the data from this interview for academic research purposes. You possess the right to cancel or withdraw from participation at any time, and you have the right to decline to answer any questions you do not want to address. Your responses to any inquiries would be much appreciated.

Would you like me to get started with the question?

Yes

No

Tick as appropriate.

SECTION A: DEMOGRAPHIC CHARACTERISTICS			
1. What is your gender?			
a. Male		b. Female	
2. Which age category do you fall under?			
a. 18-24		d. 45-54	
b. 25-34		e. 55-64	
c. 35-44		f. 65+	
3. What is your present marital status?			
a. Married or living together as husband and wife		c. Divorced or separated	

b. Widow/widower		d. Never married	
4. What is your highest level of education? *Include distance and correspondence education*			
a. Primary school		d. University	
b. Secondary school		e. Adult basic education and training/literacy classes	
c Technicon college		f. Never went to school	
5. What is your work status			
a. Self-employment		d. Unemployed	
b. Part-time employment		e. Retired	
c. Full-time employment			
6. What is your main occupation? (*Write in full*) ----------			
7. How long (in years) have you been staying in Ga-Mathabatha? - years			
8. Have you or do you know anyone in the household who was diagnosed with asbestosis?			
a. Yes		b. No	
9. Source of water for drinking and irrigation			
a. Bought water		d. River	
b. Borehole			
c. Piped water from a communal tap			
10. Source of water for domestic animals			
a. Bought water		d. River	
b. Borehole			
c. Piped water from a communal tap			

SECTION B: COMMUNITY KNOWLEDGE ON ASBESTOSIS, AND ASBESTOS DUST EXPOSURE			
11. Do you know what asbestosis (Marela) is?			
a. Yes		b. No	
15. Do you know that asbestosis is deadly and incurable?			
a. Yes		b. No	
13. Do you know what asbestos fibers are?			

a. Yes		b. No	
14. Are asbestos fibers wool-like structures that are found when you break down asbestos rock?			
a. Yes		b. No	
15. Do you know anyone in the household or relative who was diagnosed with asbestosis?			
a. Yes		b. No	
16. Which of the following are the symptoms of asbestosis			
Coughing out blood, chest pain, shortness of breath, urinating blood		e. Shortness of breath, persistent cough, chest pain, swollen fingertips	
Short memory, short eyesight, stomach pain			
Fatigue, dry cough, eye blockage, nose blockage			
Nightmares, depression, loss of appetite			

17. What level of agreement do you know the following can cause high asbestosis risk and asbestos dust exposure?

	Strongly agree	**Agree**	**unsure**	**Strongly disagree**	**disagree**
Inhalation of contaminated air blowing from Makapeng, Ga-GG, Success, and Mphanama					

Using contaminated water from Tongwane River and Mphogodima for bathing, and doing chores					
Residing in areas concentrated of asbestos such as Success, Makapeng, Mashikane villages					
Smoking cigarettes					
18. Name the villages of Ga-Mathabatha with the most asbestos concentration? _____					

19. The following are examples of meteorological variables that put people at high risk of asbestos exposure			
High rainfall			
Strong wind			
Drought			
None of the above			
SECTION C: COMMUNITY'S AWARENESS ON ASBESTOS AND ASBESTOSIS RISK			
20. Makapeng village, Success, Maseleseleng, including Tongwane river, and Mphogodima are highly concentrated of asbestos rocks and are areas of high risk to asbestosis and asbestos dust exposure.			
a. Yes	b. No		
21. People and animals that pass, collect, or drink water from Tongwane, Mphogodima, are at high risk of being exposed to asbestos dust?			
a. Yes		b. No	
22. The asbestos dust that exposes the community to asbestos is coming from post asbestos shafts, in the area?			
a. Yes		b. No	
23. Are you aware that rainfall and wind play an important role in asbestos transportation?			
a. Yes		b. No	
SECTION D: COMMUNITY PRACTICES THAT EXPOSE THEM TO ASBESTOSIS AND ASBESTOS DUST EXPOSURE?			

24. Domestic practices that expose people to asbestos: How often, do you undertake the following practices:					
	Always	**Sometimes**	**ofter**	**Rarely**	**Never**
Wash clothes, car, mop, clean using water from Mphogodima or Tongwane river					
Drink water from the Mphogodima and Tongwane river					
Use a face mask when cleaning the house and yard					

Practice subsistence farming at home					
Clean your dog or cat at home					
Slaughter cows and goats at home					
Do you eat soil					
Buy rocks, soil, concrete, sand, and bricks from local shops					
Close your windows during the windy season					
Harvest roof water into jojo tanks to drink					
25. Outdoor activities that expose communities to asbestos dust: How often are you involved in the following outdoor activities?					
	Always	**Sometimes**	**ofter**	**Rarely**	**Never**
Small-scale brick manufacturer in the community					
Collect water at Tongwane river for other reasons					
Do you pass by gravel near asbestos dumping at success, Makgoba, Maseleseleng villages					

Allow domestic animals to drink water at Bollatswene, Tongwane, and Mphogodima river or pasture near the mountain					
Practice hunting at Kholla, Lekgotse, Lebeting local mountains					
Collect firewood, rocks, or soil near local mountain					
Participated in asbestos rehabilitation construction program in the community					

SECTION E: COMMUNITY PRACTICES THAT EXPOSE THEM TO ASBESTOSIS AND ASBESTOS DUST EXPOSURE?					
26. Community perception on asbestosis					
In your own opinion, do you perceive:	**Strongly agree**	**Agree**	**unsure**	**Disagree**	**Strongly disagree**
Asbestosis as a deadly incurable disease					
Areas like Makapeng, Success and Maseleseleng as high areas of asbestos dust exposure					
Do you perceive contractors that helped in closing open shafts of asbestos helpful and reducing the exposure					
Planting vegetation on top of asbestos dumping effective in reducing the exposure					
drinking water from Mphogodima and Tongwane as the main source of asbestosis					

Consulting professional doctor as helpful when experiencing asbestos symptoms					
SECTION F: COMMUNITY PERCEPTION ON ASBESTOSIS AND ASBESTOS DUST EXPOSURE					
In your own opinion, do you perceive the following activities as major asbestos dust exposure:	**Strongly agree**	**Agree**	**unsure**	**Disagree**	**Strongly disagree**
Cleaning your house and swiping the yard without wearing face mask					
Passing near asbestos dumping with or without herds					
Consuming rocks (geophagia)					

Collecting river sand, rocks and stones from local mountains and rivers for building and renovations.					
Storing asbestos rocks and sand at home for historical purposes					
Doing chores, washing clothes, cars, and other items using water from Mphogodima					
SECTION E: COMMUNITY ATTITUDE TOWARDS ASBESTOSIS AND ASBESTOS DUST EXPOSURE					
	Important	**Very importance**	**Not sure**	**Very unimportant**	**Unimportant**
It is important to teach and spread awareness to people about the danger and risk of asbestos and the exposure					
It is important to wear face mask during windy seasons					

It is important to avoid drinking water from Mphogodima river and Tongwane					
It is important to relocate to other communities near such as Atock to avoid asbestosis					
It is important to wash off your domestic animals before they can enter the house					
To wear protective gear when going to pass asbestos dumping sites					
To avoid hunting wild animals in the mountains to avoid being exposed to asbestos					
Is it important to wear your PPE when working under					
Occupational activities that exposes people to asbestos					

APPENDIX 3: FIELD OBSERVATIONS

Appendix 3.1: Photographic evidence of observations made in Success village (24°12.1102'S, 29°53.6756'E)

Appendix 3.2. Photographic evidence of observations made Tongwane river in Success village (24°11.5064'S 29°53.9783'E)

Appendix 3.3: Photographic evidence of observations conducted in Mphogodima River and Maseleseleng (24°11.5064'S, 9°53.9783'E)

Appendix 3.4: Photographic evidence of observations conducted in Makapeng village (24°13.0793'S, 29°49.1999' E)

Appendix 3.5: Photographic evidence of observations conducted in Masioneng village (24° 12.7455'S, 29° 52.7524'E)

Appendix 3.6: Photographic evidence of observations made in village (24°12.2691'S, 29°52.3682'E)

Appendix 3.7: Photographic evidence of observations made in Olifant Rivers of Ga-Mathabatha observations (24°13'24.86388''S, 29° 52'58.18188''E)

APPENDIX 4: CONSENT FORM

Declaration by participant

By ticking this box below, I [ ] agree to take part in the research study titled: Assessing the distribution of asbestos and the community awareness and perception on asbestosis in Ga-Mathabatha, Limpopo Province, South Africa.

I declare that:

- I have read and understood this information, and it was also explained to me in a language that I understand by a trusted person.
- The researcher explained the research study to me.
- I have asked questions from the researcher, and all my questions have been answered.
- I understand that taking part in this study is voluntary, and I have not been pressured or bribed to take part.
- At any given time, I have the right to stop and leave and will not face any consequences or negative remarks for doing so.
- I have a right to ask for interpretation where I don't understand.

Signed at (place)..... On date 20….

Participants tick [ ] Witness tick [ ]

Declaration by researcher

- I will clearly and in detail explain the information in this document.
- I will use an interpreter where needed.
- I will encourage the participant/respondent to ask questions and take their time to answer the questions.
- I will give the respondent/ participant time to discuss it with others if they wish to do so.

Signed at (place)..... on (date).....

Signature……

APPENDIX 5: REQUEST LETTER TO CONDUCT THE STUDY IN Ga-MATHABATHA

University of Limpopo
P.O. Box X1106
Sovenga

0727

18th April 2023

Municipal Manager
Lepelle Nkumpi Local Municipality
P.O. Box 6352
Jane Furse 1085

Request for permission to conduct research in Lepelle Nkumpi Local Municipality

My name is Thobejane Manuel. I am a registered Masters' student in the Department of Geography and Environmental Studies at the University of Limpopo, under the supervision of Ms. MC Mothapo, Prof. H Chikoore, and Dr. F Sengani. I am hereby seeking your consent to conduct research titled 'Assessing the distribution of asbestos and the community awareness and perception on asbestosis risk inGa- Mathabatha, Limpopo province, South Africa'. The study will require the use of 250 questionnaires to conduct the survey and interviews to have background knowledge about asbestosis.
The objectives of this study are as follows:

- To assess the spatial distribution of asbestos Ga-Mathabatha community
- To analyze the patterns and trends in wind speed and direction, and describe their potential influence on asbestos exposure in Ga-Mathabatha.
- To evaluate Ga-Mathabatha community's awareness and perception on asbestosis risk

This study will contribute to the scientific knowledge of literature and serve as a guideline for interested and affected parties. This study will also serve as awareness of asbestosis in the community.

For any further information, please contact me or my supervisors on the following email; manuelthobejane@gmail.com, clodean.mothapo@ul.ac.za, hector.chikoore@ul.ac.za and fhatuwani.sengani@ul.ac.za

Yours sincerely

Manuel Teleki Thobejane

APPEDNIX 6: ETHICAL CLEARANCE CERTIFICATE

University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 3935, Fax: (015) 268 2306, Email: tukiso.sewapa@ul.ac.za

TURFLOOP RESEARCH ETHICS COMMITTEE

ETHICS CLEARANCE CERTIFICATE

MEETING: 04 December 2023

PROJECT NUMBER: TREC/1677/2023: PG

PROJECT:

Title:	Assessing The Spatial Distribution of Asbestos and the Community's Awareness and Perception on Asbestosis Risk: A Case Study of Ga-Mathabatha, Limpopo Province, South Africa
Researcher:	MT Thobejane
Supervisor:	Ms MC Mothapo
Co-Supervisor/s:	Prof H Chikoore
	Dr F Sengani
School:	Agriculture and Environmental Sciences
Degree:	Master of Science in Geography

PROF D MAPOSA
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: REC-0310111-031

Note:

i) This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioned date. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.

ii) Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application for Amendment form.

iii) PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

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