# Tuberculosis in coal mine workers in Mpumalanga

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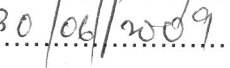
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30 June 2009

# DECLARATION

This Master of Medical Science dissertation is my own work and all primary and secondary sources have been appropriately acknowledged. The dissertation has not been submitted to any other institution as part of an academic qualification.

This dissertation has been prepared in partial fulfilment of the requirement of the Master of Medical Science degree at the Department of Occupational and Environmental Health, Nelson R. Mandela School of Medicine, University of KwaZulu-Natal, Durban South Africa.

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# ABSTRACT

## Introduction

Pulmonary tuberculosis (TB) is a disease which is both curable and preventable, with recognised complications such loss of lung function and progressive massive fibrosis (PMF). It is a major cause of pulmonary disability and mortality in the South Africa mining industry. Tuberculosis has a high social and economic cost, both for the individual concerned and for the industry as a whole. However, notwithstanding the extensive literature on TB in the mining industry, given the size and economic importance of coal mining in South Africa, there is surprisingly scanty information available on TB and other occupational lung diseases in coal mines.

A strong correlation was reported in Canada, the USA and China between coal usage and TB. This highlights the possibility of the direct impact of coal usage on TB. Although black miners have historically done jobs with the highest exposure in the coal mining industry, there have been remarkably few studies reporting the prevalence of TB and the exposure response relationship in black coal miners in South Africa.

Dust exposure in coal mines is a risk factor for occupational lung diseases such as coal workers' pneumoconiosis (CWP), chronic obstructive airways disease (COAD) and lung function deficiency. However, there are still doubts and debates about the risk in such work of tuberculosis. The aim of this study was to fill the gap in the literature by determining the prevalence and exposure response relationship of TB to coal dust exposure.

## Objective

To determine, within a sample of coal miners:
- Prevalence of tuberculosis (TB)
- Prevalence of coal workers' pneumoconiosis and past TB
- Association of outcome variables with exposure variables and underground coalmine workers' exposure as compared to that of surface workers
- Association of TB with coal workers' pneumoconiosis and past TB
- Exposure response relationship of TB, coal workers' pneumoconiosis and past TB to respirable coal dust.

## Method

A cross-sectional study of 344 employed black male coal miners at a coal mining complex with fourteen mine shafts at Secunda in Mpumalanga, was done. The records from 1 January 2000 to 31 December 2005 were reviewed.

The main outcome measure was the prevalence of current TB in coal miners. The sample consisted of 220 underground and 124 surface coal miners. The exposure variables considered were lifetime mean exposure level (LMEL) (mg/m$^3$), cumulative dust exposure (CDE) in mg-years/m$^3$, and coal mining years. Information was collected from multiple sources including hospital files, surveillance records and medical records, and cross-validated with the information from the human resources department.

Information was collected on the demographic profile, exposure, underground or surface work, area of work, smoking history, HIV status from medical records, dust exposure intensity, length of service, TB diagnosis and the methods of diagnosis and outcome of the treatment, and previous TB and CWP. Participants with current TB were either sputum culture positive or sputum culture negative TB.

**Results**

The mean age of the sample was 45.2 years, (range 28–64 years; SD = 8.2).The mean duration of service was 16.1 years (range 4.1–27.7 years; SD 5.9). There were 34 (9.9%) cases of current TB in total, of which 31 were underground coal miners and three were surface coal miners.

The prevalence of current TB reported by this study was 9.9%, with a mean age of 46.7 years and length of service of 16.2 years. The prevalence of current TB among the underground and surface workers was 14.1% and 2.4% respectively. The prevalence of CWP was 3.8%, with a mean age of 51.3 years and a mean length of service of 20.1 years. The prevalence of past TB was also 3.8%, with a mean age and length of service of 44.9 and 16.1 years respectively.

Underground coal mines workers' exposure to coal dust was high, with a lifetime mean exposure level (LMEL) and cumulative dust exposure (CDE) of 2.4 mg/m$^3$ and 33.4 mg–years/m$^3$ respectively. The difference in LMEL and CDE among underground vs. surface workers was significant, with underground exposure being higher than surface exposure, namely $p<0.001$ and $p<0.001$ respectively. The difference in length of service between underground and surface participants was not significant.

The difference in exposure to coal dust (LMEL and CDE) among participants with current and previous TB, compared to those without current and previous TB, was statistically significant, $p<0.008$ and $p<0.04$. The difference between the coal dust exposure indices (LMEL, CDE exposure duration) for participants with and without CWP was significant.

However, the difference between participants with current TB and previous TB compared to those with non-current TB and without previous TB in age and length of service years was not significant. This also applied to HIV status and smoking: the difference between participants with and without current TB was not significant.

There was a strong significant association of underground mine work with current TB, with a prevalence odds ratio (POR) of 6.62 (p<0.001).This showed that the association of exposure to coal dust with current TB was strong and significant as underground mine workers were exposed to higher coal dust concentrations than surface workers. Workers with current TB were more likely to have co-existing CWP, with a POR of 1.7 (95% CI: 0.4–7.1).

The exposure-response relationship of LMEL and CDE in participants with current TB and CWP was significant. A significant trend was observed of increasing of LMEL and CDE with an increase in the prevalence of current TB, CWP and past TB.

## Conclusions

There was a possible dose response relationship between coal dust exposure and the risk of development of pulmonary TB. The study showed that coal dust exposure was associated with pulmonary TB, and a dose response relationship with the trend of increasing coal dust exposure. It has been shown that there is a more significant and stronger association of underground coal mine work with current TB than there is in surface work.

This study has shown a significant exposure response relationship in the exposure indices (CDE and LMEL), age and length of service for CWP. This study found a high prevalence of pulmonary TB of 9.9% in black migrant coal mine workers who historically held jobs in the dustiest areas in the mining industry. The limitations of the study include the use of cumulative exposure calculated from current exposure, and the secondary healthy worker effect or survivor workforce. Dust control and HIV/AIDS programmes should be an integral part of a TB and occupational lung disease control strategy in the mining industry.

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# GLOSSARY OF TERMS

(a) *Lifetime mean exposure level.* This is the sum of the individual exposures divided by the duration of time spent in that exposure zone, reflecting different exposures over time periods in different jobs, with units mg/m$^3$

(b) *Cumulative dust exposure.* This is an estimate of the total amount of dust to which a worker has been exposed for the duration of employment on the coal mines. It was calculated by multiplying average intensity of coal dust by length of coal mining in a particular section/job description and then adding the products of that individual worker's exposure in all different sections/job descriptions (mg-years/m$^3$).

(c) *Coal workers' pneumoconiosis:* Parenchymal lung disease due to the inhalation of coal dust. The coal macule is the primary lesion formed when the inhaled dust burden exceeds the amount that can be removed by alveolar macrophages and mucociliary clearance.

(d) *Surveillance.* This is the ongoing, systematic collection, analysis and interpretation of outcome-specific data, closely integrated with the timely dissemination of these data to those responsible for preventing and controlling disease or injury.

(e) *Prevalence.* This is the proportion of people with the condition at the time of the survey. It is dependant on the group studied.

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACGIH | American Conference of Governmental Industrial Hygienists |
| AFB | acid-fast bacilli |
| BMRC | British Medical Research Council |
| CDE | cumulative dust exposure |
| CI | confidence interval |
| COIDA | Compensation for Occupational Injuries and Diseases Act (SA) |
| COAD | chronic obstructive airways disease |
| CWP | coal workers' pneumoconiosis |
| DME | Department of Minerals and Energy (SA) (now two separate departments) |
| ILO | International Labour Organisation |
| LMEL | lifetime mean exposure level |
| MBOD | Medical Bureau for Occupational Diseases (SA) |
| mg/m$^3$ | milligrams per cubic metre. |
| mg-years/m$^3$ | milligram-years per cubic metre. |
| MHSA | Mine Health and Safety Act (SA) |
| NCOH | National Centre for Occupational Health (SA) |
| NIOSH | National Institute of Occupational Safety and Health (USA) |
| NTBCP | National TB Control Programme |
| ODMWA | Occupational Diseases in Mines and Works Act (SA) |
| OEL | occupational exposure limit |
| OHSA | Occupational Health and Safety Act (SA) |
| PEL | permissible exposure limits |
| PMF | progressive massive fibrosis |
| POR | prevalence odds ratio |
| SAMODD | South African Mining Occupational Diseases Database |
| SD | standard deviation |
| SIMRAC | Safety in Mines Research Advisory Committee (SA) |
| TB | tuberculosis |
| TWA | time-weighted average |
| U/G | underground |
| WHO | World Health Organization |

# CHAPTER 1    LITERATURE REVIEW, AIMS AND OBJECTIVES

## 1.1    Tuberculosis in Mining

TB is a major public health problem in the southern African region, particularly in the mining industry [1]. It is a major cause of pulmonary disability and death, and can seriously diminish an individual's work capacity and their health in the long and short term [1, 2]. It is a major and significant occupational disease in the South African mining industry due to the high silica and dust levels. The mining industry is characterised by high incidence rates and a high prevalence of TB [1, 2].

There has been contention about the transmission of TB among underground miners in this country since the early decades of the previous century [3]. The first Director of the South African Medical Research Institute and the Miners Phthisis Bureau examined the sputum of over 300 miners after completion of their shift to establish the presence of mycobacterial TB organisms in the underground environment. Over 15% showed the presence of acid-fast bacilli (AFB) on microscopy, compared to the prevalence of 2.5% AFB in the sputum of surface workers [4]. The bacilli were shown to be present in the underground environment in this study.

TB rates in the South Africa mining industry are among the highest in the world [5]. It is the most common occupational respiratory disease in the South African mining industry [1, 2, 6]. The Chamber of Mines in 1995 reported an increase in the annual incidence of TB in the gold mining industry from 686 per 100 000 in 1989 to 1 887 per 100 000 in 1995 [7]. The mining industry certified 5 647 miners living with TB in 1999/2000 [2, 6]. The estimated incidence of TB in the South African mining industry was around 3 000 per 100 000 of the population [2].

The reported rates above confirmed that the TB epidemic in the mining industry is on the increase despite the strategies implemented. The re-certification of new and upgraded cases of pneumoconiosis with or without TB amounted to 5 603 and over 5 000 new cases of tuberculosis (>20/1 000) in 1998 [2, 8]. Another study found that the number of cases of TB per 1 000 autopsies had increased from 51 in 1991 to 161 in 2000 [9]. Occupational respiratory diseases are the most prevalent occupational diseases clustered in the mining sector [2, 10].

TB acquired during occupational exposure to silica dust and health care workers exposed to patients with open pulmonary TB is a compensable disease under the COIDA. Miners who worked 200 shifts or more of risk work, and who develop TB within one year of performing such work are reported to the Medical Bureau for Occupational Diseases (MBOD) under ODMWA. The Department of Minerals and Energy in 2002 reported 596 cases of silicosis grade 1; 262 cases of silicosis grade 2; and 1 215 cases of TB [10].

## 1.2    Epidemiology of TB

TB is the most prevalent and deadly infectious disease on earth [15]. In 1993, the World Health Organization (WHO) declared TB a global emergency and still the leading cause of death in developing countries [16]. TB is a major public health problem in the southern African region [1, 17, 18, 19]. In 2002, only six countries in the world were estimated to have had more cases of TB than South Africa, and of these five were Asian countries and one a North African country [17-21].

South Africa has an estimated incidence of TB of 536 per 100 000, a prevalence of 458 per 100 000 population and a case fatality rate of 73 per 100 000 population [17-20]. The projection in South Africa suggests that the rising HIV epidemic will result in about 3.5 million new cases of TB by 2007 and a staggering 90 000 deaths from TB [20, 21, 22].

Globally, 8.4 million people are estimated to develop TB each year, and nearly two million deaths result from the disease [21, 22, 23, 24]. The magnitude of the epidemic is staggering. One third of the world, roughly 1.9 billion people, is infected with TB [21, 24, 25]. It causes 25% of adult deaths in the developing world, and 80% of deaths in these areas occurs in adults aged 15 to 55, the most productive members of society [21, 24, 25].

## 1.3    The South African National TB Control Programme (NTBCP)

The TB control programme at mines follows the South African National TB Control Programme (NTBCP) with modifications as recommended by the Mining Occupational Health Advisory Committee [1, 26]. The guidelines and recommendations are based on the TB control principles proposed by WHO: diagnosis of TB by smear positivity, direct observation of the patient when being treated by the short-course therapy, continuous supply of drugs, and a systematic reporting of TB patients [26, 27]. South Africa has progressive Acts that govern health safety at the workplace.

South Africa has progressive legislation, namely the Mine Health and Safety Act (MHSA), the Occupational Diseases in Mines and Works Act (ODMWA, No. 208, 1993), Compensation for Occupational Injuries and Diseases Act (COIDA, No.130 of 1993) and the Occupational Health and Safety Act (OHSA) [11, 12, 13, 14]. The Mine Health and Safety Act (MHSA) and the Occupational Health and Safety Act (OHSA) require employers and employees to take responsibility for ensuring a safe and healthy environment at the workplace [2, 11, 14].

Section 13(1) of the MHSA requires an employer to establish and maintain a system of medical surveillance of employees exposed to hazards if required to do so by regulation or a notice in the Government Gazette or after having done risk assessment in terms of section 11. The system includes the TB control programme [1, 2, 11, 26]. However, there is a problem of a poor and compromised reporting system and of poor enforcement due to lack of human resources.

## 1.4    TB with Silica and Silicosis

Numerous studies in gold mines have reported significant relationships between silicosis and silica exposures with TB [28, 29, 30, 31, 32, 33]. The risk of pulmonary TB increases in miners with silicosis, and the risk of pulmonary TB suggests a dose response relationship with cumulative silica dust exposure in the absence of silicosis [28–32].

A South African cohort study found that the annual incidence of TB was 981 per 100 000 population in 335 men without silicosis, and 2 707 per 100 000 population among men with silicosis. The relative risk of TB was 2.8 (95% CI, 1.9–4.1) for men with silicosis compared to men without silicosis [28].

Epidemiological studies have shown that workers exposed to silica dust have increased morbidity and mortality from pulmonary TB [28, 29]. Dr Watkins-Pritchard informed the 1920 De Villiers Commission that out of 200 cases of simple TB, 40% were found on post mortem to be silicotic [34]. Cowie and Watkins-Pritchard believed that the inhalation of even a few particles of silica dust could predispose the individual to TB [35].

The presence of silica and the high incidence of HIV/AIDS demonstrated the multiplicative effect on the incidence of TB [2, 36]. Silicosis and silica exposure and coal mining operations are not mutually exclusive. Silica exposure in coal miners elevates the risk of silicosis and mixed pneumoconiosis and TB [37]. The Department of Mineral and Energy dust data for 2005 show quartz levels exceeding 30% of the occupational exposure limit (OEL) of 0.1

mg/m$^3$ for quartz in coal mines at Bethal, Delmas, Ermelo, Middleburg, Sasolburg, Standerton, Wakkerstroom and Witbank [38].

Numerous South African studies reported a high prevalence of occupational lung diseases in ex–miners. A prevalence study of Botswana men formerly employed in the South African mining industry found that 26.6% had a history of TB with an overall prevalence of pneumoconiosis (>1/0 profusion, by International Labour Organisation (ILO) classification) ranging from 26.6% to 31.0%, and 6.8% progressive massive fibrosis (PMF) [39]. In a study of ex-miners in the Eastern Cape region, radiographic evidence of TB ranged from 33% to 47% [40].

The prevalence of TB with and without silicosis was evident in 64.2% of participants, while silicosis with or without TB was 34% [41]. Although most of these ex-miners had previously worked on gold mines, this high prevalence of the disease suggests that a substantial risk exists among ex-miners. The extent to which this affects ex-coal miners is not as clear.

## 1.5    TB and the Prevalence of Occupational Lung Disease in Coal Mining

Several studies have reported on the prevalence of occupational lung disease in the coal mining industry. In a South African study, the prevalence of silicosis, TB and coal workers' pneumoconiosis (CWP) and moderate to severe (marked) emphysema at autopsy were 10.7%, 5.2%, 7.3,% and 6.4% respectively [42]. All these diseases except TB were associated with duration of exposure.

An unpublished South African study reported that past or present TB was more prevalent in workers with CWP than those without CWP. This contradicted the findings of a US study which concluded that "the prevalence of TB did not increase in coal miners who do not have pneumoconiosis, nor did it appear that the presence of pneumoconiosis in coal mine workers increased the risk of infection by mycobacterium, as is the case with silicosis" [43].

Two Spanish coal miner TB studies have been reported, but with large differences in rates of TB. The first cohort study among 53 753 coal miners undertaken by the Instituto Nacional de Silicosis (INS) in Asturias [44] reported an average incidence of TB of 150 per 100 000 person-years among coal miners in Asturias which was three times the TB incidence of the local area.

In a second cohort of 2 579 coal miners followed up over 20 years, there was a reported TB incidence of 8.3 per 100 000 person-years (range 2.3–21.2). This was lower than the overall

Spanish incidence of TB, which was between 12.9 to 34 per 100 000 person-years [45]. The differences in these studies in the same Spanish area were mainly due to methodical factors, healthy worker survivor and probably loss of follow-up.

## 1.6 Role of Smoking and HIV in TB rates

Smoking is an independent risk factor of TB. Several studies reported a dose response relationship between TB and smoking [30, 42, 46, 47]. An Indian case control study reported an annual incidence of TB of 1 841, 2 294 and 4 181 per 100 000 for never-, ex- and current smokers respectively [46].

HIV infection has been identified as the highest biological risk factor for developing TB, exacerbated by the collapse of the TB control programme in our health system [2, 36, 48, 49, 50]. A South African study of HIV and the prevalence of undiagnosed TB in African gold miners reported that the TB incidence was much more strongly associated with HIV (incidence ratio of 5.5, 95% CI (3.5–8.6)) than the point prevalence of undiagnosed TB (odds ratio 1.7, 95 % (0.9–3.3)) [49].

Another South African study of gold miners reported that the prevalence of TB did not differ significantly (3.3% vs. 2.2%) between HIV-infected and HIV-uninfected miners. – the unadjusted ratio was 1.5 95% CI (0.9–2.8) [50]. The estimated HIV/AIDS rate among South African miners reported in 2005 by the Chamber of Mines ranged between 20% and 30% [51].

## 1.7 Coal Dust Exposure Review

The Leon Commission of Enquiry into Safety and Health in Mining Industry in the Republic of South Africa in 1995 concluded that there was no evidence of any reduction in dust exposure over the previous forty years in the mining industry [52]. The coal dust levels in South Africa were reported to be high until late 1990s.

Epidemiological studies have demonstrated that miners have an elevated risk of developing CWP, PMF or deficits in lung function when they are exposed to respirable coal dust over a lifetime at a permissible limit of 2 mg/m$^3$. The American Conference of Governmental Industrial Hygienists (ACGIH) recommended that miners' exposure to bituminous coal dust or lignite coal dust should not exceed a TLV-TWA of 0.9 mg/m$^3$, and a TLV-TWA of 0.4 mg/m$^3$ for miners exposed to anthracite coal dust [53].

A report commissioned by a government agency in the Department of Minerals and Energy (DME) indicated that in 1996, according to the DME database, from a sample of 20 179 coal miners, approximately 25% were exposed to respirable dust levels greater or equal to 2.5 mg/m$^3$ [54]. The silica content of South African coal is an important factor in understanding the relationship of coal dust exposure and health outcomes. The South African mining industry reports that Mpumalanga, Gauteng and Free State coal mines have a lower quartz content of about 2%, whereas those of KwaZulu-Natal contain an estimated 3% of quartz [2].

The difference in the prevalence of occupational lung diseases in studies done has been attributed to coal grade and silica [2, 55]. This has been suggested as the reason for the low levels of diseases in South African coal miners as the silica content of South Africa mines averages less than 5%. Silica exposure is associated with silicosis and pulmonary TB [28–33]. Coal miners exposed to respirable crystalline silica are at risk of developing silicosis or mixed-dust pneumoconiosis [25, 26, 27, 28]. Numerous studies have reported high silica exposure in coal mining [2, 43, 44, 56, 57], ranging from 2% among South African miners [2] to 17.5% among Spanish colal mine workers [44, 45].

## 1.8    Summary of the Review

South Africa is burdened with a high incidence and prevalence of TB. It is one the top eight countries in the world in terms of the incidence and prevalence of TB and HIV/AIDS [17-21]. The mining industry, especially gold mining, has the highest rates of TB in the world at 3 000 per 100 000 [2, 51]. These findings have not been replicated in South African coal mines.

The low silica content has been suggested as the reason for the low prevalence of TB in South African coal miners. The silica content of South Africa mines averages less than 5% [2, 36, 52, 53]. Numerous studies have reported high silica exposure in coal mining, ranging from 2% among South African miners [2] to 17.5% among Spanish coal workers [44, 45]. DME dust data for 2005 show quartz levels exceeding 30% of the OEL of 0.1 mg/m$^3$ in some Mpumalanga coal mines.

The association and relationship of coal dust exposure with respiratory outcomes is well documented in several studies internationally [54] and in South Africa [69]. However, there are still debates about the association of coal dust with pulmonary TB. Numerous studies have not directly linked TB with coal dust exposure, where the coal dust lacks any quartz content. There are historical statistics that support the hypothesis linking TB and coal usage.

A strong correlation has been shown in Canada, the USA and China between coal usage and TB [58].

## 1.9    Study Rationale

There is extensive, well-documented literature on TB in South Africa, but this applies predominantly to the gold mining industry [25, 26, 27, 28, 29]. There have been few studies that have reported on the prevalence of TB in the South Africa coal mining industry (2). A strong correlation was reported in Canada, the USA and China between coal usage and TB [58]), and a Spanish coal mine study [38] reported a high incidence of TB of 150 per 100 000 person-years, which was three times the incidence of TB in the local community.

Coal dust exposure is a risk factor for occupational lung diseases such as CWP, COAD and lung function deficiency [36]. However, there are still doubts and debates about the risk in such work for TB. Given the high prevalence of the disease in South Africa, together with the prevalence of HIV, which is a known risk factor for TB [2], and the review of the international literature, which suggests that there may be an increased risk of TB among coal dust-exposed workers, the author of this dissertation believes that it is important to study TB among South African coal miners and to attempt to describe dust-related associations. The aim was therefore to determine the prevalence of TB and the exposure response relationships to coal dust exposure.

## 1.10    Aim and Objectives

### 1.10.1    Study aim
The aim of this study was to describe the prevalence of TB, and exposure-disease relationships between coal dust exposure and TB among a sample of South African coal miners from a single mine.

### 1.10.2    Study objectives
To determine, within a sample of coal miners:
- Prevalence of tuberculosis (TB);
- Prevalence of coal workers' pneumoconiosis and past TB;
- Association of outcome variables with exposure variables, including underground exposed workers as compared to that of surface workers
- Association of TB with coal workers' pneumoconiosis and past TB
- Exposure-response relationship of TB, coal workers' pneumoconiosis and past TB to respirable coal dust.

# CHAPTER 2     BACKGROUND TO COAL MINING IN SOUTH AFRICA AND THE STUDY MINE

## 2.1     Coal Mining and Geology

South Africa is the second largest coal producer in the world. The 2005 run of mine coal production for the year was 245 million tons [51], and the coal industry employed 53 971 people in 2005 [51]. This shows that the industry is employing a significant number of people in South Africa. South Africa's energy sources are mainly from coal for electricity and fuel production [2]. Coal is formed from peat deposits, mainly through dehydration and decay of plant materials [59, 60].

Coal is classified into ranks, which are associated with relative geological age and the degree to which the coalification process has progressed [59, 60].The ranking is defined in terms of the percentage of fixed carbon to the proportion of carbon that remains, and when coal is heated and volatile materials are removed, by the percentage of volatile materials and heat content [59, 60].

South African coal has a Permian geological age of 250 to 280 million years [61]. It is mostly semi-bituminous type, with anthracite found only in the KwaZulu-Natal area [2]. Semi-bituminous coal is a low-ranked coal with a volatility of 25 – 31% and an ash content of 10 – 24% [2].  The coal is primarily used for the generation of steam and electricity. The estimated fixed carbon, volatiles material and ash content of the coal are 45 - 48%, 20 - 22% and 20 – 30% respectively [59, 60, 61]. The inherent average silica content in South African coals is 3.5% [2].

## 2.2     Description of the Study Mine, Fitness Assessments and Environmental Sampling

The study was of coal miners at a multinational energy company's mining business unit, situated in the Mpumalanga Highveld area, and is the largest underground coal operation in the world [61]. The coal extraction process is 100% underground coal mining, using the bord-and-pillar method and continuous mining machines.

The complex consists of 12 active shafts, and a stockpile covering four square kilometres with an average coal stockpile of 2 million tons .The conveyer belt complex is estimated to be 462 km long, with 281 km underground and 181 km on the surface [61]. The estimated

distance that the coal is mined daily on this complex is 4 km [61]. The silica content of this coal is below 5%, therefore the effects of coal dust predominate [61]. The company is the third largest coal mining company in the country and accounts for an estimated 21% of annual South African coal production. Production is an estimated average of 42 million tons of coal annually [61].

The complex supplies coal locally to a petrochemical factory and washed coal to international markets [61]. Support services include health, safety, the environment, security, stockpiles, a geological department and human resources. Up to 31 December 2005, these business units had 7 501 full-time employees, excluding contractors, hired labour, those who left the service and subcontractors employed at the mine. The wage personnel constituted more than 65% of the total full-time employees, with Africans making up more than 95% of this population. Mine workers are required by law to have a medical certificate of fitness to do risk work, i.e. dust-exposed work.

Medical services are provided by a hospital and its satellite clinics at the mine shafts. Comprehensive medical services are provided to wage employees and include primary care, secondary and tertiary care by way of referral to third parties, medical surveillance, occupational health and emergency services. All mine workers undergo an annual medical examination at the occupational health centre to determine fitness to do risk work.

Radiological screening for mycobacterial diseases and silicosis form part of the annual medical examination. Coal miners with suspected mycobacterial diseases are investigated using a standard protocol with three sputum specimens taken over two days. Smears are made from concentrated sputum and stained with Auramine for fluorescent microscopy. Positive smears are confirmed with Ziehl-Neelsen staining. Positive cultures are sent to the mycobacteriology laboratory for biochemical species identification of mycobacterium and drug susceptibility testing of mycobacterium TB strains. Confirmed TB patients are hospitalised, treatment and management of the disease are immediately started, and contact are traced and also treated.

The dust sampling on the mines follows the directives of the DME [62]. This sampling strategy was introduced in 1992 by the Government Mining Engineer. Mines were subdivided into areas, which in turn were divided into statistical populations. Statistical populations are supposed to consist of persons generally exposed to similar dust concentrations. This population embraces 200 persons [2, 63, 64]. Five per cent of the population is sampled in six-month cycles. Individual sampling results are averaged on a person-weighted basis for

each statistical population. The results for each statistical population then produce the area average.

The Mining Complex collects dust samples as per the legal requirement and obligations to the DME [2, 63, 64]. The complex collects area and personal samples using the CIP10 gravimetric sampler. Dust and quartz analysis is done by accredited authorities or laboratories. Unfortunately for the purpose of this study, detailed quartz data was not available.

# CHAPTER 3   METHODOLOGY

## 3.1     Study Design

This was a cross-sectional study conducted in 2006 of coal miners currently employed and whose records between 1 January 2000 and 31 December 2005 were reviewed.

## 3.2     Population and Setting

A review of the records of coal mine workers in bituminous coal fields in the Mpumalanga Highveld area was conducted. The study population comprised black males –"unskilled"or "wage" coal miners. The workforce consisted of officials in supervisory position (largely white males) and manual labour (unskilled workers, who are largely African), comprising 5% and 95% of the total workforce respectively. The review included underground and surface workers. The surface workers included those working in offices, support services' central workshop, the coal supply area and beneficiation plants. These workers were generally migrant labourers from rural areas of South Africa and neighbouring countries.

## 3.3     Sampling and Sample Frame
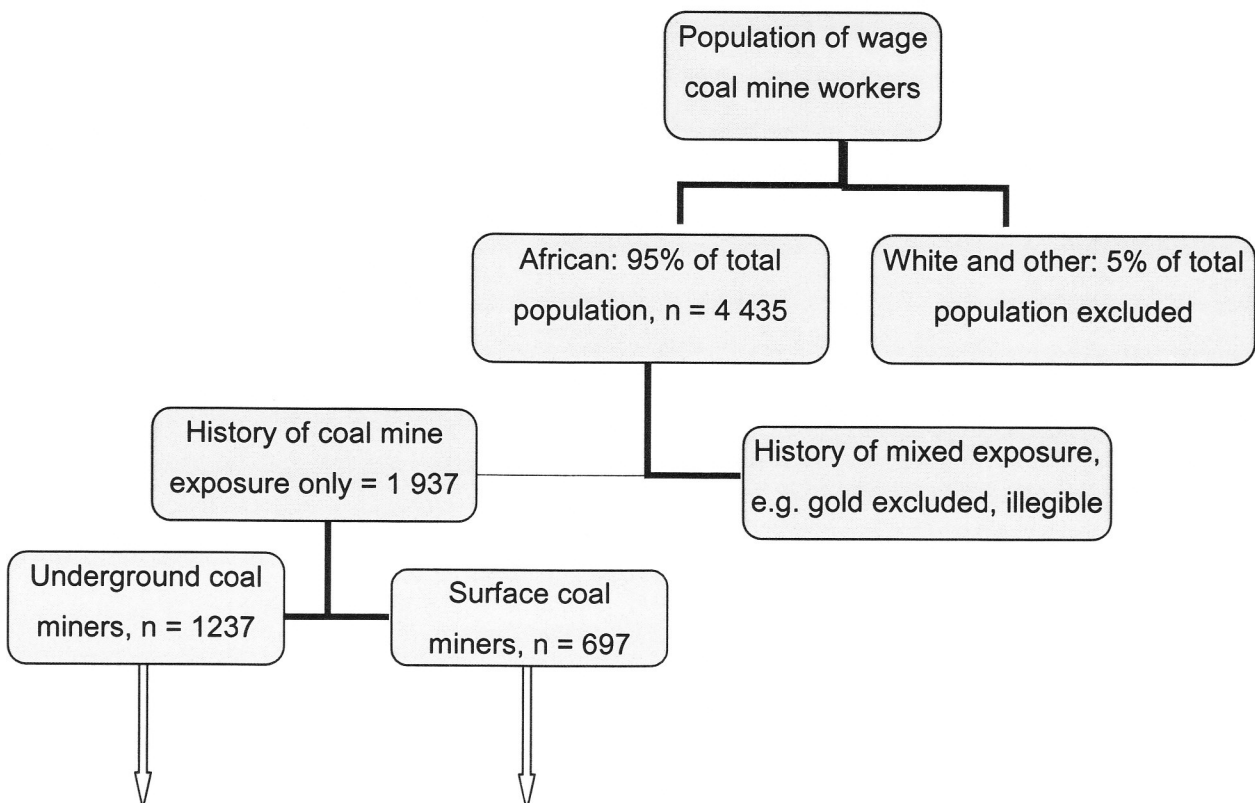


**Figure 1:   Sampling and sampling frame**
Sample randomly selected from the underground and surface proportionally using numbers.

The sample selection was taken from the population of black male "unskilled "wage employees in the mining complex.The included participants were those who derived their health benefit from the company health service, fulltime emplyees of these mining company and employees in jobs groups of "unskilled or wage" wokers. Employees in supervisory job groups and those with incomplete information were excluded. This sample was selected from a list of all full-time employees from the company's human resources databases. Based on information from available records, the population was divided into mixed exposure (i.e. history of having worked in mines other than coal mines) and only coal mine exposure (i.e. having worked on coal mines only). From the list of full-time employees, 1 934 miners had only coal mine exposure. These 1 934 employees were stratified further into underground (n = 1 237 (63.9%)) and surface work (n = 697 (36.0%)). Random sampling was done of each of these strata, using company numbers while maintaining the population proportions, i.e. the final sample comprised 64% underground and 36% surface workers.

## 3.4    Sample Size

We estimated a sample size of 324 individual records to be reviewed. An alpha level of 0.05, power of 80% and based on previous reports, the prevalence of TB in black coal miners of 6.76% was used for the estimation of the sample size. A total of 350 records were selected - 226 from among the underground workers and 124 from among the surface workers. The higher sample size was decided on because of the need to adjust for the various covariates. Six workers were excluded because of their diagnosis of silicosis. The stratification allowed for a broad range of exposure in the sample while maintaining comparisons on other variables.

## 3.5    Data Sources

### 3.5.1    Medical surveillance records

During medical surveillance each worker undergoes a full clinical assessment. These assessments are done at pre-employment or pre-placement, periodically or annually, and on termination of employment. The assessment consists of an interview using a standardised questionnaire and a medical examination. The standardised questionnaire includes a detailed respiratory history (any history of reported lung diseases, any history of TB etc.) and other organ systems.

The questionnaire also includes a history of employment, duration of employment, previous employment, different jobs occupied, areas of work, as well as information on sociodemographic characteristics and smoking habits. Data from the medical files include demographic data, TB diagnosis, method of diagnosis, silicosis, certification as pneumoconiosis, previous history of TB and management and treatment, and HIV status and management. [The diagnosis of TB is made according to the case definition described in section 3.6 below] All current TB records in the hospital TB databases were reviewed retrospectively and then verified with the existing data or patient medical records. The missing data was obtained after reviewing outpatient medical records and computerized results of the laboratory investigations. During the clinical assessment the following tests are conducted: hearing tests, eye tests, lung function test, chest x-rays and haematological investigations if warranted. Radiological screening of mycobacterial diseases and silicosis are part of the annual medical examination.

### 3.5.2 Environmental and occupational hygiene records data

The environmental control and hygiene departments provided most of the exposure data of the complex. It additionally provided demographic data, work history from the date of engagement, area of work and exposure class or level (e.g. face, back bye or surface), job titles, section in which employed, service duration in a particular area of work, job categories and occupations, composition of statistical population groups used in the routine dust sampling, and job assessment matrix. All data sources were cross-validated against each other.

The available current levels of exposures were provided for various jobs and classified in homogenous categories according to exposure level, areas of work and DME occupational hygiene strategy and guidelines recommendations. These levels were used to calculate exposure indices, lifetime mean exposure level (LMEL) and cumulative dust exposure in mg-years/m$^3$ (CDE). In summary, both these departments provided data on job categories, occupations within the categories, number of workers with job categories and occupations, age, length of service, job categories and occupation composition of the statistical population group used in the routine dust sampling programme.

### 3.5.3 Human resources records and databases

The information provided allowed validation of the demographic information provided by the hygiene and medical departments. This source provided demographic data (name, mine, period of employment, past history of employment in other industries, promotions when

available, various jobs or mines worked on within the complex, salary or employment level, previous and present residence and country or place of origin. These records provide demographic data of individuals, serial job descriptions, job categories, job titles, and occupations within categories, length of service, residence, job changes, company numbers and individual occupations.

## 3.6    Case Definitions

*Current TB:* A case of culture-positive TB was diagnosed if there were compatible clinical features (signs and symptoms and radiographic features of TB) and sputum culture was positive. Culture-negative TB was diagnosed if there were compatible radiographic changes plus two of the following: smear positive; no response to amoxicillin or radiological response to anti-tuberculosis drugs [65]. This information was obtained from the selected workers' records at the mining company.

*Past TB:* This was defined as all participants who were diagnosed using the criteria above and had completed treatment or was still on treatment in the continuous phase of TB programme before the study.

**CWP:** This was defined as all those who were reported and certified by the Medical Bureau for Occupational Diseases (MBOD). The chest X-rays are read as ILO classification of pneumoconiosis at the MBOD. The certifications were done as a statutory requirement. Outcome variables were certified CWP, past TB with current TB being the primary outcome variable.

## 3.7    Smoking and HIV

History of smoking was taken from the surveillance questionnaires which were updated annually. For the purpose of this study, smoking was classified as follows: smokers - those who smoked at the time of study; ex-smokers - those who had stopped smoking at least three months before the study; and non-smokers - those who never smoked. Negative or positive HIV status of those tested was obtained from the medical files. These tests for HIV status were done after VCT (Voluntary Counselling and Testing). Not all workers present for voluntary testing at the company services: some present for testing at external agencies, and do not make their results available to the clinical services at the company. In addition, those that do present to the company services may not have the results recorded in their files. Only 40% of the study sample had information on HIV status.

## 3.8    Exposure Assessments

The data were supplied as an Excel spreadsheet of 344 records for each of the participating workers. Several calculated exposure variables were developed, including CDE and LMEL based on current available data. Exposure variables were defined as underground vs. surface (exposure status), calculated LMEL (this was based on mean exposure levels to coal dust calculated from the history of all jobs worked by an individual in an exposure zone as obtained from available current levels), CDE in mg-years/m$^3$ and length of service in years. Because of the absence of reliable historical exposure data, all exposure variables utilised current environmental data.

In calculating LMEL and CDE, use of a current measure to approximate past exposure is an important limitation, an approach which assumes a constant exposure over time. Although it is likely that past exposures were much higher, this is the most reliable assumption compared to arbitrarily assigning a 1.5 or 2-fold higher level to past exposures, using equally arbitrary cut-off dates. This assumption will drive effect estimates toward null.

The varying levels of exposure in the different jobs or job categories over the time period that each individual participant was employed were calculated using available current level. The number of years each worker had spent in each job or job category was determined. A job-exposure matrix was compiled, where X (Jxt) is the exposure level for time period t for a particular job and available current level (J) is the exposure zone in the work environment of the complex. Current levels were used to calculate the LMEL and CDE.

### Table 1:    Development of Job Exposure Matrix

| Exposure zone/job-specific. Current concentrations used to calculate CDE | | Time periods | | | |
|---|---|---|---|---|---|
| | | T(1) | T(2) | T(3) | T(t) |
| | J(1) | X(1,1) | X(1,2) | X(1,3) | X(1,t) |
| | J(2) | X(2,1) | X(2,2) | X(2,3) | X(2,t) |
| | J(3) | X(3,1) | X(3,2) | X(3,3) | X(3,t) |
| | J(j) | X(j,1) | X(j,2) | X(j,3) | X(j,t) |

The use of historical dust data, which allows more accurate characterisations of past exposure, should have permitted calculation of cumulative exposures and mean lifetime intensity exposure to coal dust, without having to rely on modelling or assumptions. A major problem in estimating past exposures was unreliable or unavailable historical exposure data.

Several exposure variables were calculated and developed for analysis. The last available exposure level (current levels) of different exposure areas, done as per occupational hygiene regulations, was used to calculate LMELs. This was used to calculate the individual LMEL of various zones/areas and jobs worked at the mining complex.

This was calculated for individual participants by dividing the sum of exposure of individual zone by years of coal mining in that zone, and summing all such exposures to give the LMEL. The formula is:

$$[(x1 + x2)/t1] + [(y1 + y2)/t2] + [(z1 + z2)/t3].....cn/tn$$

where
x, y and z represent different exposure zones
t1.n represents years worked in that zone, providing an exposure variable in mg-years/m$^3$, tn represents total years of service.

CDE measured in mg-years/m$^3$ was constructed based on job description (category and its current exposure level, occupational history, years of service in each occupation and overall). Cumulative exposure was calculated as the sum (of all the jobs) of years spent on jobs or job categories multiplied by the current available dust concentration level for current particular job or job category. This is described by the formula:

$$CDE = \sum Xij \ Yearsij$$

where
Xij =      arithmetic current mean level for a particular mine within a specific zone, surface or underground
Years ij =   years spent in a particular mine within a specific zone

Detailed quartz data from the occupational hygiene department was not available.

## 3.9    Statistical Analysis

All data were captured on computer, double-entered with validation procedures of Epi-info [66]. The analysis was done using the Epi-info analysis package. Independent checks of range, consistency and missing data were done in Epi-info.

The outcome variables of interest were: (a) TB as the primary outcome (b) coal workers' pneumoconiosis and (c) history of previous TB. Duration of employment in coal mining industry, CDE, LMEL and surface vs. underground work were the exposure variables.

In studies of gold mine workers the prevalence of silicosis and TB increased with age and duration of service [34]. Exposure to other environmental dust exposures, e.g. silica, is associated with an increase in the risk of TB. Race and socio-economic factors were accounted for in the design by ensuring that only a single race group (African) was included in the study, and all participants were selected from a narrow employment level, implying similar socio-economic status. HIV and smoking were accounted for in the analysis of the data by stratification and adjustment in regression models.

Bivariate descriptive analysis techniques were used to describe the data. Preliminary analysis was performed before the formal statistical analysis. For categorical data frequency distribution was examined, and for continuous variables means, standard deviations, average, median and ranges were examined. This was followed by bivariate analysis of outcome (TB) and exposure variable. This analysis proceeded from univariate analysis which describes the characteristics of sample and crude associations between variables of interests. Student t-test used to test the difference of groups continuous variables. The level of significance used was 0.05. For categorical dependant variables, relative risk or prevalence odds ratio were calculated. Stratification was done to assess the role of the covariates.

## 3.10 Human Subjects

The Ethics Committee of the University of KwaZulu-Natal approved this study proposal which was a retrospective records review study. Consent was obtained from the individuals and stakeholders.

Individual results were strictly confidential; group reports were only accessible to the stakeholders on request. The identities of the participants were strictly confidential, with all participants using research identities with no names and no company numbers.

# CHAPTER 4 RESULTS

## 4.1 Descriptive Data

This sample of 344 men from this mine had a reasonably long duration of employment (mean of 16.1 years; range 4.1 – 27.7 years), with a moderate mean lifetime exposure (LMEL = 1.6 mg/m$^3$) with a range of 0–6.9 mg/m$^3$ (Table 2). The mean calculated CDE was 25.8 mg-years/m$^3$, with a range of 0 – 79.5 mg-years/m$^3$. More than half (213 or 62%) of the sample were residing in local townships and informal settlements, and 131 (38%) were residing at the mine hostel. One hundred and fifty-eight (40%) participants had been tested for HIV, of whom 41 (26%) tested positive and 117 (74%) tested negative and importantly 60% not tested.

Out of the total sample participants, 127 (36.9%) had never smoked, 102 (29.6%) were current smokers and 115 (33.4%) were ex-smokers. The length of service and age are updated annually during the mandatory medical examination. This was cross-validated with company data records from the personnel and hygiene department. The company's mining complex jobs were classified into three general categories: (a) work on surface (n = 124) (36.1%), (b) underground back bye (n = 82 (23.8%) and (c) coal face (n = 138 (40.1%).

Among those with current TB, 55.9% (19) were sputum culture positive with 44.1 % (15) sputum culture negative. But 47.1 % (16) were sputum smear positive with 52.9% (18) sputum smear negative. Among the smear positive current TB, 85% were sputum culture positive.

**Table 2: Pulmonary TB in coal miners in Mpumalanga: descriptive data (n = 344)**

| Variable | Mean, SD and range |
|---|---|
| Age (years) | |
|     Mean | 45.2 |
|     SD | 8.1 |
|     Range | (28 – 64) |
| Years of coal mining (years) | |
|     Mean | 16.1 |
|     SD | 5.9 |
|     Range | (4.1 – 27.7) |
| Mean CDE (mg-years/m$^3$) | |
|     Mean | 25.8 |
|     SD | 20.3 |
|     Range | (0 – 79.5) |
| Current smokers | 115 (36.92%) |
| Ever smoked | 102 (29.65%) |
| Never smoked | 127 (33.40%) |
| HIV status tested (n = 158) | |
| HIV positive | 41 (26%) |
| HIV negative | 117 (74%) |

## 4.2 Exposure Variables

### 4.2.1 LMEL categories

In this analysis sample subjects were grouped into three categories based on terciles of LMEL. This ranged from low LMEL (0 - 2.5 mg/m$^3$ (n = 114)), medium LMEL (2.51 – 3.5 mg/m$^3$ (n = 114)) and high LMEL (>3.51 mg/m$^3$ (n = 116)). As expected, LMEL was substantially higher in jobs at the face with the lowest concentration obtained on the surface of the mine. Most of the unexposed jobs were office work, kitchen work, hostel guards or security.

## 4.2.2    CDE categories

CDE was categorised into terciles as well. Category 3 - high CDE (high exposure), n = 114 (45.1–79.5 mg-years/m³); category 2 - medium CDE (medium exposure), n = 115 (25.1-45 mg-years/m³); and category 1 - low CDE (low exposure), n = 115 (0–25mg-years/m³).

## 4.2.3    Underground vs. surface

Of the entire records sample reviewed, 220 (64%) mine workers worked underground and 124 worked on surface (36%). There were no statistically significant differences in the mean ages (p>0.05) or years in coal mining (p>0.05) or between underground and surface miners.

As expected, there were significant differences in exposure variables across surface and underground miners. The absolute difference in LMEL between underground and surface was 2 mg/m³ (p<0.001), while for CDE the difference was 29.1 mg-years/m³ (p<0.001) (Table 2).

**Table 3:    Pulmonary TB in coal mining workers in Mpumalanga. Difference between age and exposure variables for underground vs. surface**

| Variable | Underground = 220 | Surface = 124 |
|---|---|---|
| Mean age in years (SD) | 44.7 years (8.62) | 46 years (7.2) |
| Mean coal mining years (SD) | 14.9 years (5.90) | 18.3 years (5.4) |
| LMEL (mg/m³)(SD) | 2.4 mg/m³ (0.6)** | 0.4 mg/m³(0.5)** |
| Mean CDE (mg-years/m³) (SD) | 36.3 mg-years/m3 (17.1)** | 7.2 (mg-years/m³) (9.1)** |

**p<0.001

## 4.3    Health Outcomes: Exposure Associations with Underground vs. Surface

### 4.3.1    Prevalences and descriptive data of health outcomes

The prevalence of current TB among the mine workers was 9.9% (n=34), of whom 31 (14.1%) were underground and 3 (2.4%) were surface workers. Of those with current TB, 20 (55.8%) had compatible clinical features (signs and symptoms of TB) and positive culture results, while 14 (44.2%) had negative sputum culture results, compatible radiographic

changes, smear positive, no response to amoxicillin and no radiological response to anti-TB drugs.

CWP and past TB prevalences were 3.8% respectively. Two participants with CWP had current TB, while four participants with current TB had a diagnosis of past TB. There was a minimal difference in mean exposure and mean age across all these health outcomes. Participants with current TB had a mean age and length of service of 46.7 and 16.2 years with a mean LMEL and CDE of 2.2 and 33.4 respectively. Participants with past TB had a mean age and length of service of 51.3 and 20 years with a mean LMEL and CDE of 2.24 and 45.2 respectively. Participants with CWP had a mean age of 44.9 and 16 years exposure with a mean LMEL and CDE of 1.92 and 38 respectively.

### 4.3.2    Health outcomes in underground vs. surface coal miners
(Difference in age, covariates and exposure variables underground vs. surface)

Although there was no significant difference in age and length of service between underground miners with current TB compared to surface miners with current TB, there were significant differences with regard to the exposure variables, LMEL and CDE, with absolute effects of 1.18 mg/m$^3$ and 8.2 mg-years/m$^3$ respectively.

Exposures (LMEL and CDE) were significantly different for underground and surface coal miners, both for previous TB and CWP – (t-test $p<0.001$ for both variables (LMEL and CDE)). Similarly both LMEL and CDE were significantly different for underground and surface coal miners both for previous TB and CWP – t-test $p<0.0001$ for both variables. For past TB, CWP, age and length of service were not significantly different for underground and surface coal miners.

**Table 4:** Pulmonary TB in coal mine workers in Mpumalanga: comparison between underground (U/G) vs. surface for health outcomes

(Difference between age, exposure variables and covariates)

| Variables | Current TB (n=34) | | CWP (n=13) | | Past TB (n=13) | |
|---|---|---|---|---|---|---|
| | U/G | Surface | U/G | Surface | U/G | Surface |
| Mean age (years) | 46.8 | 45.6 | 52.7 | 49.9 | 44.6 | 45.2 |
| Mean coal mining years | 17.2 | 15.2 | 20.9 | 19.3 | 15.1 | 17.1 |
| Mean LMEL (mg/m$^3$) | 2.79*** | 1.61*** | 2.87** | 1.58** | 2.38** | 1.46** |
| Mean CDE (mg-years/m$^3$) | 37.5*** | 29.3*** | 49.1*** | 41.3*** | 34.7** | 28.6** |
| | | | | | | |
| Current smokers | 2 (5.9%) | 2 (5.9%) | 3 (23.1%) | 2 (15.4%) | 1 (7.7%) | 2 (15.4%) |
| Ex-smokers | 3 (8.8%) | 1 (2.9%) | 2 (15.4%) | 3 (23.1%) | 2 (15.4%) | 3 (23.1%) |
| Never smokers | 26 (76.5%) | 0 (0%) | 2 (15.4%) | 1 (7.7%) | 3 (23.1%) | 2 (15.4% |
| HIV positive (total,41) | 3 (8.8%) | 2 (5.9%) | 2 (15.4%) | 3 (23.1%) | 2 (15.4%) | 4 (30.8%) |
| HIV negative (total 117) | 5 (17.6%) | 1 (2.9%) | 4 (30.8%) | 3 (23.1%) | 5 (31.3%) | 2 (15.4%) |

*p-value <0.05;**p-value <0.01;***p-value <0.001

## 4.4 Descriptive data, differences between those with and without health outcomes for age, covariates and exposure variables

### 4.4.1 Descriptive data and difference between those with and without CWP and past TB

The mean age of participants in the sample with CWP was 51.3 years compared with 44.9 years of those without CWP. Mean length of service of participants was 20.1 years with CWP compared to 15.9 years for those without CWP. LMEL and CDE for participants with CWP were 2.24 mg/m$^3$ and 45.2 mg-years/m$^3$ respectively.

The differences in age (p<0.008) and all exposure variables (length of service, p<0.04; LMEL and CDE p<0.0001) between those certified with and without CWP were significant.

The mean age of participants with past TB was 44.9 years compared to 45 years for those without past TB. Mean length of service was 16.1 years compared to 15.2 years for those without past TB. CDE and LMEL for past TB were 38 mg-years/m$^3$ and 1.92 mg/m$^3$ respectively.

Although there was no significant difference in age and length of service between those with and without past TB (t-test p>0.05), there was a significant difference between them in exposure variables: LMEL (p<0.04) and CDE (p<0.03).

### 4.4.2 Difference in prevalence of all health outcomes for HIV and smoking categories

The difference in prevalence of current TB in HIV-infected and uninfected participants was not significant. This was similar for other health outcomes (CWP and previous TB), with p>0.05 for all health outcomes. Those infected with HIV were 1.02 times (prevalence odds ratio) more likely to develop TB than the uninfected participants, which was not significant. There was no significant difference in smoking history among those with and without current TB and CWP and past TB (p> 0.05).

### 4.4.3 Participants with and without current TB

Although there was no significant difference in age and length of service among those with current TB compared to those without current TB, there were significant differences with regard to the exposure variables, LMEL and CDE, with absolute effects of 0.6 mg/m$^3$ and 7.8 mg-years/m$^3$ respectively.

**Table 5: Tuberculosis in coal miners in Mpumalanga: comparison between TB and non-TB descriptive characteristics**

(Difference between age and exposure variables)

| Variables | TB (n = 34) | Non-TB (n = 310) |
|---|---|---|
| Mean age (years) (SD) | 46.7 (7.2) | 45 (8.2) |
| Mean years of coal mining(years) (SD) | 16.2 (6.0) | 15 (5.3) |
| LMEL (mg/m$^3$)(SD)** | 2.2 (1.1) | 1.6 (1.1) |
| Mean CDE (mg-years/m$^3$) (SD)** | 33.4 (19) | 25.6 (20.3) |
| Current smokers | 9 (26.5%) | 118 (38.1%) |
| Ex-smokers | 11 (32.4%) | 91 (29.4%) |
| Never smokers | 14 (41.1%) | 101 (32.5%) |
| HIV positive, (total,41) | 5(12.2%) | 36(87.8%) |
| HIV negative, (total,117) | 13(11.1%) | 104(88.9%) |

**p<0.01,*p<0.05

t-test for continuous variables, and chi square for categorial variables

## 4.4 Exposure Response Associations

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### 4.4.1 Associations of health outcomes for underground vs. surface workers

Prevalence of previous TB and CWP were higher for underground workers, namely 9 (4.1%) and 11 (5%), compared to surface workers, 4 (3.2%) and 2 (1.6%) respectively. There was a statistical significant 6.6-fold greater risk for current TB between underground and surface workers, (chi-square test, p<0.001). The prevalence of previous TB and CWP among underground workers was not significant, i.e. 3.2 and 1.28 times that of underground compared to surface coal miners respectively.

**Table 6:** Pulmonary TB in coal miners in Mpumalanga: associations of exposure (underground and surface) with health outcomes

| Outcomes | Underground n = 220 | Surface n = 124 | POR |
|----------|---------------------|-----------------|--------|
| TB | 31 (14.1%) | 3 (2.4%) | 6.62 * |
| CWP | 11 (5.0%) | 2 (1.6%) | 3.2 |
| Past TB | 9 (4.1%) | 4 (3.2%) | 1.28 |

*p<0.001

### 4.4.2 Associations of primary outcome (current TB) with CWP and past TB, and CWP with past TB

Workers with current TB were more likely to have co-existing CWP, with a prevalence odds ratio of 1.7, p>0.05. Participants with CWP and current TB were older, with a mean age of 51.5 years and longer service duration of 23.6 years. Workers with TB were more likely to have had a previous history of TB, prevalence odds ratio of 4.1, (p<0.03). A strong correlation existed between increasing numbers of TB episodes and increasing dust exposure (Pearson's correlation coefficient was 0.52, (p<0.03). Mine workers with past TB were more likely to have had co-existing CWP, with a prevalence odds ratio of 5.3, p<0.03.

**Table 7:** Pulmonary TB in Mpumalanga coal miners: association of current TB with CWP and past TB

| Health outcome | TB (n = 34) | Non-TB (n =10) | POR |
|----------------|-------------|----------------|------------------|
| CWP | 2 (5.9%) | 11 (3.6%) | 1.7 (0.4 – 7.1) |
| Past TB | 4 (11.8%) | 9 (2.9%) | 4.1 (1.3 – 12.5) |

### 4.4.3　Association and trends of health outcomes with exposures (LMEL and CDE)

There were 4 (3.5%) participants with current TB in the low-exposure level category, compared to 7.9% in the medium-exposure level and 18.1% in the high-exposure level categories. This is suggestive of an ascending trend of current TB prevalence from the low-exposure category to the high-exposure category. A similar trend was seen with cumulative dust exposure categories..

The prevalence of past TB within the LMEL categories were 1.6%, 0.9%, 6% and and for CWP within these categories 0%, 1.8%, 9.5% respectively. The prevalence of past TB within the increasing CDE categories was 2.6%, 0.9% and 7.9%, while the prevalence of CWP within these categories was 3.5%, 7.8% and 18.4% respectively.

All health outcome variables were significantly associated with categories of LMEL and CDE, with positive and significant trends (Table 8). The prevalence odds ratio (POR) for TB, CWP and past TB, comparing high LMEL and low LMEL, was 5.16, undefined and 3.4 respectively. The POR for current TB, CWP and past TB, comparing high and low CDE, was 8.8, 5.26 and 3.03 respectively.

**Table 8:　Pulmonary TB in Mpumalanga coal miners: associations and trends for outcome variables in the LMEL and CDE categories**

| Health outcomes | Categories of LMEL (mg/m$^3$) | | | Categories of CDE (mg-years/m$^3$)* | | |
|---|---|---|---|---|---|---|
| | Low, 114 | Medium, 114 | High, 116 | Low, 115 | Medium, 115 | High, 114 |
| CWP | 0 (0%) ** | 2 (1.8%) ** | 11 (9.5%) ** | 4 (3.5%) ** | 9 (7.8%) ** | 21 (18.4%) * |
| Current TB | 4 (3.5%) ** | 9 (7.9%) ** | 21 (18.1%) ** | 1 (0.9%)** | 2 (1.7%) ** | 10 (8.8 %) *' |
| Past TB | 2 (1.8%)* | 1 (0.9%)* | 7 (6.0%)* | 3 (2.6%)* | 1 (0.9%)* | 9 (7.9%)* |

**p<0.001; p<0.05* (Chi-square tests for trend)

# CHAPTER 5  DISCUSSION

## 5.1    Discussion on the key findings

In this study of South African coal miners with a prevalence of TB of 9.9%, an association between exposure to coal dust and TB was found. This finding has been infrequently reported in the literature.

The study showed an association with current and past TB using a variety of different exposure variables, including crude measures (underground vs. surface), as well as more sensitive quantitative measures (LMEL and CDE). The evidence of an increasing trend in the prevalence of disease with increasing exposure provides further support for these findings. The expected association and trends seen with CWP gives confidence in the use of these exposure variables.

In addition to these exposure variables, the exposure difference between participants with and without current TB was analysed. This study reported a significant difference in LMEL and CDE between participants with and without TB (current pulmonary TB). The exposure level (LMEL) among those with current TB was 2.2 mg/m$^3$ compared to those without TB, which was 1.6 mg/m3. This study found that current TB was positively and significantly associated with dust exposure (LMEL and CDE): $p<0.01$ and $p<0.05$ respectively.

This study reported a significant trend in, and association with exposure categories of LMEL and CDE and health outcomes (TB, CWP, and past TB). Current TB prevalence trends were found with increasing mean cumulative exposure. There was a significant dose-response relationship of exposure (LMEL) with current TB. The prevalence of current TB increased with exposure increase in LMEL, ($p<0.0003$) and in CDE ($p<0.0002$). This provides evidence of a dose-response relationship between current TB and coal dust exposure.

This study compares well with numerous other studies. A study of TB in gold miners exposed to silica dust has shown an increased relative risk of 1.1 of TB among those without radiological evidence of TB, and an increasing risk with increasing quartiles of cumulative dust exposure [30].

The association and relationship of dust with TB is well reported and documented in studies done in the gold mining industry [28–33], and black coal miners are reported to have an increased risk of TB [42], but this can be due to several factors including the types of jobs they have for historical reasons, educational level and poor socio-economic background.

All exposure variables have been reported to show significant increases in the prevalence of pulmonary TB. Our findings are supported by a study conducted among Spanish coal miners, which found a TB incidence of 150 per 100 000 person years, an incidence which is three times greater than that of the general population in the same area. This is attributed to socio-economic conditions and delay in diagnosis and treatment. The majority of participants presented with complicated pneumoconiosis [44, 45].

Historical statistics support the hypothesis linking TB and coal usage. Strong correlations have been shown in Canada, the USA and China between coal usage and TB [58]. TB is the commonest cause of complicated pneumoconiosis in coal miners [44,45]. A South African study [2] reported that past or present TB was more prevalent in miners with than those without CWP.

However, this contradicts the findings of the study among South African coal miners that outcomes (CWP, bronchitis, emphysema) other than TB were statistically significantly positively associated (p<0.0001) with exposure as well as a positive trend with increasing exposure (p< 0.0001) [42]. However, high exposure to coal dust was significantly related to TB, and showed odds greater than 1.62 in participants exclusively exposed to coal.

## 5.2    Silica Exposure and TB

The silica levels in respirable coal dust on South African mines are reportedly low, and the inherent silica content of South African coal seams is on average 3.5%. The silica content in KwaZulu-Natal is 3% [2, 42]. Mpumalanga, Gauteng and Free State coal is reported to have a quartz content of about 2%, which is below the regulatory quartz level of 5%. Although the average quartz content of South African coal mines is reported to be below 5%, continuous mine machine operators and roof bolters are most exposed to higher levels of quartz.

This study finding is surprising, as the association between TB and underground mining has been generally attributed to exposure to silica dust. DME dust data for 2005 reported quartz levels exceeding 30% of the OEL of 0.1 mg/m$^3$ [38]. It is very likely that there is substantial exposure to high quartz levels on the coal mines in Mpumalanga, and this may be the primary determinant in our study findings. Similarly high level exposures have been reported elsewhere in Southern Africa. Tanzanian dust measurements showed very high dust levels during underground small-scale mining. Particularly during drilling and blasting exposure to respirable crystalline silica was about 50 times higher than the TLVs (threshold limit values) (17.37 mg/m$^3$ and 0.611 mg/m$^3$ respectively) [56, 57].

The prevalence of TB has been associated with silica exposure and silicosis [28–35]. This is supported by the differences in the prevalence of TB on gold and coal mines. The prevalence of pulmonary TB in employed older South African gold miners is very high at 35% [31] compared to the low prevalence reported in the coal mines studies of 5.2% [42]. Pulmonary TB is significantly associated with dust and silica exposure, independently of the presence of silicosis [28–31]. Several studies have provided strong evidence for an association between underground mining and TB on gold mines. In previous gold mine studies it is associated with high dust-exposure occupations. An elevated incidence of TB is associated with increasing grade of silicosis and high-exposure occupations (underground vs. surface). The incidence of TB among winch operators and other high dust-exposed occupations such as drilling was twice that in surface and maintenance workers [32].

## 5.3    The Prevalence of TB

The prevalence found in this study is comparable with that found in studies of South African gold mine workers [31].  Two Spanish studies [44, 45] reported an incidence of TB in coal basins. The first reported an incidence three times higher than the local rate of 150 per 100 000 person years, and subsequent studies of the area report a rate that is even less than the local and Spanish national rates.

South African gold mining studies reported a high prevalence of TB in ex-miners and miners [39–41]. In a recent gold mining study the reported TB prevalence was between 19.4 and 34.2% [31]. SORDSA (Surveillance of Occupational Respiratory Diseases in South Africa) reported 6.5% cases of TB among South African miners [67].

The prevalence of TB among ex-miners, reported in various studies, ranges from 26.6% [39] to 47% [40]. These studies have argued that the risk of developing TB from exposure to silica dust continues long after exposure ceases. Although the present study did not investigate ex-miners, the continued risk post-exposure is of interest, because it is likely that workers on the surface may have been previous underground workers, and may still be at risk of developing TB, resulting in an underestimation of our effect estimates.

South Africa has a high incidence and prevalence of TB, and is among the top ten countries in the world burdened with TB [17-21]. The local and general national population impact on the prevalence and incidence of TB in local industry. The TB rate in the South Africa mining industry of 3 000 per 100 000 is one of the highest in the world and higher than the national rate, probably due to a number of factors that are unique to the country and its industries [2]. Data and studies from the South African mining industry show a higher TB rate than the rates

in the communities [2]. The TB rate of the mining sector is higher than the national rate of 458 per 100 000 [2].

## 5.4    Coal Workers Pneumoconosis

The prevalence of CWP as certified by the compensation authorities in this study was 3.8%. Because of the definition used in this study, direct comparisons with other South African or international studies are not possible. However, these results lie within the range of more sensitive markers of disease reported in other South African worker-population based studies. The latter, using radiological diagnosis of disease, have found prevalences ranging from 2 – 4.2% [2, 68]. As expected, a much higher autopsy-based prevalence was reported – 7.3% [42].

One unpublished South African study reported prevalence based on radiographic diagnosis of 15.8%. This unusually high prevalence may have been due in part to the coal type – anthracite, which has been associated with a higher prevalence of disease [2, 69, 70, 71, 72]. The difference in prevalence of CWP due to the geological and geographical differences of coalfields, the nature of low-grade or high-grade coal, bituminous, semi-bituminous and or anthracite was further confirmed by several previous studies [2, 37, 70, 71].

In international studies, prevalences between 4.5 – 6.8% have been reported [37]. Our study used legal certification as the basis for the diagnosis of CWP, but we suspect that this is a less sensitive measure, as the certification process most likely underestimates the prevalence due to a much stricter process (usually a consensus decision of a panel of three to five people in the Compensation Office), exclusion of those reported and not certified, those not reported and not certified, or those not willing to come forward due to the risk of losing their jobs.

Epidemiological studies in the USA and UK have demonstrated that the prevalence of category 1, and greater CWP and PMF, are dependant on the rank of the coal dust to which miners are exposed [37, 69, 70, 71, 72]. The difference in other types of prevalence was probably due to geology, coal type (anthracite, bituminous or other types) and mining type. Bituminous, low-grade coal has been associated with lesser risk of pneumoconiosis than that posed by high-grade coal [37, 69, 70, 71, 72]. The difference in the prevalence of CWP between this study and other coal mine studies [42] is also due to methodological considerations which undoubtedly contributed to the difference in CWP prevalence.

A British study investigating the relationship of coal rank and CWP noted that the descending order of prevalence of radiological abnormalities was as follows: anthracite coal mines,

steam coal mines and bituminous coal mines [69, 70]. This study reported that a low prevalence of CWP may be associated with coal grade and type. Bituminous coal is associated with a lower risk of CWP than high-grade coal, e.g. anthracite coal [2, 69, 72].

This study reported a significant difference in age and exposure variables (length of service LMEL, CDE) between those with and without CWP. There was also a significant difference in exposure variables (LMEL and CDE) between surface workers and underground workers with CWP.

Those with CWP were older, had worked longer on the mines and had had higher exposure compared to those without CWP. This is further confirmed by the significant difference in exposure (LMEL and CDE) of underground CWP participants compared to surface participants. These findings concur with those of local studies [42, 68] and international studies on coal miners [2, 70, 73, 74].

Although the risk of past history of TB among underground workers in comparison with surface workers was not statistically significant (p>0.05), there was a positive and significant trend with other exposure variables, including LMEL and CDE (p<0.02 and p<0.005 respectively). This compares well with a study of the history of TB among Mpumalanga coal miners, which failed to show any trend in the full dataset, but the current analysis of miners showed a significant positive trend with exposure (p = 0.04) [42].

## 5.5    Exposure and occupational exposure limits

The exposure findings of this study compare well with the other studies on South African coal miners [36, 73]. The mean LMEL for the sample was 1.56 mg/m$^3$, which is above the ACGIH limits of 0.4 mg/m$^3$ and 0.9 mg/m$^3$ for anthracite and bituminous coal respectively. The mean LMEL for underground workers was 2.4 mg/m$^3$, which is higher than 2 mg/m$^3$ and far higher than the ACIGH level of 0.9 mg/m$^3$ [75]. This implies that workers are exposed to high levels of coal dust. Only surface exposure at 0.4 mg/m$^3$ was less than 2 mg/m$^3$ (DME) and 0.9 mg/m$^3$ (acid).

One report on dust levels in the South African coal mining industry gave an average respirable dust exposure of 20 179 coal miners sampled in 1996 of 1.98 mg/m$^3$, where approximately 85% of the samples were less than 3 mg/m$^3$. The average concentration in this population was 0.07 mg/m$^3$, and 25% were exposed to respirable dust levels greater than or equal to 2.5 mg/m$^3$ [54].

In a study of three coal mines in the Mpumalanga area, the mean dust levels obtained by the researchers were below 2 mg/m$^3$ [42]. This compared to the historical data obtained by the same researchers for these mines, where the levels were lower than the 1.5 mg/m$^3$ range (0.23–1.7 mg/m$^3$) [42, 76]. These historical exposure levels (from 1991 onwards) across the three mines ranged from averages of 1.30–2.5 mg/m$^3$ at the coal face [42] and compared well with the findings of this study.

According to the ACGIH, the Threshold Limit Values (TLVs) is 0.4 mg/m$^3$ for anthracite and 0.9 mg/m$^3$ for bituminous coal. This exposure standard is for coal mine dust. The South African-recommended standard of 2 mg/m$^3$ respirable dust is similar to the standards of the USA and UK of 2 mg/m$^3$ and 4 mg/m$^3$ mean concentration at the coal face respectively [75]. Although there have been recommended levels for South African coal mines, these were reportedly several fold higher until the late 1990s [42].

The values of various standards have come under scrutiny on several occasions in respect of the safety of the health of the workers and whether they are health-based or not. NIOSH recommended threshold limits to be used as a guide in the control of health hazards and should not be regarded as a fine line between safe and dangerous concentrations.

The NIOSH and ACGIH TLV's may be lower than the corresponding Occupational Safety Health Administration's (OSHA) permissible exposure limits (PEL) as they are based primarily on prevention of occupational diseases [77]. In contrast, OSHA and other standards are required to take into account the economic feasibility of reducing exposure in affected industries, public notice and comment, and judicial review.

This study reported an expected significant difference of p<0.0001 between underground workers with high exposure (mean 2.4 mg/m$^3$) compared with surface workers with low exposure (mean 0.4 mg/m$^3$).

The occupational exposure limit for respirable silica that would minimise the risk of silica-associated TB is unknown [2]. Experimental studies have shown an association between implanted silica particles and increased susceptibility to mycobacterium [28, 29, 30]. Coal dust contains silica [2].

At present, according to the occupational exposure limits contained in the guidelines for the generation of Mandatory Codes of Practice in terms of section 9(2) of the Mine Health and Safety Act, 1996 (Act 29 of 1996), exposure to silica dust is limited as follows: crystalline silica: 0,1 mg/m³; amorphous silica (inhalable): 6,0 mg/m³; and amorphous silica (respirable):

3.0 mg/m³ [2, 11]. The occupational exposure limits for airborne pollutants causing occupational lung disease (DME 2001) are: coal dust (respirable particulates) less than 5%; crystalline silica: 2 mg/m³ OEL; and crystalline silica greater than 5%: 0.1 mg/m³ OEL [2].

## 5.6    Confounding in the Study

Educational and socio-economic factors were not considered since most workers in the sample were unskilled labourers who had only primary education, and were residing in hostels and informal settlements in the local communities.

The most significant confounder in respiratory health studies is cigarette smoking. However, the overall prevalence of smoking in this study was low compared with that in other studies [46, 47], and should obviously not have had a great impact. Smoking prevalence did not differ significantly between the exposure categories. This study reported an association of smoking with current TB which was not significant (p>0.05). Several studies have reported a significant association of smoking with TB [42, 46, 47]. Data collected on smoking from medical surveillance questionnaires did not provide reliable information on the number of cigarettes smoked, and thus the number of pack-years could not be quantitatively estimated.

HIV infection has been identified as the most potent biological risk factor for developing TB, coupled with the collapse of the TB control programme in South Africa's health system [2, 36, 48, 49, 50]. All health outcomes in this study did not significantly differ in HIV-infected and uninfected participants. The prevalence odds ratio for those with HIV developing TB, compared to those without HIV, was, however 1.02 (95% CI: 0.3–3.33). This concurs with a study using sputum screening for active cases of TB. In Free State gold miners the prevalence was 2.5% (1.8–3.2%). This did not vary significantly by HIV status (3.3% vs. 2.2%) in HIV-infected and uninfected participants, an incidence ratio of 1.5 (CI 95% 0.9–2.8) and silicosis grade [50].   Studies reported that the incidence of TB was more strongly associated with HIV, an incidence ratio of 5.5 and (95% CI 3.5–8.6) than with the point prevalence of TB (odds ratio 1.7 (95% CI 0.9–3.3) [49, 50].

The association of CWP with current TB was reported to have a non-significant prevalence odds ratio of 1.5 (p>0.05). Two participants with CWP were diagnosed with current TB and the mean age was 51.5 years with a mean duration of service of 23.6 years. This is not quite consistent with the reported statement that the risk of TB does not increase in coal miners who do not have pneumoconiosis, nor does it appear that the presence of pneumoconiosis in coal miners increases the risk of mycobacterium infection [43].

However, a well documented interaction exists between pulmonary TB and pneumoconiosis in coal miners [2, 44, 45, 78] which concurs with an unpublished KwaZulu-Natal study of documented radiological abnormalities which found that past or present TB was more prevalent in miners with CWP than those without. Pulmonary TB is the commonest cause of complicated pneumoconiosis in coal miners [2]. Workers with previous TB were likely to have or to develop significant co-existing CWP with a prevalence odds ratio of 5.28 (p<0.03). This agrees with previous findings [78], which observed an association of previous TB and PMF or complicated CWP.

## 5.7    Potential Limitations of the Study

This project had several advantages and limitations, which is not unusual in most occupational health and environmental projects or studies. All recognised advantages and limitations were examined to determine their possible impact on the study and its interpretations. These were as follows: study design, validity, confounding, changes in mining methods and exposure characteristics.

These cross-sectional studies cannot confirm a causal relationship of respirable coal mine dust with current TB but the statistical analysis performed provides strong evidence for such an association. This study reported a high prevalence of current TB and CWP among workers with the highest exposure.

The participation rate in this study was high, thus minimising any threat to the validity of the data due to a low participation rate. The reason for the high participation rate was because this was a records review, and workers did not need to consent to any additional tests.

Selection bias refers to the error that might arise due to systemic differences between those included and those not included. The healthy worker effect might have been present in this study, since the study population comprised only the workers who were currently employed at the time of the study. This might contribute to reducing the measurable effects of respirable dust as the status of those who had left the mine before the study for various reasons, including health reasons, was not represented.

Selection bias might have resulted in underestimation of the prevalence of current TB and CWP in this study which may have contributed to the low prevalence. This is likely to have driven the effect estimates toward null. This study reported low prevalence of CWP, which is most likely due to the study definition of CWP. In this study it was defined as all cases reported and certified by the MBOD as CWP. This could have resulted in underestimation,

because those reported and not certified were not included, some were not reported or certified, and some who were misdiagnosed or diagnosed privately and not reported.

However, owing to the resources available for this study, other means of diagnosing CWP were not possible. The other option, namely to include all cases that were submitted to the MBOD as suspected cases of disease, would have lacked sensitivity and resulted in misclassification of disease, driving the effect estimates away from null. It was decided to accept the stricter definition.

Another limitation of this study was that exposure levels may not be representative of those throughout the working life of the miners. It was assumed that current exposures were reflective of the situation in the past. Although it is widely accepted that levels in the past were much higher, there were no quantitative data to support this assumption. Anecdotal information from key industry informants in the South African coal mining industry suggested that levels in excess of 10 times current levels had been recorded in the decade prior to 1991 [36,75].

Exposure assessment using 1.5 or even 2-fold higher past exposures, and backdating them to 10-year cut-off periods for these higher exposures, would have resulted in extremely arbitrary assumptions, with a strong likelihood of exposure misclassification. If it is correctly assumed that exposure declined over time, our assessments are an underestimation of cumulative lifetime exposure, once again, driving our estimates toward null.

Data collected on smoking from medical surveillance questionnaires did not provide reliable information on the number of cigarettes smoked, and thus the number of pack-years could not be quantitatively estimated. The biases are probably present but their impact on prevalence cannot be estimated. Because of the possibility of confounding with age, smoking and the presence of HIV infection, the exposure-outcome relationships in this study would have best been studied through the creation of regression models.

However, the absence of an association in bivariate analyses of these variables with the variables of interest, suggested that either no association existed, or that the characterisation of these variables lacked validity (for example, the incomplete data on smoking and HIV infection). Thus, including these into a regression model would not have altered the findings substantially. This weakness in the study was largely due to the available information. It was not possible to correct for this weakness.

# CHAPTER 6  CONCLUSIONS AND RECOMMENDATIONS

## 6.1    Conclusion

A dose response relationship was found between coal mine dust exposure and the risk of development of pulmonary TB. Underground coal mining showed a significant and strong association with current TB as compared to surface mining. This study reported a prevalence of pulmonary TB of 9.9% in black migrant coal miners who historically had jobs in the dustiest areas in the mining industry.

The limitations of this study, including the cross-sectional design with the resultant healthy worker effect and absence of temporality, lack of historical exposure data and lack of sensitivity for the diagnosis of CWP, are all likely to reduce the estimates of exposure and outcome. Thus the findings of a significant association between TB and coal dust exposure in our study merits further investigation and action.

## 6.2    Recommendations

### 6.2.1    Future Research

The data highlight several issues that merit investigation in future studies. A more appropriate design for causal interpretation would have been a prospective study of TB incidence. There is nevertheless a clear need to conduct a prospective cohort study of the prevalence of pulmonary TB, its incidence and its determinants in coal mines. The prospective study design would better estimate exposure, TB and CWP. Although such studies should be relatively easy because of the high incidence of TB which would yield a sufficient number of TB cases over the assessment period, attribution of adequate working life exposure would remain a problem given the poor state of exposure surveillance and different systems on South African coal mines.

### 6.2.2    Policy Implications

The Mine, Health and Safety Act states that "the employer must determine measures necessary to minimise occupational risk to which employees are exposed, control the risk at the source, and where the risk remains they must institute a programme to monitor the risk." Our study identified elevated levels of exposure, particularly for those at the coalface. There is a need for dust control at the source using available engineering controls.

A programme needs to be implemented with the involvement of all stakeholders. Dust control involves administrative policy, education of employees, control at source, engineering control, and personal protective equipment as the last resort. Industry needs to build capacity and improved training in the hygiene field.

### 6.2.3   Additional Recommendations

- There is a need for strategic and effective TB surveillance in groups exposed to high respirable dust levels in coal mines.

- Respirable dust control and silica measurements must be part of the pulmonary TB and CWP control strategy of the coal mines.

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