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AN ASSESSMENT OF IMPACTS OF SMELTER EMISSIONS ON HUMAN HEALTH: A CASE-STUDY OF SELEBI-PHIKWE BCL COPPER-NICKEL MINE IN BOTSWANA.

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AN ASSESSMENT OF IMPACTS OF SMELTER EMISSIONS ON HUMAN HEALTH: A CASE-STUDY OF SELEBI-PHIKWE BCL COPPER-NICKEL MINE IN BOTSWANA.

A dissertation submitted to the Department of Environmental Science in partial fulfillment of the Degree of Master of Science in Environmental Science.

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DEDICATION

To my family here is another tool for utilisation may we remain united together forever.

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ACRONYMS AND ABBREVIATIONS

ACS- American Cancer Society

ATS- America Thoracic Society

ATSDR- Agency for Toxic Substances and Disease Registry

BCL- Bamangwato Concessions Limited

BNEL- Botswana National Environmental Laboratory

BOPA- Botswana Press Agency

CH_4 – Methane

CO_2 - Carbon Dioxide

COPD- Chronic Obstructive Pulmonary Disease

CSO- Central Statistics Office

Cu- Copper

EPA- Environmental Protection Agency

FEV1- Forced Expiratory Volume Over One Second

GDP – Gross Domestic Product

HIS – Health Information System

H_2SO_4 – Sulphuric Acid

IAEA- International Atomic Energy Agency

ICT – Information Communication Technology

IDCC- Infectious Disease Control Centre

IT- Information Technology

KM- Kilometres

MA- Microsoft Access

MDG- Millenium Development Goals

NEPAD- New Partnership for Africa's Development

NGOs- Non Governmental Organisations

Ni- Nickel

NOx – Nitrogen Oxides

NPL- National Priorities List

PHA- Public Health Assessment

ppb- parts per billion

ppm- parts per million

RR- Relative Risk

SO_2- Sulphur Dioxide

SPM- Suspended Particulate Matter

SPSS- Statistical Package for Social Sciences

sRAW- Specific Airway Resistance

UN- United Nations

UNDP- United Nations Development Programme

UNEP- United Nations Environment Programme

UNIDO- United Nations Industrial Development Organisation

USEPA- United States Environmental Protection Agency

WHO- World Health Organisation

ABSTRACT

The general objective of the study was to ascertain the relationship between smelter emissions and human health in and around Selebi-Phikwe. In Botswana BCL mine in Selebi-Phikwe is the leading producer of gaseous emissions in the country. The area of study consisted of locations in the town of Selebi-Phikwe and the surrounding villages, which were Mmadinare to the west, Bobonong and Tobane to the east, and Sefophe to the south. According to Ekosse (2004) there were high incidence rates of respiratory cases such as coughs and common colds recorded in the local health facilities. However it had not yet been shown that occurrence of respiratory diseases was due to smelter emissions from the mine. Therefore the undertaken study was to test the hypothesis whether there was a relationship between production of gaseous emissions from BCL copper-nickel mine and respiratory case load relative to distance and direction of plume movement. This was in line with the recommendation made by Asare (1999), who suggested the need for a health impact research in Selebi-Phikwe.

The undertaken project was conducted by means of a social survey whereby a household survey was conducted using systematic sampling and a formula by Yamane (1967:886) was used to calculate the sample size. Secondary data on respiratory related diseases in health facilities and key informant interviews were also key sources of information. Data collected was subjected to both qualitative and appropriate quantitative analysis tools.

It was found that the northwest direction was the most affected by SO_2 emissions, as most respiratory cases occurred in this direction, this was also supported by the meteorological data in the form of a wind rose which showed the prevailing wind direction as westerly. However there was no consistent relationship between distance and respiratory disease incidence. This could be explained by the height of the smelter stack and the type of the plume produced. Mmadinare was found to have a high respiratory disease incidence and the study revealed that the village was in the most affected direction (Northwest) where the prevailing plume was blowing towards and in the most affected distance range(16-20 km). According to Garg, (1999), the looping plume which has a wavy character may lead to emissions not directly landing on the closest settlements. Sporadic changes of prevailing plume type and direction and migration were regarded as confounding factors to explain high respiratory incidence in settlements far from the smelter.

Engagement of self improved attitude with setting and meeting standards by the mine may go a long way in improving SO_2 emissions reduction. Stakeholder involvement (academia, community and the government) may provide improved insights into the mine's operations in the bid to attain Millennium Development Goal number seven (#7) and Botswana's Vision 2016.Given that all settlements around the smelter were affected by the SO_2 emissions, it is recommended that the Ministry of Health be on high alert of respiratory diseases in the surrounding settlements and those further away, provide free periodic medical check ups and treatment strategies. Conducting health promotion and education is recommended to clear misconceptions of relating respiratory cases to other diseases such as HIV/AIDS. For further research it is recommended that a similar study be conducted in a settlement far away from smelting facilities to act as a check on the uniqueness of the results of this study. The undertaken project provided significant insights on human health in relation to gaseous emissions production, and will assist in policy intervention as it also acted as a pilot study to a health impact assessment research that the Botswana government may decide to conduct in the future.

CHAPTER ONE

INTRODUCING THE STUDY

The study is a health impact assessment on the population surrounding the Selebi-Phikwe BCL mine smelter complex. Due to production of smelter emissions the community has continuously made an outcry of their impact on human respiratory health. The study looked into factors that could be contributing to the increase in respiratory health deterioration.

1.1 Background of the study area

1.1.1 The geographical setting (location)

Selebi-Phikwe is geographically located in the north east of Botswana about 400 kilometres from the national capital, Gaborone, 159 kilometres from the second largest city, Francistown and 60 kilometres east of Serule on the Gaborone-Francistown trunk road (Selebi-Phikwe Urban Development plan, 1997).The town's geographical co-ordinates are 21°58'' South and 27°55'' East.

1.1.2 The Population

The study was limited to Selebi-Phikwe, and the surrounding settlements, these were Bobonong, Tobane, Sefophe, and Mmadinare. Selebi-Phikwe is a mining town located in the north east of Botswana. It had a population of 48 849 thousand, (CSO, 2001).The population of the surrounding villages of interest for Mmadinare, Sefophe, Tobane, and Bobonong were 10918, 3821, 1788, and 14622 respectively (CSO, 2001).

1.1.3 Economic Activities

At the time of the study the main economic activities in Selebi-Phikwe were mining, manufacturing, construction, wholesaling/retailing and domestic services, which employed about 26, 13, 11, 11, and 10 per cent of the local work force respectively. To a greater extent, the town's economy at first depended on the mining activity that generated employment for a large number of people directly or indirectly. Nickel mining began in 1973 and has been the town's main economic activity since then. The surrounding villages however were vastly occupied by agro-pastoral farmers. In Selebi-Phikwe town there were several economic activities including local large and medium scale industries, commercial businesses such as supermarkets, wholesales and restaurants that also provided employment. In the area of study agricultural activities such as livestock keeping and arable farming provided very minimal employment as compared to industrial and commercial sectors.

1.1.4 Health Status

The health status of Selebi-Phikwe and the surrounding villages has shown that local and surrounding health centers were recording a high incidence rate of respiratory diseases. For instance, data generated by Ekosse (2005:13), revealed that common ailments, sicknesses and diseases in the area with the four most frequent health complaints being frequent coughing, headaches, chest pains and rampant influenza/common colds. The Tables 1.1.4.1 and 1.1.4.2 show the disease trend of the respiratory cases in Botswana.

Table 1.1.4.1 Respiratory Cases recorded in Botswana, (CSO; 2000-2004).

Respiratory Cases Trend In Botswana				
	Years			
Age	2000	2001	2002	2003
<1	9955	10147	9443	11241
1.0 - 4.0	21393	21521	21977	23970
5.0 - 14	27910	25222	9136	25887
15 - 44	74901	75091	20350	69749
45+	18669	19513	11576	18925
TOTAL	152828	151494	44379	149772

Source: CSO Health Statistics 2004.

Table 1.1.4.2 Coughs and Colds cases recorded in Botswana, (CSO; 2000-2004).

Coughs and Colds Trend in Botswana				
	Years			
Age	2000	2001	2002	2003
<1	66381	66950	66099	69765
1.0- 4.0	130888	130187	136478	138981
5.0- 14	106796	90465	110831	93847
15 -44	167583	161230	141310	157510
45+	38457	39410	35516	40375
TOTAL	510105	488242	490234	500478

Source: CSO Health Statistics 2004.

1.1.5 Problem Statement.

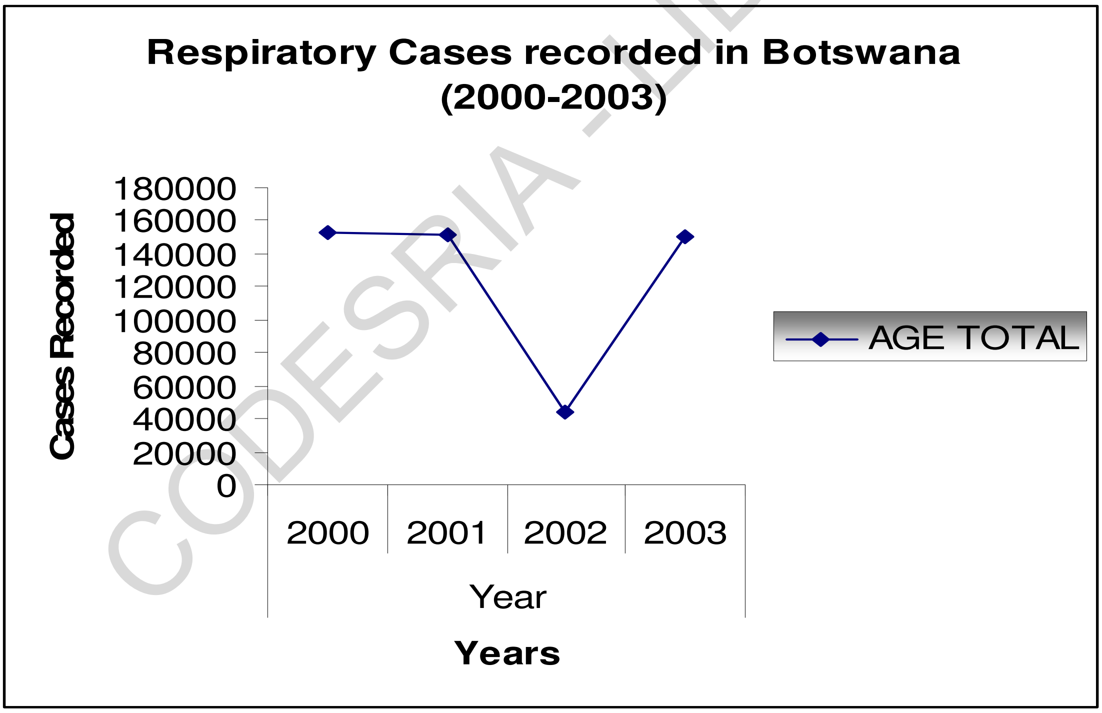
Data from 17 monitoring stations suggested that air pollution levels were high in three major settlements in Botswana including Selebi-Phikwe where the main pollutant was the SO_2 gas from the local copper-nickel smelter complex. There has been an outcry against fumes and odour produced from the mine smelter by the local community. The local health facilities were reportedly recording a high incidence of respiratory diseases (Ekosse, 2005). Generated data have revealed common ailments, sicknesses and diseases in the area with the four most frequent health complaints being frequent coughing, headaches, chest pains and rampant influenza/common colds. Recent evidence from

Botswana National Environmental Laboratory (2003:1), on the impacts of smelter emissions, showed that there were serious impacts on the population living in Selebi-Phikwe and the surrounding villages. The gases produced have apparently compromised the air quality as the local and surrounding health centres were recording a relatively high incidence rate of respiratory diseases. Therefore the study investigated the spatial occurrence of such diseases in relation to distance and direction from the mine smelter.

1.1.6 Justification

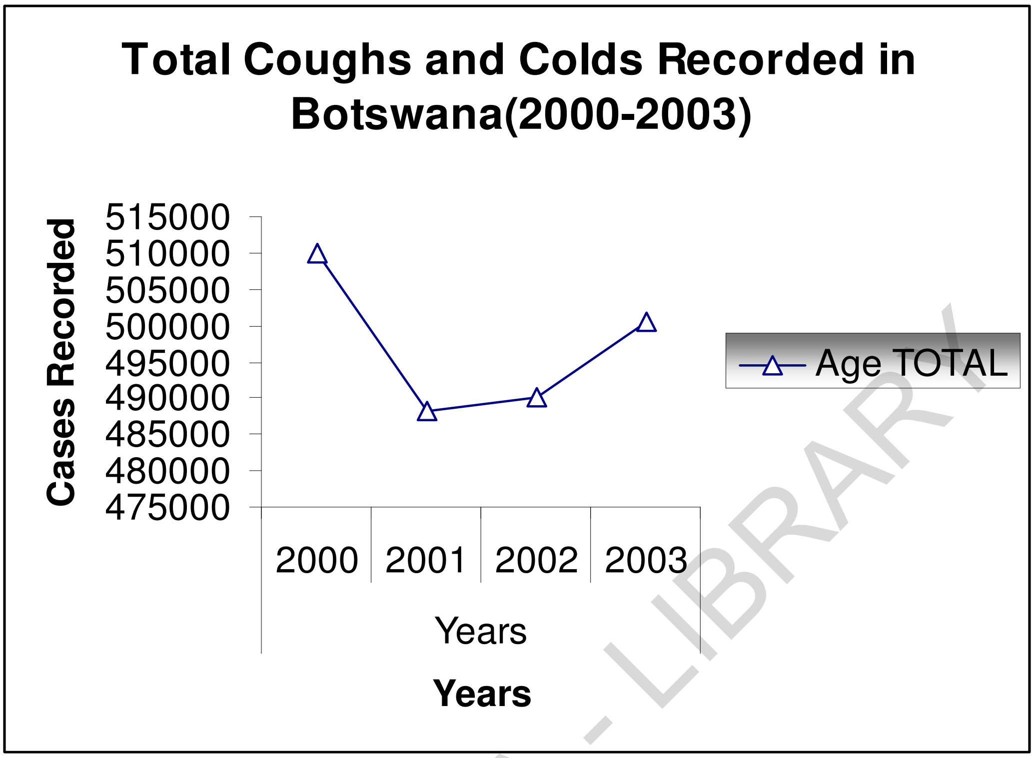
The research was justifiable both from a purely academic and policy perspective. Though SO_2 concentration levels often remained within the allowable limit of 160µg/m³ in Selebi-Phikwe, the gas damaged both natural vegetation and crops around the town, and was a health hazard, especially to asthmatic patients. This situation has compromised the attainment of National Millennium Development Goal number seven (#7), of ensuring environmental sustainability and the general commitment of Vision 2016 towards achieving Prosperity for All. Several researchers have already expressed the need to empirically investigate the spatial covariance of the gas emissions and the illness patterns within the affected areas in Selebi-Phikwe. For example it has been said that there was need for the government of Botswana to commission an independent medical research team to carry out a health impact research on the people to help establish the main health problems in the area so that appropriate control measures could be taken to forestall potential future damages (Asare, 1999; 59). This has been echoed recently when it was suggested that there should be a commission and funding of a health research project to focus on the health problems caused by the mine operations, particularly by the smelter smoke (Mengwe, 2004:67).There was therefore an urgent need to assess the extent to which gaseous production could be responsible for the reported incidence of ill-health in and around Selebi-Phikwe. Specifically, this meant establishing the relationship between residential location and the incidence of human disease, especially respiratory ailments, with the smelter as the reference point. The study was therefore not only a timely response to the current health-environment concern by research scholars but also an attempt to facilitate the achievement of the Millennium Development Goals and the ideals of Vision 2016 by providing information. Respiratory cases have been noted to be very high in Botswana this is shown in the figures below 1.1.6.1 and 1.1.6.2.

Figure 1.1.6.1: Respiratory cases in Botswana.



Source: CSO Health Statistics 2004.

Figure 1.1.6.2: Coughs and Colds recorded in Botswana.



Source: CSO Health Statistics 2004.

1.2 The Main Aim of the Study

The aim of the study was to assess the impact of gaseous emissions on the health of people in the vicinity of the mine plant in Selebi-Phikwe. The impact was a comparative analysis of different locations from the smelter, where settlements were found.

1.2.1 The Objectives of the Study

1. To assess the knowledge levels of the local community on the possible health impacts of gaseous emissions production.

2. To evaluate disease occurrence in different locations relative to the Selebi-Phikwe smelter and establish the most common (frequent) diseases in relation to locations around the smelter.

1.3 Key Research Questions

1. What was the knowledge level in the local community on the health dangers posed by gaseous emissions from the smelter? (Perceptions based on the relationship between gaseous emissions and human health).

2. To what extent was gaseous production responsible for the reported incidence of ill-health in Selebi-Phikwe and the surrounding villages? (Hospital records of respiratory cases the villages surrounding the mine).

3. Which of the settlements were worst or least affected by the smoke from the smelter in Selebi-Phikwe and nearby villages, and what were the most common diseases that occur? (Hospital records comparison of monthly incidence and prevalence per study settlement, household survey and key informant data).

4. To what extent did distance and wind direction contribute to the impacts of plume production on human health (and how frequent did plume blow towards the worst affected settlements)?
(Spatial dimension: the influence of distance from the smelter and wind direction on the impact of smelter emissions on human health).

1.4 The Rationale for Study

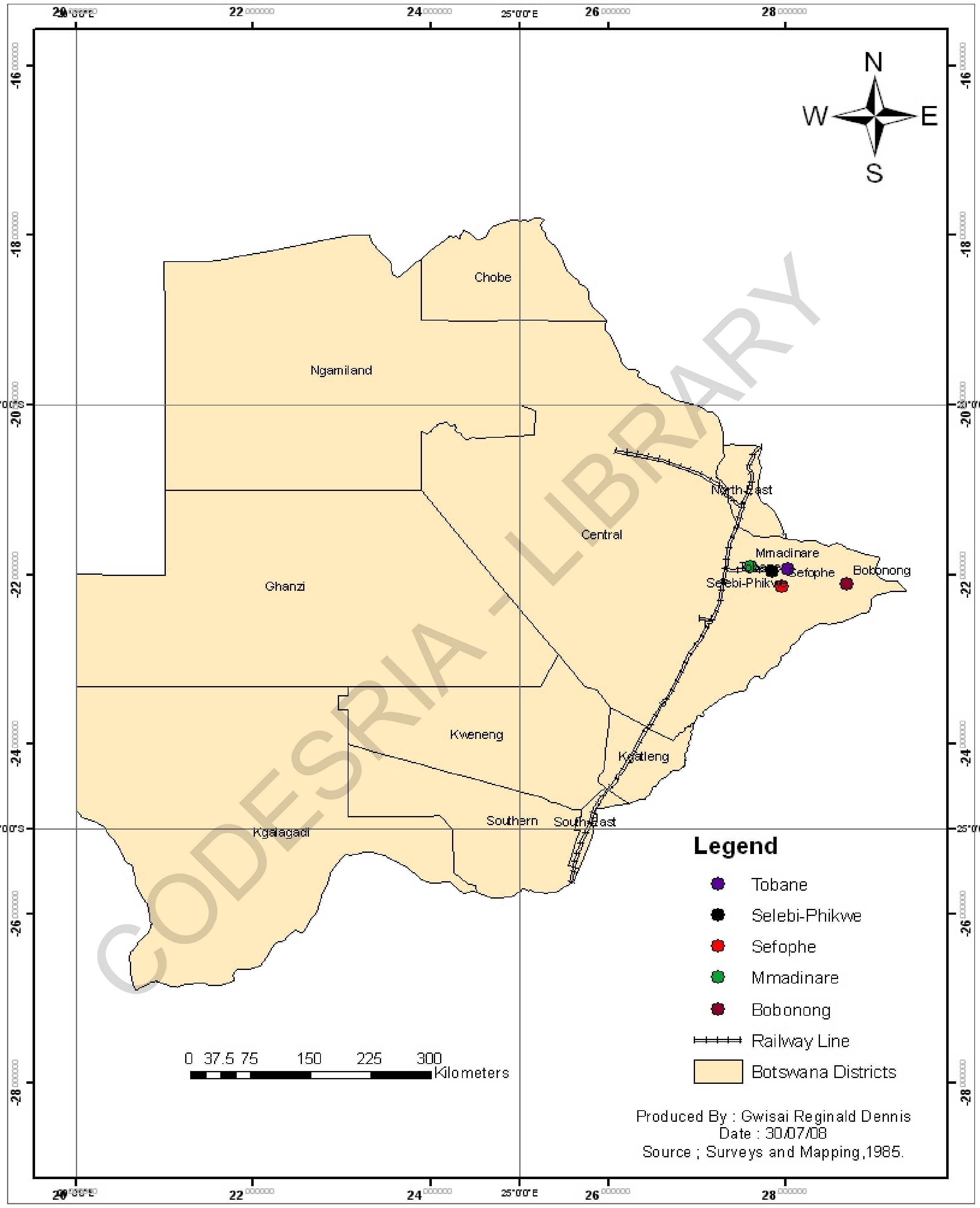
Improvement of human health is one of the goals of the Millennium Development Goals of the United Nations. Accordingly, Botswana has put measures in place to help protect and improve human health and welfare. The mining industry is a major employer in the country, with Selebi-Phikwe mine employing about 4890 people. Because of gaseous emissions from the smelter plant the employees and the surrounding settlements were at risk of contracting respiratory diseases.

The relationship between gaseous emissions produced by the smelter and the location and health of surrounding settlements was important. The undertaken health impact research attempted to reveal which settlements were affected the most so that strategies could be put in place to protect human health. Studies have indicated an increase in the incidence of respiratory diseases in Selibe-Phikwe. For instance, Ekosse (2005:11) maintains that "residents of Selibe-Phikwe area often produce symptoms of varied degrees of ailments, sicknesses and diseases." The number of settlements around the mine has increased, along with the resident population. For instance, Bobonong and Tobane, are in the east, Serule and Mmadinare in the west, and Sefophe in the south. Globally, industrial and urban air pollution is estimated to be responsible for approximately 800,000 premature deaths each year. Therefore the status of Selebi-Phikwe's gaseous production was examined to assess whether the emissions from the smelter have an impact on the settlements around it. The findings would have good health intervention policy or strategy implications.

1.5 The Scope of Study and Choice of Study Area

The proposed study was limited to Selibe-Phikwe and the surrounding settlements; these were Bobonong, Tobane, Sefophe, and Mmadinare. Selibe-Phikwe is a mining town located in the north east of Botswana. It has a population of 48 849 thousand (CSO, 2001). Nickel mining began in 1973 and has been the town's main economic activity since then. The town's geographical co-ordinates are 21°58" South and 27° 55" East. Figure 1.5.1 below shows the location of Selebi-Phikwe in Botswana.

Figure 1.5.1: Location of Selebi-Phikwe in Botswana.



Source: Botswana National Atlas, Department of Surveys and Mapping, 1985.

Smelter Emissions Impacts on Human Health in Botswana

Before mining activities begun there were two locations called Selebi and Phikwe, which straddled large undiscovered deposits of copper and nickel in the area. When the mineral wealth of the area was discovered in the 1960s, a mine and township were built in the woodland between the two locations with the combined name of Selebi-Phikwe. It is now the third largest urban centre in Botswana. Bamangwato Concessions Limited (BCL mine) is the main employer with about 4890 employees; its operations were based on the excavation of mixed Copper-Nickel ore from several shafts in deep and opencast mines. BCL was initially to stay in operation until 2010. However due to the current high nickel market prices operations were extended. The present shafts will be exhausted in a few years time, or by 2014 according to recent projections. For instance, in 2005 the Minister of Finance and Economic Development of Botswana Mr Gaolethe was quoted by, Botswana Press Agency (2003) as saying "the mining activities in Selebi-Phikwe will continue for the next ten years." A small coal fired power station was built along with the mine, to meet the electricity needs of the mining operation and the surrounding area and also contributes to air pollution.

Selebi-Phikwe was picked for the study because it hosts the only smelter in the country. And as already noted the smelter emissions were a major health concern. Respiratory diseases have been on the rise since the inception of the mine in Selebi-Phikwe. The study assessed the impact of gaseous emissions on the health of the people in and around the mining town. This impact was viewed on a comparative analysis of different locations surrounding the mining plant.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

In the past few decades, man has polluted the atmosphere, so heavily that much of the population now breathes a mixture of highly toxic gases in every lungful air (Kumar and Bohra, 2002:13). Every human being depends on the 12,500 quarts of air he/she breathes each day, yet man persists in using the sky as a refuse bin. Smoke was introduced into the air with fire and the volume of soot and smoke (SPM) increased with the advent of soft coal and the birth of industrial cities. In the years that followed, the volume of pollutants in the city air has increased faster than ever; while their nature has changed for the worse since old fashioned coal and low grade fuel oil still send soot and SO_2 into the air (Kumar and Bohra, 2002:15). SO_2 was produced as a gas and was blamed for the prevalence of respiratory diseases. Air pollution has become a severe health problem and thus a political issue in the cities of most developing economies over the last decades. In particular the concentrations of toxic pollutants in urban areas, have already reached levels that pose risk to human health (Wagner, 1994). In many cities there were a large number of industrial clusters intermingling with the residential areas and some of them even have thermal power plants located within or close to the city premises. Chile continues to face major health and air pollution challenges in the metropolitan region (which accounts for forty percent of the country's population and forty-eight percent of the GDP) and in the mining sector (with major sources of SO_2 particles and arsenic).General emission standards are still lacking for industrial processes and for emitters of toxic air contaminants (Chile Environmental Performance Review Report 2005:4).

In a full report by UNEP (1992), human health and environmental quality control have been undermined, because industries were producing harmful gases such as SO_2. Most nations have prioritised economic development and emphasis on cleaner production methods has been sidelined (United Nations, 1993:50). The impacts of gaseous emissions from industries have been a major concern particularly in developing regions like Africa where they are still emerging and growing. The most common gases produced were methane (CH_4), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrous oxides (NOx) and other hydrocarbons. However according to UNEP (2002:27), there was still lack of appropriate early warning systems, and prediction of atmospheric changes and fluctuations resulting from local air pollution. In Chile general emission standards were lacking for industrial processes and for emitters of toxic air contaminants. However air quality was being monitored, and emission inventories have been developed, but only for a few major cities and for areas surrounding copper smelters. The findings were that emissions of SO_2 remained very high, and these should be further reduced (Chile Environmental Performance Review 2005:4).This has been another serious challenge to intervention, particularly so for industries and urban air pollution, desert dust storms, savanna and grassland or forest burning and related emissions.

It has also been discovered that institutions in the regions were also weak in data collection and transformation for policymaking. Overall, most countries lacked relevant, strong and efficient regulatory bodies; therefore it was essential that these barriers be lifted urgently to meet the air pollution targets for the region.

In Botswana mining has developed to become a major economic player for the country's domestic product and rates of air pollution have been on the increase. Since its establishment in 1967 Selebi-Phikwe has experienced rapid growth in population. This was partly evidenced by the growth in settlements in and around the town. It was essential therefore to find out whether these people were not being affected by the gaseous emissions that were being produced from the mine (Murray and McGranahan, 2003).The mine operations were a major employer and were therefore a source of income for many residents.

Therefore, instead of winding up operations in 2010 as scheduled, the life of the mine has been extended to 2014.This means that people of Selebi-Phikwe and its environment will continue to be exposed to the mine's smelter emissions for a protracted period of time.

2.1 History of Mining and Air Pollution

Anthropogenic activities over the last century have raised atmospheric SO_2 concentrations by three fold orders of magnitude (Pharm *et al.,* 1996).Of greater significance was the increase in production of derived sulphate aerosol, which indirectly affects the climate system. Copper smelting, involving extraction of copper from chalcopyrite ($CuFeS_2$), liberates large quantities of sulphur gases, approximately two tonnes of SO_2 were discharged in flue gases which also contain CO_2 per tonne of copper produced. Smelters have long been recognised as significant sources of SO_2 and other pollutants (Gidhagen *et al.,* 2002), for example the environmental crisis associated with Ni-Cu smelting on NW Russia's Kola Peninsula is well known (Simonetti *et al.,* 2004). Most polluting smelters are now situated in developing countries, where modern sulphur capture technology could be unavailable or unaffordable. Approximately 50% of smelters captured less than 84% of emitted SO_2, whilst 10% captured none at all (Boon *et al.,* 2001). Most of the latter are situated in Australasia, South America, China and largely in Africa.

Blackening of lung tissues through long exposure to particulate air pollution in smoky dwellings appeared to be common in mummified lung tissue from ancient humans (Murray and McGranahan, 2003:2). In the 18^{th} and 19^{th} century unhealthy air was a suspected cause of disease long before the relationship could be scientifically confirmed. The miasma theory of disease still widely held well into the 19^{th} century blamed a wide range of health problems on bodily disturbances resulting from bad air (Murray and Mc Granahan, 2003:2). Industrialisation therefore brought documentation of local impacts of air pollution on human health and collection of statistics of deaths resulting from air pollution in London, Belgium, USA, and Japan. Due to lack of appropriate health and environmental quality control, most industries in Africa were not regulated.

The development of civilisation and rapid industrialisation by man has caused great damage to the ecosystem, things have worsened because no attention or minimum attention has been paid towards protecting the environment while executing industries and other developmental projects (Garg, 1999:621).The concept of sustainable development has been undermined as the global economy was still focusing on economic growth. For instance in Zambia SO_2 emissions from roasting and smelting operations and the burning of sulphur containing fuels were the main sources of air pollution in the Copper belt area. Concentrations of SO_2 occasionally exceeded recommended levels of 600µg/m³ per hour or 200µg/m³ per day (Zambian National Report 1997). Mining development in Botswana has also developed at a faster rate and the protection of the health of people has been undermined in the bid to attain riches.

In their study finding the relationship of smelter emitted metals in water lakes, Telmer *et, al.,* (2006) concluded that lakes within 50 km of the smelter had elevated metal concentrations in their near-surface sediments due to stack emissions but, due to element cycling and mobility, it was difficult to quantitatively determine the magnitude of metal increase attributable to the smelter. They also suggested that due to upward remobilisation, the duration of industrial metal enrichments in surface sediments (the residence time) may be increased, thereby making surface enrichments more persistent than would be predicted by the sedimentation rate.

2.2 Operations leading to production of air pollutants

Mufulira smelter in Zambia has the following main process operations; copper concentrate reception and handling, copper smelting, converting and fire refining. However according to Ross, (2005:2), there was no SO_2 abatement facility and all the gaseous emissions produced in the smelting process were vented into the atmosphere. If coal was used pollutants like fly ash, SO_2 and nitrogen oxides were produced on a large scale (UN 1993:37). In the case of oil, only SO_2 and nitrogen oxides (NOx) were produced as the major pollutants (Garg, 1999:637).Coal thus proved to be a 'dirty' fuel, and were an important source of particulate air pollution. The amount of fly ash and SO_2 produced by the coal was dependent on its quality, sulphur and ash content found in it (Garg, 1999:639).

Fly ash from smelters falls out, up to large distances from the plant. Heavy amounts of plume could go as far as three to six kilometres and the fallouts increased in distance during dry windy seasons (Garg, 1999:40). Botswana being a semi-arid land has very high temperatures and dry air; these conditions increased the rate of spread of the plume especially to the surrounding settlements.

Mining in Selebi-Phikwe causes air pollution in two ways, firstly it adds gaseous pollutants to the air and secondly it emits and adds dust particles to the atmosphere. The harmful gaseous pollutants, like sulphur dioxide (SO_2), oxides of nitrogen (NO), carbon monoxide (CO) were originating from mining activities, whereas dust particulates were produced during ore or coal handling, blasting and transportation (Garg, 1999:639).According to the BCL mine General Manager Montwedi Mphathi, in a weekly newspaper *The Botswana Gazette,* "there is an immediate requirement to cut costs, increase production so that the unit cost is marginal so that the mine can break even", (*The Botswana Gazette* 2009: B5, Week 17-23 June 2009). This could override proper safety strategies to reduce smelter emissions production at the mine.

2.3 BCL mine operations as of September 2008

BCL mine operated a mining and smelting (Outokumpu Flash Smelting Furnace) complex at Selebi-Phikwe in the North East region of Botswana. Copper-Nickel sulphide ore was mined at four shafts, namely Selebi, Selebi North, Phikwe Central and Southeast Extension.

According to the BCL mine September 2008 report, the ore was milled in the concentrator at a rate of approximately ten thousand tonnes per day with a resultant 2 500 tonnes per day of metal enriched concentrate being delivered in slurry form to the smelter. The BCL concentrates together with toll concentrates from Tati and Nkomati mines were dried before smelting. The smelter produced on average, six thousand tonnes of matte per month. The smelter was a complex plant, which consisted of six major plant areas as follows:

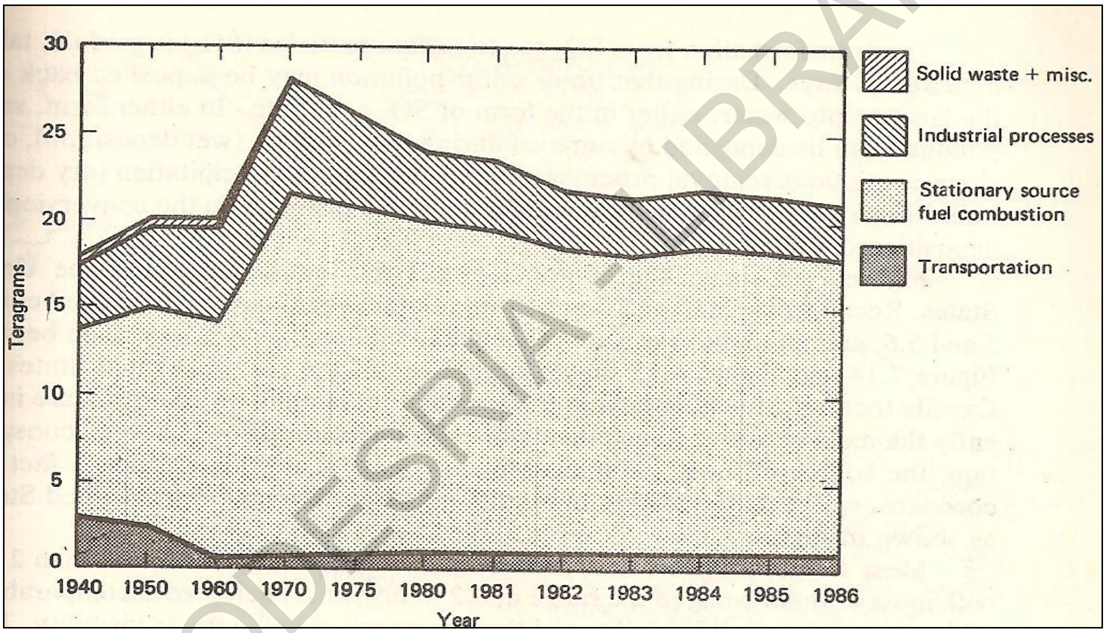
- A coal plant
- A concentrate drying plant
- A flash smelting furnace
- A waste heat boiler (WHB) and gas handling system
- A slag cleaning system including two electric furnaces
- A converting and matte handling system

The mine has measures put in place for operations and mitigating high SO_2 production. Therefore the mine has SO_2 monitoring and control strategies, for the significant environmental aspects of the mining and smelting processes.

2.4 Oxides of Sulphur

More than 80 percent of SO_2 emissions were a result of anthropogenic causes from fossil fuel combustion in stationery sources, (Masters, 1991).The only significant non-combustion sources of sulphur emissions were associated with petroleum refining, copper smelting, and cement manufacture. This was shown in the figure below, (USEPA, 1988a) showing trends of SO_2 emissions.

Figure 2.4.1: Trends of SO_2 Emissions, 1940-1986 (USEPA, 1988a).

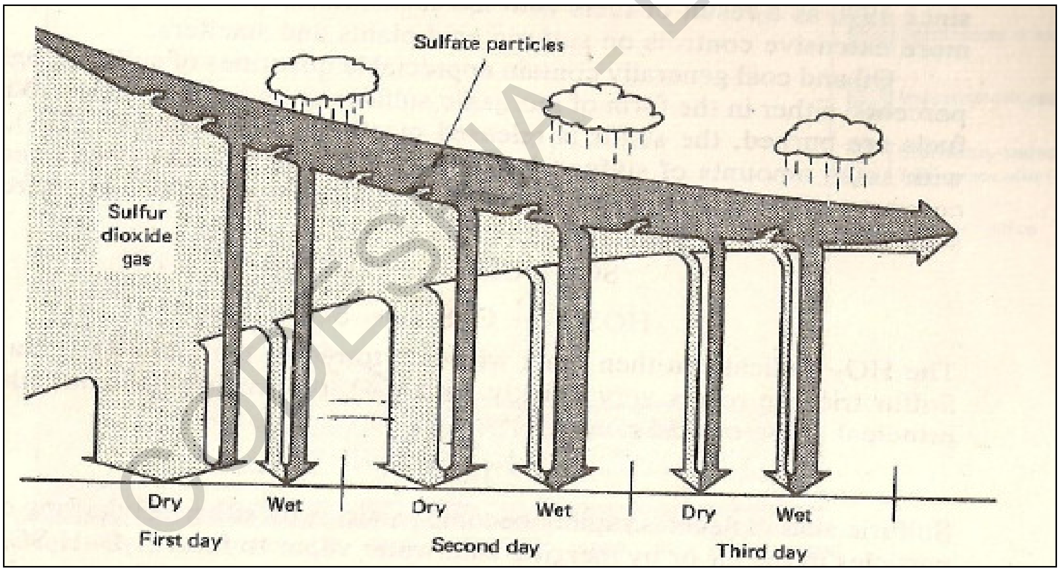


Source: Introduction to Environmental Engineering and Science, (Masters, G.M., 1991).

The total SO_2 emissions have been reduced by about 25 percent since 1970 as a result of fuels with lower sulphur content, flue gas scrubbing, and more extensive controls on sulphuric acid (H_2SO_4) plants and smelters, however respiratory cases were rising in hard hit areas.

The transformation from SO_2 gas to sulphate particles (SO_4) was gradual, taking a matter of days. During that time sulphur pollution could be deposited back onto the land or into water and inhaled by humans either in the form of SO_2 or sulphate. In either form, sulphur pollution could be deposited by removal during precipitation (wet deposition), or by slow, continuous removal processes that occur without precipitation (dry deposition). Figure 2.4.2 below suggests the effects of time and distance on the conversion and deposition of sulphur.

Figure 2.4.2: Time and distance effects on conversion and deposition of sulphur pollution, (OTA, 1984).



Source: Introduction to Environmental Engineering and Science, (Masters, G.M., 1991).

With a lag time of this nature SO_2 emission would impact on the health of people in the atmosphere after a single explosion for a prolonged continuous period of time, SO_2 gas could either be in the dry and wet form to cause harm to human health and this could be eye and nose irritations (United Nations, ECLAC and OECD, 2005).

2.5 Effects of Sulphur dioxide production

Sulphur dioxide (SO_2) is a colourless gas emitted from the combustion of coal and oil, it mainly originates in the atmosphere, from the refineries and chemical plants, smelting operations and burning of fuels. In the case of Mufulira in Zambia, there has never been a provision of SO_2 fixation at the mine smelter since the initial furnace was commissioned in 1937 and gases were vented into the atmosphere.

SO_2 has been regarded as one of the traditional pollutants of urban areas and was normally a local pollutant, especially in moist atmospheres but in oxidised forms it could persist and be transported considerable distances as fine particulate (Murray and Mc Granahan, 2003:4). Gaseous form could remain in dry atmospheres for many days and be subject to long range transport processes. As a local pollutant, ambient concentrations of SO_2 could show considerable spatial and temporal variations. Millard (1971:21) describes it as "one of the most destructive pollutants in the chemical soup we breathe." Both man-made and natural processes contributed to atmospheric SO_2. For instance, about half of the world's SO_2 emissions came from natural sources (like volcanic activity) while the other half was a result of human activity, mainly fuel combustion in coal or oil fuel stations. Human made emissions have been increasing at a rate of four percent annually (WHO 1992:16). In previous studies conducted in Mexico City, it was observed that children with moderate to severe asthma were more susceptible to air pollution, Romieu *et al.,* (2008).

Depending on the source of particulates and SO_2, the ambient air would vary (American Thoracic Society, 1996:12). In areas where fossil fuels with high sulphur content were used, such as in Beijing, China, high levels of SO_2 could be reached, especially during the warm season. However in other smelting plants in the developing nations there has been good progress in reducing SO_2 emissions for instance the Rustenburg operations in South Africa, and Impala springs in Zimbabwe, monitoring stations have been developed and have facilitated emission reductions by 8.6% (from 5.8kg per ounce in 2006 to 5.3kg per ounce in 2007). An emission control strategy has also been put in place to further reduce these emissions. (Implants Corperate Responsibility Report, 2007:10-15).

The unpleasant odour was detectable at concentrations greater than about 1ppm, although above 3ppm the sense of smell was rapidly lost. Its tropospheric concentrations range from less than 1ppb in locations very remote for industrial activity to 2ppm in highly polluted areas. It is a respiratory irritant that could cause shortness of breath, enhanced likelihood of lower respiratory tract illnesses and chronic lung disease. Even relatively short exposure to the higher concentrations found in polluted areas could cause temporary damage to human health (WHO, 1992:16). The pollutant was not found alone, and its potency was frequently enhanced by synergistic interactions with other contaminants. There were indications that in the presence of particulates, the incidence of respiratory tract disease could be increased even at concentrations as low as 30ppb SO_2 (American Thoracic Society, 1996:13). It was a significant ingredient in smogs that have claimed many lives in the past, for instance the London smog in the 1940s (Wellburn, 1994).

Health effects were observed during episodes of high pollutant concentrations (SO_2 and particles exceeding 750µg/m³) in London, New York and other areas (Murray and McGranahan, 2003:7). Air pollution has caused problems for the local communities especially SO_2 emissions, a side effect of the copper smelting process. For instance high SO_2 levels were a problem in the Zambian copper belt and various concerns persist around Vedanta Nkana and Chingola /Nchanga operations (Rose, 2007:22). High exposure episodes of several days duration were associated with bronchial symptoms (for example shortness of breath and asthma attacks) increased rate of hospital admissions, and in people with pre-existing heart and respiratory disease, death. While measured awareness and concern for potential effects have virtually eliminated severe episodes, such as the 4000 excess deaths attributed to the 1952 episodes in London, various parts of the world experienced high concentrations of pollution (UNEP, 1986:20). Kumar and Bohra (2002:16) suggest that air pollution from mines has elements to consider, these were SO_2, suspended particulate matter (SPM), and nitrogen dioxide (NO_2). However due to coal usage the production of SO_2 was very high and this resulted in many respiratory tract disease cases. Air pollution was also associated with increased daily mortality (Pope, 2000). A large number of daily mortality time series analysis have provided sufficiently convincing evidence that non-accidental mortality, including cardio-pulmonary mortality was associated with ambient particulate matter exposure in the U.S.A (Ostro *et al.,* 2007), Canada (Burnett *et al.,* 2000), Rome (Forustiere *et al.,* 2007), China (Kai *et al.,* 2007), Korea (Lee *et al.,* 2000), Greece (Katsouyanni *et al.,* 1997), and Chile (Lakmak *et al.,* 2007).

The incidence of diseases included serious threats to human, animal and plant life, increase in eye and skin irritation including cataracts, general suppression of the immune system, and respiratory diseases (UNEP 1992:177). For instance in 2005 Nkana smelter was allowed to emit 500 $\mu g/m^3$ per twenty-four hour period on average however this was above the set levels of the Zambian environmental pollution laws and about twenty-five times more than the recommended World Health Organisation standards. This has made emissions produced by KCM seriously damaging to human health of the local population (Rose, 2007:23). SO_2 was also responsible for causing acidity in fogs, smokes, and in rains hence was the major source of corrosion of buildings and metal objects (Garg, 1999:645). Health effects of energy related air pollution could be understood in three different scales that is indoor (homes and workplaces), local or regional and long range. At local or regional level, air pollution concentrations were greatly affected by the mix and size of different pollutants, topography and meteorological conditions such as atmospheric inversions. Long range air pollutants, such as ozone and acid rain were of international concern. Health effects could be acute, caused by short term air pollution episodes, chronic, from long term exposure to low levels of pollutants in the atmosphere including radio nuclides.

Acute health effects were the best well documented. These were caused principally by coal combustion in factories, mines without adequate particle emission control measures. The inhalation of air that contains SO_2 in excessive amounts could have a number of adverse health effects. Some of the possible effects as indicated by WHO, (1992), included worsening respiratory sicknesses such as chronic bronchitis from long term exposures.

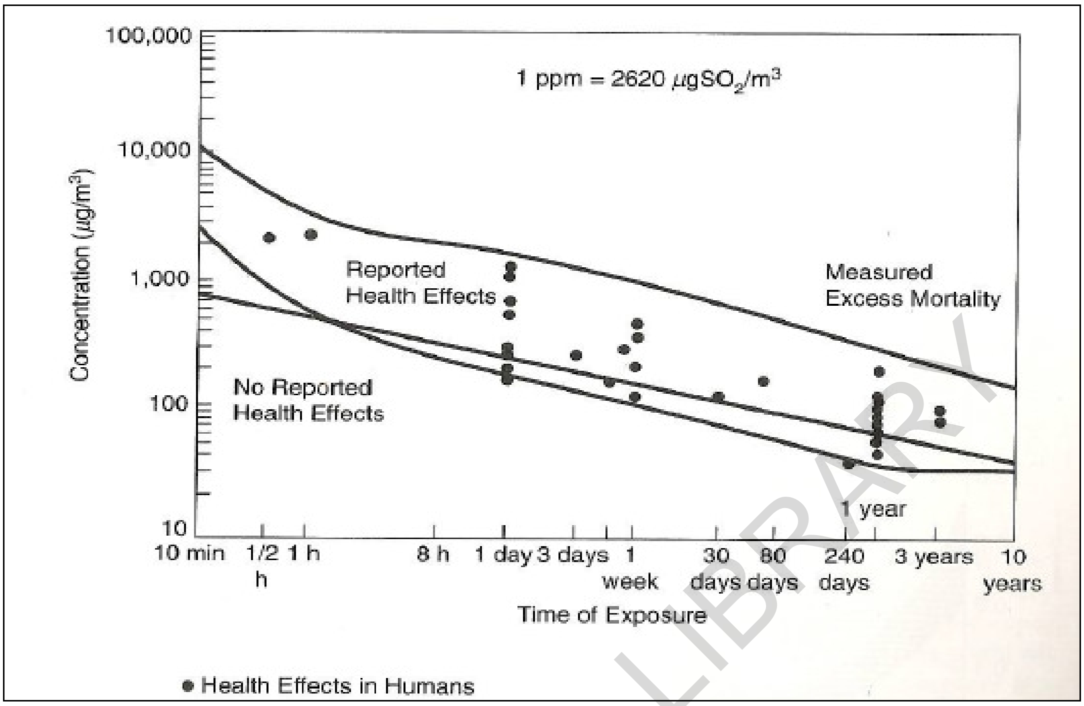
The respiratory system is involved with breathing and exchanging oxygen for carbon dioxide in the red blood cells. The common medical disorders of the upper respiratory tract were colds (coryza), sinusitis, tonsillitis, chronic tonsillitis, epistaxis, laryngitis, bronchitis, chronic bronchitis, pneumonia, tuberculosis, asthma, pulmonary emphysema, and cystic fibrosis (Hayward and Clark, 1982:65). Aggravations as well as causation of asthma and pulmonary emphysema have been considered to be due to SO_2 (Elsom, 1957:15, 24). SO_2 was also thought to cause irritation on the eyes and within the nasal passage ways (Wellburn, 1988:53). It could have different adverse impacts on human health at different levels of concentration and at different levels of exposure. The effects range from worsening of bronchiotic patients to paralysis and death. It was not possible to ascertain the exact level of concentration of SO_2 in the study areas because this was not within the scope of the paper. However, it could be seen that even at very low concentrations, SO_2 could affect human health. Patients of asthma were very badly affected by this pollutant, (Garg, 1999:645).Some quantity of atmospheric SO_2 could oxidise to form SO_3 which when inhaled would dissolve in the body fluids to form sulphuric acid (H_2SO_4) which was a very strong corrosive acid. Sulphur trioxide (SO_3) thus caused high and worse irritation and even at lower concentrations, led to severe bronchospasm.

The term suspended particulate matter (SPM) refers to a wide range of finely divided liquids dispersed into the air from combustion processes, industrial activities, and natural sources (Elsom, 1987:19). Particulates were divided into those that were water soluble and those which were not; the latter consisted of elemental and organic carbon, iron oxides (FeO) and a variety of other chemicals (Wellburn, 1988:20). Organic carbon was also known as soot made up of particles strung together in long chains (Millard, 1971:19).

Long term exposure to particulate matter could both cause and aggravate respiratory diseases (especially asthma and pulmonary emphysema) and also damage the lungs. The organic compounds present in SPM were worrying because many of them were known to be carcinogenic. The young and the old, particularly those with pulmonary and heart diseases were more susceptible to SPM. Continuous exposure of young children could have serious effects as early respiratory illnesses would develop into chronic ailments later in life (WHO 1992:20, 21). In addition, particles had an indirect effect by acting as carriers for other chemicals which otherwise would not be able to get into the lungs and SO_2 was one of them.

Health effects have been the dominant considerations from the early air pollution episodes, although the specific pollutant or groups of pollutants generating the observed effects frequently could not be identified, according to Henry *et al.,* (1996:498) there has been sufficient information to implicate certain pollutants as significant contributors. Figure 2.5.1 shows the effects of SO_2 emissions on humans from the U.S. EPA Report 450-R-92-001 (1992).

Figure 2.5.1: Health effects of SO_2 in United States of America.



Source: Environmental Science and Engineering, Moroz, W. J., (1996), (compiled from several sources).

From the Figure 2.5.1 the time lag for health effects to be experienced varied with each individual, however, the results of the study show that the effects were felt continuously right from the time of release of SO_2 gas from the smelter stacks.

2.6 Plume Movement

In meteorology and hydrology, the temperature conditions and the environment are defined by a technical term, called the lapse rate (Garg, 1999:652). According to Garg, (1999), "the lapse rate in the troposphere is the temperature of the ambient (surrounding) air which normally decreases with an increase in the altitude (height) or simply put as the rate of change of temperature with height."

The wind had an impact on the dispersion of pollutants; such movement in the air is caused by the unequal distribution of atmospheric temperature and pressure over the earth's surface and is largely influenced by the rotation of the earth. The direction of wind is always from high pressure areas to low pressure areas, settlements on the windward side of a pollution source were likely to be more polluted than those on the leeward side (Garg, 1999:656). There are several predictions on what happened to gases emitted from a source. These gases are known as plume if their source or origin was a stack. Plume types included, looping plume, neutral plume, coning plume, fanning plume, lofting plume, fumigating plume, and trapping plume. When smoke containing air pollutants is released into the atmosphere from a source such as a factory chimney, it gets dispersed into the atmosphere into various directions depending on the prevailing winds and temperature and pressure conditions in the environment. The climatological factors for Selebi-Phikwe are shown in, Table 2.1.

Table 2.1 Climatic factors that could influence plume behaviour.

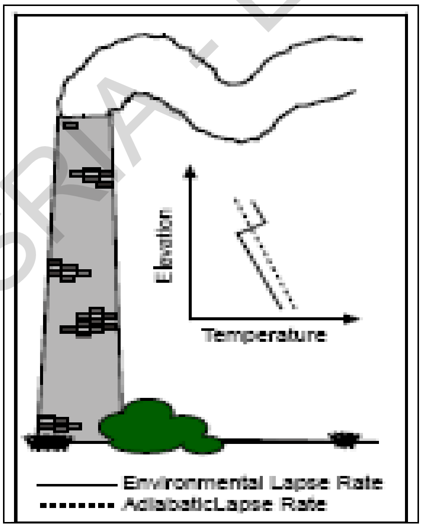
Wind direction	Prevailing wind blowing to the north west of the smelter (Mmadinare's direction).
Wind speed	Usually faster in summer and dry seasons.
Average rainfall	Low, higher in summer ranges between 50-100mm.
Temperature	Low in winter and high in summer, an average of 25-35 degrees Celsius.

Source: Department of Waste Management and Pollution Control.

2.6.1 Types of Plume

Looping plume has a wavy character and occurred in super adiabatic environments which produced highly unstable atmosphere, because of rapid mixing.

Figure 2.6.1 Looping plume.

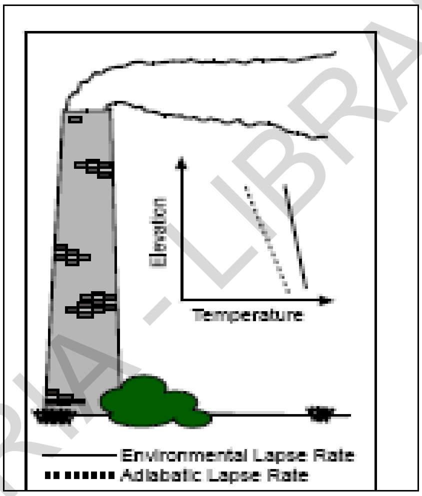


Source: Franek and Lou DeRose (2003:94).

Neutral plume is the upward vertical rise of the plume from the stack, which occurred when the environmental lapse rate is equal to or very near to the adiabatic lapse rate. The upward lifting of the plume would continue till it reached an air density similar to that of the environment.

The neutral plume tends to cone when the wind velocity is greater than thirty-two kilometers per hour and when cloud cover blocks the solar radiation by day and terrestrial radiation by night. Coning plume also occurs under sub-adiabatic conditions (when environmental lapse rate is less than the adiabatic lapse rate).Under such conditions, the environment is slightly stable and there is limited vertical mixing thereby the probability of air pollution in the area.

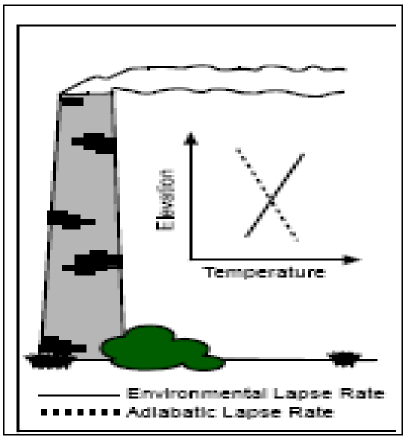
Figure: 2.6.2 Coning Plume.



Source: Franek and Lou DeRose (2003:95).

Fanning plume takes place under extreme inversion conditions caused by negative environmental lapse rate from the ground and up to a considerable height, extending even above the top of the stack, the emission would spread only horizontally as it could not lift due to extremely stable environments.

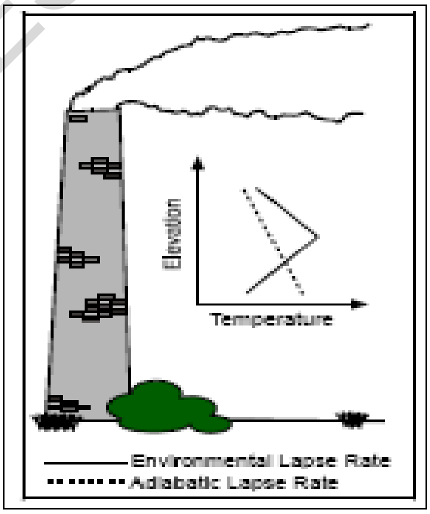
Figure 2.6.3: Fanning Plume.



Source: Franek and Lou DeRose (2003:94).

Lofting plume occurs when there is a strong super adiabatic lapse rate above a surface inversion. Such a plume has minimum downward mixing as its downward motion is prevented by inversion, but the upward mixing is quite turbulent and rapid. The dispersion of pollutants would therefore be rapid and no concentrations would touch the ground. Hence this would be the most ideal case for dispersion of emissions.

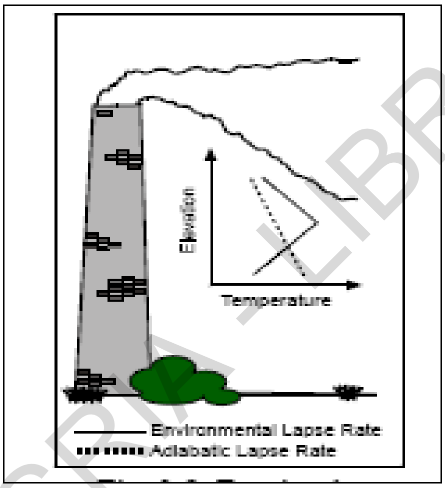
Figure: 2.6.4 Lofting Plume.



Source: Franek and Lou DeRose (2003:95).

Fumigating plume is when an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below the stack. In such a case, the pollutants can not escape above the top of the stack because of the layer and they would be brought down near the ground due to turbulence in the region above the ground and below the inversion, caused by a strong lapse rate. This represents quite a bad case of atmospheric conditions for dispersion.

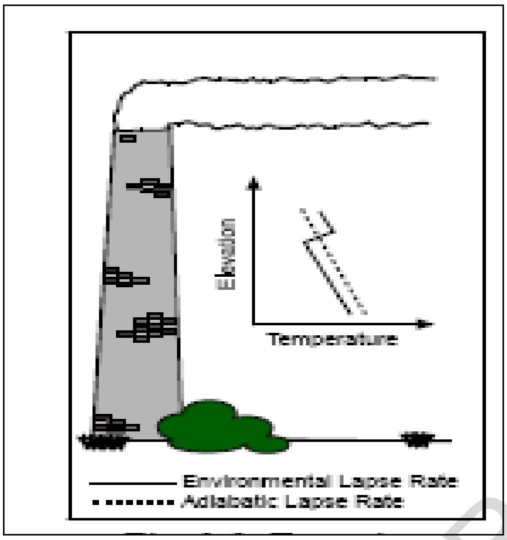
Figure: 2.6.5 Fumigating Plume.



Source: Franek and Lou DeRose (2003:95).

Trapping plume occurs when inversion layers exist above the emission source as well as below the source. Naturally the emitted plume would neither go up nor down and would remain confined between the two inversions. Such a plume was considered a bad condition for dispersion as the dispersion could not go above a certain height.

Figure: 2.6.6 Trapping Plume.



Source: Franek and Lou DeRose (2003:96).

2.7 The Respiratory System: Pollutant Movement within the body

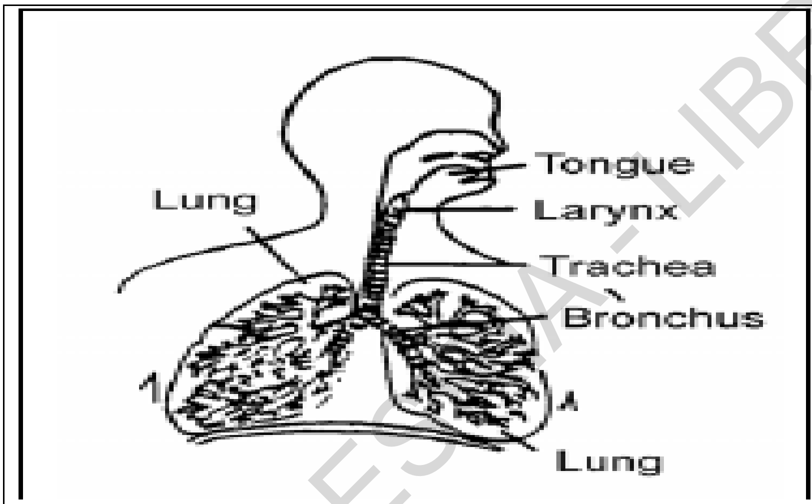
The respiratory system is the organ system that biologically is affected by gaseous emissions and led to the increasing disease case load of the human health infections under study. Knowledge of how the system is affected illustrates the possibility of such diseases occurring among different individuals at different intensities of exposure to the smelter emissions. It must be appreciated that the probability of long term effects that could not be covered by the current study or other side effects that could not be ascertained have a root cause in gaseous emissions from the mine smelter in Selebi-Phikwe.

Current concerns about health effects of airborne particles were largely based on results of recent epidemiological studies. These suggested an increase in mortality and morbidity at levels below the current standards and a stronger and more consistent effect of fine particles (less than 2.5 micrometres) that appeared to contain more of the reactive substance potentially linked to health effects (EPA, 1996, Schwartz, 1996, Wemm, 2000, Pope, 2000). Air pollutants got into the body mainly through breathing. Once they entered the body they could remain in the lungs, be exhaled, or move into the blood from the lungs. If they entered the bloodstream they were transported to all parts of the body, as they moved through and around the body, pollutants could undergo many chemical reactions especially in the liver where they became less or more toxic. The pollutant could be exhaled, it could leave the body in urine, bowel movements, sweat or breast milk or it could be stored in hair bone or fat (Evans and Wolff, 1991). Human exposure to air pollution usually manifests itself as either an acute (short term) or chronic (long term) health effect.

Typically, pollutants enter the body as air would be inhaled through the use of the mouth into the upper respiratory system. Prior to reaching the lower respiratory system, most of the larger particulate matter (>15micrometers diameter) would be removed from the body by small nasal hairs or by the mucus membranes that line the respiratory tract from the nasal cavity through the nose and throat (Talukdar and Sharma, 1991). Smaller pollutant particles (<10micrometres diameter) that escape these defence mechanisms become trapped in the cilia. The cilia are fine, hair like structures that line the respiratory system walls through the bronchioles. Their wave-like motion carries mucus and trapped particulate matter (PM) toward the upper respiratory tract for expulsion. As demonstrated, the body has several defence mechanisms to combat and expel particulate matter (PM).

The cilia are the last line of defence in the bronchioles before reaching the alveoli. Particles measuring between 1 micrometre to 0.1 micrometre in diameter that escaped capture by higher defence mechanisms eventually settle in the alveoli where it may take weeks, months or even years to expel particles. Alveolar tissue fight the foreign matter by producing phagocyte cells that would eventually envelop it, permanently holding the particulate in place. However once the particulate matter is surrounded, the soluble toxins are then removed and transported through the blood stream to other parts of the body. Although this method of trapping particulate matter in the alveolus is one of the body's natural defence mechanisms, it is still dangerous for pollutant matter to reach such depths in lung tissues.

Figure: 2.7.1 Respiratory system.

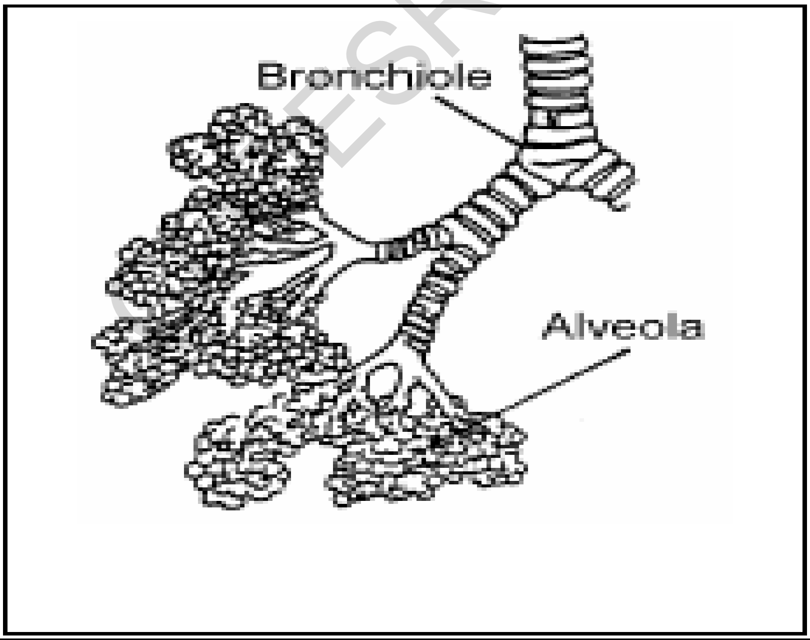


Source: Franek and Lou DeRose, (2003:134).

Gaseous air pollutants affect lung function in many ways, but most notably by slowing the action of the tiny cilia. The continual act of breathing polluted air could dramatically slow the body's ability to perform this normal, but essential, cleansing function. A breakdown of this kind of normal body function frequently resulted in pollutant particles escaping capture by the cilia and becoming deeply embedded in lung tissue. The potential, chronic health effects of particulate matter (PM) were lung cancer, pulmonary emphysema, bronchitis, asthma, and other respiratory infections (Godish, 1997).Due to the delicate nature of the bodily structures, both particulate and gaseous pollutants could have a profound effect on the upper respiratory system. From here the upper respiratory system becomes a conduit for the transport of pollutants to the lower respiratory system.

The lower respiratory system is composed of the bronchi, bronchioles and alveoli and from the area referred to as the location in the lungs where most pollutant exchange occurs. As air passes from the upper respiratory system, past the trachea, it would pass into either the left or right bronchi. Each bronchus further subdivides into smaller tubes called the bronchioles. The bronchioles end in millions of tiny air sacs called alveoli. Despite the natural cleansing process, much of the man made pollution never escapes the lower respiratory system.

Figure: 2.7.2 Alveola.



Source: Franek and Lou DeRose, (2003:135).

The direct respiratory effects of lung damage often result in bronchitis, pulmonary emphysema, lung cancer, and pneumoconiosis, cough and chest pain. Although less noticeable, the indirect effects of lung damage are of equal importance. Indirect damage could result in decreased respiratory efficiency, diminished pulmonary circulation, enlargement and weakening of the head and blood vessels, skin and eye irritations, inflammation and allergic reactions (Evans and Wolff, 1996:54).

2.8 Sulphur Dioxide (SO_2) as a Classical Air Pollutant

Based on WHO Air Quality Guidelines (1999), the key air pollutants were also termed 'classic' and SO_2 was one of them, in this section SO_2 was described with respect to health risk evaluations and recommended guideline values.

2.8.1 Short Periods of Exposure (Less than 24 hours)

Most data on acute effects of SO_2 came from controlled chamber experiments on volunteers exposed to SO_2 for periods ranging from a few minutes up to one hour. It was discovered that acute responses occurred within the first few minutes after commencement of inhalation. However further exposure did not increase effects. The effects felt included the reductions in the mean forced expiratory volume over one second (FEV_1), increases in specific airway resistance (sRAW), and symptoms such as wheezing or shortness of breath. Another observation was that these effects were enhanced by exercise that increased the volume of air inspired, as it allowed SO_2 to penetrate further into the respiratory tract.

A wide range of sensitivity has been demonstrated, both among normal subjects and among those with asthma. People with asthma were the most sensitive group in the community and hence were more susceptible to respiratory infections.

2.8.2 Exposure over a 24 hour period

Information on the effects of exposure averaged over a 24 hour period were derived mainly from epidemiological studies, (USEPA, 1997) in which the effects of SO_2, suspended particulate matter (SPM) and other associated pollutants were considered. Exacerbation of symptoms among panels of selected sensitive patients seemed to rise in a consistent manner when the concentration of SO_2 exceeded 250µg/m³ in the presence of suspended particulate matter (SPM).

In Europe more studies on industrial emissions showed that at low levels of exposure (mean annual levels below 50 µg/m³; daily levels usually not exceeding 125 µg/m³) effects on mortality (total, cardiovascular and respiratory) and on hospital emergency admissions for total respiratory causes and chronic obstructive pulmonary disease (COPD), have been consistently recorded and analysed. Most of the results have been shown in some instances, to persist when black smoke and suspended particulate matter (SPM) levels were controlled for, while in others no attempts have been made to separate the pollutant effects. In these studies no obvious threshold levels for SO_2 had been identified.

2.8.3 Long term Exposure

Earlier assessments examined findings on the prevalence of respiratory symptoms, respiratory illness frequencies, or differences in lung function values in localities with contrasting concentrations of SO_2 and suspended particulate matter (SPM), using data from the coal burning area in Europe. The lowest observed adverse effect level of SO_2 was judged to be at an annual average of 100µg/m³ when present with SPM. More recent studies related to industrial sources of SO_2, or to the changed urban mixture of air pollutants, have shown adverse effects below this level. But a major difficulty in interpretation was that long-term effects were liable to be affected not only by current conditions, but also by the qualitatively different pollution of earlier years. However, cohort studies on differences in mortality between areas with contrasting pollution levels indicated that mortality was more closely associated with SPM, than SO_2.

2.8.4 Guidelines

Based on controlled studies with asthmatics exposed to SO_2 for short periods, it was recommended that a value of 500µg/m³ (0.175 ppm) should not be exceeded over averaging periods of ten minutes. Because exposure to sharp peaks depended on the nature of local sources, no single factor could be applied to estimate corresponding guideline values over longer periods, such as an hour. Day to day changes in mortality, morbidity, or lung function related to 24 hour average concentrations of SO_2 were necessarily based on epidemiological studies, in which people were in general exposed to a mixture of pollutants, and guideline values for SO_2 have previously been linked with corresponding values for SPM. This approach led to a previous guideline 24 hour average value of 125 µg/m³ (0.04 ppm) for SO_2, after applying an uncertainty factor of two to the lowest observed adverse effect level. In more recent studies, adverse effects with significant public health importance have been observed at much lower levels of exposure. However, there was still uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects, or whether it was a surrogate for SPM with diameters below 10mm or 2.5µm, or even for some other correlated substance. There was no basis for numerical changes of the 1987 guideline values for SO_2 and thus 125µg/m³ for an average time of 24 hours, and 50µg/m³ as the annual mean were recommended. However, the current guideline values are no longer linked with SPM.

2.9 Uses of Sulphur Dioxide

Sulphur dioxide (SO_2) could be used for the following; production of sulphuric acid (H_2SO_4) and other chemicals, bleaching and digestion in paper manufacturing, refrigerant, fumigant, insecticide or fungicide, food or beverage preservative. SO_2 could be produced on-site by burning elemental sulphur or generated by chemical reaction. It may be transported or stored as a compressed liquid. SO_2 is more frequently a waste product; some industries use this waste SO_2 for any of the above uses. Industries which produce SO_2 as a by product include the following; roasting, sintering or smelting of sulphide ores, electricity or steam producers which burn coal or other petroleum fuels, paper manufacturing, and petroleum refining (sweetening).

2.10 Impacts of exposure and effects

2.10.1 Chronic Exposure

Repeated workplace exposure to SO_2 could cause lung disease or decreased lung function and respiratory cases such as bronchitis. SO_2 could add to the effects of other contaminants, which also cause these effects. In combination with other chemicals, SO_2 promoted or caused cancer. Arsenic and polynuclear aromatic hydrocarbons (found in soot, smoke and other substances) are believed to have this relationship with SO_2.

Peruvian copper smelters in the year 2001 were implicated in poor local air quality and health crisis and were aiming to reduce pollution by increasing SO_2 capture (Boon *et al.,* 2001).

2.10.2 Environmental Effects

Sulphur dioxide (SO_2) is a significant environmental pollutant. It is one of the gases which contribute to 'acid rain'. Most environmental effects of SO_2 arise from its ability to form acids. These effects include human health effects which are the focus of this study, damage to plants, erosion or discolouration of metals, stone, brick, or concrete.

2.10.3 Health Effects

SO_2 is known as an 'acid gas'. It would react with water to form sulphurous acid, which reacted further to form H_2SO_4. These acids were formed when SO_2 contacts moist membranes in the eyes or respiratory tract after inhalation. Both substances are very soluble and form acidic solutions which contain sulphite, bisulphate and sulphate ions.

2.10.4 Acute Exposure

Exposure to SO_2 would cause irritation (burning, stinging, and watering) of the eyes, nose, mouth and other parts of the respiratory tract. Changes in respiratory function would also occur. High concentrations can cause damage to the respiratory tract or even respiratory paralysis and death (UNEP, 1992).

Skin or eye contact with liquid or compressed SO_2 could cause freezing, irritation or chemical burns. People with asthma or other respiratory allergies are more sensitive to SO_2 and hence susceptible to respiratory infections (Ekosse, 2004). Low concentrations can trigger asthmatic reactions with symptoms of wheezing, chest tightness, shortness of breath and coughing. Physical activity and the presence of other contaminants such as airborne particulates increase the effects of SO_2 for asthmatics (DeKoning, 1987). The irritation caused by SO_2 could aggravate medical conditions, such as cardiovascular disease. Affected individuals would require medical treatment or hospitalisation.

2.10.5 Health Assessment and Data

Health assessment has been an essential planning tool for policy making and has created more proper directions for attaining intended goals locally, nationally and globally. Adverse health outcomes due to environmental exposures have represented a broad spectrum of effects. They range in scale from the population to the individual and in magnitude of effect from premature death to severe acute illness or major disability, chronic debilitating disease, minor disability, temporal minor illness, discomfort, behavioural changes, temporary emotional effects as minor physiological change (De Koning, 1987).

Health data are clearly of primary importance in environmental issues and studies. They basically perform two main roles firstly; they provide indicators of the effects of known exposures to environmental pollution on human health. As such, data on health outcome when linked to appropriate environmental data could be used to assess or confirm exposure-effect relationships within the study area, or to quantify the contribution of specific exposures to total incidence, prevalence, mortality or morbidity (Corvalan *et al,* 2000). Therefore in a similar manner, monitoring health outcomes could show the effects of changes in exposure, due for example in policy interventions, or the adoption of new technologies and strategies that would improve the community's health status. Health data could provide an indication of the possible existence of previously undetected exposures. Thus variations in health outcome can be used to infer the existence of underlying variations in exposure which needed further investigation (Briggs *et al.,* 1995).

2.11 Operations, pollution control and co-pollutants

According to the regional president of a multinational company, Xiaoling Liu (2009), the owners of New Zealand's only aluminium smelter warned that the plant could close, putting 3500 jobs at risk, if the government's emissions trading scheme passed in its present form. This showed how smelters were impacting on the environment and how other governments were dealing with the cases at hand.

Modernisation of the Ilo smelter in Peruvia was done in the year 2006 and was expected to result in a capture of 93% of the SO_2 emissions produced, (Boon, *et al.,* 2001;Centers for Disease Control, 2005).This reduced drastically the amount of the gas produced and its impacts on the health of the population were significantly reduced.

2.11.1 Sulphur dioxide and its co-pollutants

In Southwest U.S., (Pope *et al.,* 2007) made a comment on mortality from copper smelter emissions that contentions of changes in exposure to secondary sulphate alone were not sufficient to explain the observed mortality effects, and that the incidence and mortality effects were more likely due to changes in exposure to co-pollutants, such as biologically active metals and black smoke.

Mortality reductions in Hong Kong were also associated with reductions in SO_2 exposure (Hedley *et al.,* 2002). In Dublin, although sulphates were not measured, the banning of bituminous coal certainly resulted in an abrupt reduction in particulate pollution including sulphate particles (Clancy *et al.,* 2002).

In addition to the intervention studies discussed above, there is ample epidemiologic evidence that sulphate pollution, as part of complex mixtures, contribute to adverse health effects. For example, the Harvard Six-Cities Study, Dockery *et al.,* (1993) and the American Cancer Society prospective cohort studies, Pope *et al.,* (2002) of long-term air pollution exposure found both fine particulates and sulphate particles to be associated with mortality risk. A workshop of several research teams on source apportionment of particulate matter health effects found that the sulphate-related component of fine particles was most consistently associated with daily mortality, Thurston *et al.,* (2005). The relative toxicity of sulphates per se and the additive or synergistic effects of related co-pollutants remained a matter of study and debate Chen *et al.,* (2006); Grahame and Schlesinger, (2007). Nevertheless, epidemiologic studies of the adverse health effects of air pollution (Pope and Dockery, 2006) have implicated fine particulate pollution from at least three general sources; coal combustion, high-temperature industrial processes, and traffic sources.

Overall, the literature suggested that sulphates were part of mixtures of fine particles that included metals, black carbon, and other by-products of coal combustion, high temperature industrial processes that contributed to adverse health effects. Pope *et al,* (2002) concluded that the results of, "emissions analysis of the mortality effects of the copper smelter strike," contribute to the growing body of evidence that ambient sulphate particulate matter and related air pollutants were adversely associated with human health.

Savard *et al.,(*2006) suggested that the potential adverse health effects of air pollution, particularly among susceptible sub-populations, continued to be of concern, not only in rapidly expanding cities in developing countries where levels of air pollution had increased significantly, but also in North American and Western European cities where levels have been decreasing. This was largely based on studies conducted at the Harvard School of Public Health; the *New York Times* reported in 1993 that SO_2 and PM in the ambient air were responsible for premature mortality in the United States. From the year 1993 hundreds of research papers investigating the association between SO_2, PM and various health end points have appeared in the literature, and it has become abundantly clear that the relationship between air pollution and health was a complex one. Many studies, some conducted by exponent scientists, showed that the interpretation of epidemiological studies of air pollution was difficult because of a myriad of methodological problems.

2.12 Difficulties of an epidemiological study

One of the major difficulties of air pollution epidemiology was that the health risks, if any, of current ambient levels of air pollution were extremely small when compared to the traditional risk factors, such as cigarette smoking. As a consequence, it was difficult to distinguish the signal that is the effects of air pollution, from the noise of natural fluctuations in health events, such as hospital admissions and deaths attributable to other, non-pollution-related factors, such as weather.

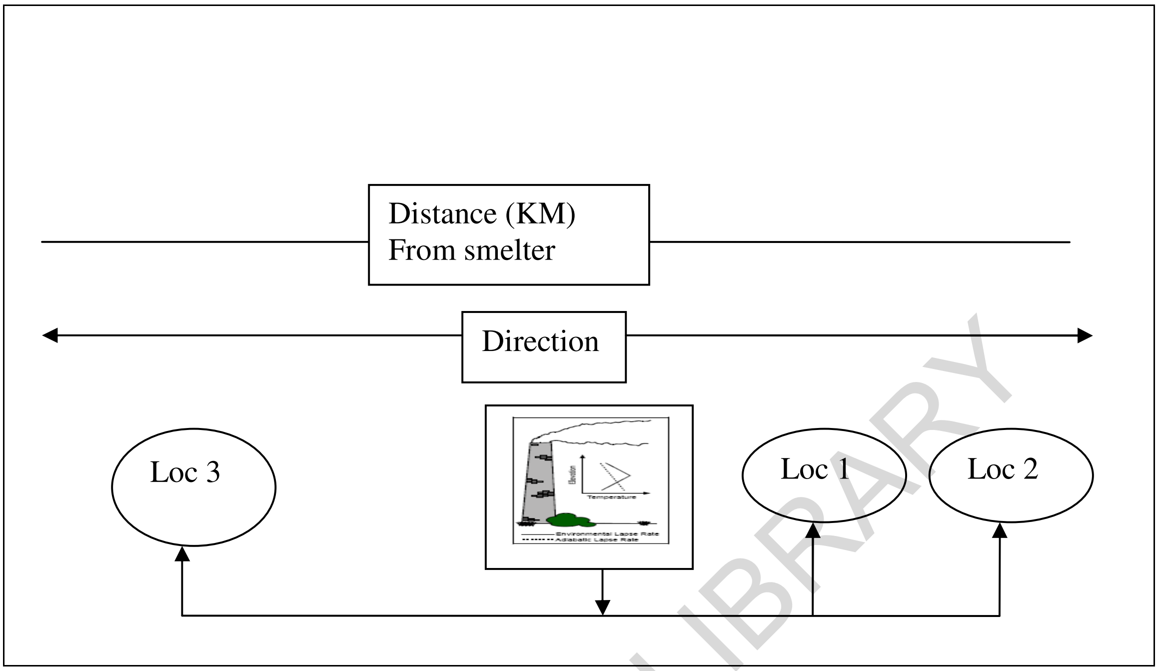
The first "intervention" study Pope *et al.,* (1992), examined PM mortality associations over four years, encompassing closure of a Utah steel mill, here sulphate was not measured as SO_2 levels were low. Mortality rates were 40% greater than expected when the mill was operating, suggesting toxicity of mill emissions. The strongest associations were found to be with respiratory diseases, then cardiovascular diseases. Filter extracts when the mill was operating contained high levels of lead, copper, and zinc and were more toxic. Frampton *et al.,* (1999), Mattson and Guidotti, (1980) found women living in communities near copper smelters (1968–1975) in Arizona experienced highly elevated relative risks (RRs) for acute respiratory disease mortality, averaged RR for all six mining towns (40,000 combined population) was 5.61.

2.13 Conceptual Framework

Smelter emissions blow in different directions, to varying distances at different times (Figure 2.13.1). Coal has been termed the lead material in smelter emissions production and major elements produced are SO_2 gas and suspended particulate matter. Settlements on the windward side of a pollution source were likely to be more polluted than those on the leeward side (Garg, 199:656).The distance of settlements under study from the smelter varied. Therefore there was need to investigate the relationship between the distance and direction of settlements from the smelter and the occurrence of respiratory disease load.

Continuous exposure of young children has shown serious effects as early respiratory cases could develop into chronic ailments later in life (WHO 1992:20, 21).Various levels of exposure gave different consequences of ailments to different individuals, this meant that the immune systems of individuals varied hence various levels of exposure affected human beings differently. This was supported by Garg (1999:645) that even at low concentrations, SO_2 could affect human health. In most cases many health effects have been observed during episodes of high pollutant concentrations (greater than 750 micrograms per cubic metre), for instance in London and New York, high levels of exposure resulted in death (Murray and McGranahan, 2003:7). With the help of systems thinking, Figure 2.13.2, portrays the relationship of gaseous production and human health status.

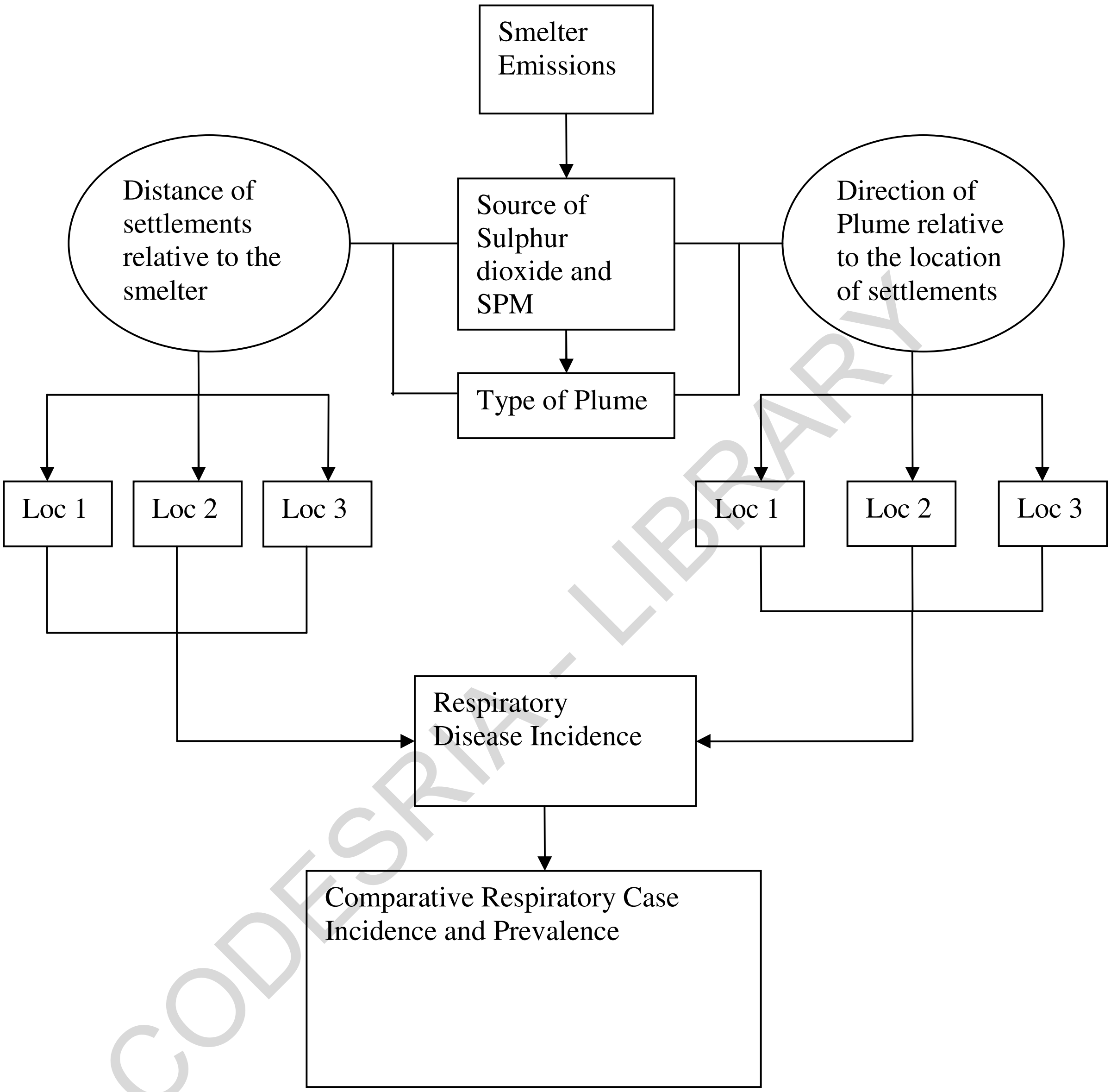
Figure 2.13.1 Comparative assessment of smelter emissions along transects.



Source: Author's construct, 2008.

The frame work was to ascertain the location that suffered the most from respiratory cases due to smelter emissions, taking into account the influence of both distance and direction of population (settlements) relative to the smelter plant.

Figure: 2.13.2 Conceptual Framework.



Source: Author's construct, 2008.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 INTRODUCTION

This chapter presents the research methodology, both primary and secondary data was generated. The study employed both qualitative and quantitative data. The chapter discusses types of data and how data was generated and analysed.

3.1 Data Types

This sub-section discusses types of data and methods of data collection.

3.1.1 Primary Data

Primary data was original data derived from a new research study and collected at source (Babbie, 2004:10). The data was generated to address a specific issue before data collection (Kitchin & Tate, 2000; Flowerdew & Martin eds., 1997). In this study, primary data was collected to provide a historic and current description of the health status in Selebi-Phikwe and the surrounding villages.

3.1.2 Secondary Data

This was data that came from information sources that were already in documented form. It is information that was collected for a purpose other than that for the specific project at hand, but provided information that was relevant to the current project. The advantages are that it was cheaper to obtain and was usually of proven quality and provided the researcher with unraveled contextual material (Kitchin & Tate, 2000).While on the other hand it was not flexible since one could not customise it to one's needs and its quality was unverifiable (Flowerdew & Martin eds, 1997). In the study monthly respiratory cases were gathered.

3.1.3 Quantitative Data

Quantitative data was generally structured and consisted of numbers or empirical facts that could be easily quantified and analysed using statistical techniques. It was useful as it made observations more explicit and allowed the researcher to aggregate, make comparisons and summarise data. The advantage was that it allowed for statistical analysis, for instance the calculation of the mean, standard deviation and complex models (Babbie, 2004). However, quantitative data has a potential loss of richness in meaning (Babbie, 2004; Kitchin & Tate, 2000).This type of data was both primary and secondary.

3.1.4 Qualitative Data

Qualitative data deals in words and typically verbal description of an issue or information need. It is guided by fewer universal rules and standardised procedures than statistical data. Qualitative data here included some responses from the questionnaire survey. This data type could also be primary or secondary data.

3.1.5 Methods of Data Collection

The above forms of data were collected using the following procedures, instruments or data sources.

3.1.6 Social Survey

Social survey is commonly applied in human geography to study populations. This approach would enable an assessment of human health issues through the in-depth analysis of a single person based on their experience in the area.

The strength of using a social survey was that it permitted reliable measurement of the health status of the local community in relation to the production of gases. This took into account the duration of gaseous exposure, and the timing. According to Wrigley, (1986: 98), "this method could provide useful data, to identify structural parameters of exogenous determinants on choice behaviour." Above all it provided a database suitable for studying short term responses to policy changes. It is an efficient way of collecting information from a large number of respondents and statistical techniques could be used to determine validity, reliability and significance. Surveys are flexible in the sense that a wide range of information could be collected. They could be used to study attitudes, values, beliefs and past behaviours. Because they are standardised, they are relatively free from several types of errors and relatively easy to administer. There is an economy in data collection due to the focus provided by standardised questions. Only questions of interest to the researcher are asked, recorded, codified and analysed. Time and money was not spent on tangential questions.

The shortcomings of this method were that, it depended on subjects' motivation, honesty, memory, and ability to respond. Subjects would not be aware of their reasons for any given action; they may have forgotten their reasons. They would not be motivated to give accurate answers; in fact they would be motivated to give answers that present themselves in a favourable light. Structured surveys, particularly those with close ended questions, may have low validity when researching affective variables. Errors due to non-response may exist that is, people who chose to respond on the survey could be different from those who did not respond, thus biasing estimates. Survey question answer-choices could lead to vague data sets because at times they were relative only to a personal abstract notion concerning "strength of choice". For instance "moderately agree" could mean different things to different subjects, and to anyone interpreting the data for correlation. Even yes or no answers are problematic because subjects could for instance put "no" if the choice "only once" was not available.

3.1.6.1 Household Questionnaire Survey

A structured questionnaire was used to conduct the interviews to facilitate compilation of statistics, to evaluate the relationship between the factors under study and to focus on the subject matter. The questionnaire focused on collecting data on the following variables; on frequency of visits to a health facility, types of health problems experienced, and the most common diseases in the community. The questionnaire included close and open ended questions.

3.1.6.2 Sampling for Household Survey

Probability (cluster) sampling was used using the systematic sampling technique (Groves, 1989).The advantage of the interval sampling was that it was very easy to use while on the other hand if there was a systematic cycle in a population, when applied it would not give a proper representation of the population. The study population was

Selebi-Phikwe and the surrounding villages, Mmadinare, Sefophe, Tobane and Bobonong.

The research question answered by this method was about the knowledge level of the local community on the health dangers posed by the gaseous emissions from the smelter. This was to gather proper information on smelter emissions, their intensity and directions of blow during different seasons. In every household the respondent was an eligible age to understand general health and environmental effects.

Sampling referred to selecting a certain number of units from the total population of the study. The population of Selebi-Phikwe areas of interest (Botshabelo and BDF residence camp) was 17 248, Bobonong's 14 622, Tobane's 1 788, Sefophe's 3 821 and Mmadinare's 10 918.The average numbers of people per household in rural areas of Botswana was 6 (CSO, 2001).Therefore the household population sizes for the four study areas were as follows,

Table 3.1: Population Disaggregation.

Location	Population	Number of Households
Selebi-Phikwe (BDF camp, Botshabelo)	17248	2874
Bobonong	14622	2437
Tobane	1788	298
Sefophe	3821	637
Mmadinare	10918	1820
TOTAL	48397	8066

Source: CSO 2001.

The selection of sample sizes was based on 95% confidence level. Yamane's (1967:886) formula for deriving the sample size was adopted in this study and was stated as follows,

$$n = N/1+N (e)^2$$

Where n = sample size.
N = population size (number of households in this case).
e = level of precision

Total sample size = $8066/1+8066(0.08)^2$
= 8066/1+8066(0.0064)
= 8066/52.6224
= 153

Therefore a sample for each cluster village was deduced as a percentage of the total number of households as follows,

Selebi-Phikwe sample size = (2874/8066)153
= 54

Bobonong sample size = (2437/8066)153
= 46

Tobane sample size = (298/8066)153
= 6

Sefophe sample size = (637/8066)153
= 12

Mmadinare sample size = (1820/8066)153
= 35

To support and strengthen the household survey quantities, concentrations of aerosols collected using aerosol profilers and other monitors were collected from the Botswana National Environmental Laboratory. This was meant to help show the amount of aerosols that could be reaching different locations to be able to ascertain the relationship between human health and gaseous emissions and suspended particulate matter.

3.2 Key Informant Interviews

These are qualitative in-depth interviews with people who know what is going on in the community. The purpose of key informant interviews was to collect information from a wide range of people including community leaders (chiefs and village heads), professionals, or residents who had first hand knowledge about the community. These community experts, with their particular knowledge and understanding, provided insights on the nature of problems and gave recommendations for solutions.

The method was very informative as most of the information given was not only from a personal perspective but from well known documented records. As there was need for data from the clinics and hospitals in the surrounding villages, health officials at the mine clinic and in the villages were interviewed. Questions answered were how frequent do smelter emissions blow towards the villages? An interview with the local authorities gave an insight on population settlements and health problems faced due to air pollution.

Face to face interviews were used as a data collection instrument and prior arrangements were sought to set appointments for the interviews to be conducted. These gave more information, free exchange of ideas and helped the interviewer to ask more complex questions and thereby got more detailed responses and recorded them down as the interview progressed. After finishing a key informant interview, the researcher made an analysis of the interview and typed up interview notes, using the audiotapes to fill in any gaps. The interviewer considered organising qualitative data right from the data entry stage into major categories. These categories were most commonly the interview questions that were asked. This way, one ended up with a document of all the interviewees' discussions organised under each question and answering question by question helped to answer the research aims and objectives.

The strengths of key informant interviews were that:-

a) One got in-depth information about respiratory infections.

b) Detailed and rich data was gathered in a relatively easy and inexpensive way.

c) Allowed the interviewer to establish rapport with the respondent and clarify questions.

d) Provided an opportunity to build or strengthen relationships with important community informants and stakeholders.

e) Raised awareness, interest, and enthusiasm around an issue.

f) Informants could clarify issues as needed.

Disadvantages that were faced were,

a) Difficulties in selecting the right key informants as they represented diverse backgrounds and viewpoints.

b) It was challenging to generalise results to the larger populations unless interviewing many key informants.

c) The researcher could have overlooked the perspectives of community members who were less visible. There was a need to combine with other methods, because representativeness of the total community was difficult to achieve. Hence the household survey conducted earlier.

d) Informants could have been giving their own impressions and biases.

e) The researcher's relationship with the informant could have influenced the information gathered.

The numbers of key informants interviewed were about nineteen people.

Table 3.2: Key Informants interviewed.

Key Informants	Number	Justification
Chiefs/village head/councilor	7	Have in-depth knowledge of the status of the village or area, if not they are able to lead us to some one who maybe able to tell us about the area over a long period of time.
District health heads (CMO,DNO,DEHO),and representative heads in sampled health centres	6	Have better knowledge and understanding of cases under study and may give insight on the disease under study.
Council Secretary's Office	1	To gather more history on the development of the towns and villages, future plans and concerns that maybe rising due to the mining industry.
Environment representative from BCL	1	To understand the status position of the mine and how they have reduced the smelter emissions and to understand about the levels of gases production.
Council Officer	1	To understand how they think policy can be affected by the mining activities.
NGO or CBO and School Environmental clubs	1	Their contribution and their concerns towards protecting the health of the community.
Total	19	

Source: Author's schedule 2009.

Given the financial and time constraints, the study was limited to assessing the influence of spatial variables and assumed that distance and direction from the smelter complex were not related to factors such as age, type of energy used, and smoking/snuff. These were captured and used to find out if they had an influence on respiratory cases as they could be competitors.

(Key informants- were based on snow bowling concept, the principle worked well until the law of diminishing returns started to take place.)

3.3 Clinical Records (secondary data)

Records from health centres were collected for data analysis. The outpatient monthly register was used to view the frequency of cases reported in each health centre. The respiratory diseases were tabulated to view their incidence and prevalence. The thresholds of respiratory diseases were necessary to see how cases were managed and the threshold over the years was compared to see if there was an increase or decrease in the number of cases reported at each health centre. A list of the disease ranks was tabulated according to their frequency of occurrence and the total number of cases per given time for instance a year. The listing was divided into four quarters to see the time (period) when the respiratory infections frequently occurred.

In a health impact research, records from the hospital confirmed and cleared out the information gap especially on the myths about production of the plume from the mine in relation to the infections.

The advantages of using secondary data were that,

a) Health centres were the main entry point for the local population in case of reporting, that meant a majority of the cases experienced were reported.

b) There was ease of access of this type of data to the researcher as reporting systems had been developed to pass information for instance the internet, health information clerks and the development of Information Systems sections in every government department.

c) Data could be acquired at a low cost and helped clarify the research questions or even answer the research questions.

d) Finally secondary data showed insights where difficulties in conducting a primary research were experienced.

Disadvantages of secondary data sources included the following,

a) From the clinical records we may experience a group of people who may suffer from diseases of interest but could have taken the infections from somewhere else while reporting to the same clinic.

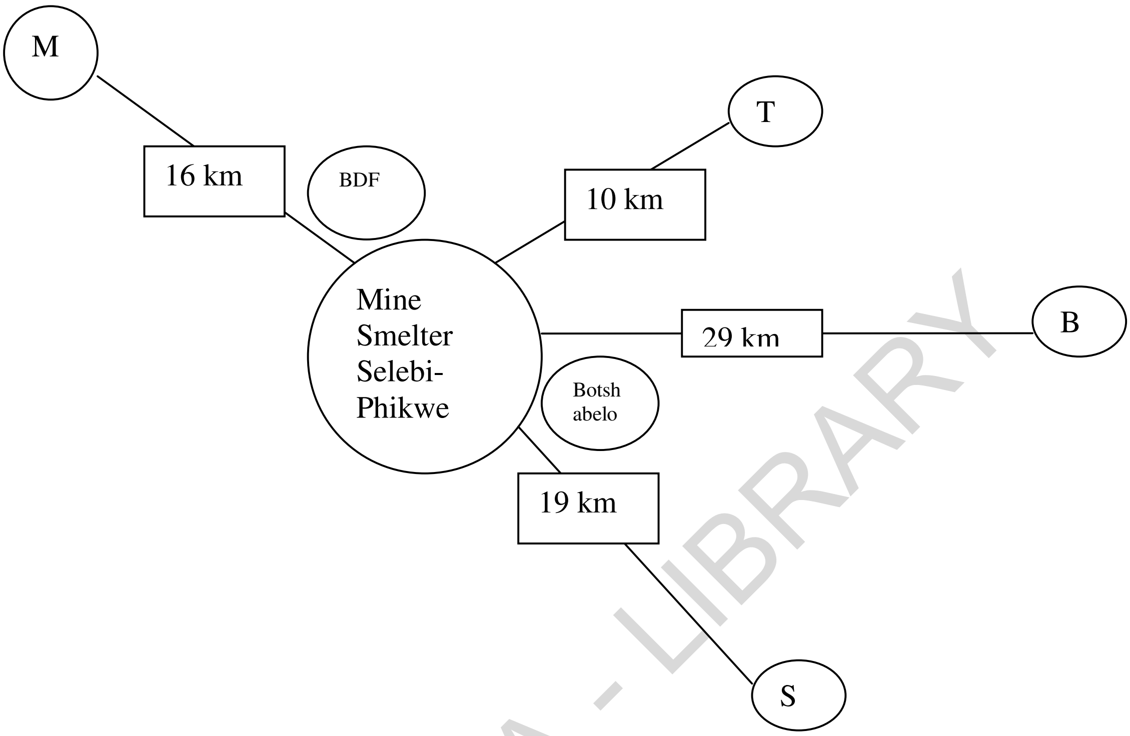
b) The researcher collected data from those who reported to clinics while there could be some who preferred traditional healers. This could have given an under or over score of the true picture.

c) Secondary data was not specific to the researcher's needs and therefore there was inefficient spending for information which was not timely and had missing reports and could be too old to use for the relevance of the current research.

d) It was not proprietary information as most of those who received secondary data did not have much information advantage.

The clinical records were collected from Selebi-Phikwe and four villages which had varying direction and distance from the mine smelter. Figure 3.3.1 shows the distance of villages from the mine smelter.

Figure 3.3.1 Distance of villages from mine smelter along straight line distances.



Key
M – Mmadinare.
T - Tobane.
S - Sefophe.
B - Bobonong.

▲
North

Source: Author's construct 2008.

The study was on a comparative basis of different locations. Reaching these compared locations was of paramount importance as the major independent variables were distance and direction and therefore the reference point was the smelter plant (transect analysis).The time frame for the collection of data was from the year 2000 going back as this was the only available data. Even with data from the Health Information System (ICT and Health Information Database) there was still need to administer household questionnaires. This was because we needed to capture the perceptions of the local community and to apply triangulation for validating the results of the study.

3.4. DATA ANALYSIS

This sub-section discusses how data was analysed.

3.4.1 Analysis of Household Survey Data

The household survey data was coded to allow for data input into the computer. Microsoft Access and Statistical Package for Social Sciences (SPSS) softwares were used for database design and data input. The results were presented in tables and line graphs to show the relationship between distance or direction in relation to the incidence of respiratory cases, using standard statistical procedures with the aid of Microsoft Excel and SPSS softwares. The data in tables and graphs was analysed and discussed to articulate the intensity of the relationships of variables in concern and any anormalies shown by the data.

3.4.2 Analysis of Key Informants Data

Data obtained was summarised and the respondents' views were compared to reflect disparities between the areas under study.

3.4.3 Analysis of clinical records

For the clinical records data analysis, a database was designed in the excel spreadsheet tailor made for the capture and analysis of secondary data. Information was presented in tables and graphs to show the frequency of exposure to the smelter emissions in the villages, and what common respiratory cases were suffered after such exposure, and historical data was subjected to time series analysis. Tables below show how relationships would be established.

Table: 3.3. Illustration

	Frequency range 1	Frequency Range 2	Frequency Range 3
Direction 1			
Direction 2			
Direction 3			

Source: Author's Construct 2008.

Table: 3.4.Illustration

	Disease prevalence/incidence 1	Disease prevalence/incidence 2
Distance 1		
Distance 2		

Source: Author's Construct 2008.

Table: 3.5. Illustration

	Incidence/Prevalence 1	Incidence/Prevalence 2
Direction 1		
Direction 2		

Source: Author's Construct 2008

The impacts were viewed on a comparative analysis of different locations surrounding the mining plant smelter. Therefore the spatial dimension was based on the influence of distance and wind direction on the impact of smelter emissions on human health.

Table 3.6: Summary of Methodology versus the Research Objectives

Objectives Of the Study	Key Research Questions	Methods to be used	Sources of Data	Type of Data	Strategy for Data Analysis
1.Assessing the knowledge of the local community on the possible health impacts of gaseous emissions production	What was the knowledge level of the local community on the health dangers posed by gaseous emissions from the smelter? To what extent was gaseous production responsible for the incidence of ill-health in Selebi-Phikwe?	Social survey, Questionnaires and interviews Key Informants	The local population in the areas of comparison. Key informants	Quantitative Qualitative	Data coding & entry into a statistical database. Generation of graphs, charts & tables as appropriate. Cross tabulations to establish association between knowledge & respondents attributes. Content analysis for qualitative data.
2. (a) To evaluate disease occurrence in different locations relative to the Selebi-Phikwe smelter. (b) Establish the most common(frequent) diseases in relation to locations along transects from the smelter	Which settlements were most affected? What were the common diseases that occurred in each settlement? To what extent did distance & direction contribute to the impacts of plume production on human health?	Records from the clinics and hospital Clinical records Key Informants	Clinic and hospital Clinic and hospital Interviews	Quantitative Quantitative Qualitative	Computation of key descriptive statistical indices (mean, std dev.) Kendall's correlation analysis. Generate the incidence and prevalence rates of respiratory cases. Time series analysis. Notes focusing on the health area of interest that is respiratory infections. Tables and graphical displays of distance and incidence of respiratory diseases.

Source: Author (2008)

3.4.4 Quality control regarding data collected

Secondary data from the clinics was confirmed by the database within the health information system (especially at district level).

3.4.4.1 Data Collection stage

1. Sampling –avoided gender bias this was done by the researcher to avoid the bias based on the gender of the household respondents.
2. Asking questions- the researcher did not ask leading questions.
3. Assessed questionnaires after the household respondents had answered. Careful consideration of questionnaire was done, sometimes questionnaires were taken back to the respondent if need arose.
4. Sampling size (Yamane's formula 1967) had a confidence level of 95%.
5. Triangulation system of validation (household data, key informant interviews, and secondary data) if these were pointing to the same concern then the issue was validated.

3.4.4.2 Data Analysis

1. Coding system on the questionnaires (allowed data quality in entry into packages such as SPSS).Good input in programs produced good output in results.
2. There was also application of tests such as the Kendall's correlation coefficient, these validated results in analysis.

3.5 Ethical Considerations

The researcher secured research permits from the Government of Botswana (from the following ministries, Ministry Of Health, Ministry Of Environment and Tourism, Ministry Of Local Government); to study in the areas of interest and application letters were submitted. To collect data, permission was sought from local authorities (written applications were made and permission granted, copies of these on appendix), to aid the comparative study of Selebi-Phikwe and the surrounding villages, through the local chief, village heads and the district administrators and council secretary's office. The purpose of the study was explained to all the respondents, and informed consent was obtained verbally and respondents in the household survey were made to sign a consent form. Professionalism, confidentiality and privacy were maintained throughout the study and all the participants were advised of this. This was done to avoid hostilities of interviewees and to reduce suspicion of the local community and this facilitated the identification of a translator or an accompanying research assistant who knew the study area. This increased the chances of the researcher gaining easy access to the targeted population. The research was conducted transparently, with the full consultation, permission and knowledge of the stakeholders who among others are the state, policy makers, administrators, managers, NGOs, CBOs, and household respondents. The use of any electronic recording instruments was divulged to respondents before the interviews. Confidentiality of data and information was maintained at all times. Full acknowledgement of data and information was made without prejudicing its source, where it was deemed necessary. Regulations regarding intellectual property rights were adhered to (This included a letter of consent co-signed by respondents and the researcher; see appendix XI).

3.6 Data collected from clinic records and BNEL records

1. Ward of origin of each patient attending the clinics that were visited.
2. Respiratory related cases incidence and prevalence data, such as common colds, and bronchitis (if data was available, as far back prior to the mine as possible).
3. Total attendance per given time period for instance monthly, quarterly and annually.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.0 INTRODUCTION

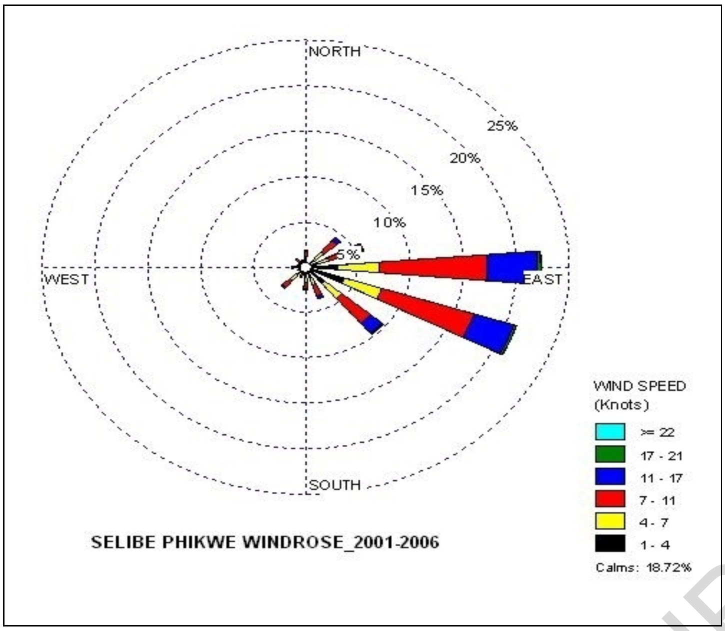
This chapter focuses on the presentation, analysis and discussion of results. The results are based on data collected through the household survey, records from the Botswana National Environmental Laboratory, key informant interviews and records from the health facilities. Wherever appropriate, findings from cognate studies conducted elsewhere are comparatively integrated into the discussion.

4.1 OVERVIEW ON THE RELATIVE LOCATION OF THE STUDY SITES

The study focused on settlements surrounding the Selebi-Phikwe BCL mine smelter. The sites were Botshabelo, BDF camp, Madinare, Sefophe, Tobane and Bobonong (Figure 3.3.1). It was found that in most cases the plume produced by the smelter blew towards the Mmadinare (northwest) direction. Settlements on the windward side of a pollution source were likely to be more polluted than those on the leeward side (Garg, 199:656). In Selebi-Phikwe, at the time of the study, there were monitoring stations selected to analyse SO_2 emissions based on distance and direction. Health facilities were chosen in the respective study sites and respiratory health data was collected from them.

The most prevailing wind was the easterly air flow followed by the southeasterly airflow (Figure 4.1). Therefore the locations that were most likely to be hard hit were those located in the west and northwest directions; in the study these were BDF camp and Mmadinare.

Figure 4.1: Wind Rose for Selebi-Phikwe.



Source: Botswana MET Department 2008.

4.2 ASSESSMENT OF POLLUTION AND RESPIRATORY DISEASE KNOWLEDGE LEVELS

The knowledge levels of the community were captured to get an overview of awareness levels of SO_2 pollution and its relationship to human health in the study sites. The household questionnaire tool was used to gather the data. This gave a clear picture of the perceptions, some of which were statistically tested to validate their strength with respect to the respiratory health scenario linked to the SO_2 emissions produced by the BCL mine smelter.

4.2.1 Environmental problems in the study area

In all the villages air pollution was reported by most respondents. They observed that SO_2 produced from the mine affected human beings and plants. The respondents cited gaseous emissions from the mine as the major environmental problem, which they claimed resulted in a high number of cases of chest pains and coughing. In particular, the smoke from the mine was blamed for causing eye and respiratory problems. For example, in Mmadinare 95% of the respondents agreed that SO_2 pollution was responsible for respiratory morbidity in their village.

4.2.2 Evaluation of disease occurrence in relation to locations around the smelter

The common diseases according to rank are listed in Table 4.1. HIV/Aids and Tuberculosis were still perceived to be of high prevalence followed by common colds and coughing. This suggested a strong link between low immunity and respiratory cases, probably aggravated by SO_2 pollution. Indeed, the second most highly ranked diseases were TB and Flu, which may be considered predatory on a population with compromised immunity.

Table 4.1: Disease Ranks in Community.

	1st Rank	**2nd Rank**	**3rd Rank**	**4th Rank**	**5th Rank**
Tobane	Asthma	TB	Hiv/Aids	Coughing	
Sefophe	Hiv/Aids	TB	Sugar Diabetes	BP	BP, Knee problem
Mmadinare	Hiv/Aids	TB	BP	Coughing	Coughing
Botshabelo	Hiv/Aids	TB	Asthma	Flu	Asthma, Coughing
BDF	Asthma	TB	Flu	Coughing	
Bobonong	TB	Flu	Flu	Coughing	Coughing

Source: Author's Survey January 2009.

The majority of the population experienced body weakness (62%) and most of them felt the weakness in the morning (44%). The majority experienced common colds (70%) and most often accompanied by a blocked nose (44%).

This could be as a result of plume production. Most respondents felt the effect more in the morning than the rest of the day, as the day progressed their bodies adapted and they felt better while exposure would be continuous, as the smelter operates 24 hrs a day. This may also be related to the findings reported by Boon *et al.,* (1999) that SO_2 concentrations peak at night or early morning.

The majority of the respondents experienced headaches (78%). The highest frequency of the headaches to most was once a month (36.1%).The most common type of headache was the temple headache (60.7%) and many experienced an acute headache (50%). These headaches were associated with common colds which could in turn be linked to SO_2 pollution.

4.2.3 Contributions made by BCL mine

In Selebi-Phikwe they did their shut down (complete closure of smelting operations) twice a year in August and December 2008. The BCL mine also facilitated awareness campaigns on respiratory diseases (World TB Day campaign) and educated the local population to go for Tuberculosis tests and the treatment of other respiratory related diseases (campaign). It has created a facility for free medication for all their workers and dependents and has built an Infectious Disease Control Center as a donation to Mmadinare community.

4.2.4 Solutions to the environmental problems suggested by respondents

Respondents suggested that smoke production from the mine should be minimised for example by increasing the height of the smelter for the plume to come out weakly concentrated. This would lead to gaseous emissions and particles taking long to reach the ground so as to reduce the intensity of the toxic SO_2 emissions. They recommended encouragement of the BCL mine to improve the smelting equipment so that less SO_2 was produced. Closing the smelting plant and relocating smelting services from Selebi-Phikwe site was recommended by those who felt the gaseous emissions were out of control. More periodic shut downs (complete closure of operations) at the mine for servicing equipment were encouraged as a means of reducing the smoke from the smelting plant. As the last option, some respondents recommended relocation of the population within the mine's vicinity.

<u>4.2.5 How BCL mine could assist in dealing with the community's health suggestions from respondents</u>

The mine was called upon to find proper solutions to prevent smoke from affecting the community's health, first by conducting more periodic shut down processes, secondly by improving, cleaning and servicing the smelter to reduce plume production. It was proposed that the mine should find possible ways of reducing smoke emissions by acquiring more effective equipment to reduce smoke production.

The mine was encouraged to build more clinics which were specialising in respiratory related diseases. It was called upon to provide free health services and excellent medical facilities to the community. The respondents felt they needed better health facilities, as they were facing a shortage of necessary equipment and expertise for some of their health problems. The respondents proposed that the mine should educate and facilitate the public programmes such as campaigns to enlighten them on protecting their health status, especially on respiratory cases such as tuberculosis and bronchitis.

4.2.6 Factors Influencing Perception of Sulphur Dioxide Emission Impacts

This section presents a number of cross tabulations intended to gauge the influence of various respondent characteristics or attributes on perceptions of SO_2 impact on human health.

4.2.6.1 Education versus Emission Impact

Among the respondents that agreed that SO_2 emissions affected human health the majority had reached secondary level education while among those who disagreed, the majority had attended secondary education. However in terms of magnitude there were more respondents that agreed pollution had an effect (77%) than those who disagreed (23%).

For the group of respondents who agreed, at $p = 0.05$ in testing the association using Kendall's correlation analysis, there was a positive correlation ($r = 0.67$) between educational level and perception of pollution effect on human health. This suggested that as the educational level increased the community became more aware of the effects of pollution on human health.

Table 4.2: Association of educational level with emission impact.

	Pollution Effect on Human Health		
Educational Level	YES	NO	TOTAL
None	7	4	11
Primary	22	5	27
Secondary	55	20	75
Tertiary	33	7	40
Total	117	36	153

Source: Author's Household Survey January 2009.

4.2.6.2 Age versus perception of Emission Impact

There were more respondents who said yes than no to pollution effect. Of those who said yes the age group (21-30) contributed the majority (41%), (Table 4.3). Among the respondents who said yes, at p = 0.05 in testing the relationship using Kendall's correlation analysis, there was a negative correlation (r = - 0.6) between age groups and perception of pollution effect on human health. Therefore as age increased, the perception of pollution effect on human health decreased.

Table 4.3: Age association with emission impact.

	Pollution Effect on Human Health		
Age Group of Respondent	YES	NO	TOTAL
11 – 20	14	7	21
21 -30	48	12	60
31- 40	26	9	35
41- 50	20	5	25
50+	8	2	10
TOTAL	116	34	151

Source: Author's Household Survey January 2009.

4.2.6.3 Age versus Pollution Perceptional Effect

This cross tabulation is to show the relationship between age and pollution perceptional effect. The majority (70%) of all age groups strongly agreed that pollution affected their health, (Table 4.4). At p = 0.05, using Kendall's correlation analysis, there was a negative correlation (r = - 0.5) between age and degree of pollution perception of strongly agree. Therefore, just like for the binary (Yes/No) case above, age seems to have an inverse relationship with perception of the pollution effect. Given the positive relationship observed between education and perception of SO_2 impact (Table 4.2), this result probably indicated that the elderly were less educated.

Table 4.4: Age association with pollution perceptional effect.

	Pollution perceptional effect					
Age	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
11- 20	9	5	1	2	2	19
21 -30	26	16	6	4	7	59
31 – 40	11	12	2	3	6	34
41-50	14	4	1	2	4	25
50+	3	2	3	2	0	10
Total	63	39	13	13	19	147

Source: Author's Household survey January 2009.

4.2.6.4 Purpose of Stay versus Emission Impact

There were more respondents, who said emissions had an adverse effect on human health (76.3%) than those who said no (23.4%), (Table 4.5).The majority of the respondents were living in their home village with the yes and no categories recording 61% and 64% respectively. Therefore there were significantly more respondents who perceived the pollution effect than those who did not.

Table 4.5: Purpose of stay association with emission impact.

	Pollution Effect on human health		
Purpose of Stay	YES	NO	TOTAL
Home village	68	23	92
Employment	34	6	40
Schooling	9	2	11
Visiting	5	5	10
Total	116	36	152

Source: Author's Household Survey January 2009.

4.2.6.5 Purpose of Stay versus Pollution Perceptional Effect

The majority were those who strongly agreed and agreed (69%). Most of these (57%) came from the home village category (Table 4.6).

Table 4.6: Purpose of stay association with pollution perceptional effect.

	Pollution Perceptional Effect					
Purpose of Stay	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Home village	36	21	10	10	12	89
Employment	18	14	1	1	5	39
School	5	3	2	0	1	11
Visiting	4	1	0	2	2	9
Total	63	39	13	13	20	148

Source: Author's Household survey January 2009.

The results in Tables 4.5 and 4.6 suggest that the longer one lives in the area of study the higher were the chances of experiencing and perceiving pollution effect.

4.2.6.6 Gender Distribution according to study sites

The respondents' population shows that the males were fewer than females; males were about half the population of females in the study area (Table 4.7). At the time of the study more females were found in households than males, most males were reportedly out at work places.

Table 4.7: Gender according to study sites.

Gender of Respondent	**Botshabelo**	**BDF Camp**	**Mmadinare**	**Sefophe**	**Tobane**	**Bobonong**
Male	32%	35%	42%	17%	33%	34%
Female	68%	65%	58%	83%	67%	66%

Source: Author's Household survey.

4.2.6.7 Gender versus Emission Impact

Seventy-nine percent (79%) of the males agreed that SO2 emissions adversely affected human health while 75% of the females agreed (Table 4.8). Therefore there was an almost equal level of perception across gender. This shows that despite the lopsided distribution of respondents by gender (Table 4.7), the level of perception remained equal.

Table 4.8: Gender of Respondents association with emission impact.

	Pollution effect on human health		
Gender of Respondents	YES	NO	TOTAL
Male	79%	21%	100%
Female	75%	25%	100%
Total	76.5%	23.5%	100%

Source: Author's Household Survey January 2009

4.2.6.8 Gender versus Pollution Perceptional Effect

Table 4.9 shows the relationship between the two variables; gender of respondent and pollution perceptional effect. About 74% of males strongly agreed and agreed and 67% of the females agreed and strongly agreed. This further confirmed the level of perception in Table 4.8.

Table 4.9: Gender of respondent association with pollution perceptional effect

	Pollution perceptional effect					
Gender of Respondent	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Male	24	13	6	2	5	50
Female	40	26	7	11	15	99
Total	64	39	13	13	20	149

Source: Author's Household survey January 2009.

4.2.6.9 Location of Respondents versus Perception of Emission Impact

The majority of the people who perceived adverse effects of SO_2 pollution came from Mmadinare (95%), this village was located in the most affected direction (northwesterly direction), and was found in the distance range 16-20km (Table 4.11).

Despite being close to the smelter, BDF camp recorded a much lower perception. This could probably be due to the height of the stack as the plume released seemed to go to further distances than BDF's location. The type of the plume produced was the looping plume and according to Franek *et al.,* (2003) the looping plume has a wavy character and goes further distances before making a fall out.

Interestingly, settlements located in the opposite direction to the plume (Botshabelo, Sefophe, Bobonong and Tobane), had almost equal or higher levels of perception than BDF. A possible explanation could be the sporadic changes in the direction of the plume which cold blow towards these study sites for example the conning plume which was the second most prevailing plume type. This plume type occurred in the winter seasons (mild atmosphere) which had sub-adiabatic conditions (Table 4.10). Under such conditions, the environment was slightly stable and there was a limited vertical mixing thereby increasing the probability of air pollution in any direction in the area (Franek *et al.,* 2003: 95). According to the mine employees the conning plume in the winter season blew most frequently towards the southeast direction. It has also been observed in Russia that even at low concentrations, SO_2 can affect human health (Garg, 1999:645). This was further supported by health officials who believed that respiratory cases in these sites could emanate from the migration patterns of the population (Section 4.4.4). This was also in line with Morrison's *et al.,* (2007) observation that some socioeconomic activities contributed to high respiratory disease spread even to the least affected directions.

Table 4.10: 1997 Plume Characteristics.

	Time					
		Lofting	Fanning	Conning	Looping	Fumigating
%Mean Frequency	07 00 hrs	9	18	29	46	7
	1200 hrs	11	11	23	48	6
	1800hrs	10	6	26	56	7

Source: Botswana National Environment Laboratory Annual Report 1997.

Among the respondents who said yes to pollution effect, using Kendall's correlation analysis at p = 0.05, a positive association was revealed between respondent's area of location and perception of pollution effect on human health (r = 0.60).

As noted earlier, the height of the stack and the type of the plume (looping) could be contributing to the distance affected by the plume (16- 20 km range). The direction of the prevailing plume probably further confirmed the high respiratory disease load in Mmadinare (see also Franek *et al.,* 2003).

Table 4.11: Respondent's Area of Location association with emission impact.

Settlements	**Distance from Smelter km**	**Direction from Smelter**	**Emissions Cause Disease**	
			% Agreeing	**% Disagreeing**
Botshabelo	5	Southeast	57	43
BDF Camp	4	Northwest	64	36
Tobane	10	Northeast	83	17
Mmadinare	16	Northwest	95	5
Sefophe	19	Southeast	92	8
Bobonong	29	East	75	25

Source: Author's Household Survey January 2009.

4.2.6.10 Correlation between Age and Gender Disease Incidence

Applying Kendall's correlation analysis to Table 4.12 at $p = 0.05$, there was a positive correlation between the age of males and respiratory case incidence ($r = 0.7$). That meant as age of males increased the respiratory disease incidence also increased.

Table 4.12: Male Disease Incidence by Age groups.

Males Age Category	<20	31-40	41-50	51-60	>60
Respiratory Case Incidence	0	1	8	10	8

Source: Author's Household Survey January 2009.

Similarly, using Kendall's correlation analysis at $p = 0.05$, there was a positive (but weaker) correlation between age of females ($r = 0.4$) and respiratory case incidence depicted in Table 4.13.

Table 4.13: Females Disease Incidence by Age groups.

Females Age Category	<20	31 - 40	41 - 50	51 - 60	> 60
Respiratory Case Incidence	0	4	10	9	3

Source: Author's Household Survey January 2009.

4.2.7 Summary Points from Section 4.2

- The most common diseases as ranked by the communities were HIV/Aids, Tuberculosis, Flu/Common colds, in that order of prevalence.
- The population felt greater impact in the morning; as the day progresses their bodies adapted and they felt better although exposure was continuous. This is also consistent with the fact that SO_2 concentrations tend to be highest during the night or early in the morning.

- A high percentage of respondents experienced headaches, and body weakness. This suggested a strong link between respiratory diseases and SO_2 emissions.
- The perception on respiratory health effects was at the same level for both males and females.
- In the winter season the prevailing conning plume blew towards the southeast direction where Botshabelo and Sefophe were located.
- As educational level increases the community became more aware of the association between pollution effect and human health.
- There was a weak but negative correlation between distance and pollution perceptional effect, as the distance increased the perception of pollution effect decreased.
- There was a positive correlation of respondents' location and pollution effect, however this was not consistent. The height of the stack and the type of plume blowing supported the anomaly as reflected in Section 4.5.4 .The wavy character of the looping plume made it to fall out at further locations from the stack (Franek *et al.,* 2003).
- As the timeframe of living in the study area increased the higher the perception of adverse pollution effect.
- The number of those who felt pollution effect was higher than that for those who did not.
- Perception of adverse effects of SO_2 pollution was inversely related to age of respondent.

- Migration could be a confounder, probably accounting for the high level of awareness of the adverse effect of SO_2 emissions on human health among respondents in settlements outside the prevailing plume direction. However, this phenomenon may also be related to the observed fact that even at low concentrations SO_2 could affect human health (Garg, 1999:645).
- It would appear that as both males and females grew older they became more vulnerable to respiratory infections because the reported incidence of respiratory diseases increased with age for both sexes. This could be related to the observation by WHO (1992:20, 21) that continuous exposure of young children to SO_2 emissions had shown serious effects as early respiratory cases could develop into chronic ailments later in life.

4.3 A SPATIO-TEMPORAL COMPARISON OF SULPHUR DIOXIDE EMISSIONS AND RESPIRATORY DISEASE INCIDENCE (1981-2000)

4.3.0 Introduction

At the time of the study there were nine SO_2 monitoring stations in Selebi-Phikwe, namely: Selebi-Phikwe Secondary School, Orlando, Water Utilities, Kopano, Hospital, Botshabelo, Township West, Low Density and the smelter station just besides the furnace at BCL mine. For this study, records were obtained from six of the stations. Table 4.14 below indicates the distances and directions of the six stations relative to the smelter. Respiratory disease incidence records were obtained from health facilities in Selebi-Phikwe, Mmadinare, Sefophe, Tobane and Bobonong**.**

Table 4.14: Location and direction of monitoring stations.

STATION	**DISTANCE FROM SMELTER**	**DIRECTION FROM SMELTER**
Selebi-Phikwe Secondary School	4.2 kilometres	South West
Water Utilities (WUC)	1.1 kilometres	North West
Hospital	4.2 kilometres	South West
Township	5.2 kilometres	South West
Low Density	4.7 kilometres	South of South West
Botshabelo	3.8 kilometres	South East

Source: Botswana National Environmental Laboratory 1999.

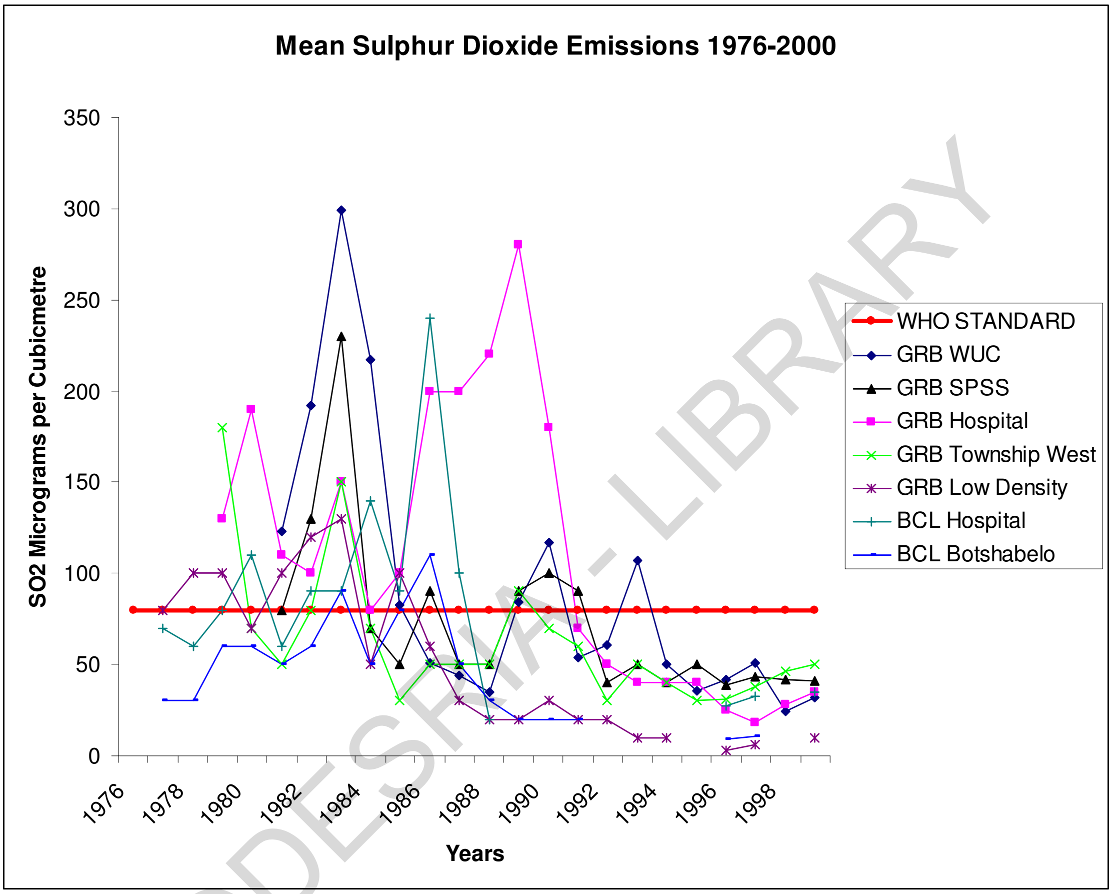
4.3. 1 Spatio-temporal trends in SO2 emissions

Figure 4.3 displays trends in the mean SO_2 emissions from 1976 to 2000. It is evident from these graphs that SO_2 emissions have been above the WHO standard of 80µg/m³. From the year 1976 the SO_2 emissions were showing levels higher than the WHO regulated standard to the year 1990. As from 1991 the emissions were relatively lower than the average stipulated standard, in the range of 3 µg/m³ to 50 µg/m³.The Water Utilities Cooperation station recorded the highest in the year 1985.

For most of the stations the monitoring stations recorded higher than the average WHO standards from 1976 to 1988, and recorded below thereafter. This reflected an improvement in the control of SO_2 emission quantities. Stations closer to the smelter recorded higher SO_2 emissions than those far away although this was not consistent. The inconsistency could be due to the height of the smelter stack (Franek *et al.,* 2003). In general, the monitoring stations in the westerly direction recorded higher SO_2 emissions than those in other directions.

Most of the stations recorded emissions above the normal stipulated datum WHO standard of 80µg/m³. Botshabelo station generally recorded most emissions that were lower than the average standard. This could be as a result of the direction and distance of the monitoring station which is located opposite the prevailing plume direction.

Figure 4.2: Shows SO_2 emissions for residential monitoring stations, 1976 to 1999.



Source: Botswana National Environmental Laboratory 1976-2000.

When comparing the mean SO_2 emissions with the WHO standard it was found that the Water Utilities Cooperation and the Hospital stations recorded a mean higher than the WHO standard (Table 4.15), these were among the nearest monitoring stations in terms of transect distance from the smelter. Water Utilities Cooperation and the Hospital stations were also found to be in the direction of the prevailing plume. While the other monitoring stations recorded lower mean SO_2 emissions than the WHO standard (80µg/m³), they were located in further distances from the smelter.

Table 4.15: Comparison of Mean SO_2 emissions with WHO standards.

STATION	**Mean SO_2 Emissions (µg/m³)**	**≤ 80 µg/m³**	**> 80 µg/m³**	**Distance**	**Direction**
1.GRB WUC	90		√	1.1 km	North West
2.GRB SPSS	72.4	√		4.2 km	South West
3.GRB HOSPITAL	109		√	4.2 km	South West
4.GRB Township	63	√		5.2 km	South West
5.GRB Low Density	52	√		4.7 km	South South West
6. BCL Botshabelo	46	√		3.8 km	South East

Source: Botswana National Environmental Laboratory 1976-2000.

Smoke from the mine had an effect on most of the population all year round, many had no idea at which time of the year they suffered from respiratory diseases as it seemed they were common right throughout the year. Among the four quarters of the year the July to September period recorded the highest incidence of respiratory diseases (Table 4.16). This was the dry season when the plume blew with the dry airflow and was not disturbed or diluted by the rain. According to Lins (1986), studies in the United States revealed higher SO_2 emission levels during the winter than the summer (rainy) seasons. In general, as Savard *et al.,* (2006) have observed, the adverse health effects of air pollution (such as SO_2 emissions) continued to be of concern, not only in rapidly expanding cities in developing countries where levels of air pollution have increased significantly, but also in North American and Western European cities where levels have been decreasing.

Table 4.16: Respiratory Disease Occurrences.

Period of Year	% Suffering from Disease
January - March	4.5
April – June	6.1
July – September	12.9
October – December	6.1
All Year Round	31.1
No Idea	39.1

Source: Author's survey January 2009 adopted from the household survey.

4.3.2 Spatio-temporal trends in respiratory Disease Incidence and Prevalence Rate

4.3.2.0 Introduction

The burden of disease was an important indicator of the health status of a population. Therefore this section reflects how disease incidence and prevalence have been advancing over a period of eight years in and around Selebi-Phikwe.

Prevalence is the total number of cases (new and old) of a given disease during a given period or moment, in a given population, divided by the total population.

It is calculated as follows:

$$\text{Prevalence Rate} = \frac{\text{number of cases of a given disease at a moment/period}}{\text{Total Population}} \times 100$$

Generally, the population size is calculated taking its size at the middle of the period**;** when this is not available the end-year population size is adopted.

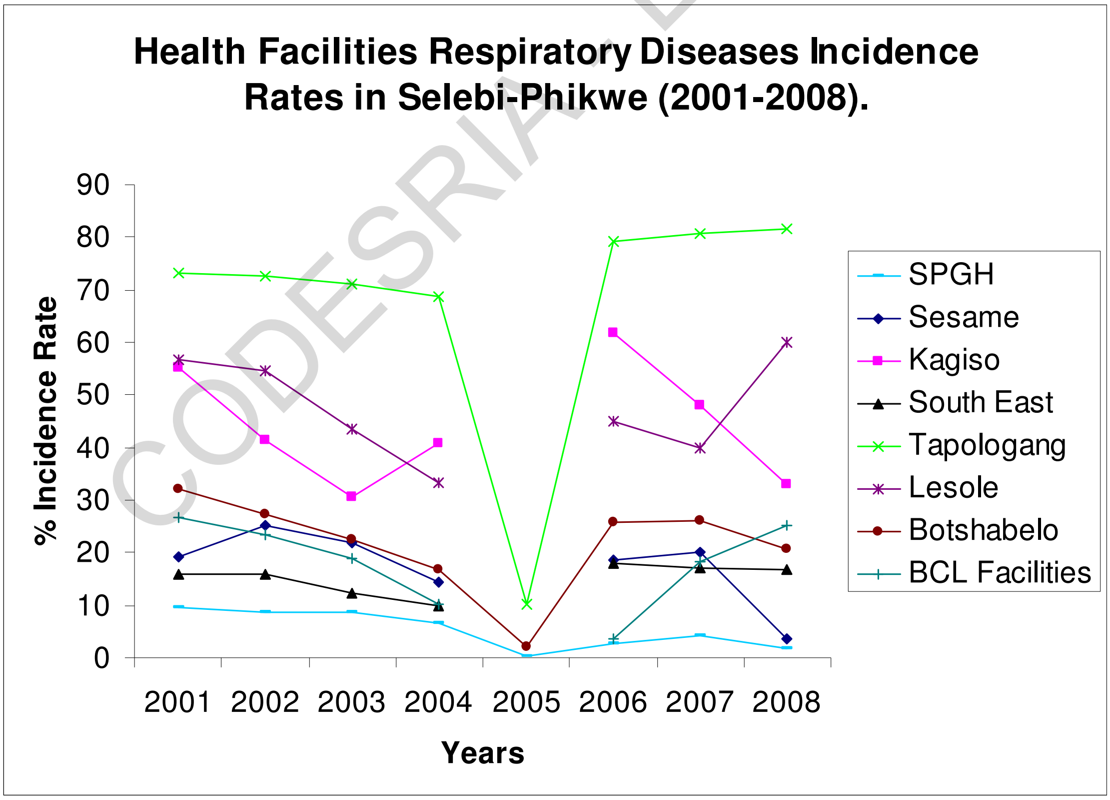
Incidence is the number of new cases of a given disease, during a given period in a given population, divided by the population at risk. Generally, since it is difficult to know the population at risk, the total population is used.

$$\text{Incidence Rate} = \frac{\text{new cases of a disease during a given period}}{\text{Population at risk during that period}} \times 100$$

4.3.2.1 Respiratory cases Incidence Comparison

When the health facilities in Selebi-Phikwe were compared it was found that the incidence rate for Tapologang was the highest for the years 2001 to 2008. The general trend showed that there was a decrease in the incidence rates from 2001 to 2005 then a rise from 2006 to 2008 (Figure 4.3). Along a transect Tapologang is southwest, one of the most affected directions and is closer to the smelting processes, as compared to other facilities.

Figure 4.3: Health Facilities Incidence and Prevalence Rates of Respiratory diseases.



Source: Selebi-Phikwe Town Council Public Health Department February 2009.

From Table 4.17 direction appeared not to have an influence on the mean respiratory disease incidence as the listed directions appeared to have the varied levels. Most of the locations were found in the same distance ranges of the 0-5 km and 5-10 km; however the mean respiratory disease incidence rates were significantly different in all the health facilities. Of significance Tapologang, Kagiso, and Lesole had high mean incidence rates despite being in different directions and being found at different distances from the smelter.

Table 4.17: Mean Respiratory Disease Incidence in Selebi-Phikwe (2001-2008).

Health Facility	**Mean Respiratory Incidence (%)**	**Direction**	**Distance from Smelter Rank**	**Ranks of Mean Respiratory Incidence (%)**
SPGH	5.4	Southwest	6	8
Sesame	17.6	Southwest	8 (Furthest)	6
Kagiso	44.4	Southwest	7	3
South East	15.1	Southwest	5	7
Tapologang	67.1	Southwest	1 (Closest)	1
Lesole	47.6	Southeast	2	2
Botshabelo	22	Southeast	3	4
BCL Facilities	18	Southwest	4	5

Source: Selebi-Phikwe Town Council Public Health Department 2009.

When the areas of study were compared (Table 4.19), it was found that the highest change in respiratory disease incidence was experienced in Mmadinare (162%), followed by Bobonong (96%) and Botshabelo recorded a decrease (-0.5%). Mmadinare had the highest recorded cases, the village was found to be in the direction of the prevailing plume and in the most affected distance range (16-20km), (sub section 4.5.1).

From the year 2005 respiratory disease cases increased, this could have been as a result of the cumulative effects of the SO_2 emissions released over the years as the body's immunity of individuals varies in the population. Settlements away from the prevailing plume direction were less affected. BDF camp had a low increase this could be explained by the prevailing plume type which is the looping plume. The looping plume has a wavy character thus when released it lands at further distances (Franek *et al.,* 2003).

Table 4.18: Respiratory Disease Incidence Rates.

Incidence					
	Years				
Location	**2005**	**2006**	**2007**	**2008**	**% Change**
Bobonong	13.7	20.11	26.9	26.9	+96
Mmadinare	6.1	12.1	N/A	16.0	+162
Sefophe	16.1	31.5	23.2	22.7	+41
Tobane	13.6	25.8	26.3	21.1	+55
Botshabelo	20.8	25.7	26.2	20.7	-0.5
BDF Camp	19.2	19.3	20.2	21.6	+12.5

Source: Health facilities, MOH and MLG.

4.3.3 Summary Points: Time, Distance, Direction and SO_2 emissions & respiratory disease incidence

- Prior to 1990, SO_2 emission levels in the Selebi-Phikwe area were well above WHO standards and below those levels thereafter.
- Monitoring stations closest to the smelter recorded the highest SO_2 levels.
- The disease percentage change was higher for settlements away from the smelter than those closer to the smelter.
- The mean respiratory case incidence appeared to be varied in all the health facilities however the influence of distance and direction appeared minimal and insignificant.
- The general trend shows that in the study areas of comparison there was an increase in the incidence rates of respiratory cases[1].

[1] The recording system for the respiratory incidence rates was found to be very poor as most of the monthly data was missing in health facilities.

4.4 DISEASE OCCURRENCE ACCORDING TO DIRECTION

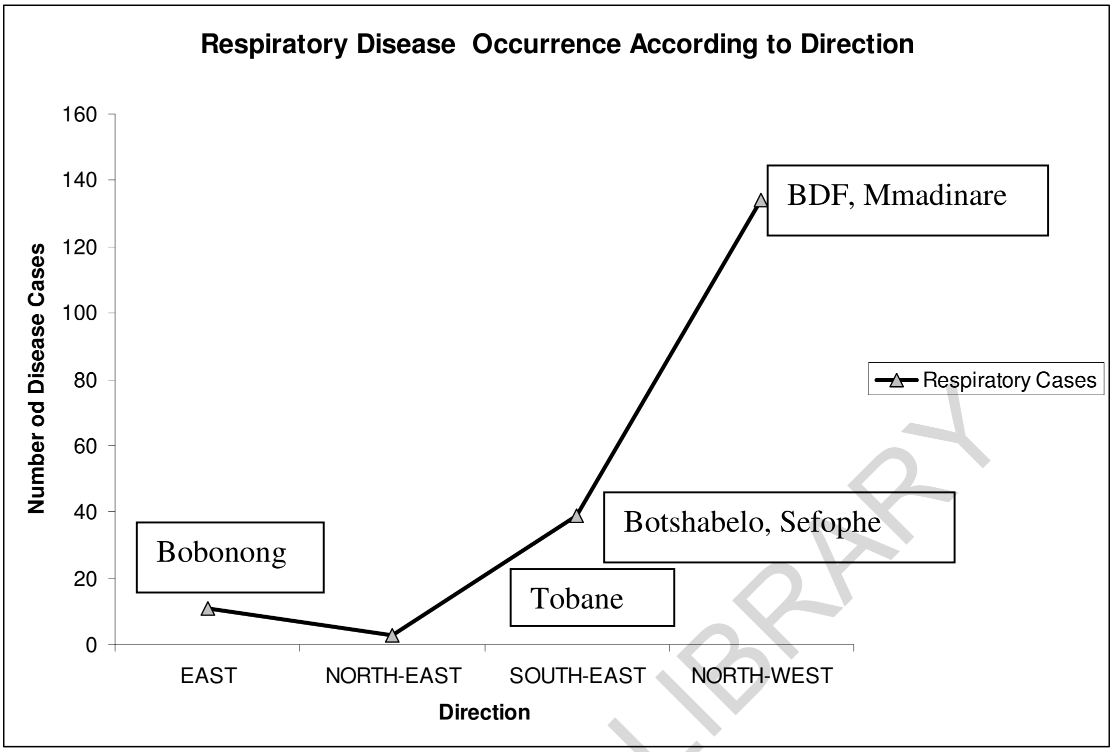
4.4.0 Introduction

This section seeks to determine the incidence of respiratory diseases in relation to the direction of the prevailing plume. The assessment was aimed at revealing which of the settlements were most affected by the plume produced by the BCL mine smelter in Selebi-Phikwe and establishing whether there was correlation between their relative location with respect to smelter emissions and the incidence of respiratory diseases.

4.4.1 Graphical and Statistical Evidence

According to household survey data, the direction most affected by SO_2 emissions was the North West, with a relatively high case load followed by the low recordings of Southeast and thirdly the Eastern direction (Figure 4.5). This was generally in line with wind rose information (Figure 4.1). Settlements found in the most affected directions were BDF camp, Mmadinare (Figure 4.1). This confirmed further the effects of SO_2 emissions on the health of the settlements located in that direction (Table 4.11 above). Common diseases in this direction were coughs and common colds. Figure 4.6 reflects disease burden data.

Figure 4.5: Direction and Claimed Respiratory Disease Incidence from household survey.



Source: Author's survey January 2009 adopted from the household survey.

4.4.2 Pollution effect based on direction from smelter

As already observed, the majority of the respondents who claimed that smelter emissions affected their health came from the most affected settlements. These settlements (BDF and Mmadinare) were found to lie in the northwest of the smelter as shown in Figure 4.6.

4.4.3 Pollution perception health effect based on direction

The majority of the respondents agreed that SO_2 pollution had an effect on their health (Table 4.19), and the most affected direction was the northwest. Therefore this may be used to confirm that the direction of the plume contributes to the high incidence of respiratory cases in the study area. The south east direction was second in pollution effect. As already observed, this may be due to the confounding effect of the sporadic changes in plume direction (sub-section 4.2.6.9 and Table 4.10), and the migration network which took place within the study area (see also sub-section 4.4.4 below).

Table 4.19: Direction versus pollution perception.

		Emissions Cause Disease	
Direction from Smelter	**Study settlement**	**% Agreeing**	**% Disagreeing**
North West	BDF Camp, Mmadinare	55	3
East	Bobonong	7	9
South East	Sefophe	35	8
North East	Tobane	6	18

Source: Author's survey January 2009 adopted from the household survey.

4.4.4 Evidence from Key Informants in affected directions

Five health workers and three council officials were interviewed. The health workers implicated BCL mine as a source of respiratory cases in the town and respiratory cases were reported to be increasing at an alarming rate among BCL mine employees. Many resident employees were reported to come to health facilities to ask for transfers on medical grounds as a result of respiratory health problems, especially among tertiary sector employees in the mining town. The observation was that even those not employed at the mine were detrimentally affected. Many patients were frequently reporting coughs and colds, and chest pains in the health facilities.

Health officials interviewed expressed concern on health issues in the hard hit areas, especially Mmadinare in the northwestern direction. They pointed out the air pollution problem as a major cause of respiratory cases. Due to the severity and prevalence of respiratory cases, an infectious disease control centre was developed in Mmadinare. They therefore welcomed the present study as a timely study that would give more evidence on the relationship between SO_2 emissions and respiratory diseases. They emphasised on low immunity status in the community and identified respiratory cases, HIV/Aids and Tuberculosis as common problems in the area. Concern was expressed on the air pollution impact on the local community and the Ministry of Health was on high alert for respiratory cases as the burden of disease was increasing at an alarming rate. Smoke from the mine was found to have an effect on the population all year round; this was confirmed by the cases reported throughout the whole year. This was echoed by the respondents from the household survey as most of them experienced respiratory diseases right throughout the whole year (Table 4.16).

However there was inconsistency in disease occurrence as shown by the southeast direction where Botshabelo and Sefophe are located. Most respiratory cases were attributed to smelter emission because of the sporadic changes in the plume direction, and the migration network. Most administrative work for Sefophe village was done in Selebi-Phikwe town, the distance of the village from the mine is very close, and the village populace visits Selebi-Phikwe for business frequently. Most residents of this village have a history of residing or working in Selebi-Phikwe. Educational facilities were thought to be a factor as there is no senior secondary school and colleges, therefore residents go for these levels of education in Mmadinare, or Selebi-Phikwe, and these areas are the hardest hit settlements. They also felt development projects such as road and pipeline construction were contributing to the incidence of respiratory cases. The Key Informants, therefore, concluded that socio-economic associations and development projects most likely accounted for the high incidence of respiratory cases in Sefophe.

4.4.5 Summary Points

- The SO_2 emissions were mainly in the westerly direction.
- Respiratory case incidence was very high in the SO_2 plume affected direction as compared to the other directions.
- According to health officials respiratory cases have been on the rise and were a cause for concern for the Ministry of Health.
- Sporadic changes in plume type and direction (conning plume prevailing in winter season), and migration were major confounders which played a major role in increasing the burden of disease in settlements away from the prevailing plume direction.

4.5 DISEASE OCCURRENCE ACCORDING TO DISTANCE

4.5.1 Graphical and Statistical Evidence

In assessing the effect of distance on respiratory disease burden resulting from the BCL mine smelter; it was found that some distance ranges were most affected than others. The respiratory diseases suffered by the population were undulating along transects from the mine smelter, and the most hard hit distance was the 16-20 km range. The second most affected distance was the 0-5 km range which was the closest to the smelter. The respiratory cases recorded are reflected in Figure 4.6 below which shows the distances affected by respiratory cases.

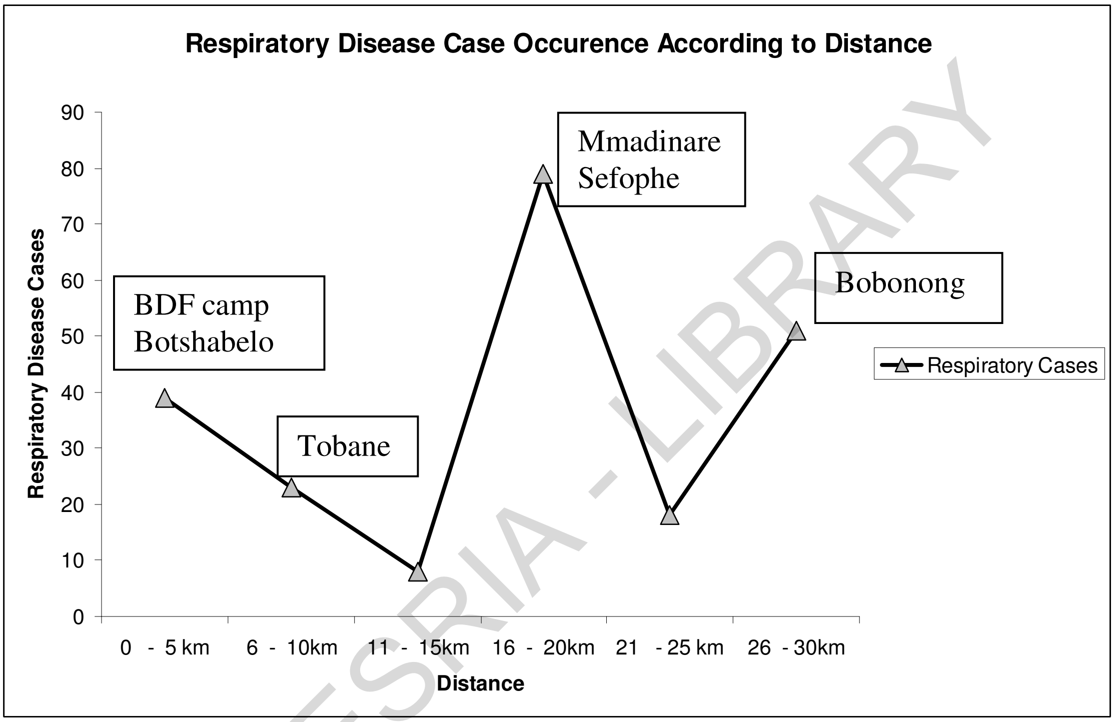
The pattern of respiratory cases experienced in the distance ranges shows that the way the plume blows along a distance impacts on the health of the people. The settlement found in this range of distance was Mmadinare, this confirms the high respiratory cases experienced in the village. The most frequent plume type produced was the looping plume, a fact also confirmed by the Botswana National Environmental Laboratory results (1981-2000 annual reports). According to Franek and Lou DeRose (2003:94), the looping plume has a wavy character and occurs in super adiabatic environments which produces highly unstable atmosphere, because of rapid mixing.

The disease pattern reflected a relationship between SO_2 emissions and disease occurrence. The emissions had an effect on respiratory health especially in Mmadinare which is in the 16-20km range and has a very high prevalence of coughs and common colds. This could be as a result of the looping plume which has a wavy character (Franek *et al.,* 2003).This plume type has played a major role in increasing the case load of respiratory diseases in Mmadinare. This is further confirmed by emissions from smelters which fall out up to large distances from the plant. Heavy amounts of plume could go as far as three to six kilometres and the fall outs increase in distance during dry windy seasons (Garg, 1999:40).

BDF had lower perceptions of respiratory cases, this could be due to the height of the stack which when it produces the plume it goes to further distances, secondly the type of plume blowing does not go down immediately after release but travels longer distances before it settles down.

Using Kendall's correlation analysis at p = 0.05, there was a weak positive relationship (r = 0.133). However the experience of Mmadinare and Bobonong suggests that this relationship was not consistent, hence the weak and insignificant correlation.

Figure 4.6: Distance and Claimed Respiratory Disease Occurrence.



Source: Author's household survey January 2009.

<u>4.5.2 Respiratory health pollution effect based on distance from smelter</u>

The pollution perceptions in the community reflected the pattern of disease occurrence along transects (Table 4.21). For the yes pollution perception, using the Kendall's correlation analysis at p = 0.05, a negative but insignificant correlation (r = -0.33) was revealed, again revealing a very uncertain relationship between distance from SO_2 source and respiratory disease incidence. This is also reflected in Figure 4.6 above.

Table 4.20: Pollution perceptions.

		Distance					
		0 - 5 km	6 -10 km	11 -15 km	16 - 20 km	21 -25 km	26 -30 km
Pollution perception	YES	97%	93.8%	100%	83.3%	100%	69%
	NO	3%	6.2%	0%	16.7%	0%	31%

Source: Author's Household survey 2009.

4.5.3 Pollution perception based on distance from the Smelter

Pollution perceptional effect varied inconsistently with distance as it was undulating. This could be due to the type of plume that is blowing (frequent looping plume). However there was a general decline of perceptional agreement as distance from the smelter increases (Table 4.21). The effects of the type of plume were contributing to this trend of information.

For those agreeing that emissions caused disease, using the Kendall's correlation analysis at p = 0.05, there was a negative correlation (r = -0.5). As distance increased the perceived impact of emissions was undulating, but indirectly (between 0 and 32).

Table 4.21: Pollution Effects

	Emissions Cause Disease	
Distance from Smelter	**% Agreeing**	**% Disagreeing**
0 – 5 km	32	1
6 – 10 km	12	1
11 – 15 km	4	0
16 – 20 km	30	5
21 – 25 km	2	0
26 – 30 km	12	0
31 – 35 km	0	0
36 – 40 km	11	31

Source: Author's Household survey 2009.

4.5.4 Key Informants views on the distance variable

The various interviews conducted reflected on the lack of consistency in disease occurrence as distance increased from the smelter. In Bobonong and Sefophe the health workers felt the SO_2 impacts were not directly affecting them but instead the population had direct migration links with Selebi-Phikwe they could have contracted the respiratory diseases during that short exposure timeframe. The respiratory disease link with the smelter emissions was based on the fact that some residents were employees in Selebi-Phikwe, hence some respiratory disease cases reported could be linked with the exposure to SO_2 emissions. Such cases were reported in Bobonong and Sefophe. Health employees in Selebi-Phikwe and Mmadinare strongly linked respiratory cases with SO_2 emissions produced by the BCL mine smelter as they were closer in distance and in the direction of the prevailing plume, respectively. They revealed that most cases reported were not stable and were literally below the thresholds set. However high blood pressure, HIV/Aids, Tuberculosis incidence and prevalence rates were high and rising. They attributed this to low immunity status of most patients that have visited the health facilities.

4.5.5 Summary Points: Distance and respiratory disease incidence

- The graphic evidence shows the 16-20km distance range as the most affected and Mmadinare village is located within this range.
- Using Kendall's correlation analysis there was a negative but insignificant correlation between distance and respiratory cases. Respiratory disease incidence seems to decrease with distance from the SO_2 source, but this trend was not consistent. This is further supported by emissions from smelters which fall out up

to large distances from the plant. Heavy amounts of plume could go as far as three to six kilometres and the fall outs increased in distance during dry windy seasons (Garg, 1999:40).

- The key informants closer to the smelter attributed respiratory cases to SO_2 emissions, while those far away felt the impact was not direct but the population had access to the closer settlements hence would contract the disease when they had traveled closer to the mine smelter. Thus movement in and out of Selebi-Phikwe could be a confounding factor here.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 INTRODUCTION

This chapter presents conclusions drawn from the results of the study. It also presents recommendations informed by the study's findings. This study has raised some important issues relating to the health impacts of smelter emissions in the various study settlements. It explored the influence of various factors on respiratory disease incidence and on people's perception of health risks associated with SO_2 emissions. These factors included distance and direction to the smelter complex, and various respondent characteristics (e.g. education, age, and length of residence). These issues were discussed with reference to the study's conceptual framework (Figure 2.13.2) which was informed by the systems thinking approach and emphasises on the cause and effect relationship.

5.1 Conclusion

5.1.1 Assessment of Pollution and Respiratory Disease Knowledge levels

Study respondents displayed a high awareness of SO_2 emissions and their link to respiratory health problems. The study confirmed the concerns raised by previous studies regarding the adverse effect of SO_2 emissions on human health (e.g. Ekosse, 2005; Asare, 1999). However, in terms of prevalence, respiratory ailments competed with HIV/AIDS for first rank (Table 4.1).This could suggest that HIV-related depression of immunity may be exacerbating people's vulnerability to SO_2. Indeed, the second most highly ranked diseases were Tuberculosis and flu, both of which are major opportunistic diseases. However, this inference should be treated merely as a hypothesis that needs confirmation by a separate study.

The community felt greater pollution impact in the morning. This could have been due to varying diurnal SO_2 concentrations near the smelter which peak at night or in the morning at the mining plant (Boon *et al.,* 1999). As the day progressed their bodies adapted and they felt better although pollution was continuous. This revealed the continuity of the impacts despite the population not recognising that. The majority of the population experienced headaches and body weakness. These were found to be the major first line indicators of the impact of gaseous emissions by health officials and they further confirmed the strong link between respiratory diseases and SO_2 emissions.

Based on the education status, the older generation was found to be less educated than the younger generation in the responding population. This gave an insight that there were fewer precautionary measures being applied by the older generation hence they were highly affected by the respiratory infections. There were more female than male respondents. However both males and females had the same level of perception on respiratory health effects despite their occupation and migration patterns. Therefore the burden of respiratory diseases was affecting both sexes at the same level and had similar consequences experienced. In validating the population's knowledge levels, it was found that as educational level increased the community became more aware of the association between the pollution effects and human respiratory health malfunctions; this was revealed by the types of disease cases experienced and the experience on how the population contracted them. Based on settlement comparison, the height of the stack and the behaviour of the plume type blowing played a major role in influencing the perception of the respondents in the various locations as more settlements away from the smelter appeared to be more affected (Franek *et al.,* 2003).

The impacts of pollution were realised more as the respondent's residence timeframe increased. This gave evidence on the cumulative effects of SO_2 emissions produced since the inception of the mine. As both males and females grew older they became more vulnerable to respiratory cases and they perceived adverse respiratory health effects with age. This was further confirmed by other studies which reported that continuous exposure of young children revealed serious effects as early respiratory cases could develop into chronic ailments later in life (WHO 1992:20, 21).

Migration was a confounder and probably played a role in increasing the burden of respiratory disease in settlements further away from the smelter and located opposite to SO_2 plume. This was supported by Garg (1999:645) who reported that even at low concentrations SO_2 could affect respiratory human health. Therefore the mine must be encouraged to reduce smoke production and find proper alternatives for cleaner production (see recommendations below).

5.1.2 Spatio-Temporal comparison of sulphur dioxide emissions and respiratory disease incidence (1981-2000)

Prior to the year 1990, it was observed that SO_2 emission levels were well above the WHO datum standard, and below thereafter. This reflects that major steps were taken by the BCL mine to reduce the gaseous emissions. From the Botswana National Environmental Laboratory, it was found that monitoring stations closer to the smelter recorded the highest SO_2 levels, which revealed the influence of distance in the spread of the gaseous emissions. However the respiratory disease percentage change over time was higher for settlements further away from the smelter than those closer to it. The height of the stack and the changes in plume type and direction could have contributed to the variations. Within Selebi-Phikwe the mean respiratory case incidence appeared to be influenced by neither distance nor direction as it varied haphazardly among the health facilities (Figure 4.3). However, despite the reduction of SO_2 emissions after the year 1990, the general trend showed that in the study sites of comparison there was an increase in the incidence of respiratory cases. This probably reflects the cumulative effects of production of SO_2 emissions on various individuals within the population as their immunity varies. Loss of immunity due to HIV/AIDS prevalence could also be summarised as a confounding factor here.

5.1.3 Disease Occurrence according to Direction

SO_2 emissions were mainly towards the westerly direction. This was confirmed by the wind rose (Figure 4.1). It was discovered that respiratory case incidence was very high in the SO_2 plume affected directions as compared to the other directions. According to health officials, respiratory cases have been on the rise and were a cause for concern for the Ministry of Health. Because of this, all the health facilities in the study area were on high alert for respiratory disease cases. Due to sporadic changes in plume type and direction, areas found on the south east were also affected by SO_2 emissions. Migration was viewed by respondents as a confounder which played a role in increasing the burden of respiratory disease in settlements away from the prevailing plume direction. This therefore revealed that regardless of location all the settlements around the smelter were more or less being affected by the gaseous emissions produced by the BCL mine smelter complex.

5.1.4 Disease Occurrence according to distance

Mmadinare village was the most affected, although it was found in the 16-20 km range of distance. There appeared to be a negative correlation between distance and the incidence of respiratory cases, although this trend was inconsistent. This was further confirmed by Garg (1999) who found out that emissions from smelters could fall out up to large distances from the plant. Weather conditions and the height of the stack could have contributed to this pattern, especially in view of the dominance of the looping plume in the area. Key informants closer to the smelter blamed the smelter complex for the respiratory diseases incidence while those far from the smelter felt migration could also be playing a major role in increasing the burden of respiratory cases.

5.2 RECOMMENDATIONS

5.2.1 General

The Selebi-Phikwe smelter complex is the most persistent SO_2 source in the area of study, with emissions averaging 80μg/m³ per year. However there, is uncertainty on actual SO_2 emissions from inadequate constraints on their conversion rates and temporal variability. Most of the data on emissions was secondary data already averaged and the excessive pollution point periods (SO_2 explosions) were not clearly ascertained. Concentrations of SO_2 near the smelters vary diurnally, peaking at night or in the morning at the mining plant (Boon *et al.,* 1999).This is probably a result of the temperature dependence of the rate constant for the SO_2 to sulphate conversion (Eatough *et al.,* 1994).This further explains why the majority of the respondents felt greater impact in the morning (headaches and body weakness).

Some uncertainties remain over the precise details of pollution control technologies and related emission removal efficiencies at the smelters. The best possible way to overcome these uncertainties is by BCL mine conducting studies itself. A continuous improvement philosophy can be used. This may include certification of Selebi-Phikwe site to the ISO 14001 Environmental Management System standard and conducting environmental auditing schemes to improve on pollution control strategies.

An Environmental Performance Agreement can be signed by BCL committing themselves to certain percentage reductions of SO_2 below their existing regulated limits in time frames linked to the completion of studies on technological opportunities for achieving these reductions. A target date for achieving the percentage reductions should be no later than 2016, when Botswana's vision of sustainability needs to be achieved. Another way is to have an open and transparent public process to develop the Environmental Performance Agreements and to ensure routine public reporting on progress.

5.2.2 Settlements around the Smelter

Given that settlements far from the smelter appear to be more affected, equal frequent medical check ups and treatment strategies of the community's health should be put in place regardless of distance from the smelter. The plume produced should be purified and made less harmful before release. As it appears that even areas away from the plume direction seem to be adversely affected also, precautionary measures such as treatment strategies and medical check ups should be put in place in all settlements surrounding the mine smelter regardless of direction. The Ministry of Health has to be on high alert in all the study sites. This therefore shows that the existence of the smelting plant is more dangerous hence advocacy for its relocation may be the ultimate solution.

5.2.3 Respiratory Disease Incidence

Given the positive association between education or length of stay and awareness of SO_2 emission impact on respiratory health, a cohort study maybe done to follow up individuals for a longer period of time to ascertain the relationship, as HIV/AIDS and respiratory cases seem to have a close association in people's minds, more health promotion and education activities must be conducted to clear out misconceptions and make the community to be more alert on signs and symptoms of respiratory diseases. A study to confirm the assumed relationship between HIV/AIDS and vulnerability to SO_2 emissions is also recommended.

5.2.4 Control of Sulphur Dioxide Emissions

Use of Timmins is a clean modern operation, which results in more than 98% fixation of sulphur present from the smelter feed, which is captured and converted to H_2SO_4. This has been tested in Falcon Bridge Canada. BCL may also conduct a SO_2 abatement project to capture fluid bed roaster off-gas. It may focus on reducing continuous emission levels rather than the annual emission level which is normally low while high exposures could have been experienced during the course of the year.

BCL may install wet scrubbing of fluid bed roaster gases to produce H_2SO_4. In addition BCL could find uses for H_2SO_4 within the country and perhaps also export if financial resources permit. The programme could have proved to be unviable before but if proper export business trading entities are identified as the target market, this may be a sustainable project. The mine may also upgrade the electrostatic precipitator for converting gases; in addition they may upgrade the electrostatic precipitator in the top blown rotary converters plant and install scrubbers to remove the SO_2.

A continuous converting process can be implemented, this process is critical to any plans to further reduce emissions of dust and SO_2.The fixation of SO_2 is a possible route for the Selebi-Phikwe mine.

5.2.5 Protection from Sulphur Dioxide (SO_2)

With SO_2 being a contaminant in the workplace, it was observed that employees at the mine used goggles, nose and mouth respiratory covers. While these were worn separately, it may be safer, simpler and more comfortable to use a full face respirator.

5.2.6 Regulatory propositions

Regulations for emission trading may help reduce gaseous emissions and these should be reviewed annually in order to see that it does not worsen regional imbalances in environmental health by promoting intensification of localised air pollution.

Instead of focusing on the WHO health standards that BCL mine seems to meet, it should be made clear whether BCL mine is meeting its targets of emission reduction based on the proposed timeframes taking into account other methods that could improve the smelting process. The method of calculation the Ministry of Environment (Department of Waste Management and Pollution Control, Air Pollution Control Unit), and Mines Department use reaches the allowable figures for the non-ferrous smelting sector. However it does not appear clear; therefore the relevant departments in the Ministry should clarify that by making the method of calculation public.

All mining facilities must strive towards continuous improvement. Both the government and industry organisations should promote research and development to develop sustainable new technologies that produce the least harmful effect on the environment and the health of the local population. The government should obtain due advice from the academic community through research for proper policy making. The mine should also prioritise to substantially reduce their emissions during the period May-September when SO_2 emissions are very high.

The Department of Waste Management and Pollution Control may come up with a Clean Air Plan for Industry which encourages the mines such as BCL to pursue technically feasible reductions that are economically achievable from the industrial sub-sectors. A combination of emission thresholds and design capacities would be used to identify facilities for SO_2 reductions. This would ensure that BCL mine contributes to reducing their SO_2 emissions. Requiring those facilities to reduce their SO_2 emissions will create a level playing ground within the mining sector and will ensure that reductions occur. It would also encourage facilities to improve their operations and become more efficient. BCL mine may establish two types of SO_2 limits; first the intensity based variable limits, with a recalculation provision if the stipulated emissions are exceeded due to an increase in production. Secondly (as already noted) an emissions trading system with a regulatory SO_2 tonnage limit may be adopted in the near future although it is yet to be available in the country or region.

5.2.7 The Influence of Health Effects Assessment

Health concerns drive the regulatory agenda for air pollutants, especially for SO_2 emissions. Therefore, an improved understanding of the health effects of air pollution is essential for informed decision making and the development of effective, science-based standards and control strategies. Regulation of the sources of SO_2 found to be most harmful to human health will result in the greatest societal and environmental benefit. Research results on the health impacts of SO_2 sources and components could also be important in decisions about the viability of the mining of copper and nickel as a natural resource and coal as a current and future fuel option in Botswana.

5.2.8 Control Site

From the study, the sites away from the prevailing plume direction were deemed to control for the spread of SO_2 emissions. However, given the confounding factors such as migration within and between the study sites and the sporadic changes in plume direction, conducting a similar study in a settlement far away from the smelting facilities to act as a check on the uniqueness of these results should be encouraged.

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APPENDICES

APPENDIX 1

Key Informant Interview Questions.

Institutional Key Informant questions for Hospital/Clinic.

Department of Environmental Science, University of Botswana.

TOPIC: An assessment of impacts of mine emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.
This study is for academic purposes only. I wish to assure you that whatever you tell me will be treated in confidence and will not be used against you.
Date of Interview…………….. Name of Interviewee………………………
Area's Local Name…………..
1. What is the name for the health centre ?....................................
2. For how long has this centre been in operation? ………………….
3. What is the patient attendance rate per day in the hospital or health centre? ……………………………………………………….
4. What is the most commonly reported diseases at the centre? List in order of highest case load.
1)……………………………
2)……………………………
3)……………………………
4)……………………………
5)……………………………

5. What do you think are the possible causes of those diseases reported?

	DISEASE	PROBABLE CAUSE
1		
2		
3		
4		
5		

6. Which specific diseases are common in the following areas in the town according to your records?

AREA	DISEASE
1.	
2.	
3.	
4.	
5.	

7 a). Which period of the year recorded the highest respiratory diseases?
....
7 b). What could be the major cause of the cases during this period?
....
8. In which part of the town/village are respiratory infections reported from?
....
9. How far do smelter emissions go and how frequent do they blow towards the area?
....
10. Do you experience a huge turn out in case reporting at the health centre after an episode of plume production? ....

APPENDIX II

Questions for Key Informant at BCL Copper-Nickel Mine.

Department of Environmental Science, University of Botswana.

TOPIC : An assessment of impacts of mine emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.

This study is for academic purposes only. I wish to assure you that whatever you tell me will be treated in confidence and will not be used against you.
Date of Interview…………….. Name of Interviewee………………………
Area's Local Name…………..
1. For how long has BCL been in operation? ( ).
2. How many people are employed by BCL? ( ).

Category of staff	Number		
	Locals		Expatriats
	Hinterland	Batswana	
Senior Technical Staff			
Senior Admin Staff			
Technical Staff			
Admin Staff			
Labourers(Miners)			

3. What kind of protective clothing is given to the employees?.....................................
4. What type of mining methods are employed by BCL mine?.....................................

Type of Method	Tonnes of ore extracted	Percentage of method employed.
1. Opencast (pit) mining.		
2. Underground mining.		
3. Others (specify).		

5. What measures have been taken to reduce smelter emissions at source?........................
6. What has the mine done to improve the health status of the local community?.............
7. Does the mine provide health education to employees and residents of Selebi-Phikwe especially on smelter emissions?
 1. YES ( ) 2. NO ( ).
If yes how? ....
8a). Is there any health action plan or policy in this mine?
1. YES ( ) 2. NO ( ).
 b). If 'yes' how do you prepare the company's health action plans for implementation?
…………………………………………………………………………………………
8c). Who are involved in the preparation and implementation? …………………………
8d). Why do you involve them? ………………………………………………………

9. Does the mine have life/health insurance policies?
1.YES [ ] 2.NO [ ].
If yes what is covered by the policies? ………………………………………
10. Have health problems hindered the expansion of the mine's operations?
1. YES ( ) 2. NO ( )
If yes how……………………………………………..
11. What are the future development plans of the mine? …………………………………
12. How will these development plans affect Selebi-Phikwe and near by villages' health status? ………………………………………………………………………………

APPENDIX III

Questions for Selebi-Phikwe(Key Informant) Town Council Officer.

Department of Environmental Science, University of Botswana.

TOPIC: An assessment of impacts of mine emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.
This study is for academic purposes only. I wish to assure you that whatever you tell me will be treated in confidence and will not be used against you.
Date of Interview…………….. Name of Interviewee………………………
Area's Local Name…………..

1. What are the main health problems faced by Selebi-Phikwe and its surroundings?
....
2. What are the main causes of these problems? ....
3. How are these problems being addressed by the council?
…………………………………………………………………………………………
4. Do you think the physical expansion of the town contributes to air pollution in Selebi-Phikwe?
1. YES [ ] 2.NO [ ].
If yes please give reasons …………………………………………………………………

APPENDIX IV

Questions for Non Governmental Organisations of Community Based Organisations.

Department of Environmental Science, University of Botswana.

TOPIC : An assessment of impacts of mine emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.

This study is for academic purposes only. I wish to assure you that whatever you tell me will be treated in confidence and will not be used against you.
Date of Interview…………….. Name of Interviewee………………………
Area's Local Name…………..

1. What is the name of the organization? …………………………………………
2. How long has the organization been in operation? ……………………………
3. What are your main objectives? ……………………
4. What is your comment on the health and environmental situation in this area?
....
5. What are the health problems being faced by the local population?

1)……………………………………………………………………………………
2)……………………………………………………………………………………
3)……………………………………………………………………………………
4)……………………………………………………………………………………

6. What are the causes of each of the problems mentioned above? ………………
7. How has your organization contributed in solving the problems mentioned? …
8. How do you see the future health status of Selebi-Phikwe and the surrounding villages? ………………

APPENDIX V

Interview Schedule for Key Informants.

Department of Environmental Science, University of Botswana.

TOPIC : An assessment of impacts of mine emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.

This study is for academic purposes only. I wish to assure you that whatever you tell me will be treated in confidence and will not be used against you.
Date of Interview…………….. Name of Interviewee………………………
Area's Local Name………….. Status in Community……………………..
Length of stay ……………….

1. Do you think the smelter is a health hazard to the town/village?
1. YES ( ) 2. NO ( ).
If yes how severe is the hazard?

1) Very severe
2) Severe
3) Moderately severe
4) Weakly severe
5) Not severe

2. Which part of the town/village are experiencing serious episodes of gaseous emissions?……………………………………………………………………
3. Is the local community knowledgeable about gaseous emissions as a health hazard?

1. YES ( ) 2.NO ( ).
If yes how knowledgeable is the community?

1) In-depth knowledge.
2) General knowledge.
3) Very little knowledge.
4) No knowledge.
5) No idea.

4. What source of information alerts the public about the emissions as a health hazard?

1) Documents
2) Officials
3) Awareness Campaigns
4) No source at all

5. a) How frequent do you experience episodes of gaseous emissions in your area?

1) More than twice a year
2) Twice a year
3) Once a year
4) No idea

5. b) In which period of the year are these episodes experienced?

1) Jan-Mar.
2) Apr-Jun.
3) July-Sept.
4) Oct-Dec.
5) All year round.
6) No idea.

6. How has the community leadership facilitated the reduction of gaseous emissions from the mine ?
……………………………………………………………………………………………
4. What contributions has the mine made towards improving the health of the people?
……………………………………………………………………………………
5. Do you think production of sulphur dioxide emissions contributes to the morbidity rate in your village or area?
1. YES (   ) 2.NO ( ).
If so how? …………………………………………………………………………
6. Do you think your area is the worst affected?

1. YES ( ) 2. NO (   ).
If yes why?
…………………………………………………………………………

APPENDIX VI

HOUSEHOLD QUESTIONNAIRE

AN ASSESSMENT OF IMPACTS OF SMELTER EMISSIONS ON HUMAN HEALTH: A CASE-STUDY OF SELEBI-PHIKWE BCL COPPER-NICKEL MINE IN BOTSWANA

UNIVERSITY OF BOTSWANA

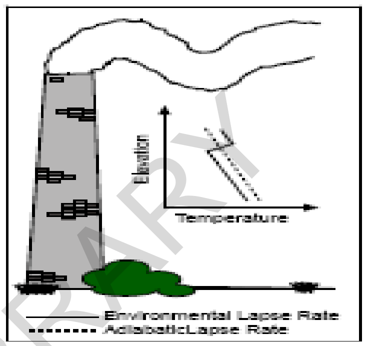

Table of Contents

Introduction

Thank you for your participation in the study by completing this questionnaire on the impacts of smelter emissions on human health in Selebi-Phikwe and the surrounding villages (Sefophe, Mmadinare, Tobane and Bobonong), in Botswana. This study is for academic purposes only. All information collected will be treated confidentially and will not be revealed. It is suspected that environmental and human health problems may have ensued within Selebi-Phikwe due to the smelter emissions. Inhabitants of the Selebi-Phikwe area and the surrounding villages are often infected with symptoms of diseases and diseases related to pulmonary health complications. Therefore there is need for advance solutions which may be implemented.

The basis of the study will consist of questionnaires, personal interviews and collection of data from hospitals/clinics in Selebi-Phikwe and surrounding villages. All the information obtained from this study will be strictly confidential, and made available as research findings at scientific conferences, seminars and workshops and eventual publication in scientific journals. Any additional information provided will be very much appreciated.

This questionnaire is divided into the following main sections:

SECTION 1: Questionnaire for individuals which should be answered by individuals.

Kindly Note the following:

- Please read through the whole question before making a choice.
- Your answer should be marked with a cross in the box provided below or next to your choice.
- Where a question requires a written explanation as the response kindly write concisely on the space provided.
- Where a question requires more than one answer, it will be made clear.
- Be very frank with your answers.

SECTION 1: Questionnaire for individuals

Date of Interview ……………………………………………………………………
Name of Interviewee (optional)…………………………………………………..
Area (Address)………………………………………………………………………

1.1 Demographical, geographical and biographical data.

1.1.1 Gender

1.1.1 Gender	1).Male		2).Female	

1.1.2 Age Group	1). 0-10 yrs	2). 11-20 yrs	3). 21-30 yrs	4). 31-40 yrs	5). 41-50 yrs	6). + 50 yrs

1.1.3 Occupation	1).

1.1.4 How long have you lived in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, and Tobane?					
	1). 0-5 yrs	2). 6-10 yrs	3). 11-15 yrs	4). 16-20 yrs	5). 21-25 yrs
	6). 26-30 yrs	7). 31-35 yrs	8). 36-40 yrs	9). 41-45 yrs	10). > 45 yrs

1.1.5 How far are you from the mine smelter ?(distance in kilometers)			
1).0-5 km	2).6-10 km	3).11-15 km	4).16-20km
5).21-25 km	6).26-30 km	7). 31-35 km	8). 36-40 km

1.1.6 In which direction from the smelter are you located ?			
1).North	2).South	3).East	4).West
5).North East	6).South East	7).North West	8).South West

1.1.7 Do you agree that the pollution from the mine has negatively affected human health?	1).Yes		2).No	
1.1.8 If answer to 1.1.7 is yes, how strongly do you agree?				
1).Strongly	2).Agree	3).Neutral	4).Disagree	5).Strongly

Agree				Disagree

1.1.9 In order of importance, what are the common diseases in this community?				
1).1st in rank	2).2nd in rank	3).3rd in rank	4).4th in rank	5).5th in rank

1.1.10 What disease affects your household most often?

1.1.11 How long does it take you or any other member of the family to recover from the disease mentioned in 1.1.10?				
1).Hours	2).Days	3).Weeks	4).Months	5).Years

1.1.12 In order of severity which of the following do you think affects your health the most?			
1).Smoke from the mine	2).Dust from the mine	3).Vibrations due to the mine	4).Others (specify)

1.1.13 In rank order, during which period of the year do you mostly suffer from respiratory problems?					
1).Jan-Mar.	2).Apr-Jun.	3).July-Sept.	4).Oct-Dec.	5).All year round.	6).No idea.

1.1.14 In rank order, during which time of the year does plume frequently blow to your direction?					
1).Jan-Mar	2).Apr-Jun	3).July-Sept	4).Oct-Dec	5).All year round	6).No idea

1.2 Household Health History and status.

1.2.1 Have you ever visited the health facility in your area?		1).Yes		2).No	
1.2.2 If answer 1.2.1 is yes, for what health problem?		1).Yes		2).No	
1.2.3 How often do you visit the health facility					
1).Weekly	2).Monthly	3).Once in three months	4).Twice a year	5).Once a year	

1.2.4 Is your father alive?	1).YES		2).NO	

1.2.5 If yes how old is he?					
1). < 20 yrs	2). 21-30 yrs	3). 31-40 yrs	4). 41-50 yrs	5). 51-60 yrs	6). > 60 yrs

1.2.6 How long has your father lived in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, Tobane?				
1). 0-5 yrs	2). 6-10 yrs	3). 11-15 yrs	4). 16-20 yrs	5). 21-25 yrs
6). 26-30 yrs	7). 31-35 yrs	8). 36-40 yrs	9). 41-45 yrs	10).> 45 yrs

1.2.7 Does your father suffer from any of the following?						
1). Asthma	2). Respiratory cases	3). Bronchitis	4). Sore throat	5). Coughs and colds	6). High blood pressure	7). Allergies

1.2.8 If answer to 1.2.4 is no, at what age did your Father die?					
1).< 20 yrs	2).21-30 yrs	3). 31-40 yrs	4). 41-50 yrs	5). 51-60 yrs	6). > 60 yrs

1.2.9 Is your mother alive?	1).YES		2).NO	

1.2.10 If yes how old is she?					
1).< 20 yrs	2).21-30 yrs	3).31-40 yrs	4).41-50 yrs	5).51-60 yrs	6).> 60 yrs

1.2.11 How long has your mother lived in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, Tobane?					
	1).0-5 yrs	2). 6-10 yrs	3). 11-15 yrs	4). 16-20 yrs	5). 21-25 yrs
	6). 26-30 yrs	7). 31-35 yrs	8). 36-40 yrs	9). 41-45 yrs	10). > 45 yrs

1.2.12 Does your mother suffer from any of the following?						
1).Asthma	2).Respiratory cases	3).Bronchitis	4).Sore throat	5).Coughs and colds	6).High blood pressure	7).Allergies

1.2.13 If answer to 1.2.8 is no, at what age did your mother die?					
1).< 20 yrs	2).21-30 yrs	3).31-40 yrs	4).41-50 yrs	5).51-60 yrs	6).> 60 yrs

1.2.14 Do you have any living brothers?		1).YES		2).NO	
1.2.15 How many?	1).One	2).Two	3).Three	4).Four	5).More than four

1.2.16 How long have your brothers lived in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, Tobane?					
	1). 0-5 yrs	2). 6-10 yrs	3). 11-15 yrs	4). 16-20 yrs	5). 21-25 yrs
	6). 26-30 yrs	7). 31-35 yrs	8). 36-40 yrs	9). 41-45 yrs	10). > 45 yrs

1.2.17 Does any of your brothers suffer from any of the following?													
1).Asthma		2).Respiratory Cases		3).Bronchitis		4).Sore throat		5).Coughs and colds		6).High blood pressure		7).Allergies	
1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO

1.2.18 If answer to 1.2.12 is no, how many are deceased?											
1.2.19 If deceased, at what age in years, and how many?											
1). < 20	No.	2). 21-30	No.	3). 31-40	No.	4). 41-50	No.	5). 51-60	No.	6). > 60	No.

1.2.20 Do you have any living sisters?		1).YES		2). NO	
1.2.21 How many ?	1). One	2). Two	3). Three	4). Four	5). More than four

1.2.22 Does any of your sisters suffer from any of the following?													
1). Asthma		2). Respiratory cases		3). Bronchitis		4). Sore throat		5). Coughs and colds		6). High blood pressure		7). Allergies	
1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO	1). YES	2). NO

1.2.23 If answer to 1.2.15 is no, how many are deceased?											
1.2.24 If deceased, at what age in years, and how many ?											
1). < 20	No.	2). 21-30	No.	3). 31-40	No.	4). 41-50	No.	5). 51-60	No.	6). > 60	No.

1.2.25 How long have your sisters lived in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, Tobane?					
	1). 0-5 yrs	2). 6-10 yrs	3). 11-15 yrs	4). 16-20 yrs	5). 21-25 yrs
	6). 26-30 yrs	7). 31-35 yrs	8). 36-40 yrs	9).41-45 yrs	10). > 45 yrs

1.3 General Complaints about Personal Health.

1.3.1 Do you have general body weakness?	1). YES		2). NO	
1.3.2 If answer to 1.3.1 is YES, what time of the day do you have body weakness?				
1). Morning	2). Afternoon	3).Evening	4). Night	5). All day

1.3.3 Do you often have flu or common cold?	1).YES		2). NO	
1.3.4 If answer to 1.3.3 is YES is the flu/cold accompanied by any of the following?				
1). Sore throat	2).Runny Nose	3). Blocked Nose	4). Body pains	5). High Temperature

1.3.5 Do you experience headaches ?	1). YES		2). NO	
1.3.6 If answer to 1.3.5 is YES, how often do you experience headaches?				
1). Once a week	2). Once a month	3). Once every three months	4).Once every six months	5).Not sure

1.3.7 If answer to 1.3.5 is yes, what type of the headaches?				
1). Front	2).Temple(sides)	3). Back	4). Centre	5). All over

1.3.8 Severity of the headache ?				
1). Dull	2).Moderate	3).Acute	4). At times dull & at times acute	5).Not sure

1.3.9 Do you cough often?	1).YES		2). NO	
1.3.10 If answer to 1.3.9 is yes, how often do you cough?				
1). Regularly Everyday	2). Once a day	3).Once a week	4). Once a month	5). Not sure

1.3.11 What time of the day do you usually cough?				
1). Morning	2). Afternoon	3). Evening	4). Night	5). All day

1.3.12 What is the cause of the cough?				
1.3.13 Do you spit regularly?	1).YES		2).NO	
1.3.14 If answer to 1.3.13 is yes, what type of sputum?				
1). Clear sputum	2). Milky sputum	3). Greenish sputum	4). Sputum with blood	5). Black sputum

1.3.15 What time of the day do you usually spit?				
1). Morning	2). Afternoon	3). Evening	4). Night	5). All day

1.3.16 What is the cause of your spitting?				
1.3.17 Does the spitting affect your work/lifestyle?	1).Yes		2).No	

1.3.18 Do you experience chest pain regularly?	1).Yes		2).No	
1.3.19 If answer to 1.3.19 is YES, how often do you experience the chest pain?				
1).Daily	2).Weekly	3). Monthly	4). After three months	5). Not sure

1.3.20 If answer to 1.3.18 is yes, what type of chest pain?				
1). Dull	2). Moderate	3). Acute	4). At times dull & at times acute	5).Not sure

1.3.21 What time of the day do you have a chest pain?				
1). Morning	2). Afternoon	3). Evening	4). Night	5). All day

1.3.22 What brings about the chest pain?				
1.3.23 Does the chest pain affect your work/lifestyle?	1).Yes		2).No	
1.3.24 Do you experience shortness of breath regularly?	1).Yes		2).No	
1.3.25 If answer to 1.3.24 is YES, what type of shortness of breath?				
1).Dull	2). Moderate	3). Acute	4). At times dull & at times acute	5). Not sure

1.3.26 What time of the day do you experience shortness of breath?				
1). Morning	2). Afternoon	3). Evening	4).Night	5). All day

1.3.27 What brings about the shortness of breath?				
1.3.28 Does shortness of breath affect your work/lifestyle?	1).Yes		2).No	

1.4 Past Personal Medical History.

1.4.1 Have you had any significant or major illness?	1).Yes		2). No	
1.4.2 If answer to 1.4.1 is yes, what type of illness?				
1.4.3 Were you resident in Selebi-Phikwe, Tobane, Sefophe, Mmadinare, Bobonong when illness occurred?	1).Yes		2). No	

1.4.4 For how long did you have the illness (approximate years)?				
1). Less than one	2). Between one and two	3). Between two and three	4). Between three and four	5). More than four

1.4.5 What was the cause of the illness mentioned in 1.4.2 ?				
1.4.6 Are you now healed of the illness mentioned in 1.4.2?	1).Yes		2).No	

1.4.7 Do you regularly undergo medical examination?	1).Yes		2).No	
1.4.8 Were you resident in Selebi-Phikwe, Bobonong, Mmadinare, Tobane, Sefophe when the medical examination occurred?	1).Yes		2).No	

1.4.9 How often do you undergo medical examination?				
1).Once in three months	2).Once in six months	3).Once a year	4).Once every two years	5).Not sure

1.4.10 Indicate what type of medical examination you underwent?				
1). X-ray	2). Lung function test	3). Blood test	4). Urine test	5).Other (specify)

1.4.11 Have you ever been hospitalized ?	1).Yes		2). No	
1.4.12 Were you resident in Selebi-Phikwe, Bobonong, Tobane, Sefophe, Mmadinare when you were hospitalized?	1).Yes		2).No	

1.4.13 If answer to 1.4.11 is yes, where were you hospitalized?				
1). Mmadinare	2). Sefophe	3). Tobane	4). Selebi-Phikwe	5). Bobonong
1.4.14 What was the reason for hospitalization?				

1.4.15 Have you had Rheumatic fever as a child?	1).Yes		2).No	
1.4.16 If answer to 1.4.15 is yes, were you resident in Selebi-Phikwe, Bobonong, Tobane, Mmadinare, Sefophe?	1).Yes		2).No	
1.4.17 Have you had Tuberculosis?	1).Yes		2). No	

1.4.18 If answer to 1.4.17 is yes, where were you resident when you had tuberculosis?				
1). Selebi-Phikwe	2). Mmadinare	3). Sefophe	4). Tobane	5). Bobonong

1.4.19 Do you have asthma?	1).Yes		2). No	
1.4.20 If answer to 1.4.19 is yes, at what age did you have asthma?				

1.5 Past and present treatment/medication.

1.5.1 Do you take medication for pain?	1). Yes		2). No	

1.5.2 If answer to 1.5.1 is yes, how often do you take the medication?				
1). When the pain occurred	2). Three times a day	3).Two times a day	4). Irregularly	5). Not sure

1.5.3 What type of medicine do you take for pain?				
1). Panado	2). Aspirin	3). Codeine	4). Ibrufen	5). Other(specify)

1.5.4 What type of pain is the medication taken for ?				
1). Headache	2). Period pains	3). Back pain	4). Abdominal pain	5). Other (specify)

1.6 Socio-Economic section

1.6.1 What type of Energy do you use in your household?

1.6.2 What is the purpose of your stay in Selebi-Phikwe, Bobonong, Mmadinare, Sefophe, Tobane?				
1).Employment	2).Schooling	3).Home town	4).Visiting	5). Other (specify)

1.6.3 What do you think are the environmental problems of Selebi-Phikwe or Mmadinare or Tobane or Sefophe or Bobonong in order of significance?
1).
2).
3).
4).

1= Most significant
n= Least significant

1.6.4 In your own view, what can be done to solve the environmental problems in 1.1.16 and the surrounding areas?	
Problems	Solutions
1).	
2).	
3).	
4).	

1.6.5 How could the BCL mine assist in dealing with the community's environmental health problems?

1.6.6 Educational Level ?			
1). None	2). Primary	3). Secondary	4). Tertiary

1.6.7 What contribution can you mention that has been done by the BCL mine to improve the health of this community?

1.6.8 Do you smoke?	1).Yes		2).No	

1.6.9 Do you take alcohol?	1).Yes		2).No	

1.7 Consent Form

I... of ....voluntarily and freely without being forced, agree to be a participant in the research entitled *An assessment of the impacts of smelter emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.* The research is being conducted by Mr Reginald D. Gwisai who is an MSc student at the University of Botswana, in the department of Environmental Science. I understand the purpose of this project is to assess the impact of gaseous emissions on the health of people in the vicinity of the mine plant in Selebi-Phikwe. The impact is a comparative analysis of different locations from the smelter, where settlements are found.

I understand that, if I agree to participate in this project, I will be asked questions lasting at most two hours, about my personal experiences and knowledge about smelter emissions production and their impact to the health of the population in my area of location. I understand that my conversation with the researcher will be tape recorded in order to provide the researcher with an accurate and complete record of our discussion. The tapes will then be kept by the researcher in a locked filing cabinet to which only the researcher has access.

By participating in this project, I will not incur any personal risk. All my responses to the researcher on the questions posed to me will be identified by a subject numerical code and kept confidential. My name will not appear on any of the results of the study and only pseudonyms and aggregated group responses will be reported.
I understand that there will be benefits from participating in this research project even if they might neither be direct or immediate. Such benefits would be in the form of improving the health status of the populations in and around the mine smelting operations in Selebi-Phikwe. A final summary, in aggregate form of the report, may be sent to me upon my request.

I understand that I have the right to ask and have answers to any query concerning this study and I reserve the right to withdraw my participation at anytime, if I choose to, without any prejudice. Questions, if any, about this research project have been answered to my satisfaction.

I understand that I may contact Mr Reginald D. Gwisai at the University of Botswana, Department of Environmental Science,236/213 Earth Science Building,P.B.0022 Gaborone, Phone 393-5800 and/or The Secretary, Health Research and Development Committee, Ministry of Health, P.B. 0038

Gaborone, Phone 3170585 for any queries about this research or my rights I have read and understood the contents of this form. Signed……………………………… Date………………………………. Place……………………………….

APPENDIX VII
Study Permit Ministry of Health.

Telephone: (267) 3632000
FAX (267) 353100
TELEGRAMS: RABONGAKA
TELEX: 2818 CARE BD

MINISTRY OF HEALTH
PRIVATE BAG 0038
GABORONE

PULA

REPUBLIC OF BOTSWANA

REFERENCE No: PPME: PS 13/18/1 Vol IV (6)   28 November, 2008

PERMANENT SECRETARY
MINISTRY OF HEALTH
RESEARCH UNIT
28 NOV 2008
P/BAG 0038
GABORONE
REPUBLIC OF BOTSWANA

Mr.Gwisai
University of Botswana
Department of Environmental Science
P/Bag 00704
Gaborone

Dear Mr. Gwisai

<u>Permit: "An Assessment of the Impacts of Smelter Emissions on Human Health: a case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana</u>

Your application for a research permit for the above stated research protocol refers. The HRU met on the 13 November, 2008 and reviewed your proposal. We note that you have satisfactorily revised the protocol as per our suggestions.

Permission is therefore granted to conduct the above mentioned study. This approval is valid for a period of one year effective 28 November, 2008.

This permit does not however give you permission to collect data from the selected facilities without approval from the management. Consent from the identified individuals should be obtained at all times.

The research should be conducted as outlined in the approved proposal. Any changes to the approved proposal must be submitted to the Health Research Unit and Development Division in the Ministry of Health for consideration and approval.

Furthermore, you are requested to submit at least one hard copy and an electronic copy of the report to the Health Research Division, Ministry of Health within 3 months of completion of the study. Approval is for academic fulfilment only. Copies should be submitted to all other relevant authorities.

Yours sincerely

P. Khulumani
For/Permanent Secretary

PERMANENT SECRETARY
MINISTRY OF HEALTH
RESEARCH UNIT
28 NOV 2008
P/BAG 0038
GABORONE
REPUBLIC OF BOTSWANA

2

APPENDIX VIII

Study Permit Ministry of Local Government.

TELEPHONE: 3658400
TELEGRAMS:
REFERENCE: PHCS 1/7/10 I (6)
FAX: 3972250/3901976

REPUBLIC OF BOTSWANA

MINISTRY OF LOCAL GOVERNMENT
PRIVATE BAG 006
GABORONE
BOTSWANA

02 February, 2009

Dear Reginald Dennis Gwisai,

PERMISSION TO CONDUCT RESEARCH - YOURSELF

Permission is hereby granted for you to conduct research as per approval by the Research Unit of Ministry of Health: Reference No: **PPME: PS 13/18/1 Vol IV (6)**, dated November 28th, 2008.

Please note that this permission does not however give you authority to collect data from the selected sites without prior consultation with the management of the districts.

By copy of this letter, the Selibe-Phikwe Town Council and Bobirwa Sub-District Council management is hereby informed and requested to assist you.

Yours Sincerely,

R. Tidimane
For Director, Primary Health Care Services

Cc: Town Clerk – Selibe Phikwe Town Council
Senior Assistant Council Secretary – Bobirwa Sub-District Council
Attention: Chief Public Health Officer

APPENDIX IX

Research Permit Ministry of Environment.

TELEPHONE: 3914955

TELEGRAMS: MEWT

TELEX:

TELEFAX: 3914861

REFERENCE: EWT 8/36/4 IV (59)

REPUBLIC OF BOTSWANA

MINISTRY OF ENVIRONMENT,
WILDLIFE AND TOURISM
PRIVATE BAG BO 199,
GABORONE
BOTSWANA

ALL CORRESPONDENCE MUST BE ADDRESSED TO

THE PERMANENT SECRETARY

24th November 2008

Mr Reginald Dennis Gwisai
University of Botswana
Department of Environmental Science
Private Bag UB 00704
Gaborone

Dear Sir,

APPLICATION FOR A RESEARCH PERMIT
AN ASSESSMENT OF THE IMPACTS OF SMELTER EMISSIONS ON HUMAN HEALTH: A CASE STUDY OF SELEBI-PHIKWE BCL COPPER-NICKEL MINE IN BOTSWANA

Reference is made to your application for research permit dated 21st October, 2008 on the above subject matter.

We are pleased to inform you that you are granted permission to conduct a research entitled: **An assessment of the impacts of smelter emissions on human health: a case study of Selebi-Phikwe BCL Copper-Nickel Mine in Botswana.** The research will be conducted at Selebi-Phikwe, Mmadinare, Sefophe, Tobane and Bobonong.

This permit is valid for a period effective from the **19 October 2008** to the **30 April 2009.**

This permit is granted subject to the following conditions:

1. Payment of Research Permit Fees is waived.

2. Signing and submission of an Agreement between Government of Botswana and Independent Researchers (to be sent to you at

a later date).

3. Copies of videos/publications produced as a result of this project are directly deposited with the Office of the President, National Assembly, Ministry of Environment, Wildlife and Tourism, Department of Waste Management and Pollution Control, National Archives, National Library Service, Research and the University of Botswana Library.

4. This permit does not give authority to enter premises, private establishments or protected areas. Permission for such entry should be negotiated with those concerned.

5. You conduct the study according to particulars furnished in the approved application taking into account the above conditions.

6. The research team comprises of **Reginald Dennis Gwisai, Prof: R. Chanda, Prof: T.D. Gwebu and Prof: B.P. Parida.**

7. Failure to comply with any of the above conditions will result in the immediate cancellation of this permit.

8. The applicant should ensure that the Government of Botswana is duly acknowledged.

Thank you.

Yours faithfully

R.M. Mojaphoko
For/Permanent Secretary

cc. Department Waste Management and Pollution Control

encl.

APPENDIX X

Authorisation by Sub-Bobirwa District.

Fax 2619296

Bobirwa Sub District Council Telegrams: "CENDICO

P.O. BOX 334 BOBONONG BOTSWANA

Assistant Council Secretary.................. 2619274
Secretary Residence.............................. 2619275
Senior Accountant................................. 2619291
Senior Education Secretary 2619282
D.H.T. 2619300/315
Works Centre 2619231

In reply please quote

REF NO. BSD/H/1/3 (5)

26/03/09

Mr. Gwisai
University of Botswana
Department of Environmental Science
P/Bag 0074
GABORONE

Dear Sir

RE: REQUEST TIO CONDUCT A RESEARCH

Permission is hereby granted for you to conduct a research as per the approval from the Permanent Secretary in the Ministry of Health, referenced no: PPME-PS 13/18/1 IV (6) dated 28/11/08.

Thank you.

Yours faithfully

(A. Makoni)
SENIOR ASSISTANT COUNCIL SECRETARY

SENIOR ASSISTANT COUNCIL SECRETARY
BOBIRWA SUB-DISTRICT COUNCIL
2009 -03- 2 6
P.O. BOX 334
BOBONONG BOTSWANA

APPENDIX XI

Consent Form

I……………………………………………………………… of ……………….voluntarily and freely without being forced, agree to be a participant in the research entitled *An assessment of the impacts of smelter emissions on human health: A case-study of Selebi-Phikwe BCL Copper-Nickel mine in Botswana.* The research is being conducted by Mr Reginald D. Gwisai who is an MSc student at the University of Botswana, in the department of Environmental Science. I understand the purpose of this project is to assess the impact of gaseous emissions on the health of people in the vicinity of the mine plant in Selebi-Phikwe. The impact is a comparative analysis of different locations from the smelter, where settlements are found.

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I understand that there will be benefits from participating in this research project even if they might neither be direct or immediate. Such benefits would be in the form of improving the health status of the populations in and around the mine smelting operations in Selebi-Phikwe. A final summary, in aggregate form of the report, may be sent to me upon my request.

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I understand that I may contact Mr Reginald D. Gwisai at the University of Botswana, Department of Environmental Science,236/213 Earth Science Building,P.B.0022 Gaborone, Phone 393-5800 and/or The Secretary, Health Research and Development Committee, Ministry of Health, P.B. 0038 Gaborone, Phone 3170585 for any queries about this research or my rights

I have read and understood the contents of this form.

Signed.....................................

Date......................................

Place.......................................