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ASSESSING THE IMPACTS OF GASEOUS EMISSIONS ON HUMAN HEALTH AROUND SELEBI – PHIKWE BCL COPPER NICKEL MINE, BOTSWANA

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ABSTRACT

The aim of the study was to ascertain the relationship between smelter emissions and human health in and around Selebi – Phikwe. Previous studies reveal that there are high incidence rates to respiratory cases. A household social survey and key informant interviews were conducted. Mmadinare in the northwest (16 – 20 kilometres) was found to have a high respiratory disease incidence and the study reveals that the village is the most affected by sulphur dioxide emissions. The study provides insights on human health in relation to gaseous emissions production, and will assist in policy intervention for sustainability on health issues as it acts as a pilot study to a health impact assessment research that maybe conducted. Furthermore for sustainable development and planning there is need for improved clean development mechanisms and health strategies to manage respiratory case loads so as to achieve an improved health scenario in communities around the smelter.

Keywords: Smelter Emissions, Human Health, Respiratory Cases, Selebi – Phikwe, Botswana.

INTRODUCTION

The health impact assessment study aimed at assessing gaseous emission impacts on the health of 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. This has affected the economic sustainability of families as the working force may not be highly productive. The study looked into factors that could be contributing to the increase in respiratory health deterioration. The health status of Selebi-Phikwe and the surrounding villages has shown that local and surrounding health centres were recording a high incidence rate of respiratory diseases. For instance, data generated by Ekosse (2005), 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. 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). Recent evidence shows that there are serious impacts on the population living in Selebi-Phikwe and the surrounding villages (Botswana National Environmental Laboratory, 2003). 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. This has also led to unsustainable ambient air quality levels. Therefore the study investigated the spatial occurrence of such diseases in relation to distance and direction from the mine smelter.

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. The sustainability of the natural environmental has been compromised as most of the natural vegetation may be lost due to cumulative effects of the continuous production of gaseous emissions. 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 (Asare, 1999; Mengwe, 2004; Ekosse, 2005). 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). 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). 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. Furthermore, the study prevails as a sustainable pilot for future planning both in the mining and health sectors, hence creating a balance for sustainable yardsticks which will allow for environmental, economic and health sustainability.

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. The improvement of human health is one of the major targets within the Millennium Development Goals perspective of the United Nations. Accordingly, Botswana has put measures in place to help protect and improve human health and welfare as a sustainable development endeavour. 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 for sustainable development. 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 Selebi-Phikwe. For instance, Ekosse (2005) maintains that "residents of Selebi-Phikwe area often produced symptoms of varied degrees of ailments, sicknesses and diseases." The number of settlements around the mine had 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 for sustainable viability. The proposed 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 (Figure 1). 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 27º 55" East.

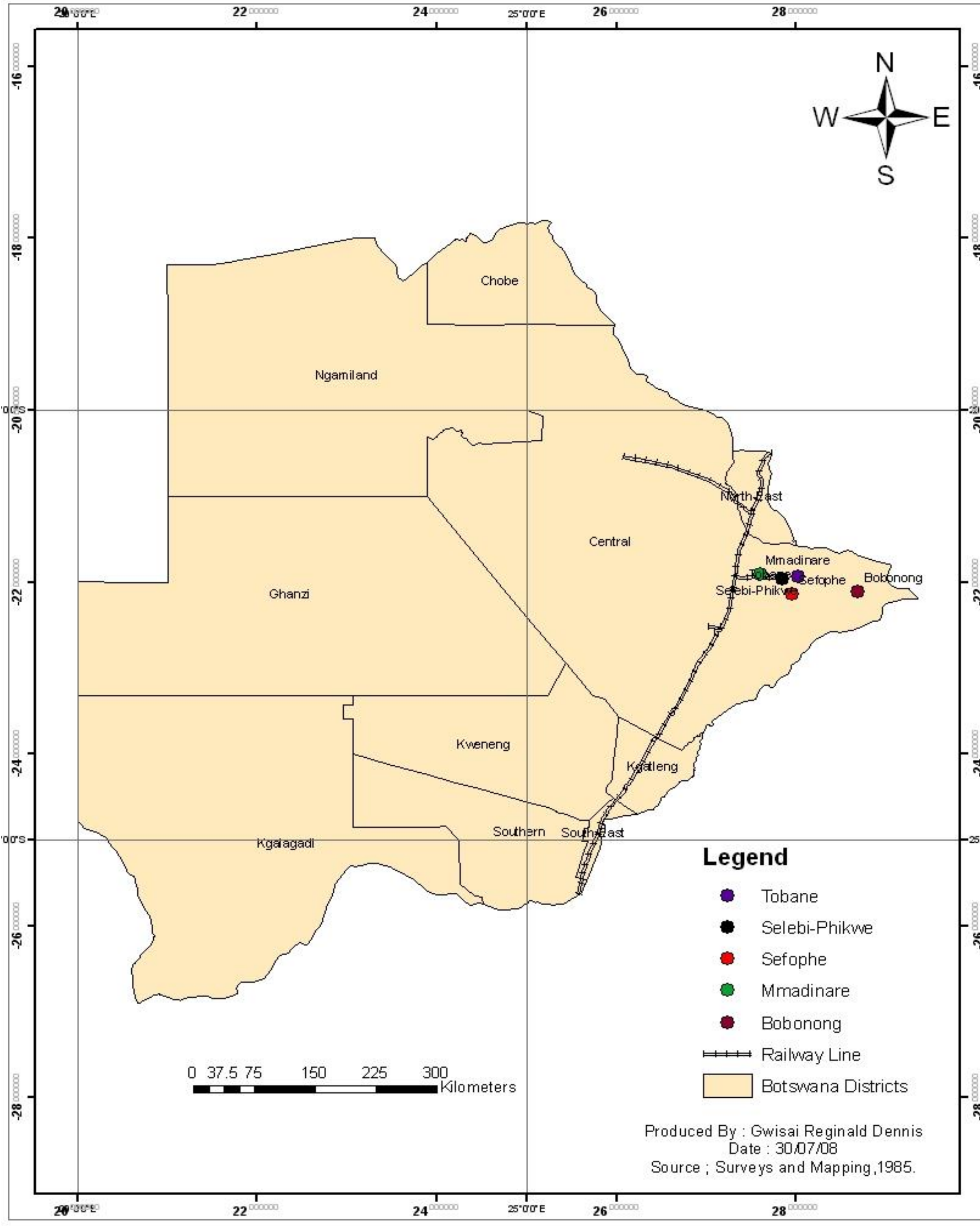

Figure 1: Location of Selebi-Phikwe in Botswana.

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

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 were anticipated to be exhausted 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 selected for the study because it hosted the only smelter in the country; hence this dimension was important for sustainable development. Furthermore, 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.

MATERIALS AND METHODS

A social survey was conducted and data was collected from the local settlements surrounding the smelter complex (153 Respondents). These were Selebi-Phikwe, Mmadinare, Sefophe, Tobane and Bobonong. Questionnaires and Key Informant Interviews were used to gather data from the local community (Wrigley, 1986; Yamane, 1967). Furthermore to enhance triangulation secondary data was collected in relation to health impacts affecting the local communities. Descriptive statistics was generated in the form of tables and graphs. Data was analyzed using Statistical Package for Social Sciences SPSS (Version 16) and Kendall's correlation technique was used to assess the significance of the associated relationships. Research permission was sought from all the relevant stakeholders and ethical procedures and confidentiality was maintained throughout the study.

RESULTS AND DISCUSSIONS

The most prevailing wind was the easterly air flow followed by the south easterly airflow (Figure 2). 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 the west side of Selebi-Phikwe and Mmadinare.

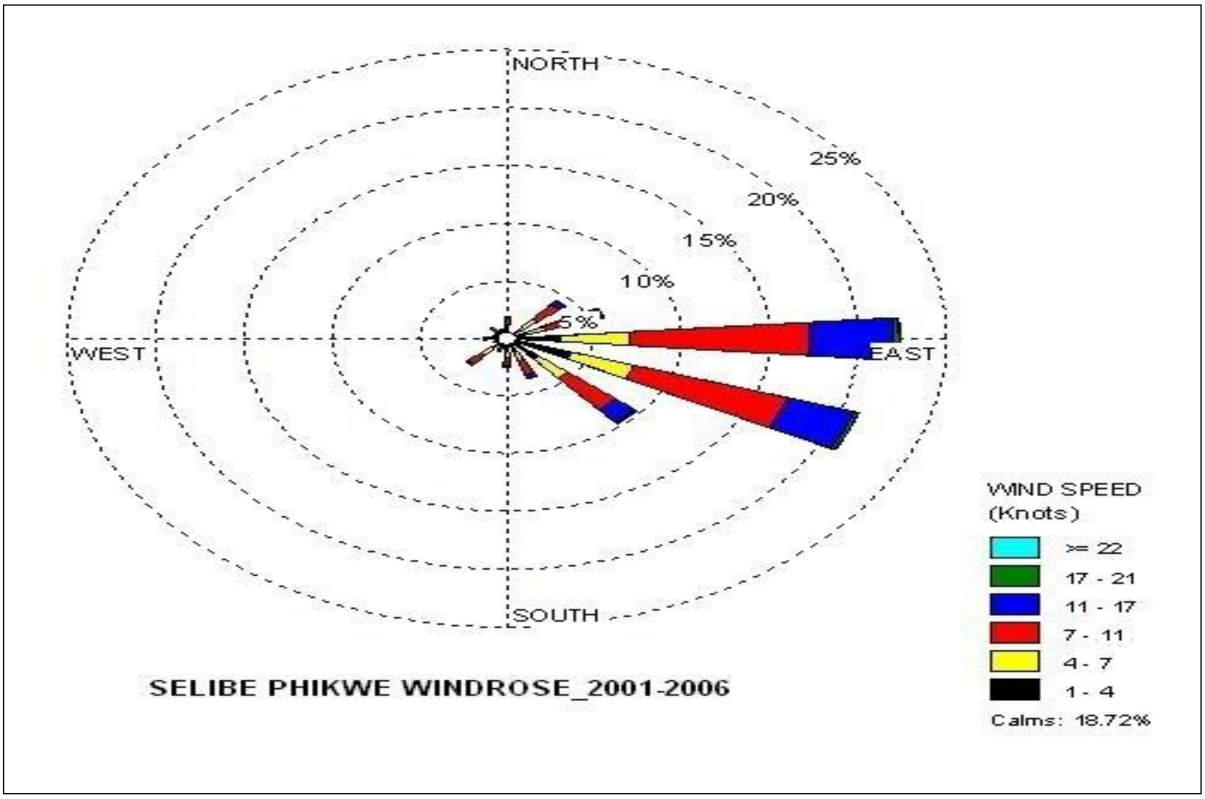

Figure 2: Selebi-Phikwe Wind rose

Source: Botswana MET Department 2008.

Environmental Problems

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.

Disease Occurrence in Relation to Locations around the Smelter

Human Immunodeficiency Virus and Acquired Immunodeficiency Syndrome (HIV and AIDS) and Tuberculosis (TB) were still perceived to be of high prevalence followed by common colds and coughing (Table 1). 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 (common colds), which may be considered predatory on a population with compromised immunity.

Table 1: Disease Ranks in Community.

	1st Rank	2nd Rank	3rd Rank	4th Rank	5th Rank
Tobane	Asthma	Tuberculosis	HIV/Aids	Coughing	------------
Sefophe	HIV/Aids	Tuberculosis	Sugar Diabetes	High Blood Pressure	High Blood Pressure, Knee problem
Mmadinare	HIV/Aids	Tuberculosis	High Blood Pressure	Coughing	Coughing
Botshabelo	HIV/Aids	Tuberculosis	Asthma	Flu(Common Colds)	Asthma, Coughing
BDF	Asthma	Tuberculosis	Flu(Common Colds)	Coughing	--------------
Bobonong	Tuberculosis	Flu(Common Colds)	Flu(Common Colds)	Coughing	Coughing

Source: Author's Survey January 2009.

The majority of the population experienced body weakness (62%) and common colds (70%). 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 was operating 24 hours 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 most common type of headache was the temple headache (61%) and many experienced an acute headache (50%). These headaches were associated with common colds which could in turn be linked to SO_2 pollution.

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 (north westerly direction), and was found in the distance range 16-20 kilometres. Despite being close to the smelter, the westerly side of Selebi-Phikwe 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 the westerly settlements of Selebi-Phikwe. 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 (Table 2).

Interestingly, settlements located in the opposite direction to the plume (Botshabelo, Sefophe, Bobonong and Tobane), had almost equal or higher levels of perception than the westerly settlements of Selebi-Phikwe. A possible explanation could be the sporadic changes in the direction of the plume which could 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. Under such conditions, the environment was slightly stable and there was limited vertical mixing thereby increasing the probability of air pollution in any direction in the area (Franek *et al.,* 2003). 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). This was further supported by health officials who believed that respiratory cases in these sites could emanate from the migration patterns of the population. This was also in line with Morrison's *et al.,* (2007) observation that some socio-economic activities contributed to high respiratory disease spread even to the least affected directions.

Table 2: 1997 Plume Characteristics.

	PLUME TYPES					
	Time Of Day	**Lofting**	**Fanning**	**Conning**	**Looping**	**Fumigating**
%Mean Frequency	**07 00 HRS**	09	18	29	46	07
	12 00 HRS	11	11	23	48	06
	18 00 HRS	10	06	26	56	07

Source: Botswana National Environment Laboratory Annual Report 1997.

Among the respondents who said yes to pollution effect, using Kendall's correlation analysis, there was a positive correlation between respondent's area of location and the pollution perceptional effect on human health ($r = 0.60$; $p = 0.05$), (Table 3). 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 kilometre range). The direction of the prevailing plume probably further confirmed the high respiratory disease load in Mmadinare (Franek *et al.,* 2003).

Table 3: Respondent's Area of Location Association with Emission Impact.

Settlements	**Distance from Smelter km**	**Direction from Smelter**	**Emissions Cause Disease**	
			% Agreeing	**% Disagreeing**
Botshabelo	05	Southeast	57	43
West S-Phikwe	04	Northwest	64	36
Tobane	10	Northeast	83	17
Mmadinare	16	Northwest	95	05
Sefophe	19	Southeast	92	08
Bobonong	29	East	75	25

Source: Author's Household Survey January 2009.

The Relationship between Respiratory Case Load and Age

Applying Kendall's correlation analysis, there was a positive correlation between the age of males and respiratory case incidence ($r = 0.7$; $p = 0.05$). That meant as the age of males increased the respiratory disease incidence also increased. Similarly, using Kendall's correlation analysis, there was a positive (but weaker) correlation between age of females ($r = 0.4$; $p = 0.05$) and respiratory case incidence.

Spatio-Temporal Trends in SO_2 Emissions

SO_2 emissions have been above the World Health Organisation (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 emissions in the year 1985 (Figure 3). 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 and the type of plumes (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.

Among the four quarters of the year the July to September period recorded the highest incidence of respiratory diseases. 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 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.

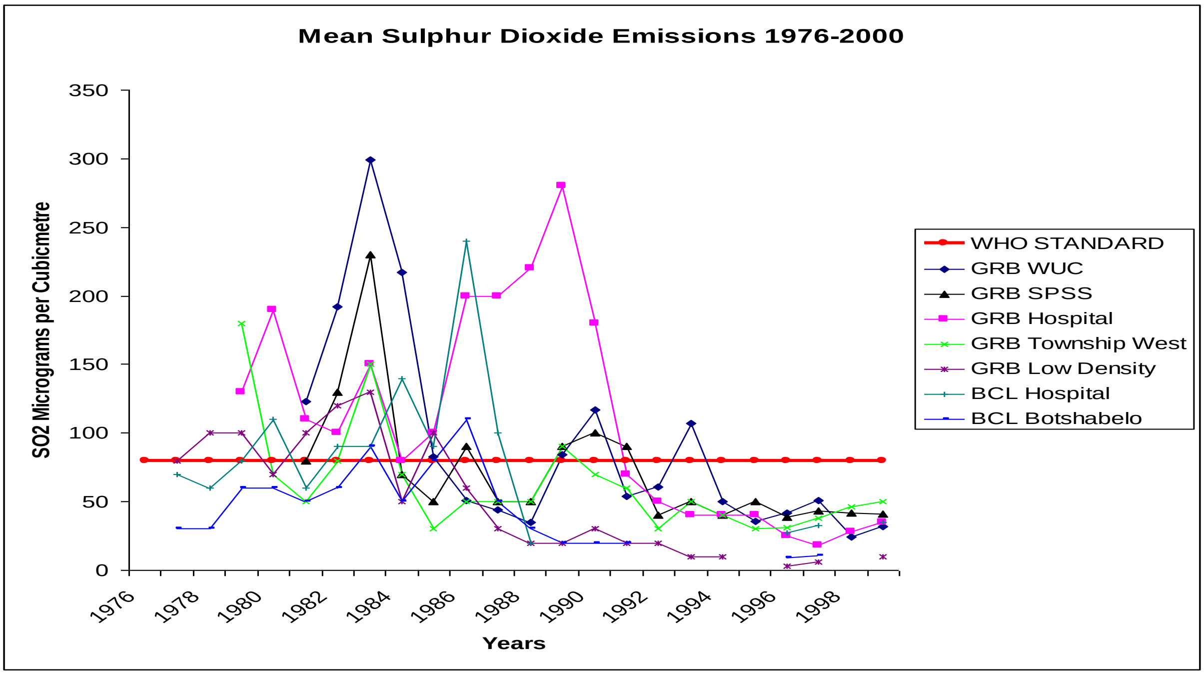

Figure 3: Shows SO_2 emissions for residential monitoring stations, 1976 to 1999.

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 Corporation and the Hospital stations recorded a mean higher than the WHO standard (Table 4), these were among the nearest monitoring stations in terms of transect distance from the smelter. Water Utilities Corporation 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: Comparison of Mean SO_2 Emissions with WHOStandards.

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.

Disease Occurrence and Pollution Perception Health Effects According to Direction

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 5). This was generally in line with the wind rose information (Figure 2). Settlements found in the most affected directions were the westerly settlements of Selebi-Phikwe and Mmadinare (Figure 5). This confirmed further the effects of SO_2 emissions on the health of the settlements located in that direction. Common diseases in this direction were coughs and common colds. The majority of the respondents agreed that SO_2 pollution had an effect on their health 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 and the migration network which took place within the study area.

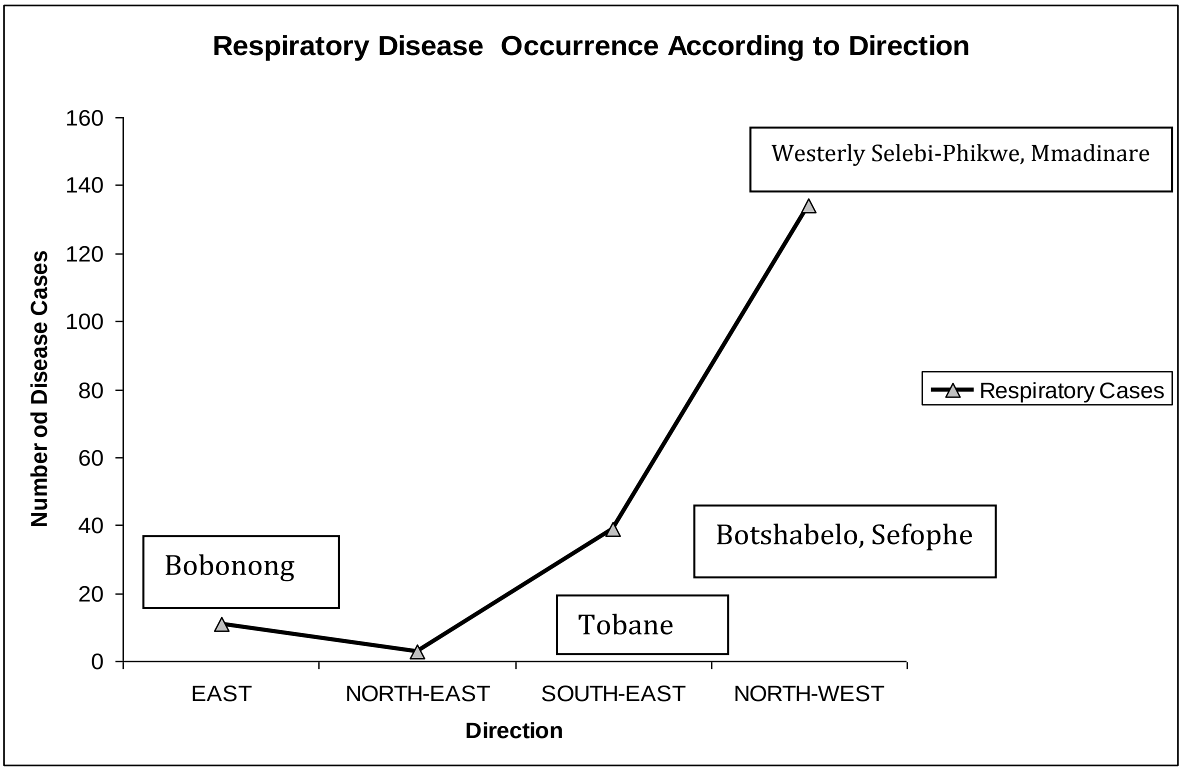

Figure 5: Direction and Claimed Respiratory Disease Incidence from household survey.

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

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. Respiratory problems were frequently reported were coughs, common colds, and chest pains. Air pollution appears to be the major cause of respiratory cases. Due to the severity and prevalence of respiratory cases, an infectious disease control centre was developed in Mmadinare. There is low immunity status in the community and ailments identified were respiratory cases, HIV/Aids and Tuberculosis as common problems in the area. This further confirms the perceptions of the affected communities. 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. Furthermore this was echoed by the respondents from the household survey as most of them experienced respiratory diseases throughout the whole year.

Disease Occurrence According to Distance

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 kilometre range. The second most affected distance was the 0-5 km range which was the closest to the smelter. 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), 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 16-20 kilometre 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).

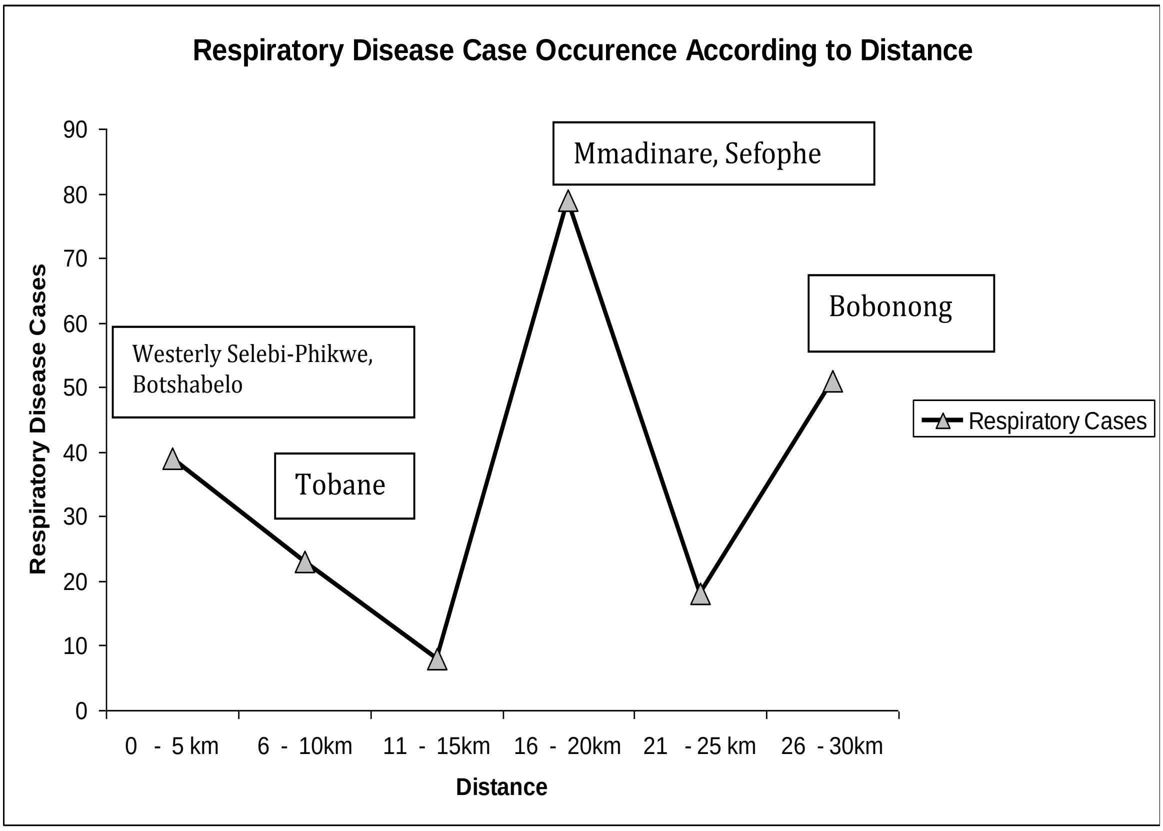

Figure 6: Distance and Claimed Respiratory Disease Occurrence.

Source: Author's household survey January 2009.

CONCLUSION AND RECOMMENDATIONS

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.

The graphic evidence shows the 16-20 kilometre distance range as the most affected and Mmadinare village is located within this range. 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 travelled closer to the mine smelter. Thus movement in and out of Selebi-Phikwe could be a confounding factor here.

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 (Ekosse, 2005; Asare, 1999). 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). 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. The lack of knowledge aspect needs to be improved so as to attain better health awareness and acquire sustainable strategies to reduce respiratory disease incidence and prevalence. 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 (WHO 1992). Length of stay appears to have a major bearing on respiratory health problems; this will require a sustainable categorised intervention based on residence time in affected environments. 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.

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. Therefore as BCL mine continues to improve on sustainable emission reduction strategies while monitoring gaseous emission, a clean sustainable environment may be attained as a long term goal. SO_2 emissions were mainly towards the westerly direction. This was confirmed by the wind rose. Mmadinare village was the most affected, although it was found in the 16-20 kilometre range of distance (Garg, 1999).

Some uncertainties remain over the precise details of pollution control technologies and related emission removal efficiencies at the smelters. More sustainable clean development mechanisms are required to reduce the levels of pollutants in ambient air and concentrations of smelter emissions. The best possible way to overcome these uncertainties is by BCL mine conducting studies itself. A continuous improvement philosophy can be used, which is a more attainable and sustainable strategy. 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 them 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. Such innovations have a major bearing to the sustainable development of the communities located around the smelter complex.

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. This is a sustainable approach that will also reduce uncertainties of confounding factors such as migration. Given the positive association between education and/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 relationships of association. This will guarantee sustainable confirmations of causality on respiratory health problems.

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. BCL may also conduct a SO_2 abatement project to capture fluid bed roaster off-gas. BCL may install wet scrubbing of fluid bed roaster gases to produce H_2SO_4. A continuous converting process can be implemented; this process is critical and sustainable to any plans to further reduce emissions of dust ($PM_{2.5}$ and PM_{10}) and SO_2. Regulations for emission trading may help reduce gaseous emissions and these should be reviewed annually. 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, which becomes a sustainable development concept. 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.

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 sustainable informed decision making and the development of sustainable effective, science-based standards and control strategies.

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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