COMMUNITY-BASED RESEARCH ON THE ENVIRONMENTAL AND HUMAN HEALTH IMPACTS OF A LATERITE NICKEL MINE AND SMELTER IN SOROWAKO, INDONESIA

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COMMUNITY-BASED RESEARCH ON THE ENVIRONMENTAL AND HUMAN HEALTH IMPACTS OF A LATERITE NICKEL MINE AND SMELTER IN SOROWAKO, INDONESIA

by

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Abstract

Community-based research between Memorial University of Newfoundland and the Indigenous Sorowako Association (KWAS) assessed the environmental and potential human health impacts of an operational three-decades old laterite nickel mine and smelter in Sorowako, Indonesia. An active air sampler and health questionnaire were used in this study to assess seasonal and diurnal patterns of air quality and prevalent health conditions.

Air was sampled with the use of a high volume air sampler to determine average total suspended particulates (TSP) and airborne metal concentrations. Twelve-hour air samples were collected over approximately five days and five nights during both the dry and rainy seasons in six communities. The six communities were located at different distances and directions from the nickel mines and smelter. Air samples were also collected at a reference site located further away from the smelter during the rainy season only. The composition of various metals was analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Twenty-four hour dust fall accumulation in approximately 20 households in the seven communities previously mentioned, as well as in 20 homes located on Lake Matano were recorded with an area standardized Kim wipe swipe.

Communities closer to and downwind from the smelter had significantly higher mean TSP values in the day of the dry season than communities further away from the smelter. Average concentrations of nickel, cobalt and chromium were higher in the day than in the

night in the dry season in communities closer to and downwind from the smelter. There was only a slight significant regression of airborne nickel concentration with increasing distance from the smelter in the day of the dry season (Linear $r^2= 0.276$, $p=0.006$, Linear $r^2= 0.066$, $p=0.207$) but not in the night of the dry season. Dust fall accumulation did not vary significantly among the communities, except in Kampung Baru, a site also exposed to sawmill dust.

A confidential health questionnaire administered by community volunteers assessed potential links between prevalent health conditions and mining and smelting in the area. Twenty households were selected in a convenience sampling in the eight communities where dust fall accumulation was also studied. Adult and child versions of the questionnaire focused on respiratory and skin health conditions but also surveyed prevalence of other illnesses, and health determinants.

Questionnaire responses showed that some health conditions typical of exposure to airborne particulates and nickel, such as asthma, rhinitis, and skin tumours, were more prevalent in areas closer to and downwind from nickel mining and smelting compared to Malili, a community located further away from the mines and smelter. Several positive correlations between ambient air pollution levels, dust fall accumulation in households, and health conditions typically found in nickel industrial areas suggested a potential human health impact of mining and smelting.

The community-based investigation provided a foundation for the community to continually monitor, assess, and address environmental and health concerns.

Acknowledgements

Several friends and organizations were instrumental in the completion of this community-based research and thesis. I thank all for their contribution. I especially thank my supervisor Evan Edinger for his constant patience, guidance and support. His diverse research interests and dedication to applying sound science to enhance the well-being of the environment and communities from the Arctic to the tropics is inspiring. I am very grateful to Anver Rahimtula who provided insight as a member of my thesis committee. I thank Yusri Yusuf, the community-based research project coordinator from the Indigenous Sorowako Association (KWAS), who dedicated much time and energy towards training many people in several communities on the various sampling and health questionnaire techniques.

I thank the many organizations that recognized the importance of this community-based research for Sorowako and provided the funding to make the project a reality. These organizations include the Environmental Defense Fund, United Steelworkers' Humanity Fund, NSERC, and Memorial University of Newfoundland. The Hesperian Foundation also provided funds to bring together community representatives for a focus group discussion on mining and health. I am also grateful to the Canada Corps/AUCC scholarship that allowed me the opportunity to return to Sorowako to present the analytical results of the thesis and complete the thesis in consultation with the community counterpart of the research team. The CanadaCorps/AUCC scholarship also gave me the opportunity to present my thesis work in the form of a guide that outlined practical methods for communities wanting to monitor their environment and human health.

I owe much gratitude to Siti Maimunah at the Mining Advocacy Network (JATAM), who edited large amounts of translated materials. Thank you also to Andrie Wijaya (Ambon), Siti Faroh (Phatox), and Hairuddin (Ullet) also with JATAM, who assisted in various aspects of the project. Thank you also to Indah Fatinaware, Ian, and Jansen at the South Sulawesi office of Friends of the Earth Indonesia (WALHI), and Idam Ghel (Bhotghel) and others at the Youth Education and Advocacy Foundation (LAPAR) who assisted greatly with arranging local travel and sampling equipment for the project.

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Thank you to the health questionnaire participants and the team of community representatives who volunteered to facilitate responses to the questionnaire in their communities, including the Wasuponda community organization (LEPMAWASP), the Lake Towuti community organization (LKDT), and the Wawondula community organization (HIMAWAN).

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Finally, I thank the Sorowako and Karonsi'e Dongi community, who made my stay in Sorowako feel like home and always a pleasure to return. There must be something to the local legend that says one who tastes the water from Lake Matano will always return.

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List of Abbreviations

Al	aluminum
Ba	barium
Ca	calcium
CFM	cubic feet per minute
C.L.	confidence limit
cm^2	cubic centimetre
Co	cobalt
Cr	chromium
Cu	copper
EPA	Environmental Protection Agency
Fe	iron
FSMT	Mine Victims' Solidarity Forum
HNO_3	nitric acid
HVAS	high volume air sampler
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
ICEHR	Interdisciplinary Committee on Ethics in Human Research
KRAPASKAD	Karonsi'e Dongi Indigenous Alliance
KWAS	Indigenous Sorowako Association
km	kilometre
KT	kilotonne
MgO	magnesium oxide
Mn	manganese
MT	megatonne
μg/L	microgram/Litre
$\mu g/m^3$	microgram/cubic metre
μm	micrometre
mg/m^3	milligram/cubic metre
mg/L	milligram/Litre
mL	millilitre
mm	millimetre
Ni	nickel
NE	Northeast
NW	Northwest
$(FeNi)_9S_8$	pentlandite
P	phosphorous
Pb	lead
PAL	pressure acid leaching
PM	particulate matter
PM10	particulate matter with a diameter less than 10 microns
PM2.5	particulate matter with a diameter less than 2.5 microns
ppb	parts per billion
ppm	parts per million
PT Inco	PT International Nickel Indonesia

PUSKESMAS	Community Health Services
Rp	Rupiah (Indonesian currency)
RSD	relative standard deviation
$Si0_2$	silica
SE	Southeast
SW	Southwest
S	sulfur
Ti	titanium
TSP	total suspended particulates
TSS	total suspended solids
WHO	World Health Organization
Zn	zinc

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Preface

The study was designed by myself and my graduate supervisor Evan Edinger. The sampling was done by myself, Evan Edinger, the coordinator of the community-based research, Yusri Yusuf, and a team of volunteers from various community organizations involved in the project. The volunteers were trained in sampling procedures mainly by Evan Edinger, Yusri Yusuf and myself. Data analysis and interpretations found in this thesis were done by myself with input from Evan Edinger. Chapters 3 and 4 of this thesis were co-authored by myself, Evan Edinger and Yusri Yusuf. I prepared the thesis with editorial input from Evan Edinger.

Chapter 1: Introduction to Community-Based Research on the Environmental and Human Health Impacts of a Laterite Nickel Mine and Smelter in Sorowako, Indonesia

1.1. Introduction

Nickel mining and smelting of sulfide ore bodies in countries such as Canada, Norway and Russia have been associated with several serious environmental and human health effects such as ecosystem degradation and respiratory and skin health conditions (Norseth, 2003; Ontario Ministry of Environment, 2001a; Eisler, 1998; ICPS, 1991b; Environment Canada, 1987; Chan, 1986; Nieboer and Nriagu, 1992; Goldberg et al., 1992) but relatively little research has been done on the environmental and human health impacts of laterite nickel mining and smelting in tropical regions such as Sorowako, Indonesia (Fig. 1.1). Concerns about these effects have been expressed in the Sorowako community and it was thus deemed important to assess the impacts of the large-scale three-decades old laterite nickel mines and smelter operation in Sorowako using community-based research. This research is also significant given predictions that most growth in nickel production over the next decade will come from tropical laterite nickel mines (Dalvi et al., 2004) and since relatively little research has been published on the environmental and health impacts of laterite nickel mining.

The study focused on spatial and temporal patterns of air pollution and prevalent health conditions to identify potential links with the nickel mining and smelting.

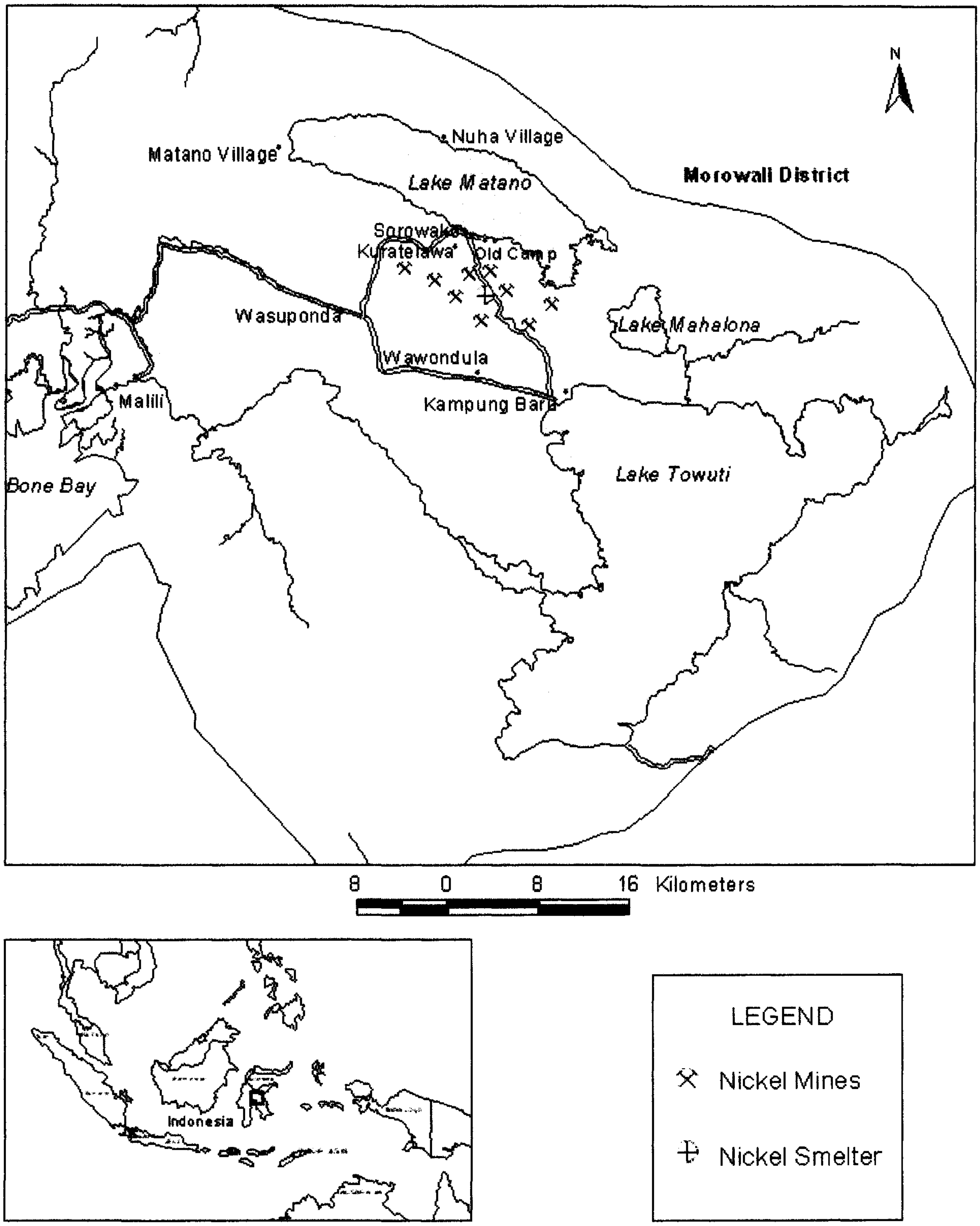

Fig. 1.1. Location of study area.

1.2. Study Design and Research Goals

1.2.1. Community-Based Research

The research was community-based, where the Sorowako Indigenous Community Association (KWAS) and other community organizations directly participated in the research and assessment of the effects of the nickel mine and smelter on their communities' environment and health. Research was mostly focused around issues raised by native Sorowakans during discussions in 2000 and 2002. Community members mostly expressed concern about the environmental and human health effects of smelter fallout, mine and smelter runoff, and domestic sewage input into Lake Matano (Fig. 1.2) (Edinger and Best, 2001).

Fig. 1.2. Sorowako Village and PT Inco smelter, June 2002. Credit: Evan Edinger.

Members of the community participated in training sessions on air sampling in 2002 and 2004. Focus group discussions on health questionnaire administration and assessment were done with community volunteers in early August 2004. A presentation and focus group discussion on the environmental and health effects of nickel mining and smelting was done after the health questionnaire results were collected in late August 2004. Community members were directly involved in as many aspects of the environmental sampling and data analysis as possible (Fig. 1.3). The collaborative community-based research provided skills to community members in environmental monitoring and mitigation. Community members are now able to supplement and compare environmental monitoring data with that collected by the mining company and thus are better able to critique and inform public policy decision-making on such items as environmental assessment processes, mining regulations, and community health.

Fig. 1.3. Community training on air sampling techniques, Wasuponda, August 2004.

The community-based research results also provided a baseline for the current environmental and human health status of communities surrounding the nickel mining and smelting operation active since 1977. The results will be useful for future project planning and risk assessments, which in turn may lead to operational strategies and policies that further reduce the environmental and human health impact of nickel mining and smelting.

1.2.2. Components of the Study

The extent and patterns of air and freshwater pollution caused by nickel mining and smelting was examined using standard environmental sampling and analysis (see Chapter 3). The freshwater pollution research is ongoing and not complete enough for inclusion in this thesis. A health questionnaire was administered in eight communities at varying distances and directions from the nickel mine and smelter to identify prevalent health conditions (see Chapter 4). The health questionnaire was also useful to identify any potential links between prevalent health conditions noted in the questionnaire results and air contaminant levels found in the air quality investigation.

The air pollution component of the study included observing spatial patterns of total suspended particulate (TSP), airborne metal concentrations and domestic 24-hour dust fall accumulation. The results were used to determine if elevated levels were associated with distance from the nickel mines and smelter and prevailing wind direction.

The lake water and sediment pollution aspect of the study included observing spatial trends in total suspended solids (TSS) and metal concentrations dissolved in surface waters and in lake sediments. It was expected that there would be elevated levels of TSS and metal concentrations in both water and sediments nearest to the river mouths that carry mine and smelter effluent into the lakes and that TSS and metal concentrations would decline with distance from the shore.

The *butini* fish (*Glossogobius matanensis*), which is endemic to Lakes Matano, Mahalona and Towuti, and the native *gabus* snakehead murrel (*Channa striata*) were sampled from the lakes to identify metals burden in the fish muscle tissue and liver (Fig. 1.4). Gills and other external features were examined for indications of fish disease. Also analysed for the same parameters, were the introduced *mujair* tilapia fish *(Oreochromis mossambicus)*, which were collected in the recreational fishing pond of Kuratelawa, an abandoned mining area where the indigenous Karonsi'e Dongi community have recently settled (Fig. 1.5).

Fig. 1.4. *Butini* fish from Lake Mahalona with absent teeth, August 2004. Credit: Evan Edinger.

Fig. 1.5. Water sampling at Kuratelawa, an abandoned mining area and recent settlement area of the Karonsi'e Dongi community, August 2004.

The health questionnaire component of the study included assessing prevalent health conditions in eight communities, including the communities with air sampling stations; Malili, situated further away from the mines and smelter at approximately 20 km southwest; and the shanties over the waters of the southern shore of Lake Matano that are exposed to unsanitary and damp living conditions (Fig. 1.2). It was expected that prevalent health conditions such as respiratory and skin health conditions linked to exposure to particulate matter and nickel from nickel mining and smelting would be more prevalent in communities closer to and downwind from the mines and smelter. It was also expected that respiratory health conditions, in particular asthma, would be more prevalent in children because of their increased vulnerability to air pollution (NRC, 1999), and parasite-borne diseases would be more prevalent in the community living in the shanties over the waters of Lake Matano.

Chapter 2: Laterite Nickel Mining and Processing Techniques and its Environmental Impacts

2.1. History of Nickel and its Production

Nickel was discovered by Cronstedt in 1751 (Lide, 1998). The word "nickel" originates from the German word kupfernickel, meaning either "devil's copper" or "St. Nicholas' copper", because it was often mistaken for copper, which was used before nickel. Nickel gained widespread use in the early 1800s in European countries where it was called "German silver." By 1860, nickel was being used in European coins (Swift, 1977; Sangaji, 2002). From the industrial revolution to today, nickel has become a metal of high demand because it is a main ingredient in stainless steel found in such items from the kitchen sink to automobiles and weapons. One of the world's leading nickel mining companies, Inco Limited from Canada, has a specialty nickel products division tasked to research, develop and market new products that contain nickel as a key ingredient. Such products include parts for electronics, rechargeable batteries for electric/hybrid vehicles, fuel cells and cellular phones (Inco, 2005a).

Most of the world's nickel has been produced from massive sulfide deposits like those found in the Sudbury Basin of Ontario. Nickel is found in the sulfide mineral pentlandite ($(FeNi)_9S_8$) and is normally associated with pyrrhotite ($Fe_{(1-x)}S$ ($x = 0$ to 0.2)), pyrite (FeS_s), and chalcopyrite ($CuFeS_s$). Nickel is found in most meteorites. The Sudbury deposit is thought to have resulted from an ancient meteorite impact (Lide, 1998).

By 1980, an estimated 17 million tonnes of nickel had been removed from highly localized ore deposits to land surfaces, and mining and other industrial activities had emitted about 1 million tons of nickel into the atmosphere with deposition concentrated near areas of nickel smelting or refining (e.g. Sudbury, Ontario; Norilsk, Russia; and Noumea, New Cale nia). Massive redistribution of nickel impacted the amount of nickel in ecosystems, and thus increased the nickel flux between ecosystems (Nriagu, 1980).

Nickel production from 1950 to 2003 increased eight fold from approximately 140 KT/year in 1950 to 1200 KT/year in 2003 (Dalvi et al., 2004). Although laterite nickel production has been occurring for over one hundred years, the world nickel supply has mainly come from sulfide nickel ore bodies (Dalvi et al., 2004). In 2003, lateritic nickel accounted for 42 % of nickel sourced (approximately 510 kt Ni), while in 1950, laterite nickel ore accounted for less than 10% (Dalvi et al., 2004). However, it is approximated that one third of the world's emerged continental areas are covered in lateritic soils (Brown et al., 1994; Nahon, 1986) and 70% of the world's land-based nickel resources are contained in laterite ores (Dalvi et al., 2004). The percentage of lateritic nickel production is expected to increase by 51% by 2012 (Dalvi et al., 2004). Nickel supply growth tends to follow economic cycles and global events (Dalvi et al., 2004) such as wars.

Laterite nickel deposits are currently being explored and exploited in Indonesia, Australia, New Caledonia, the Philippines, Dominican Republic, Guatemala, Cuba, Colombia, and Puerto Rico (Sangaji, 2002; Lannon 2002, McCutheon, 2001) (Fig. 2.1). Major existing nickel sulfide mining operations are found in Russia, Canada, Zimbabwe, Botswana and Australia (Sangaji, 2002). In Canada, most of that nickel is found in nickel-copper ores and mined underground as opposed to lateritic surface mining such as in Sorowako (Ripley et al., 1996, p. 151; Lannon, 2002).

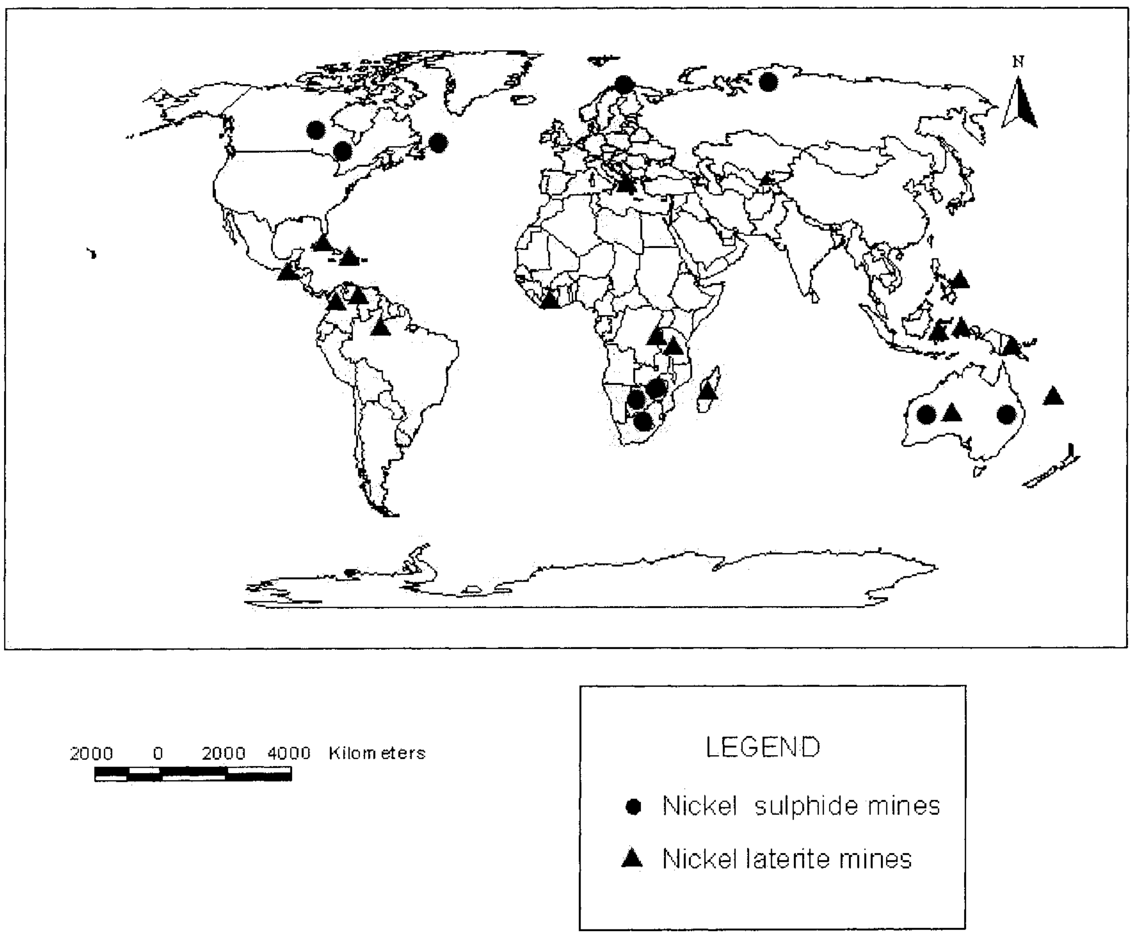

Fig. 2.1. Major nickel sulfide and laterite mines in the world.

2.2. Laterite Nickel Ore

The nickel deposit in Sorowako, Indonesia is a lateritic nickel oxide ore deposit. Scottish scholar Dr. Francis Buchanan coined the term laterite from the latin word "later" meaning brick stone. Dr. Buchanan was conducting studies in India in 1880 when he discovered laterites, a soft weathered material that hardened and became impermeable to air and water (Dagenais and Poling, 1999). Nickel in the tropics is also found in garnierite ($(Ni,Mg)_6Si_4O_{10}(OH)_8$), a type of serpentine mineral, that is created by hot groundwater alteration of ultramafic igneous rocks or peridotite. Peridotite or garnierite is transformed into laterites by intense tropical weathering in the soil (Dagenais and Poling, 1999; Edinger, in press).

Lateritic ores of nickel occur in the tropics and sub-tropics as a complex oxide of silicon, iron and magnesium (Lannon, 2002). Cobalt is also found in nickel oxide deposits like those in Sorowako (UNEP, 1993). Most lateritic nickel ore deposits have both silicate and limonitic ore types present in varying proportions (Environment Canada, 1982). Silicate ores, which are the common ore type in Sorowako, have been treated almost exclusively by pyrometallurgical processes whereas limonitic ores that have high iron, lower nickel content and higher cobalt-to-nickel ratios have been treated using hydrometallurgical processes (Environment Canada, 1982; UNEP, 1993; Lannon, 2002).

Laterites develop commonly in cratonic rocks and in the case of Sorowako in ultramafic rocks through physical and chemical transformations of peridotite exposed to air and water over a long time (Brown et al., 1994). Iron crusts develop deep in soil profiles under warm, humid conditions, when iron leaches from overlying soils and blends with secondary minerals deeper in the soil profile. This material hardens and becomes resistant to erosion in later dry periods (Dagenais and Poling, 1999).

A laterite soil prof e consists of an overlying iron-rich surface soil layer, generally 0-2 metres thick, composed of weathered products, and plant and humic matter. The layer immediately below the surface soil layer is the laterite layer, which is further subdivided into a laterite and saprolite layer. The laterite layer, typically 1-25 metres thick and also known as the zone of accumulation, is composed of highly weathered material enriched in secondary iron and/or aluminium oxides. The laterite layer is generally the hardest of the layers because of iron mineral formation and recrystallization. The saprolite layer, immediately below the laterite layer, is composed of weathered silicate material. This weathered material, which is typically 1-100 metres thick, originates from the parent rock layer or the bottom layer in the typical laterite soil profile (Dagenais and Poling, 1999).

2.3. Laterite Nickel Mining and its Environmental Impact

Relatively little research has been done on the environmental impacts of tropical lateritic nickel ore mining and processing; research has tended to focus on hard rock sulfidic nickel ore mining and processing. Conclusions about the environmental effects of mining of sulfide ores including landscape changes, acid mine drainage, leaching, and waste volume and distribution, cannot be extended to laterite ores because of the differences involved in both operations.

Laterite deposits are found near to the soil surface and thus strip mining is normally done rather than underground mining used to exploit sulfide ore bodies. In laterite mining, large areas of vegetation are removed for strip mining, and pits are usually relatively shallow. Pits are generally operated for a short time then backfilled and revegetated (Edinger, in press).

Dagenais and Poling (1999) observed that lateritic deposits had lower acid generating potential compared to sulfide deposits due to the presence of much less sulfur. Fewer associated metals were also observed in the leachate of lateritic deposits than in the leachate of hard rock deposits. Leachate of hard rock deposits contain various metals, which generally come from the oxidation and dissolution of primary sulfides in the deposit. The presence of silicates and absence of primary reactive minerals such as sulfides lower the potential for acid generation and metal leaching (Dagenais and Poling, 1999; Edinger, in press).

Laterite mining produces smaller volumes of tailings and thus less tailings dust compared to other types of ore mining. Laterite host rock also does not require crushing to separate the ore from host ultramafic rocks, which in turn limit reactions that occur when surface area of dust particles are increased in crushing (Dagenais and Poling, 1999; Edinger, in press).

2.4. Laterite Nickel Ore Processing and its Environmental Impact

2.4.1. General Overview of Nickel Processing Methods

Initial nickel ore processing involves physical separation of the nickel from the ore, and includes milling, which involves crushing and grinding. Flotation is then used to separate the components. Chemical reagents are sometimes used to enhance collection of mineral products (Lannon, 2002). The concentrate in most cases is smelted using pyrometallurgy into a matte, a nickel-rich sulfide that is then ready for further refining. Concentrate is also processed by hydrometallurgy where nickel briquettes or pure metal are formed rather than intermediate matte produced in pyrometallurgical processing (UNEP, 1993, p.5). Over double the amount of current known world laterite nickel reserves including limonite and nontronite is suitable to be processed through hydrometallurgy (8600 MT) whereas pyrometallurgy has been used to process serpentine, saprolite and garnierite nickel reserves (4000 MT) (Dalvi et al., 2004).

Pyrometallurgy of lateritic nickel ores involves drying the ore, calcining (heating to decompose carbonates, hydrates and other compounds), reduction in kilns, and smelting in a furnace (Dalvi et al., 2004). Either a reduction smelting process for nickel matte or a ferronickel process is then applied. The PT Inco smelter in Indonesia uses matte processing because of the relatively high iron to nickel ratio (>6), lower $Si0_2$ and MgO ratio (1.8 to 2.2), and lower melting point slag (<1600 °C) (Environment Canada, 1982,

p. 78-79; Dalvi et al., 2004). Hydrometallurgy is used for processing limonitic ores either using ammoniacal process leaching or acid process leaching. Pyrometallurgy is too energy expensive for limonitic ores because of the relatively low concentration of nickel and the large proportion of iron (UNEP, 1993).

For environmental reasons, hydrometallurgy is the preferred processing option because less pollution and energy usage is involved. PT Inco built hydroelectric facilities in the late 1970s to power its Sorowako project to offset the costs of running its pyrometallurgical plant when fuel prices increased. The hydroelectric energy source significantly reduced operating costs and made the PT Inco project only one of two noted low cost global nickel producers (Dalvi et al., 2004).

Hydrometallurgy involves using a water-based solution to extract nickel and other metals from ore or a partially refined body (Lannon, 2002, p. 17). Examples of hydrometallurgy include in situ leaching, ammonia based leaching, chlorine based leaching, pressure acid leaching (PAL), and pressure oxidative leaching. Hydrometallurgy is favoured over pyrometallurgy because it does not involve sulfur dioxide emissions (Ripley et al., 1996, p. 37; Sirois et al., 1983). For example, chlorine based leaching is preferable over PAL because it involves lower operating costs, improved work environments, increased quality of metals, increased production per unit volume of tank, and lower metal losses in effluents (Lannon, 2002, p. 25).

2.4.2. Nature of Emissions

Despite the environmental advantages of hydrometallurgy, the process still has the environmental problem of solid and liquid waste from leaching processes. Leachate often consists of finer particles that may become airborne and reactive (Lannon, 2002, p. 28). For example, in the ammonia leach process, traces of ammonia in the discarded tailings and in other effluents can pollute surface water. Overall nickel recovery by the ammonia leach process is also lower (76%) compared to pyrometallurgical processes (85% or higher) (Environment Canada, 1982, p. 86). A closed-circuit system ensures that less waste is released into the environment.

The Sudbury Basin area of Ontario has been the site of over one hundred years of nickel mining and smelting. The industry and its visible environmental degradation has become the case study on environmental effects of nickel mining and pyrometallurgical processing of sulfide ore bodies. Nickel and copper processing plants lie within a 15 km radius of the city of Sudbury (Ontario Ministry of Environment, 1982a).

In the 1880s, large copper and nickel reserves were re-discovered in the Sudbury basin during the building of the transcontinental railway. The extent of this ore body is evident in that it is still being mined and processed today by Canadian multinational nickel companies, Inco and Falconbridge. Until 1929, metallurgical processing of this ore involved open heap or surface roasting. The sulfur dioxide emissions caused widespread deforestation. After 1929, smelters began venting all their gases through stacks of increasing height. No data is available for the early period of nickel smelting in Sudbury but it is estimated that with eleven roasting yards in operation between 1890 and 1930, 10.2 MT of sulfur dioxide was emitted into the atmosphere in the processing of 25.4 MT of ore, which equated to an annual average sulfur dioxide emission rate of 255 KT (Ripley et al., 1996, p. 171).

Sulfur dioxide gaseous emissions to the atmosphere are one of the most significant environmental effects of nickel smelting because it can lead to acid deposition, which can inhibit and kill vegetation, and acidify soils and lakes. An exposure of 0.3-0.5 ppm of sulfur dioxide can damage plants, especially conifers, which are more sensitive than broad-leafed trees (Down, 1977, p. 16-18). Sulfur dioxide has effects on humans and organisms at low concentrations of 0.3-0.5 ppm with respiratory irritation occurring at 5 ppm (Down, 1977, p. 63). Studies on remote lakes around the Inco Sudbury nickel smelters suggest that acid fallout acidified lakes and destroyed fish populations as far away as 65 km (Down, 1977, p. 63).

Sulfur dioxide emissions generated from the 150-metre stacks operating since the 1930s were 4 Mt per year by 1970. Inco's 381-metre "super stack" was built in 1972 to disperse the emission and reduce local air pollution but this did not effectively reduce air pollution as pollutants were only displaced further away from the smelter as well as introduced to a larger volume of air (Down, 1977, p. 83; Environment Canada, 1982). Recent additions of technologies to clean atmospheric emissions have included scrubbers and acid plants that have reduced sulfurous emissions (Ripley et al., 1996, p. 170). With the installation of new technology, sulfur dioxide emissions were reduced to 1.5 Mt per year in 1979 (Ripley et al., 1996, p. 171; Campbell and Marshall, 1991).

Today, more and more sulfur dioxide is being captured and marketed as elemental sulfur, sulfuric acid, calcium sulphite and sulfate (Ripley et al., 1996, p. 41; MacLatchy, 1994). However, surpluses of sulfur have also resulted in part due to sulfur being a by-product of the oil and gas industries. More recently sulfur has been used in foam products, concrete, asphalt, paints and coatings (Ripley et al., 1996, p. 42). Since the 1990s, strict emission regulations and awareness of long-term effects of pollution and health effects on workers have brought smelters down to a 99.8% sulfur dioxide capture rate. However, many nickel processing plants continue to operate below standards in countries including Canada. Inco's super stack in Sudbury emitted 5000 tons of sulfur dioxide daily in 2000 (Habashi, 2000; Lannon, 2002, p. 15).

Besides sulfur dioxide gas emissions, metallic particulate emissions are also generated from nickel smelters (Ripley et al., 1996, p. 170). Particulate matter can be either chemically inert or chemically reactive (Ripley et al., 1996, p. 42). Particulate exposure can also be hazardous to the environment and human health, depending on the amount and its heavy metal content (Aswathanarayana, 2003). Typically, arsenic, cadmium, cobalt, copper, mercury and nickel are emitted in these particulate emissions depending on what heavy metals are found in the ore body (Ripley et al., 1996, p. 152). In Sorowako, nickel, cobalt, and some copper and other heavy metals are present but arsenic and mercury are not. In Sudbury, iron, copper, nickel, lead, arsenic, cobalt and several other heavy metals are mainly found in particulate emissions (Ripley et al., 1996, p. 171; Scheider et al., 1980). In May 2005, the Commission for Environmental Cooperation listed Inco's Sudbury refinery as one of the top industrial sources of airborne lead in North America (CEC, 2005).

Enclosure, particulate collectors (mechanical, fabric filters, wet scrubbers, electrostatic precipitators) and other preventions of releases are effective in reducing point sources of particulate matter (Down, 1977, p80). In 1996, it was estimated that 98% of the dust and at least 90% of fumes generated at smelters were reduced with the use of electrostatic precipitators (ESPs) (Aswathanarayana, 2003). Mining companies benefit in the long term from recovering metals in dust particles emitted from their operation but often do not proceed, citing the costs of installing cleaning technologies that includes down time maintenance costs (Lannon, 2002, p. 14).

Tree belts around industries reduce air pollution and noise. Ten square kilometres of beech can collect approximately 63 tons of dust from the atmosphere while the same area of pine and spruce can collect 36.4 and 32 tons respectively (Aswathanarayana, 2003).

2.4.3. Effects of Emissions on Soil, Water, Flora and Fauna

Soil, water, flora and fauna are also affected by smelter emissions as well as by smelter slag and tailings disposal (Ripley et al., 1996, p. 42). Modern processing plants are producing less slag as a percentage of finished product because of improved processes and better metal recovery. However, acid mine drainage can also result from water runoff from slag heaps (Lannon, 2002, p. 16).

Sudbury soils are today the subject of a multi-million dollar soil contamination study. In the 1970s, soils were contaminated with nickel, copper, cobalt, and aluminium deposited at increasing distances from the Sudbury smelters in amounts known to inhibit vegetation growth (Ripley et al., 1996, p. 172; Whitby and Hutchinson, 1974). Attributed to this contamination, litter decomposition was noted as abnormally slow (Ripley et al., 1996, p. 172; Freedman and Hutchinson, 1980). Soil quality was visibly degraded on steep slopes and ridges three kilometres from the smelters (Ripley et al., 1996, p. 172). When revegetation work began in 1969 near the smelter, the soils were so acidified that seeds died upon contact with the soils, and planted trees died within two years (Habashi, 2002). In the 1970s, vegetation normally found within a 30-kilometre radius of Sudbury could no longer be found. This extensive damage and loss of forest, ground vegetation, and soil cover, and biodiversity was linked to acidity, elevated concentrations of metals in soils, fire, metal fallout, loss of soil, microclimatic changes, or a combination of these factors (Ripley et al., 1996, p. 172). White pine, the most economically important tree in the Sudbury Basin, was found to be especially sensitive to sulfate exposure, with damage observed after only a few hours of exposure of 25-30 ppb sulfate (Ripley et al., 1996, p. 172; FPACAQ, 1987). White pine damage occurred over 1850 square kilometres (Ripley et al., 1996, p. 172; Linzon, 1971). Applying lime to the soils, and planting grass and clover, as well as the erection of the super stack that dispersed acid deposition helped the vegetation to regenerate (Habashi, 2002).

Sulfates and metal concentrations in both water and lake sediments decreased further away from emission sources (Ripley et al., 1996 Yan and Miller, 1982). The diversity of macrophytes and algae was lower near metal sources (Ripley et al., 1996, p. 175). Algal productivity was limited by nickel and copper concentrations (Ripley et al., 1996, 1975; Whitby et al., 1976).

Biodiversity of wetland species was visibly reduced more than 10 kilometres from the smelters. Only a few species of *Sphagnum* were observed within a 30-kilometre radius of the smelters. Species diversity was observed as particularly low in marshes and areas of open water (Ripley et al., 1996, p. 175). In most of these areas, only cattails and reeds were found, which are metal tolerant (Taylor and Crowder, 1983). The hydrology of several wetlands was changed with loss of biodiversity (Ripley et al., 1996, p. 175).

Beamish et al. (1975) surveyed five lakes in Sudbury and found that the lakes were all acidic. The lakes were all relatively deep lakes and predominately situated on drainages, which had lost their soil cover as a result of ground-level sulfur dioxide present from early smelting practices. A pH level of 4.5 was observed in these lakes, which is lethal to fish and amphibian eggs and young (Task Force on Water Quality Guidelines, 1987). There were no fish captured in the most acidic lake surveyed (Ripley et al., 1996, p. 177). A lake's bedrock geology affects its buffering capacity or ability to absorb acid rain and prevent acidification (Beamish and Harvey, 1972; Belzile et al., 1997; Gunn and Keller, 1995; Edinger, in press).

Waters sampled in the northern regions of the Sudbury White-fish Lake Indian Reserve were found to exceed several international guidelines for drinking water such as pH, alkalinity, sulfate, chloride, nickel, copper, zinc, iron, lead, cadmium, manganese, sodium, potassium, magnesium, calcium, hardness, silicate, total dissolved solids, conductivity, total dissolved nitrogen, suspended nitrogen, total dissolved phosphorous, suspended phosphorous, and chlorophyll a (Beamish et al., 1975). Dissolved copper and nickel concentrations were greater than 6 μg/L and 150 μg/L respectively, levels toxic to most fish species during early stages of life (Task Force on Water Quality Guidelines, 1987). Food chains were disrupted with the decreased fish population (Ripley et al., 1996, p. 177).

Feathers of ruffed grouse, mallards and black ducks, and squirrel fur and human hair sampled in the 1970s and early 1980s in the Sudbury region showed elevated levels of metals (Ripley et al., 1996, p. 177; Ranta et al., 1978; Rose and Parker, 1982; Lepage and Parker, 1988).

Further environmental controls were applied to smelter emissions in the 1970s, which caused acidity to decrease and pH to normalize (from 4.1 to 6.4 in 13 years), sulfate ion concentrations to decrease (from 1319 mg/L to 11.9 mg/L in 4 years), and biodiversity of algal, invertebrate, macrophytic and fish species to increase in Sudbury's lakes (Ripley et al., 1996, p. 179; Beggs and Gunn, 1986; Dillon et al., 1986; Hutchinson and Havas, 1986; Keller and Pitblado, 1986; MacIsaac et al., 1986; Kelso and Jeffries, 1988). These improvements were linked to a decrease of approximately 90% in metal concentrations of copper, nickel, and cobalt in the water (Ripley et al., 1996, p. 179). Trees also began to recover with increased environmental controls (Ripley et al., 1996, p. 180; Freedman and Hutchinson, 1980). Seedlings of birch, aspen and oak were reported in areas that previously were reported absent in the 1960s (Ripley et al., 1996, p. 180).

2.5. Laterite Nickel Mining and Processing in Sorowako and its Environmental Impact

Laterization in Indonesia like in New Caledonia, Cuba and the Philippines occurred in plateau, crest and spur landforms in Tertiary to Mesozoic island arcs and continental collision zones (Dalvi et al., 2004). Indonesia accounts for the world's fourth largest laterite nickel reserves at 12%, preceded only by New Caledonia (21%), Australia (20%), and the Philippines (17%) (Dalvi et al., 2004).

The laterite nickel mines in Sorowako are located on the top of hills (Fig. 2.2). Surrounding the nickel mines are communities, forest and agricultural areas and three lakes. The nickel mining is open-cast where vegetation and overburden are removed, and the laterite and saprolite layers located immediately above weathered peridotite bedrock are extracted with bulldozers and excavators. This lateritic soil is up to 40% iron and about 1% nickel. The ore is transported to screening sites and the processing plant by large diesel-electric trucks. Screening is used rather than crushing because the nickel ore is found concentrated within lateritic soils. The screens filter out unweathered rock to capture the weathered nickel rich ore (Edinger and Best, 2001). Today, mined out areas are backfilled to minimize land contour changes. Sedimentation ponds are also being used today around current mines to hinder mining runoff into Lake Matano (D. Tetradiono, Pers. Comm., 2004).

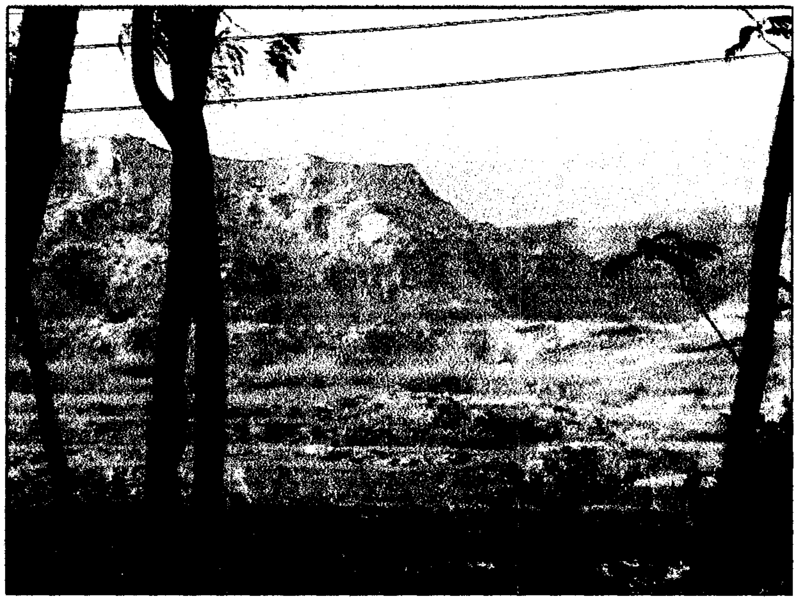

Fig. 2.2. PT Inco laterite nickel mines in Sorowako, August 2004.

Stripping the land involves forest damage and associated erosion. Land opened up for mining leads to increased access by other forms of resource exploitation and industries with associated environmental impacts (e.g. logging). Illegal logging is a problem that has yet to be regulated effectively by the Indonesian government. Artisanal sawmills are found along the shores of Lake Towuti at Kampung Baru.

In terms of reclamation, PT Inco has a current two to four year revegetation program (D. Tetradiono, Pers. Comm., 2004). However, there are large tracts of abandoned mining land not yet reclaimed including land around the Karonsi'e Dongi community's settlement in Kuratelawa. PT Inco stated that in 2001, 1868 hectares of 2351 hectares mined were revegetated (YTM, 2003).

PT Inco's smelter has been producing nickel matte since 1977. Sorowako nickel ore is stockpiled, dried in drying sheds, mixed with silica (SiO_2) and sulfur in a reduction kiln for conversion from oxides (laterites) to sulfides. The sulfide product is then smelted in electric furnaces to yield nickel matte with 75-78% nickel content that is then shipped to Japan (D. Tetradiono, Pers. Comm. 2004).

Before PT Inco's Fourth Line Expansion Project in 2000, the capacity of the PT Inco smelter was 45 KT of nickel matte per year. The expansion project increased this capacity by another 23 KT of nickel matte per year. Installation of more hydroelectric facilities is planned to permit a further 16 KT increase in nickel matte production per year by 2007 (Dalvi et al., 2004).

Both the smelter and unpaved roads contribute to the dusty environment found in Sorowako. Air pollution in Sorowako, and the community-based research results of an air quality investigation is discussed in further detail in Chapter 3. The smelter emits metalliferrous dust particles, sulfur dioxide gases, and soot throughout the day and night (Fig. 2.3). The smelter has relatively short stacks with a local fallout zone as opposed to the long distance fallout transport that occurs at the Russian Norilsk or Sudbury Inco nickel smelters. According to PT Inco, of the twelve stacks in operation, almost all comply with Indonesian air quality guidelines. ESPs installed on the dryers and kilns over a period from 1997 to 2003 significantly reduced air pollution from the smelter (P. Sampetoding, Pers. Comm., 2004). One furnace stack was recently equipped with a relatively new technology called 'hoe-ram bag house' by company officials in 2005. This furnace stack has for the first time met air quality guidelines but the other furnace stacks currently do not meet air quality guidelines. PT Inco plans to install the cleaning technology on the remaining furnace stacks in phases; they state costs as the reason for the delay (D. Tetradiono, Pers. Comm., 2005).

Fig. 2.3. PT Inco nickel smelter in Sorowako, August 2004. Credit: Evan Edinger.

Smelter emissions influenced by prevailing winds, travel Southwest of the smelter during the day towards the Kampung Baru Village and Lake Towuti area, and Northeast to

Northwest of the smelter during the night towards Sorowako (Fig. 2.3) and the Lake Matano areas. Smelter fallout has had an effect on buildings in the nearby communities where roofs are reported to deteriorate more quickly since the smelter began operations. Villagers also report that clothes left outside overnight are sometimes covered in a layer of dust by morning. Vegetation near the smelter is covered in a pervasive layer of dust. When it rains near the smelter, particles can often be seen in the raindrops (Edinger and Best, 2001).

Smelter runoff has mainly been diverted into the Lamoare River, which flows through the eastern end of Sorowako village into Lake Matano, and the Lamangke River, which flows into Lake Mahalona (PT Inco, 1995). Large red sediment plumes are visible where the rivers drain into the lakes, especially in the rainy season or after large rainfall events (Fig. 2.4) (Edinger and Best, 2001). Check dams recently installed along these two watercourses are reducing particulate metal loading in these lakes associated with the smelter runoff (P. Sampetoding, Pers. Comm., 2004). Nearby lakes, rivers and streams are also affected by deforestation, erosion and garbage. Lake Matano is also affected by domestic sewage input.

Fig. 2.4. Mine and smelter runoff into Lake Mahalona. Credit: Mairi Best, October 2000.

Waste in the form of hot molten slag is deposited into slag dams (Fig. 2.5) (D. Tetradiono, Pers. Comm., 2004). The molten slag once dried can become another source of pollution where the surface layer can be disturbed and redistributed elsewhere by the wind.

Fig. 2.5. Slag disposal site, August 2004. Credit: Evan Edinger.

Chapter 3: Community-Based Monitoring of Seasonal Airborne Dust and Metal Concentrations and Potential Human Health Impacts in Communities Surrounding a Laterite Nickel Mine and Smelter in Sorowako, Indonesia

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To be submitted to: Water, Air and Soil Pollution

3.1. Introduction

Nickel mining and smelting are major pollution sources of airborne particulates and metals. Heavy metal and particulate fallout from smelters can discolour and erode buildings, contaminate soils, vegetation and water, and cause sickness and mortality in organisms (Goldberg et al., 1985; Eisler, 1998; Norseth, 2003; Dockery, 2001; Edinger, in press). Sorowako, Indonesia is the site of a nearly three-decades old large-scale laterite nickel mining and smelting operation (Fig. 3.1). Surrounding the PT Inco nickel mines and smelter are villages, lakes, forest and agricultural areas. The Sorowako smelter has relatively short stacks where local fallout occurs. The Norilsk smelter in Russia and the Inco super stack in Sudbury, Ontario, Canada are taller and deposition occurs further away from these smelters.

After concerns were expressed in Sorowako and surrounding communities regarding the effects of the nickel mines and smelter on air quality and human health, a community-based research team was established to examine the spatial and diurnal patterns of total suspended particulates (TSP) and airborne metals as well as domestic 24-hour dust fall accumulation related to nickel mining and smelting. Community-based monitoring involved participation by community members in air sampling and analysis.

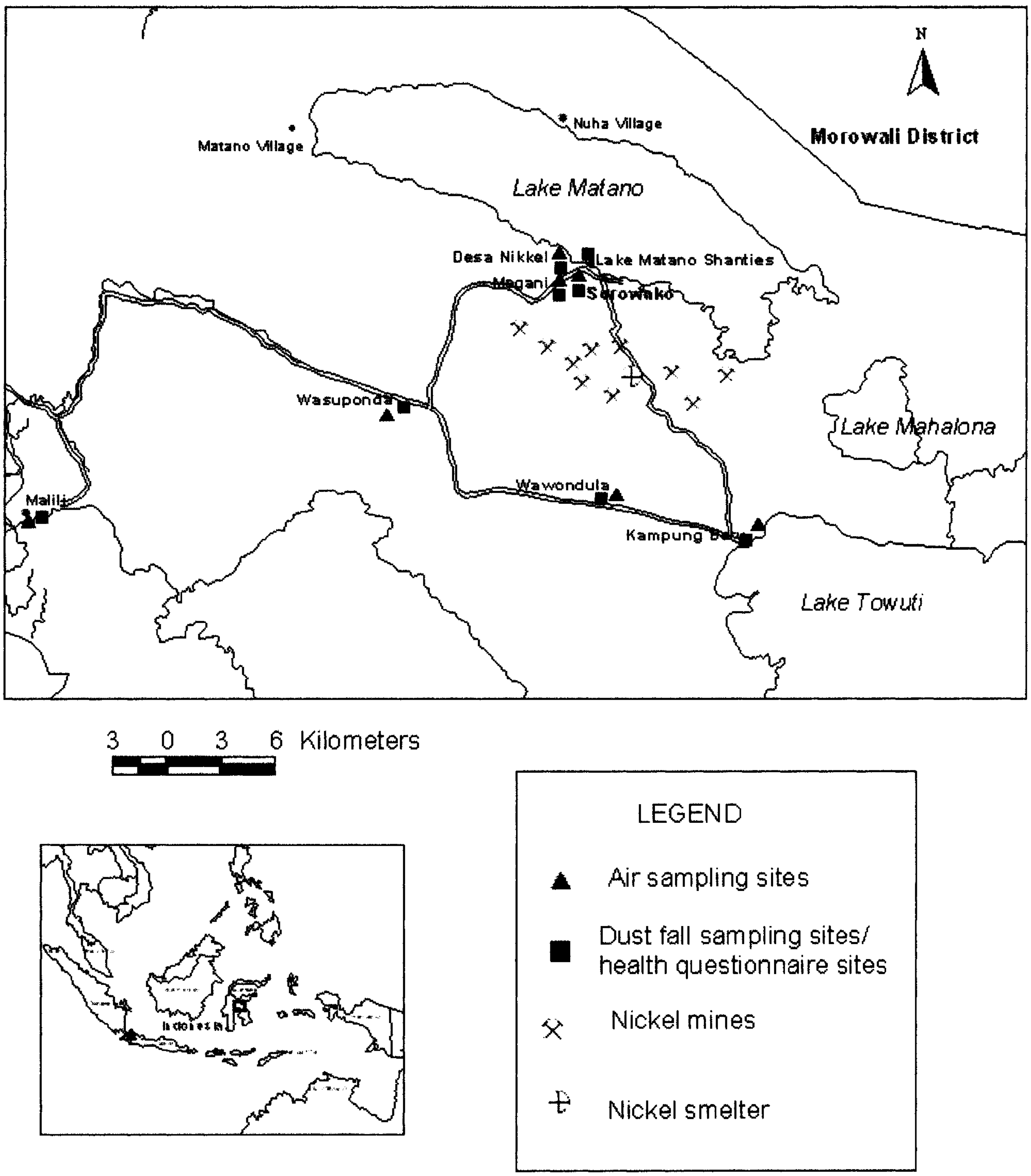

Fig. 3.1. Location of study area.

Air pollution studies around sulfide nickel mining and smelting operations gained prominence in the early 1970s in the Sudbury basin area of Ontario, Canada (Ontario Ministry of the Environment, 1982). The results of these investigations led to regulations and controls to reduce air pollution from nickel mining and smelting. However, relatively little research has been done on the effects of laterite nickel oxide mining and smelting in the tropics and sub-tropics like that found in Sorowako. This research is significant because both ore types contain different elements and the mining and processing methods of each differ and thus involve different environmental impacts (Dagenais and Poling, 1999). Most of the expanding nickel production capacity in the next decade will also come from tropical laterite nickel mines (Dalvi et al., 2004).

Air pollution has been noted as possibly Indonesia's most severe environmental problem with serious implications for public health. Respiratory tract inflammation, which tends to be linked to poor air quality, was the sixth leading cause of death in Indonesia after accidents, diarrhea, cardiovascular disease, tuberculosis, and measles. The use of leaded gasoline and forest fires are major sources of air pollution in Indonesia and in the larger Southeast Asia region (EIA, 2004). Near Caracas, Venezuela, a nickel smelter and refinery was opened in 2001. Today local residents today complain that pollution has caused poor crops and various health conditions including asthma and respiratory problems in children and contact dermatitis, a skin condition that can be caused by nickel exposure (Medina, 2005).

Studies on air pollution and its effects on human health are particularly complex in developing countries such as Indonesia where other factors like poor nutrition and sanitation, and low immunization coverage must be considered. Nevertheless, health impacts of air pollution on these populations may also be more severe (ESCAP, 2001). Subpopulations more at risk from air pollution include those with chronic disease, such as cardiopulmonary disease, asthma or other respiratory diseases, skin disorders, as well as the elderly, infants and children (NRC, 1999). Acute respiratory diseases are the second leading cause of death in children in Indonesia (Browne et al., 1999).

This research shows that the levels of total suspended particulates (TSP) and several airborne metals as well as domestic 24-hour dust fall accumulation in each community are affected by the season and time of day as well as by the proximity of the community to the smelter.

3.2. Materials and Methods

3.2.1. Study Site

Sorowako's lateritic iron and cobalt rich nickel ore is mined from the top of hills (Fig. 3.2). The smelter (Fig. 3.3) is located near the mines on a ridge overlooking the town. Six communities located near the nickel mines and smelter were selected to study seasonal and diurnal variations in TSP and airborne metals as well as to provide insight into their potential sources (Fig. 3.1). Air was also sampled from Malili, a community located further away from the mines and smelter, during the rainy season only. Additionally, domestic 24-hour dust fall accumulation was measured in these communities, as well as in the homes over Lake Matano (Fig. 3.1).

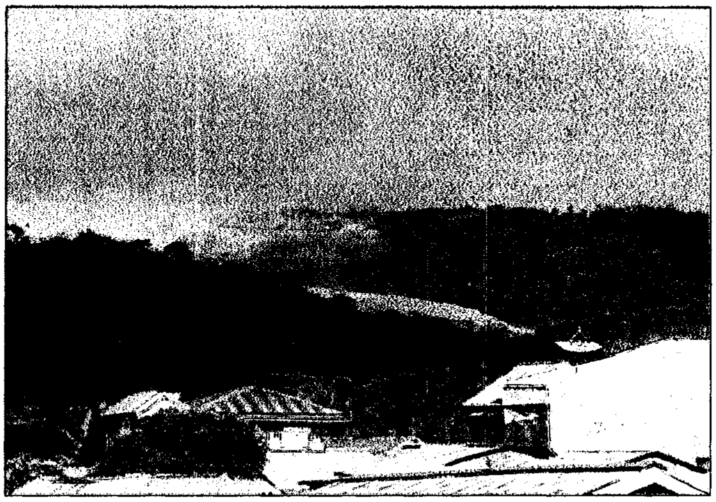

Fig. 3.2. PT Inco laterite nickel mines in Sorowako, August 2004. Credit: Evan Edinger.

Fig. 3.3. PT Inco smelter in Sorowako, September 2005. Credit: Daya.

Table 3.1 summarizes information for each study site including distance and direction from the nickel mines and smelter, and site characteristics. All sites were residential and located at varying directions and distances from the mines and smelter. Generally, all the sites experience moderate to high traffic in the day and have one main paved road and several dirt roads intersecting the community. It was expected that TSP, airborne metal concentrations and domestic dust fall accumulation would be elevated in communities closer to and downwind from the smelter such as Magani, Sorowako, Desa Nikkel and Wawondula, especially in the dry season.

The study area experiences a monsoonal climate with alternating rainy and dry seasons. Sorowako's average temperature ranges from 19 to 31 °C. Average monthly rainfall varies from below 200 mm during the dry season and to above 200 mm in the rainy season (PT Inco 2004; PT Inco, 1995). However, during the dry season in June 2004, monthly average rainfall was 290.9 mm (PT Inco, 2004). Monthly rainfall in June 2004 was lower in the nearby communities of Wawondula (118.3 mm) and Wasuponda (97.2 mm) (PT Inco, 2004).

Average wind speed in Sorowako varies from 0.9 to 7.1 m/s (PT Inco, 2004). Villagers reported that local winds have been shown to vary but dominant daytime winds are NW-SE and NE-SW, transporting smelter fallout towards Lake Towuti and the communities of Wawondula, Kampung Baru, and Wasuponda. Villagers also reported that prevailing night winds are SW-NE and SE-NW, transporting smelter fallout over Sorowako, Desa Nikkel, Magani, and the Lake Matano area. According to Matano Village residents, located 22 km NW from the smelter on the far western part of Lake Matano, smelter fallout reaches Matano Village about two days a month (Fig. 3.1) (Edinger and Best, 2001). The wind observations were corroborated by qualitative observation during the sampling periods. There is no weather station in the area that records 24-hour wind direction. The PT Inco plant site records wind speed but not wind direction while the PT Inco airport only records wind direction for a few hours each day, usually before a plane is set to land at the airport.

Mixing of soot/smoke, sulphur, and laterite dust from dryers, reduction kilns, and stacks occurs in the air above the smelter (Edinger and Best, 2001). Rain has been observed to nucleate around dust particles, with large black soot and red iron-rich laterite dust parts found within raindrops (Edinger and Best, 2001). Vegetation surrounding the smelter site is covered in dust. Community members have linked the smelter dust to lower agricultural productivity in surrounding areas (Ballard, 2001). A black oily grime layer is sometimes observed on the surface waters of Lake Matano in the early morning (Edinger and Best, 2001).

Besides the nickel smelter, other sources of ambient air pollution in the area include dirt roads, transportation, disturbed mining areas, and waste sites. Many of the homes in the communities surrounding the smelter are susceptible to the entrance of dust from outside. The homes are constructed with open spaces in the walls and windows. Doors are often left opened during the day. The homes are also located near dirt roads.

Table 3.1. Characteristics of study sites.

Site	Distance/direction from smelter	Characteristics of study site
1. Magani	4.5 km, NW	Prevailing night winds blow smelter fallout here. Some paved roads and some limestone roads. Less traffic in daytime compared to Sorowako. Air sample taken at a residence.
2. Sorowako	5.5 km, NW	Prevailing night winds blow smelter fallout here. Some paved roads with intersecting roads made of slag waste rock. Frequent traffic in daytime. Air sample taken at the village administration office yard.
3. Homes on Lake Matano	6 km, NW	Homes built over Lake Matano, next to Desa Nikkel and Sorowako. Damp, unsanitary conditions, surrounded by garbage and sewage. Prevailing night winds blow smelter fallout here. No air sample taken in this community (dust sample only).
4. Desa Nikkel	6 km, NW	Prevailing night winds blow smelter fallout here. Roads made of slag waste rock with few paved roads. Frequent traffic in daytime. Air sample taken at the village administration office backyard.
5. Wawondula	7.5 km, SW	Settlement area for PT Inco unskilled workforce. Prevailing day winds blow smelter fallout here. Main road is paved and others made of slag waste rock. Less traffic in daytime compared to Sorowako. Air sample taken in front yard of a residence.
6. Kampung Baru	11 km, SE	Artisanal sawmills are located here along the Lake Towuti shore. Prevailing day winds blow smelter fallout here. Main road is paved and others are dirt roads. Less traffic in daytime compared to Sorowako. Air sample taken at a mosque yard near the shore of Lake Towuti.
7. Wasuponda	11.5 km, SW	District capital. Settlement area for PT Inco workforce. Day winds sometimes blow smelter fallout here. Main road is paved and others made of slag waste rock and backfill. Less traffic in daytime compared to Sorowako. Air sample taken in PT Inco's health clinic next to trees.
8. Malili	20 km, SW	Site of local administration office and port. Day winds sometimes blow smelter fallout in this direction but is outside of PT Inco's expected smelter fallout zone. Paved roads with only a few roads not paved yet. Frequent traffic in daytime. Air samples were taken during the rainy season only.

3.2.2. Sampling Collection and Preparation

3.2.2.1. TSP and Airborne Metals

Community members received training on how to use a high volume air sampler (HVAS) for air sampling for TSP and metal concentration analysis. Community members took samples over 12-hour periods for approximately five consecutive days in August and September 2004, during the dry season, at each of the six sampling stations. The 12-hour sampling periods were partitioned for day at approximately 06.00 h to 18.00 h and for night at approximately 18.00 h –06.00 h (Figs. 3.4-3.5). Air sampling in the same locations occurred again from December 2004 to February 2005 (the rainy season) to determine seasonal variations. The air in Malili was also sampled similarly in November 2005.

Figs. 3.4 and 3.5. Community volunteers preparing to take an air sample (L) and retrieving the air sample (R) during an air sampling training, June 2002 (Credit: Evan Edinger). *Note: Data from this site were not used in the monitoring program because of problems with electrical supply and nearby vegetation.*

The HVAS, which is primarily used today for airborne metals analysis, sampled air at 1.4 m above the ground (Wight, 1994; Intersociety Committee, 1989). Differences in power surges, and power outages were initially identified as causing variations in the HVAS flow rate. This variation was minimized with the use of a voltage stabilizer. The HVAS operated on an average flow rate of 44 CFM in the dry season and 38 CFM in the rainy season.

Whatman QMA glass-fiber filters (20 x 25 cm^2, 0.1 μm pore-size) were used as the filter medium because of its high collection efficiency (99.9%), resistance to corrosive gases, low water uptake, and relatively low overhead costs (EPA, 1999). However, 0.45 μm pore-size glass-fiber filters were used in the Malili air sampling due to availability of these filters. These filters are generally free of target metals for measurement but still contain chemical impurities so blanks (unused filters transported to and from the field) were used in the analysis (Intersociety Committee, 1989; Pio, 1991).

Sampling methods were designed to highlight general spatial and temporal (seasonal and diurnal) patterns in TSP and airborne metals concentrations between communities, and not to detect background concentrations, differences in particulate matter (PM) size (PM10 or PM2.5), micro-climatic differences, or the effects of chemical transformations or horizontal turbulent diffusion (Munn, 1978; Steingraber, 1997).

Sampling sites were constrained to sites that were secure, accessible and where sufficient voltage was found to power the HVAS for 12 hours. Village administration offices, mosques and a hospital in these communities were sites of adequate voltage and subsequent sampling. Samplers should be located at least 5 to 10 m from buildings or twice the difference in elevation of buildings, and in open areas with little or no vegetation (EPA, 1997; Browne et al., 1999). Samplers should be at least 20 m from nearby trees. Trees can be sources of PM in the form of detritus, pollen, or insects (EPA, 1997). The Wasuponda sampling site was located next to trees because it was one of the only sites in the community with sufficient electricity to power the HVAS. This was also the site of PT Inco's air monitoring station, which would allow a comparison with the community-based monitoring results. However, this data was not made available to the community. The winds off the lake near the Kampung Baru sampling location may have caused lower amounts of TSP and airborne metals than that found in the Kampung Baru community further away from the lake. It was also impossible to obtain background samples at least 100 km from large population centres and 100 m from roads and wood burning because of the limited electricity sources to power the HVAS (EPA, 1997).

3.2.2.2. Heavy Metal Composition Analysis

A 2.54 x 20.32 cm^2 strip of the sampled area of each filter was taken using a plastic ruler. The weight of each filter strip was recorded. Each filter strip was then folded accordion style and placed in the lower part of a 150 mL beaker. Blank and duplicate samples were also prepared to test quality assurance. Ten millilitres of 8M HNO_3 acid was added to each sample. The sample was then covered with a watch glass and refluxed gently on a hot plate at low temperature (>100 °C) for 30 minutes. After cooling, the inner beaker walls and watch glass were rinsed with deionized water. Approximately 10 mL of nanopure water was then added to remaining filter material and left to sit for 30 minutes to allow the acid to diffuse from the filter into the solution. The extraction fluid in the beaker was then transferred to a 20 mL graduated vessel. The filter digestate was diluted with nanopure water to approximately 20 mL. The final volume and weight of the solution was recorded before ICP-MS analysis to determine metals composition (EPA, 1999).

3.2.2.3. Domestic 24-hour Dust Fall Accumulation

A dust sample was taken from approximately twenty households in each of the eight communities that participated in the health questionnaire component of the community-based research (see Chapter 4); Magani, Sorowako, homes over Lake Matano, Desa Nikkel, Wawondula, Kampung Baru, Wasuponda and Malili (Fig. 3.1). A measured sample area was cleaned near a window. After 24 hours, a pre-weighed Kim wipe was used to swipe that same area. The Kim wipes were then measured for final weight to determine the amount of dust that fell in a 24-hour period, normalized to unit area. A clean and unused Kim wipe was used as a control.

3.2.3. Data Analysis

Airborne metals in the samples were calculated using the following equation:

C = [(μg metal/mL) x (Final extract volume (mL)/strip)(9) - Fm]/Vstd

where:

C = concentration, μg metal/m^3

μg metal/mL = metal concentration obtained from ICP-MS analysis.

Final extract volume (mL)/strip = total volume of sample extracted from extraction procedure (approx. 25 mL).

$$9 = \frac{\text{Useable filter area, [20 cm x 23 cm (8" x 9")]}}{\text{Exposed area of one strip, [2.5 cm x 20 cm (1" x 8")].}}$$

Fm = average concentration of blank filters, μg.

Vstd = standard air volume pulled through filter, m^3

The percent relative standard deviation (RSD) was calculated for metals of concern for the five certified reference materials analysed by ICP-MS at the same time as the air samples (Table 3.2). The percent RSD showed the magnitude of error relative to the mean.

Table 3.2. Percent relative standard deviation (RSD) on certified reference materials of various metals of concern.

Standard	Al	Ti	Cr	Mn	Co	Ni	Cu	Zn
t143	9.0782	17.0608	5.1987	156.9624	142.8542	39.3231	69.2329	16.4975
t145	3.7989	18.0964	7.3724	74.7742	1.9945	11.3835	7.0432	13.6704
t153	5.5572	10.6993	5.4818	8.1456	<DL	55.8424	13.9821	34.836
t155	4.1344	19.8346	10.8895	20.3892	2.9657	78.7414	42.019	17.2906
t171	17.016	99.8588	3.4854	72.5964	147.3428	9.0339	84.1188	47.2882

The percent mean weight of various metals (Figs. 3.8-3.15) was calculated from the total mean weight of the total TSP.

Univariate analysis of variance (ANOVA) using post-hoc tests Tukey (assuming equal variance) and Dunnett C (assuming unequal variance) were used to test significant differences ($\alpha=0.05$) of seasonal and diurnal TSP and airborne metal concentrations, as well as domestic 24-hour dust fall accumulation in the dry season. Kruskall-Wallis, a non-parametric test, was used on the domestic dust fall data since non-normal distribution was expected.

Regression using linear and exponential trend lines was used to determine whether day or night TSP and airborne nickel concentrations in the dry and rainy season were decreasing with distance from the smelter. Similar regressions were used to determine this with the 24-hour TSP and airborne nickel concentrations.

Pearson correlation analysis was used to determine any positive or negative associations between metals, and sites, seasons and times of the day in order to identify potential sources.

3.3. Results

3.3.1. Spatial Distribution of TSP and Airborne Metals

Overall mean TSP levels ranged from 26.92 $\mu g/m^3$ in Malili during the night in the rainy season to 157.47 $\mu g/m^3$ in Wawondula during the day in the dry season (Tables 3.3 and

3.4). Univariate analysis of variance of TSP levels of all samples indicated no significant difference between communities on a spatial basis alone. However, temporal differences in TSP and metals concentrations between sites wer noted (see Sec. 3.3.2).

Metals used in the statistical analysis that denoted smelter fallout and/or road dust sources included nickel (Ni), cobalt (Co), chrome (Cr), copper (Cu), manganese (Mn), and zinc (Zn). Road dust indicators used in the analysis included aluminium (Al), silica (Si) and titanium (Ti). A saprolite ore sample taken west of Lake Mahalona in June 2002 indicated major components of Fe> Ca> Ni > Cr > Mn > Co > Ti > Zn > V. Zn and Ti are not expected to be originate from the smelter fallout so ambient levels of these metals would suggest a potential road dust source. Strong separate TSP-Ti, TSP-Si, Al-Ti and Al-Si correlations would indicate road dust as a potential source. Strong separate Ni, Co, and Cr correlations with TSP with no associations with Si or Ti would indicate a smelter fallout source.

Table 3.3. Day and night mean, standard deviations and maximum concentrations of TSP ($\mu g/m^3$) and various metals found at each sample station in the dry season (μg metal/m^3).

Metals	TSP Day	TSP Night	Al Day	Al Night	Ni Day	Ni Night	Co Day	Co Night	Cr Day	Cr Night	Mn Day	Mn Night	Zn Day	Zn Night	Ti Day	Ti Night
D.L. (ppb)	-	-	0.980-1.798	0.980-1.798	0.085-0.211	0.085-0.211	0.007-0.185	0.007-0.185	0.202-0.601	0.202-0.601	0.200-0.209	0.200-0.209	2.824-3.125	2.824-3.125	0.216-0.393	0.216-0.393
Magani, Day N= 5, Night N=5																
Mean	111.53	46.79	0.527	0.108	0.272	0.036	0.013	0.002	0.053	0.008	0.091	0.013	0.027	0.012	0.039	0.005
S.D.	26.23	32.58	0.224	0.051	0.102	0.020	0.003	0.001	0.030	0.003	0.022	0.006	0.016	0.003	0.017	0.004
Max.	146.43	103.4	0.901	0.189	0.436	0.063	0.017	0.003	0.104	0.013	0.125	0.023	0.054	0.015	0.067	0.010
Sorowako, Day N= 5, Night N=5																
Mean	81.32	75.07	0.371	0.223	0.237	0.188	0.012	0.010	0.051	0.037	0.091	0.075	0.029	0.016	0.012	0.007
S.D.	38.41	25.42	0.250	0.131	0.193	0.113	0.009	0.006	0.049	0.020	0.068	0.041	0.017	0.002	0.009	0.002
Max.	135.2	114.28	0.700	0.448	0.461	0.313	0.023	0.017	0.125	0.073	0.165	0.116	0.060	0.019	0.024	0.014
Desa Nikkel, Day N= 4, Night N=4																
Mean	86.66	63.96	0.313	0.193	0.128	0.127	0.007	0.005	0.037	0.027	0.057	0.042	0.037	0.028	0.013	0.008
S.D.	22.03	24.81	0.118	0.091	0.045	0.054	0.003	0.002	0.023	0.010	0.025	0.018	0.019	0.013	0.006	0.004
Max.	116.59	97.80	0.514	0.320	0.190	0.181	0.011	0.008	0.070	0.037	0.093	0.065	0.064	0.047	0.022	0.013
Wawondula, Day N=3 Night N=4																
Mean	157.47	106.55	0.364	0.190	0.247	0.115	0.014	0.007	0.037	0.018	0.105	0.053	0.040	0.0257	0.010	0.005
S.D.	23.90	41.68	0.063	0.056	0.095	0.034	0.004	0.002	0.013	0.003	0.024	0.017	0.009	0.006	0.001	0.002
Max.	179.4	163.00	0.436	0.255	0.345	0.144	0.017	0.009	0.051	0.020	0.130	0.068	0.050	0.034	0.011	0.006
Kampung Baru, Day N= 5, Night N=5																
Mean	68.35	89.56	0.225	0.192	0.087	0.102	0.005	0.006	0.015	0.017	0.043	0.046	0.023	0.031	0.009	0.007
S.D.	38.41	29.96	0.082	0.071	0.061	0.048	0.003	0.003	0.009	0.007	0.022	0.021	0.009	0.012	0.002	0.003
Max.	104.26	118.87	0.206	0.257	0.160	0.159	0.008	0.009	0.027	0.025	0.070	0.076	0.037	0.047	0.012	0.009
Wasuponda, Day N= 4, Night N=5																
Mean	74.41	54.72	0.216	0.120	0.070	0.023	0.003	0.001	0.013	0.008	0.043	0.020	0.027	0.020	0.006	0.004
S.D.	15.43	7.26	0.086	0.028	0.048	0.006	0.002	0.000	0.005	0.001	0.017	0.005	0.007	0.004	0.003	0.001
Max.	92.42	65.98	0.299	0.169	0.142	0.030	0.006	0.001	0.021	0.009	0.061	0.028	0.037	0.025	0.010	0.007
Mean	96.62	72.78	0.336	0.171	0.173	0.0990	0.009	0.005	0.034	0.019	0.072	0.041	0.030	0.022	0.015	0.006
S.D.	33.32	22.39	0.137	0.071	0.089	0.061	0.004	0.003	0.017	0.011	0.027	0.022	0.007	0.007	0.012	0.001
Max.	179.40	163.00	0.901	0.448	0.461	0.313	0.023	0.017	0.125	0.073	0.165	0.116	0.064	0.047	0.067	0.014

Table 3.4. Day and night mean, standard deviations and maximum concentrations of TSP (µg/m^3) and various metals found at each sample station in the rainy season (µg metal/m^3).

Metals	TSP Day	TSP Night	Al Day	Al Night	Ni Day	Ni Night	Co Day	Co Night	Cr Day	Cr Night	Mn Day	Mn Night	Zn Day	Zn Night	Ti Day	Ti Night
D.L. (ppb)	-	-	2.538-3.917	2.538-3.917	0.132-9.202	0.132-9.202	0.008-0.053	0.008-0.053	1.707-6.495	1.707-6.495	0.148-0.829	0.148-0.829	0.714-9.202	0.714-9.202	0.110-0.535	0.110-0.535
Magani, Day N=5, Night N=5																
Mean	84.51	83.64	0.095	0.128	0.085	0.054	0.003	0.003	0.013	0.012	0.038	0.029	0.026	0.025	0.003	0.005
S.D.	39.09	51.56	0.057	0.142	0.088	0.050	0.003	0.003	0.011	0.010	0.032	0.023	0.021	0.028	0.001	0.008
Max.	151.8	170.2	0.193	0.379	0.236	0.135	0.008	0.008	0.032	0.028	0.084	0.066	0.061	0.074	0.005	0.019
Sorowako, Day N= 4, Night N=6																
Mean	87.83	107.23	0.129	0.230	0.058	0.182	0.004	0.009	0.007	0.033	0.033	0.024	0.031	0.072	0.004	0.009
S.D.	15.02	72.17	0.036	0.247	0.035	0.218	0.002	0.010	0.003	0.046	0.010	0.006	0.014	0.072	0.001	0.009
Max.	104.8	250.0	0.181	0.721	0.104	0.607	0.006	0.029	0.010	0.124	0.041	0.031	0.044	0.207	0.006	0.025
Desa Nikkel, Day N= 5, Night N=5																
Mean	107.58	88.61	0.197	0.147	0.147	0.105	0.102	0.057	0.022	0.012	0.021	0.006	0.028	0.011	0.007	0.006
S.D.	48.18	19.46	0.117	0.042	0.154	0.034	0.010	0.038	0.018	0.006	0.046	0.013	0.051	0.017	0.005	0.002
Max.	188.33	113.87	0.375	0.199	0.388	0.146	0.263	0.104	0.047	0.018	0.104	0.029	0.120	0.041	0.016	0.008
Wawondula, Day N= 5, Night N=5																
Mean	80.0	79.76	0.102	0.161	0.102	0.085	0.004	0.004	0.014	0.018	0.043	0.037	0.032	0.03	0.002	0.006
S.D.	12.80	17.13	0.065	0.069	0.172	0.046	0.007	0.002	0.019	0.008	0.032	0.016	0.042	0.016	0.001	0.003
Max.	100.88	90.87	0.216	0.231	0.409	0.125	0.017	0.005	0.048	0.025	0.087	0.063	0.107	0.044	0.004	0.009
Kampung Baru, Day N= 5, Night N=5																
Mean	70.85	79.54	0.084	0.089	0.033	0.110	0.015	0.005	0.006	0.013	0.016	0.044	0.02	0.034	0.003	0.003
S.D.	19.89	30.44	0.057	0.064	0.021	0.148	0.031	0.005	0.004	0.016	0.0122	0.053	0.012	0.033	0.002	0.002
Max.	105.7	125.90	0.075	0.191	0.062	0.371	0.069	0.013	0.013	0.04	0.03	0.136	0.034	0.088	0.006	0.005
Wasuponda, Day N= 5, Night N=4																
Mean	76.13	62.62	0.086	0.160	0.029	0.086	0.002	0.004	0.007	0.014	0.02	0.031	0.019	0.034	0.003	0.006
S.D.	35.14	26.47	0.046	0.032	0.014	0.066	0.001	0.002	0.003	0.009	0.006	0.013	0.01	0.016	0.002	0.002
Max.	135.98	91.24	0.142	0.184	0.051	0.183	0.004	0.007	0.012	0.027	0.029	0.049	0.036	0.05	0.006	0.007
Malili, Day N=6, Night N=6 *Sampled in November 2005.																
Mean	38.58	26.92	0.896	0.980	0.014	0.030	0.002	0.002	0.003	0.005	0.013	0.015	0.041	0.017	0.022	0.022
S.D.	8.27	18.56	0.670	0.057	0.011	0.040	0.001	0.002	0.003	0.006	0.010	0.016	0.046	0.004	0.017	0.001
Max.	52.87	58.57	1.436	1.076	0.025	0.111	0.003	0.007	0.006	0.017	0.023	0.047	0.125	0.022	0.033	0.024
Mean	77.93	75.47	0.265	0.316	0.067	0.093	0.019	0.012	0.010	0.015	0.026	0.027	0.028	0.032	0.006	0.008
S.D.	25.48	33.68	0.175	0.109	0.075	0.086	0.008	0.009	0.009	0.014	0.021	0.020	0.028	0.027	0.005	0.003
Max.	188.33	250.0	0.375	1.076	0.409	0.371	0.263	0.104	0.048	0.124	0.104	0.136	0.125	0.207	0.033	0.025

3.3.2. Temporal Distribution of TSP and Airborne Metals

In the dry season, mean TSP varied from 68.35 μg/m^3 in Kampung Baru to 157.47 μg/m^3 in Wawondula during the day and from 46.79 μg/m^3 in Magani to 106.55 μg/m^3 in Wawondula during the night (Fig. 3.6; Table 3.3). In the rainy season, mean TSP concentration varied from 38.58 μg/m^3 in Malili to 107.58 μg/m^3 in Desa Nikkel during the day, and from 26.92 μg/m^3 in Malili to 107.23 μg/m^3 in Sorowako during the night (Fig. 3.7; Table 3.4). Samples taken during the rainy season in Malili, further away from the smelter, had relatively lower average TSP values of 30.09 to 52.97 μg/m^3 in the day, and 11.04 to 58.57 μg/m^3 in the night. Samples taken during the rainy season in the other communities had mostly lower mean TSP levels with less diurnal difference than the dry season. In the dry season samples, mean TSP levels in the day were significantly higher than in the night in both Magani and Wasuponda (ANOVA: $P<0.01$, $F(1, 8) = 11.98$ and $P<0.02$, $F(1, 8) = 9.73$ respectively).

Major elemental composition (iron (Fe), magnesium (Mg), calcium (Ca), phosphorous (P), and sulphur (S)) in the dry and rainy season air samples are presented in Figs. 3.8-3.11. These elements were found in similar percentages in all communities during the days of both seasons but varied in the night of both seasons. In Malili, the reference site, a different major elemental composition than the others communities was observed; Ca was greater than 4% and Si was greater than 2% during the day and night of the rainy season. Both these elements were lower in other communities. A limiting factor in the analysis of the airborne metal composition was high and variable detection limits of S. This detection limit ranged from 1750 to 12026 ppb in batches of air samples analysed.

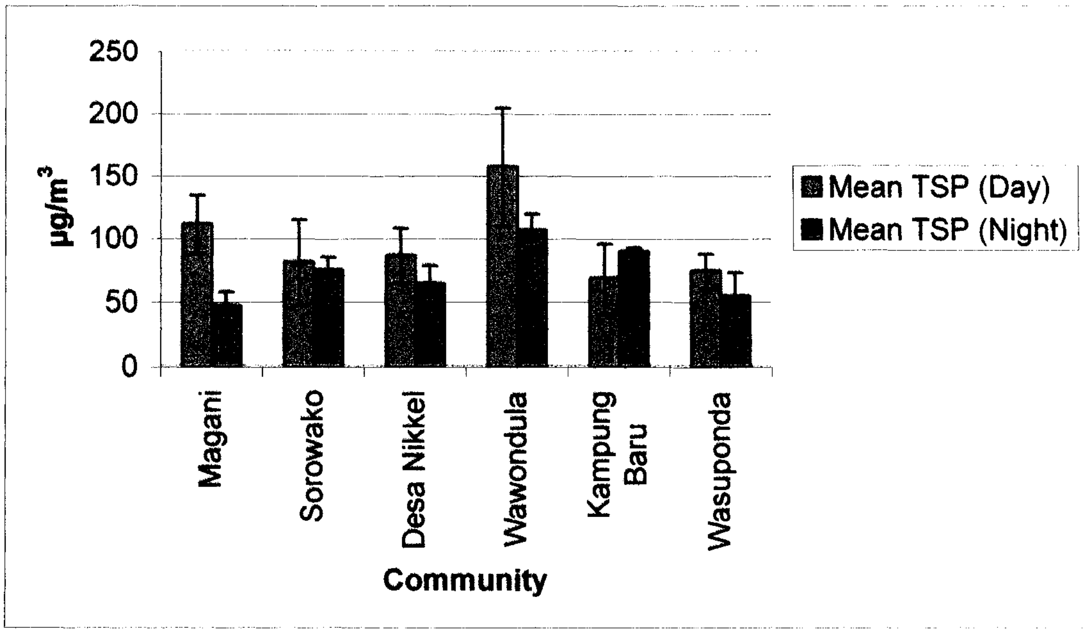

Fig. 3.6. Mean day/night TSP of dry season samples (with 95% C.L.).

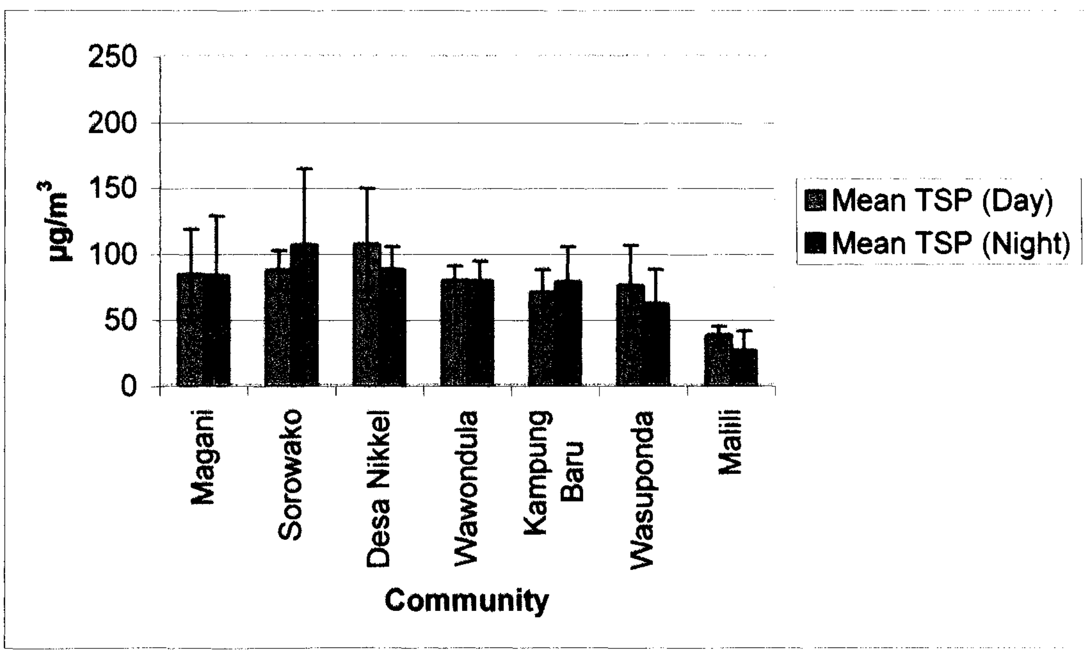

Fig. 3.7. Mean day/night TSP of rainy season samples (with 95% C.L.).

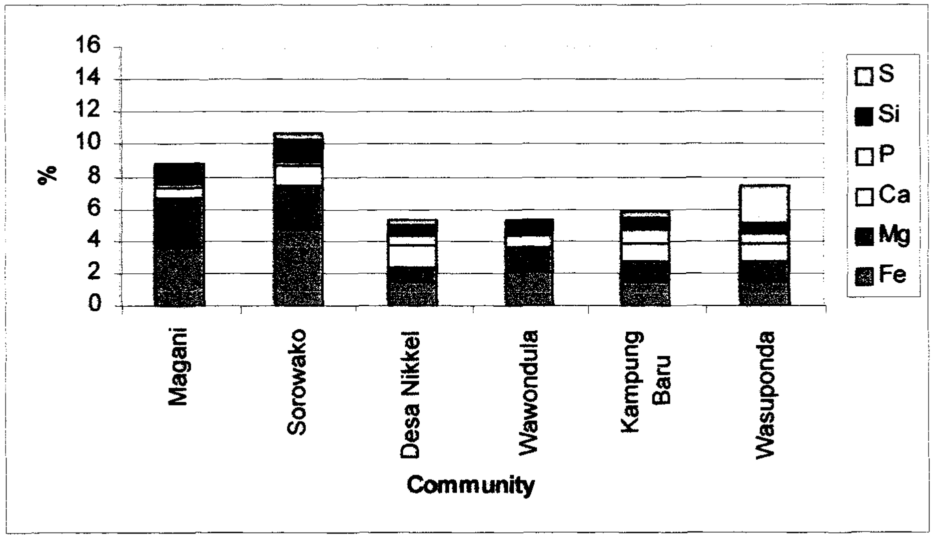

Fig. 3.8. Mean major element composition in dry season day samples.

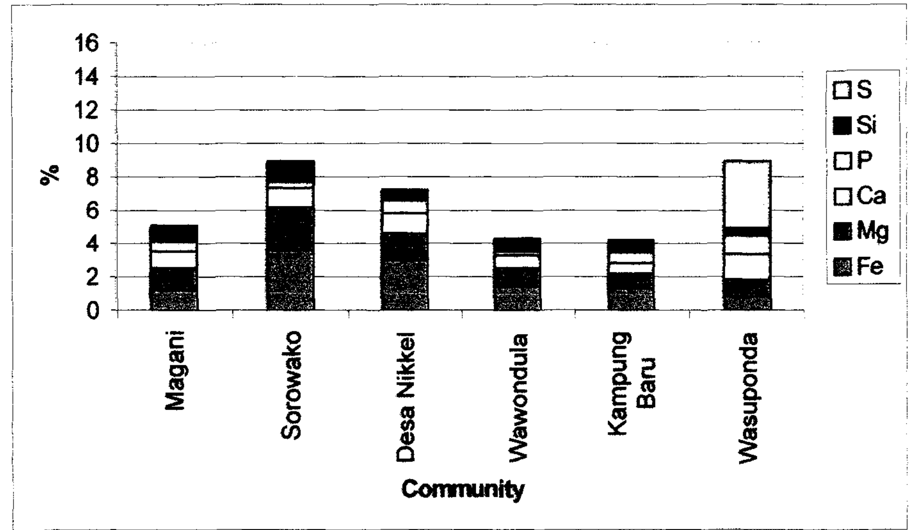

Fig. 3.9. Mean major element composition in dry season night samples.

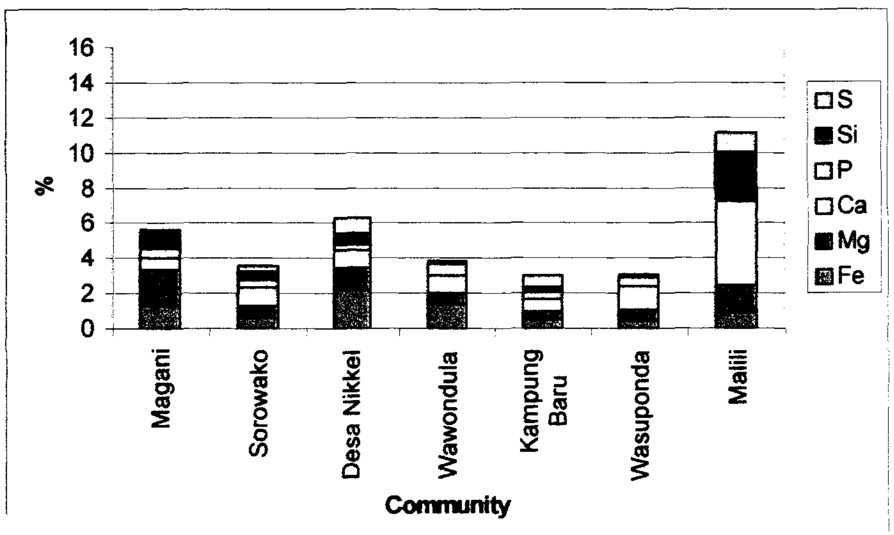

Fig. 3.10. Mean major element composition in rainy season day samples.

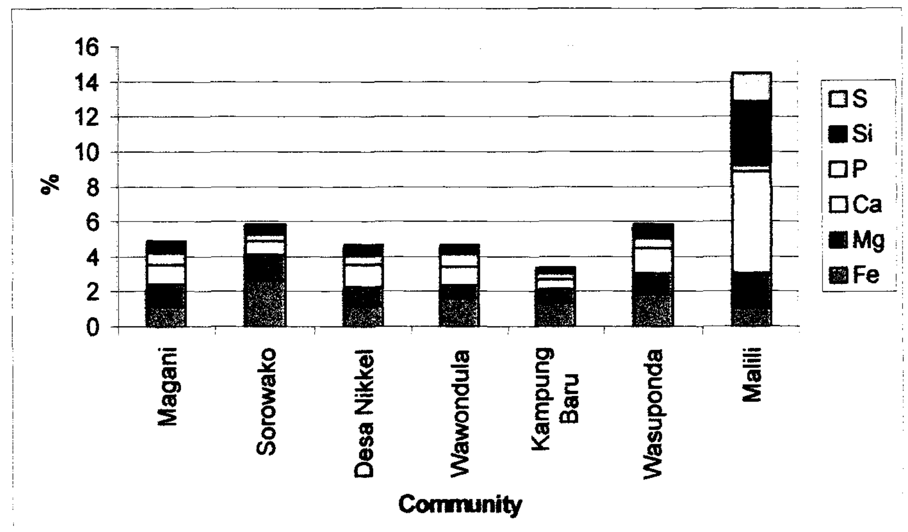

Fig. 3.11. Mean major element composition in rainy season night samples.

Trace elemental composition (aluminum (Al), nickel (Ni), copper (Cu), lead (Pb), manganese (Mn), zinc (Zn), chromium (Cr), barium (Ba), bromium (Br), titanium (Ti) and cobalt (Co)) in the dry and rainy season air samples are presented in Figs. 3.12-3.15. In each community, these metals were higher in the dry season than in the rainy season. These metals also tended to be higher during the day of the dry season than during the night of the dry season. Higher levels of Al were recorded in Malili than in the other communities. Copper is recorded at higher levels during both the day and night in the dry season than during the rainy season in Sorowako. Copper is also higher in the night rainy season sample from Wawondula.

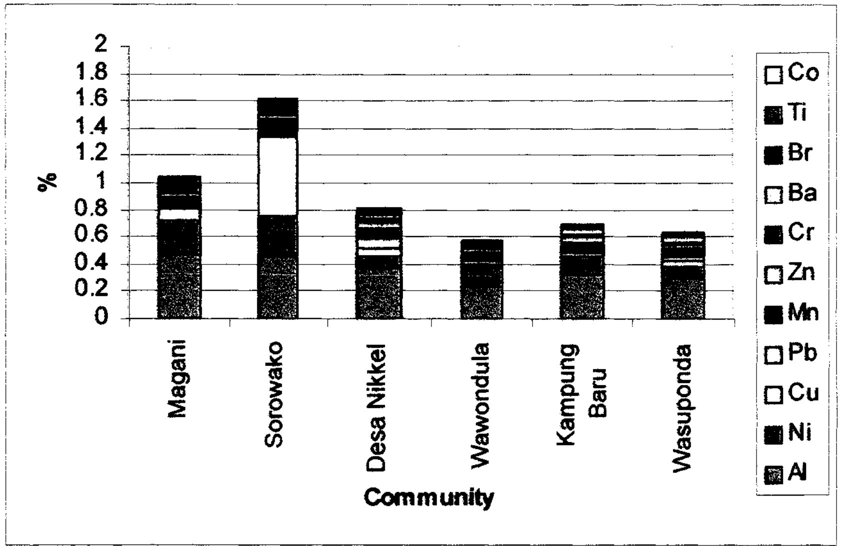

Fig. 3.12. Mean trace element composition in dry season day samples.

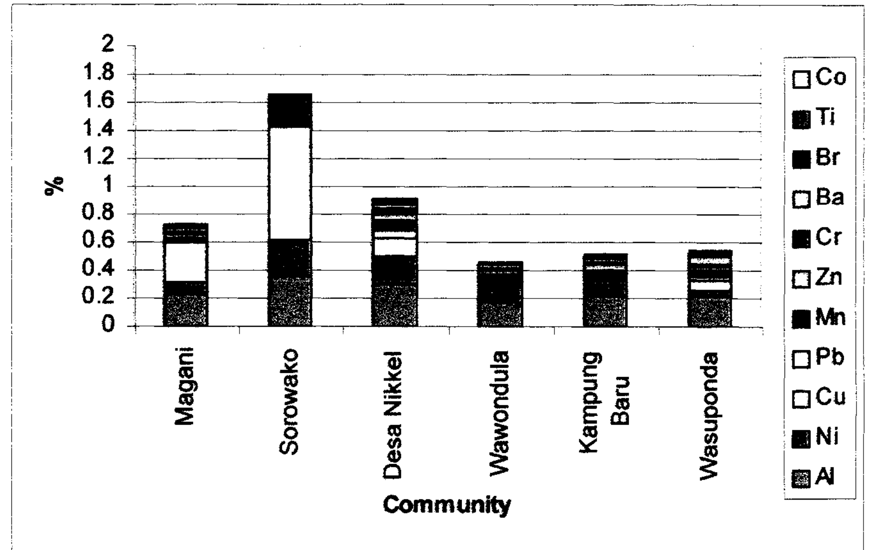

Fig. 3.13. Mean trace element composition in dry season night samples.

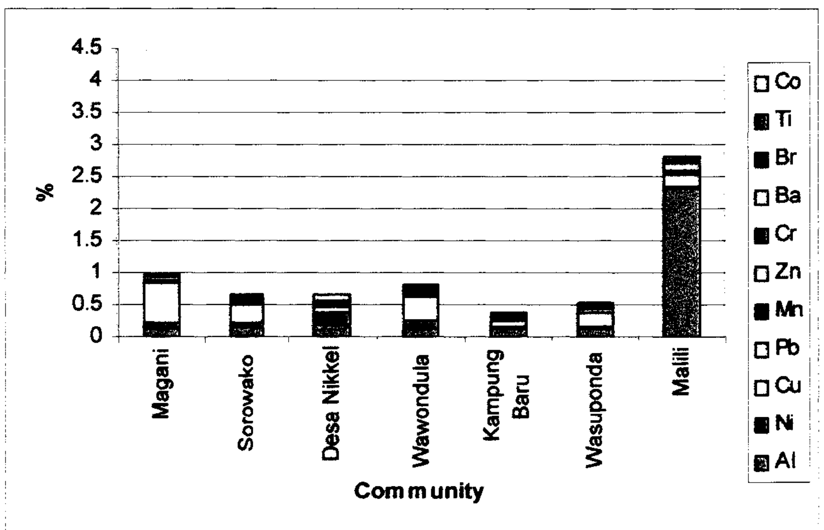

Fig. 3.14. Mean trace element composition in rainy season day samples.

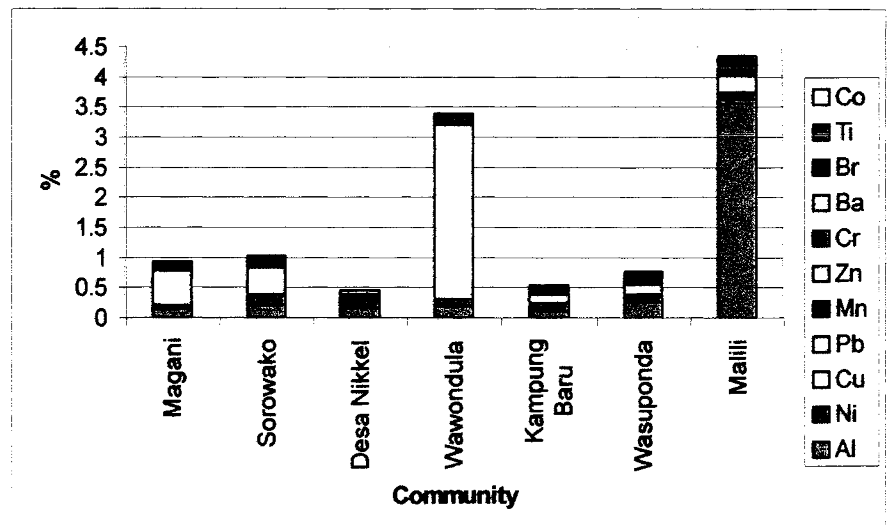

Fig. 3.15. Mean trace element composition in rainy season night samples.

Mean air Ni concentrations were significantly higher in the day than night in Magani and Wawondula (ANOVA, $p<0.001$, $F(1, 8) = 25.82$ and $p<0.047$, $F(1, 8) = 6.86$ respectively) (Figs. 3.16 –3.17).

Mean air Co concentrations were significantly higher in the day than night in Magani and Wawondula (ANOVA, $p<0.0001$, $F(1, 8) = 51.59$ and $p<0.03$, $F(1, 8) = 8.82$ respectively).

^{53}Cr was presented throughout the results because it was the isotope of Cr consistently found in relatively higher amounts. This may be due to interference in the ICP-MS analysis with either the ^{53}Cr isotope or the ^{52}Cr isotope. Mean air Cr concentrations were significantly higher in the day than night in the dry season in Magani and Wawondula (ANOVA, $p<0.01$, $F_{(1, 8)} = 11.32$ and $p<0.03$, $F_{(1, 8)} = 8.89$ respectively).

Mean air Mn concentrations were significantly higher in the day than night in Magani and Wawondula (ANOVA, $p<0.0001$, $F_{(1, 8)} = 56.74$ and $p<0.02$, $F_{(1, 8)} = 11.15$ respectively).

Mean air Ti concentrations were significantly higher in the day than night in Magani and Wawondula (ANOVA, $p<0.001$, $F_{(1, 8)} = 20.54$ and $p<0.007$, $F_{(1, 8)} = 19.36$ respectively).

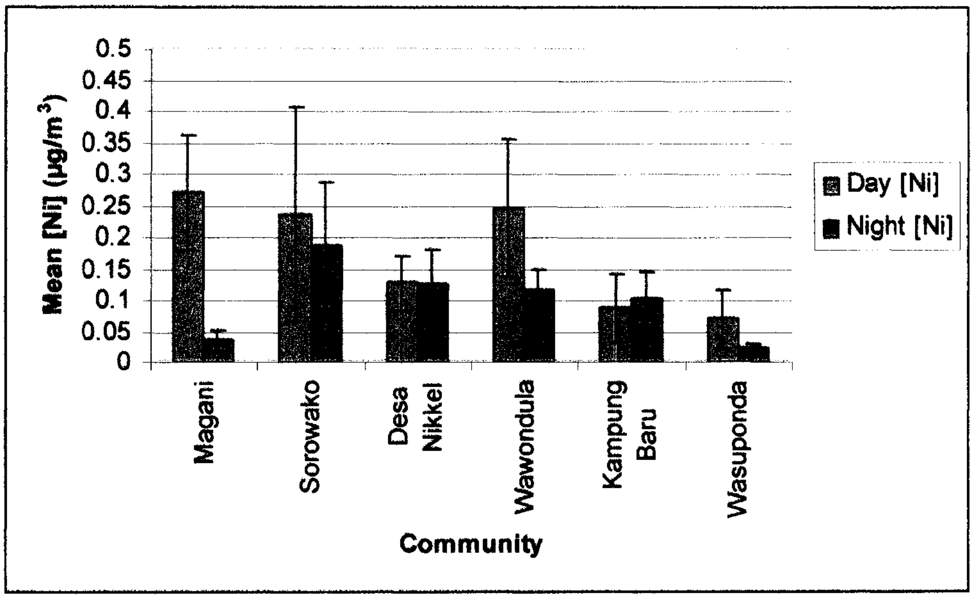

Fig. 3.16. Mean day and night airborne Ni concentrations (µg/m^3) in the dry season (with 95% C.L).

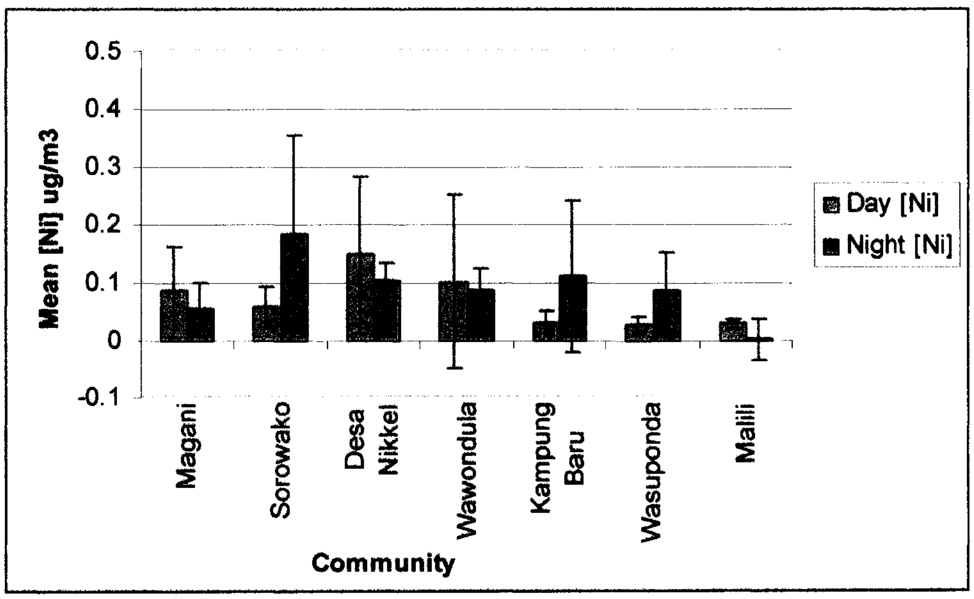

Fig. 3.17. Mean day and night airborne Ni concentrations (µg/m^3) in the rainy season (with 95% C.L.).

Linear and exponential regression analysis revealed a significant regression of TSP concentrations in both the day and night of the rainy season with distance from the smelter (Linear r^2=0.310, p=0.001, Exponential r^2=0.493, p=0.000, and Linear r^2=0.275, p=0.001, Exponential r=0.490, p=0.000 respectively). No significant regression was found for dry season day and night TSP concentrations with distance from the smelter (Figs. 3.18-3.21). In this analysis, the regression of 24-hour TSP concentrations in the rainy season with distance from the smelter was significant (Linear r^2=0.083, p=0.000, Exponential r^2=0.459, p=0.000) (Fig. 3.23). No significant regression was found for 24-hour TSP concentrations in the dry season (Fig. 3.22). There was a significant regression of day airborne Ni concentrations in the dry season with distance from the smelter (Linear r^2=0.276, p=0.006, Exponential r^2=0.066, p=0.207) (Fig. 3.27). No significant regression was found for night airborne Ni concentrations in the dry season with distance from the smelter (Fig. 3.28). There was also a significant regression of airborne Ni concentrations in the day during the rainy season with distance from the smelter (Linear r^2=0.122, p=0.040, Exponential r^2=0.303, p=0.001) (Fig. 3.29). No significant regression was found for night Ni concentrations in the rainy season with distance from the smelter (Fig. 3.30). This analysis also revealed a significant regression of both dry and rainy season 24-hour airborne Ni concentrations with distance from the smelter (Linear r^2=0.158, p=0.003, Exponential r^2=0.065, p=0.063 and Linear r^2=0.081, p=0.016, Exponential r^2=0.213, p=0.000 respectively) (Figs. 3.31-3.32).

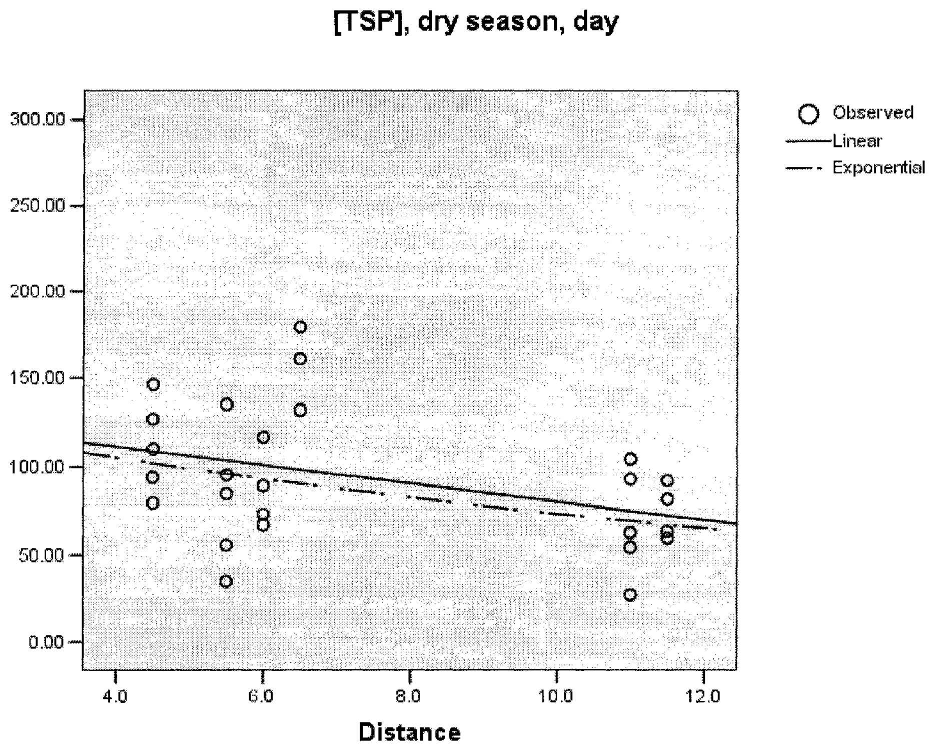

Fig. 3.18. Linear and exponential regressions of dry season day TSP concentrations vs. distance from the smelter. Linear r^2=0.153, p=0.048, Exponential r^2=0.146, p=0.054.

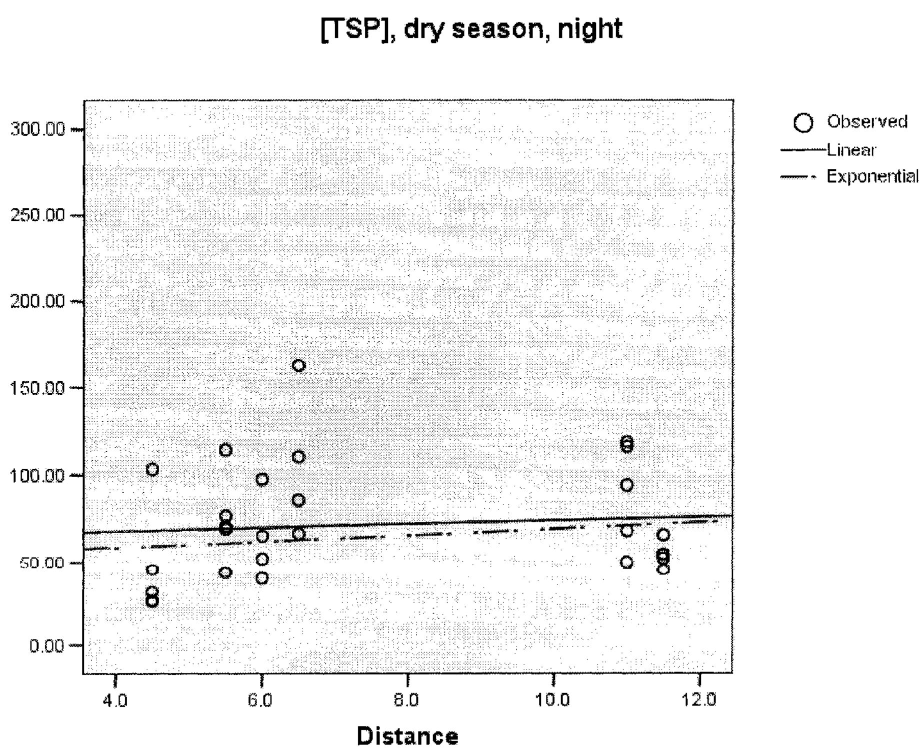

Fig. 3.19. Linear and exponential regressions of dry season night TSP concentrations vs. distance from the smelter. Linear r^2=0.008, p=0.659, Exponential r^2=0.029, p=0.390.

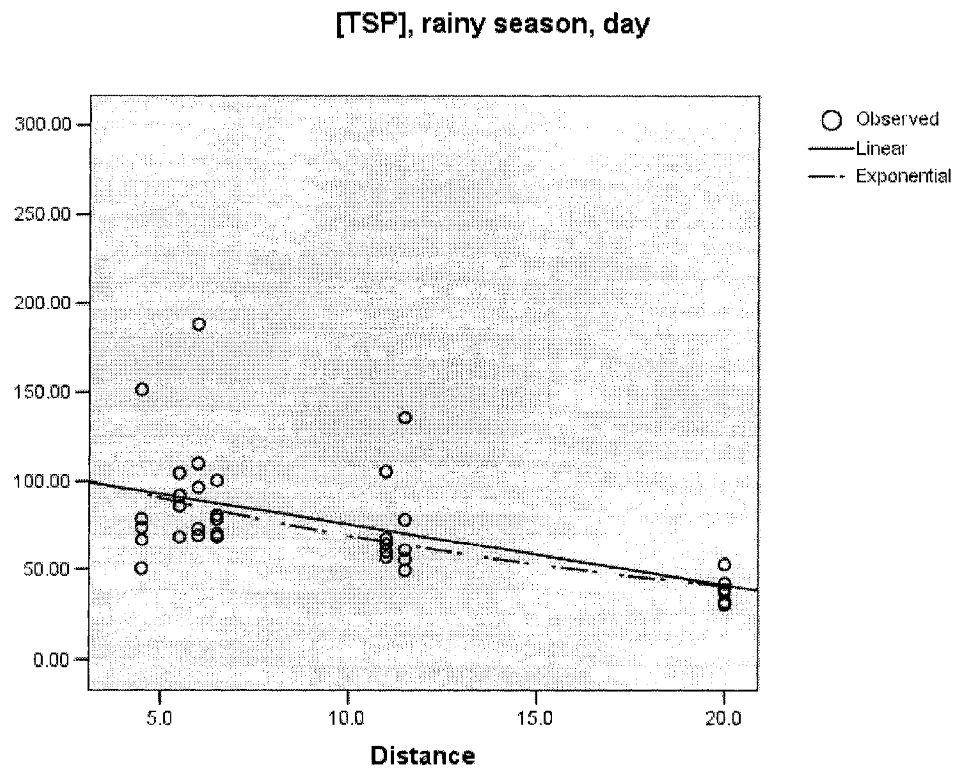

Fig. 3.20. Linear and exponential regressions of rainy season day TSP concentrations vs. distance from the smelter. Linear r^2=0.310, p=0.001, Exponential r^2=0.493, p=0.000.

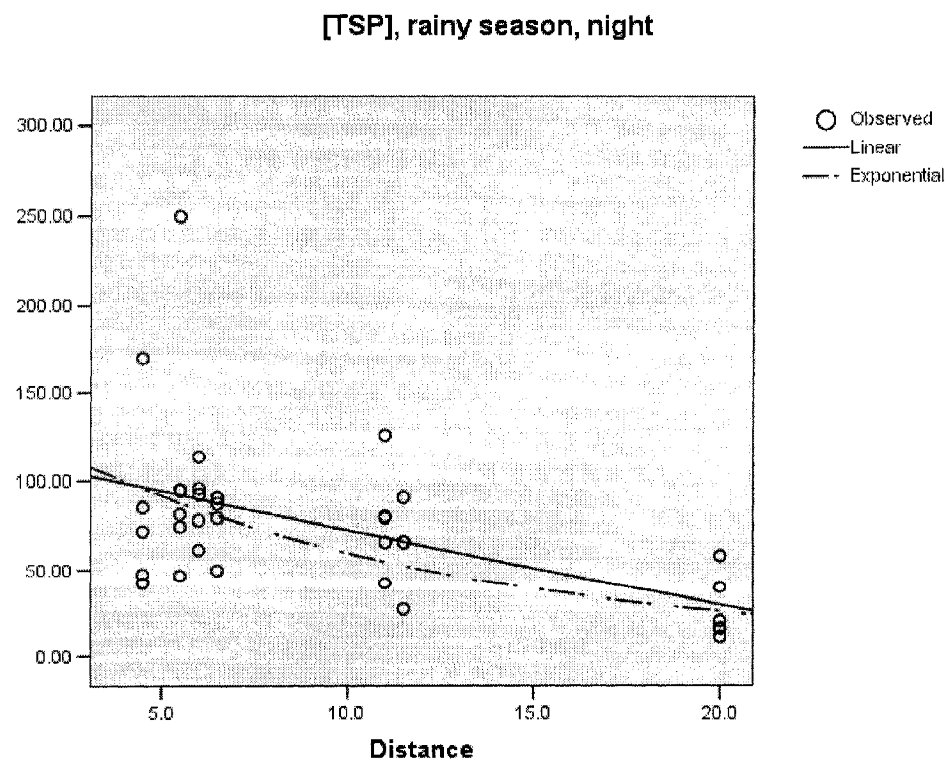

Fig. 3.21. Linear and exponential regressions of rainy season night TSP concentrations vs. distance from the smelter. Linear r^2=0.275, p=0.001, Exponential r^2=0.490, p=0.000.

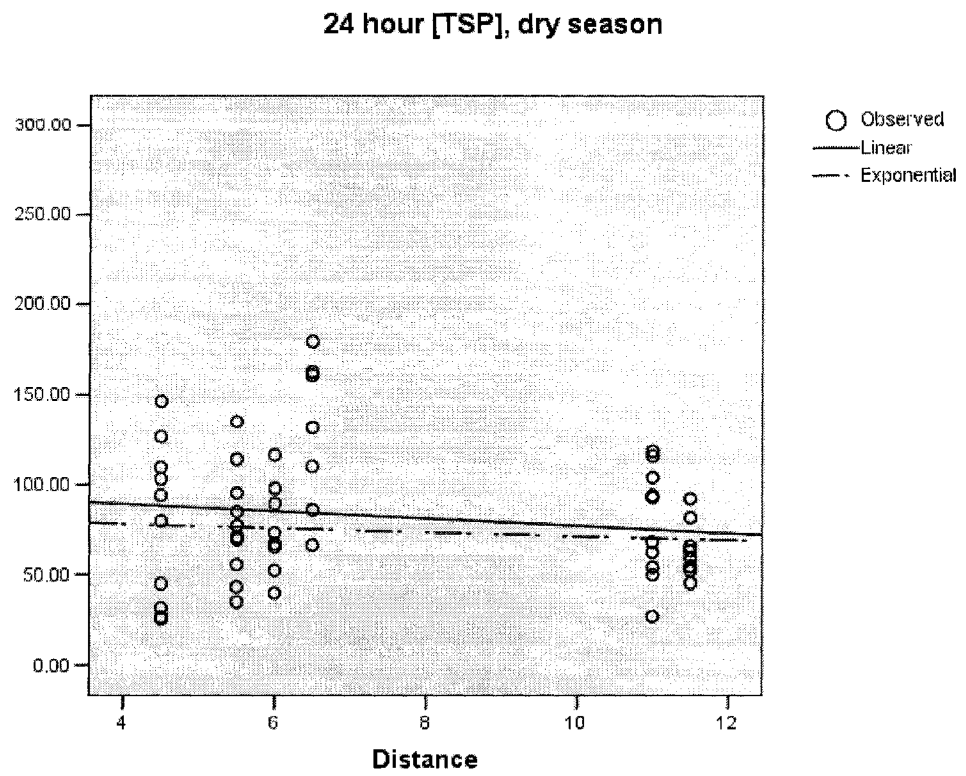

Fig. 3.22. Linear and exponential regressions of 24-hour dry season TSP concentrations vs. distance from the smelter. Linear $r^2=0.025$, $p=0.256$, Exponential $r^2=0.008$, $p=0.509$.

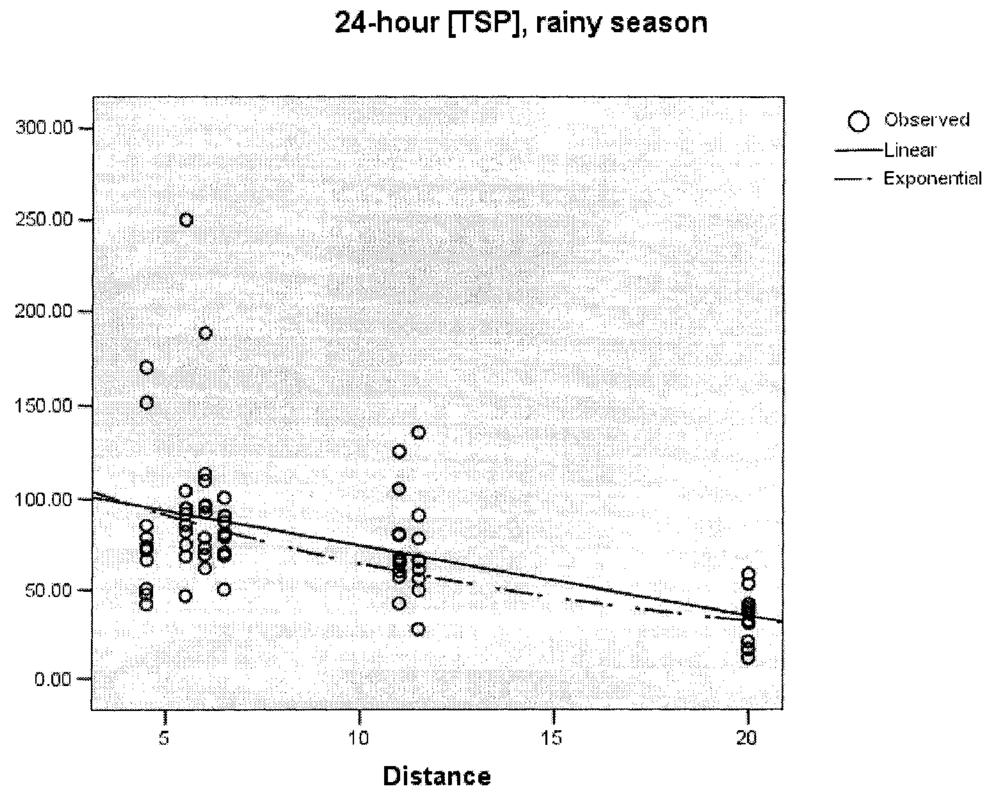

Fig. 3.23. Linear and exponential regressions of 24-hour rainy season TSP concentrations vs. distance from the smelter. Linear $r^2=0.283$, $p=0.000$, Exponential $r^2=0.459$, $p=0.000$.

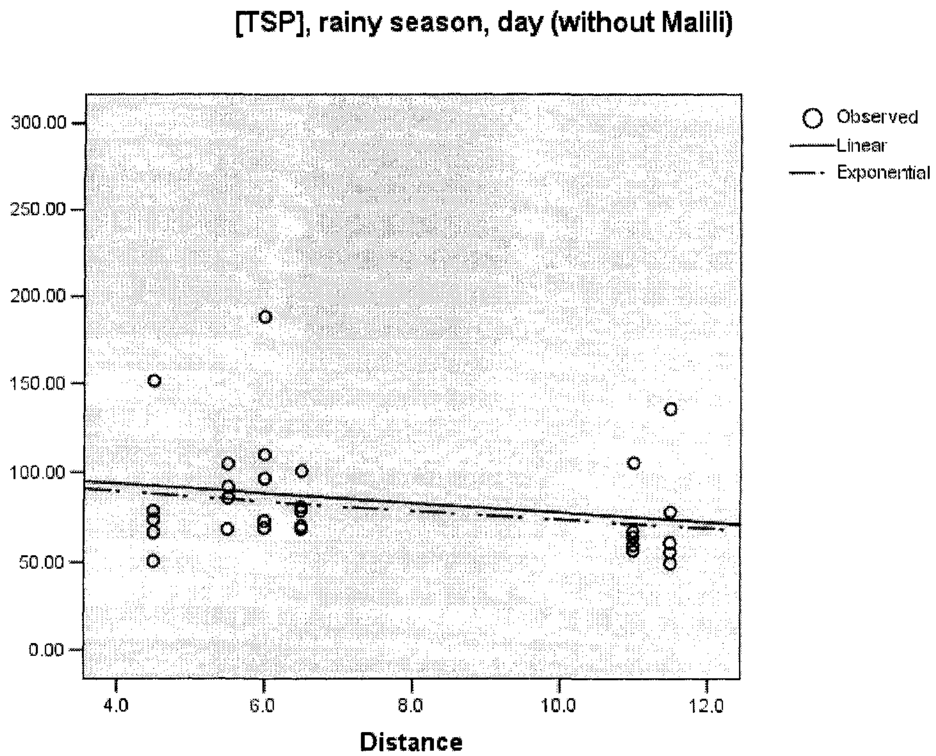

Fig. 3.24. Linear and exponential regressions of rainy season day TSP concentrations (without Malili) vs. distance from the smelter. Linear r^2=0.057, p=0.212, Exponential r^2=0.080, p=0.136.

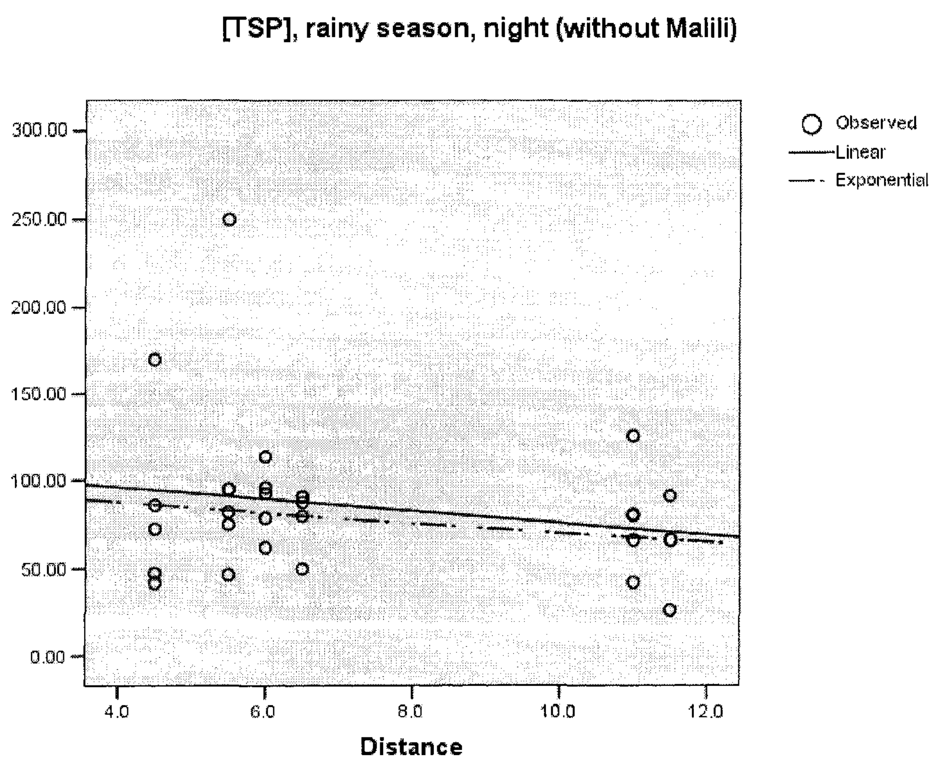

Fig. 3.25. Linear and exponential regressions of rainy season night TSP concentrations (without Malili) vs. distance from the smelter. Linear r^2=0.048, p=0.247, Exponential r^2=0.055, p=0.214.

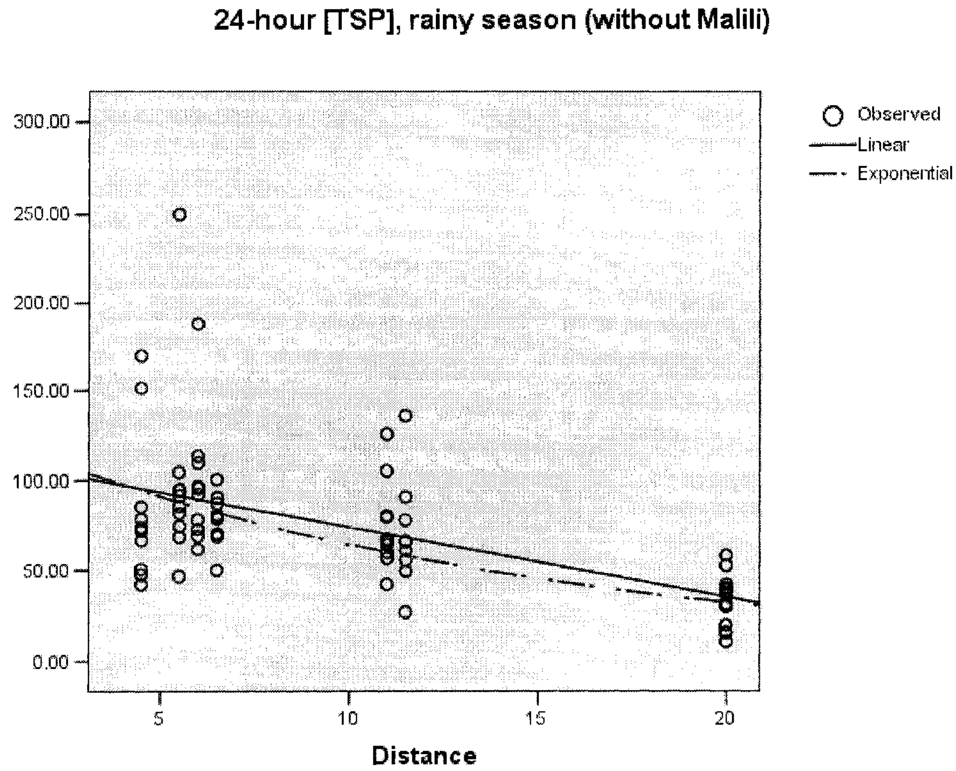

Fig. 3.26. Linear and exponential regressions of 24-hour rainy season TSP concentrations (without Malili) vs. distance from the smelter. Linear r^2=0.283, p=0.000, Exponential r^2=0.459, p=0.000.

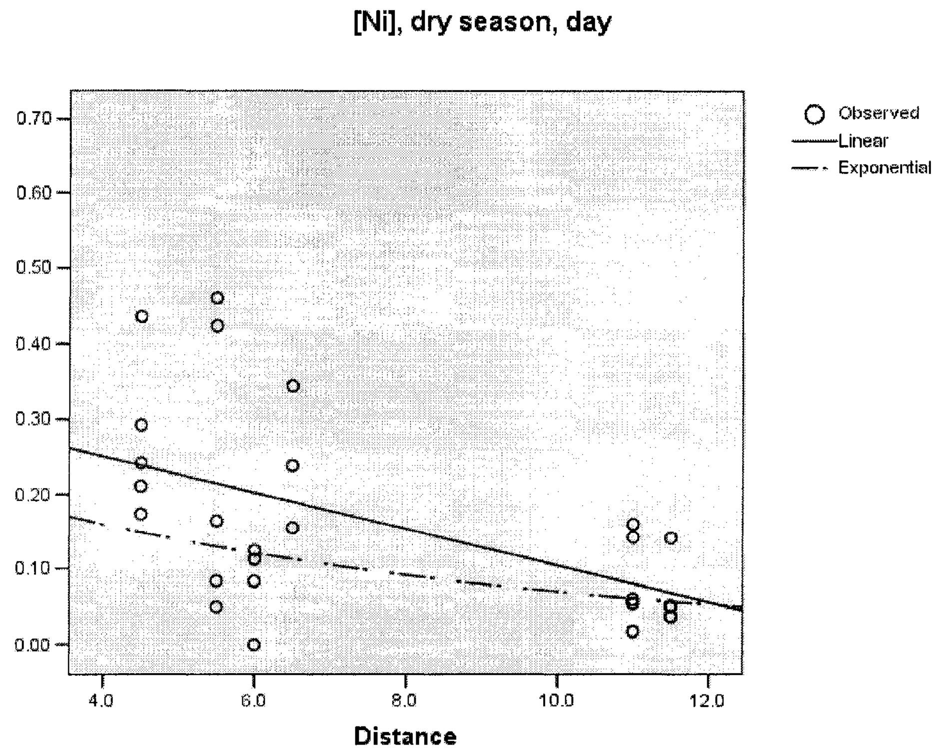

Fig. 3.27. Linear and exponential regressions of dry season day airborne nickel concentrations vs. distance from the smelter. Linear r^2=0.276, p=0.006, Exponential r^2=0.066, p=0.207.

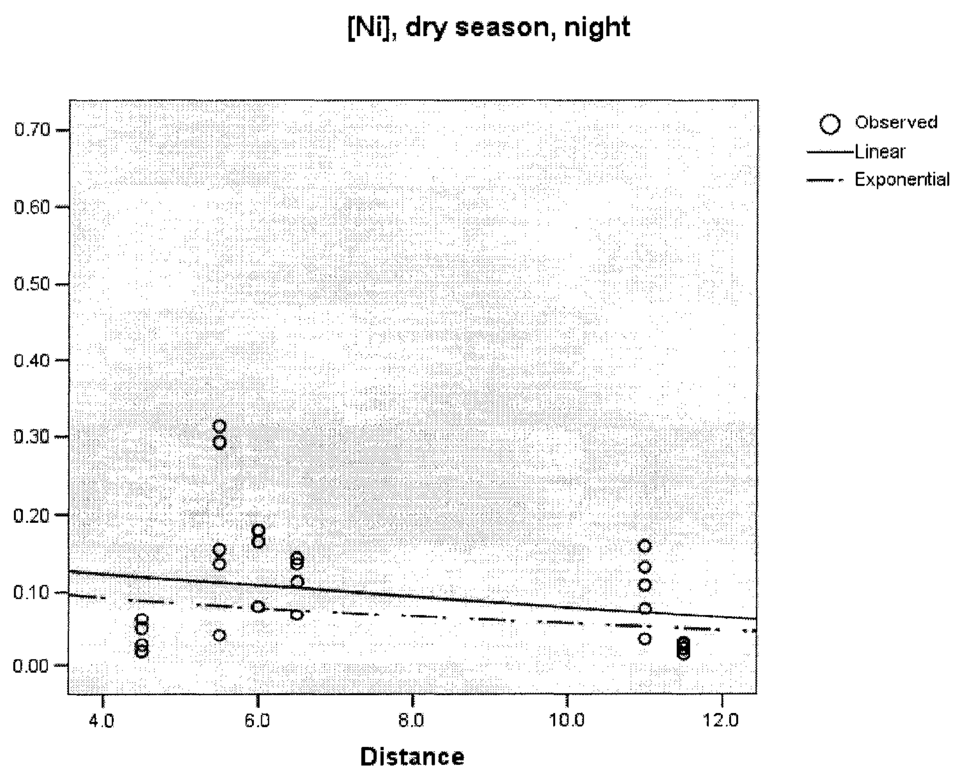

Fig. 3.28. Linear and exponential regressions of dry season night airborne nickel concentrations vs. distance from the smelter. Linear r^2=0.072, p=0.166, Exponential r^2=0.077, p=0.154.

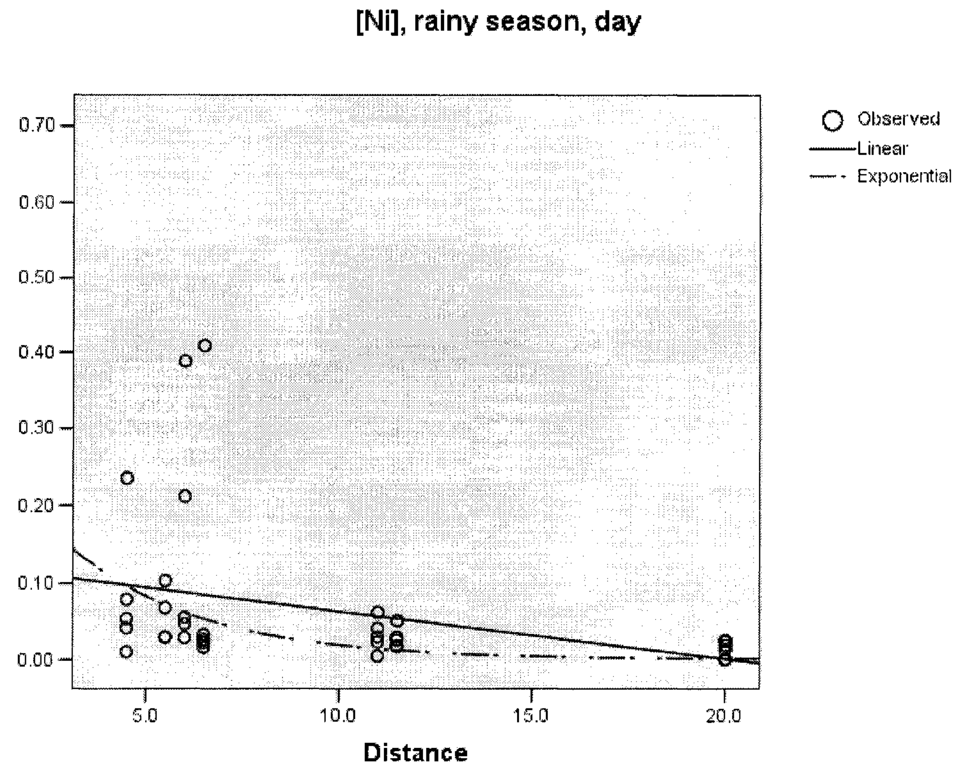

Fig. 3.29. Linear and exponential regressions of rainy season day airborne nickel concentrations vs. distance from the smelter. Linear r^2=0.122, p=0.040, Exponential r^2=0.303, p=0.001.

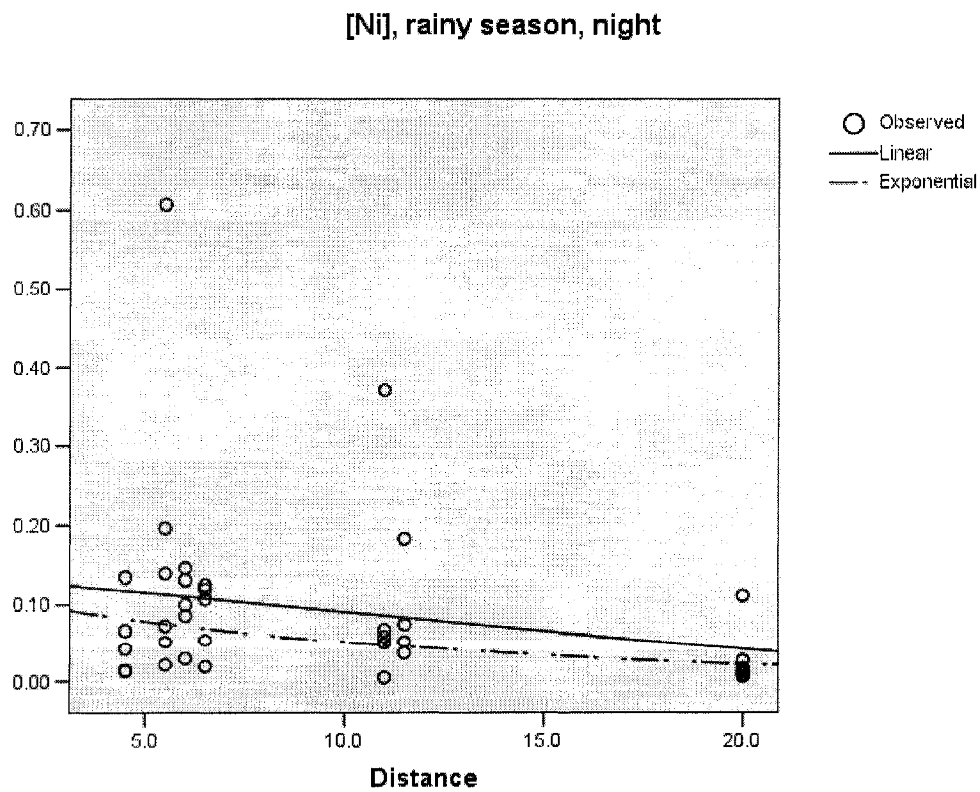

Fig. 3.30. Linear and exponential regressions of rainy season night airborne nickel concentrations vs. distance from the smelter. Linear r^2=0.054, p=0.172, Exponential r^2=0.168, p=0.013.

24-hour [Ni], dry season

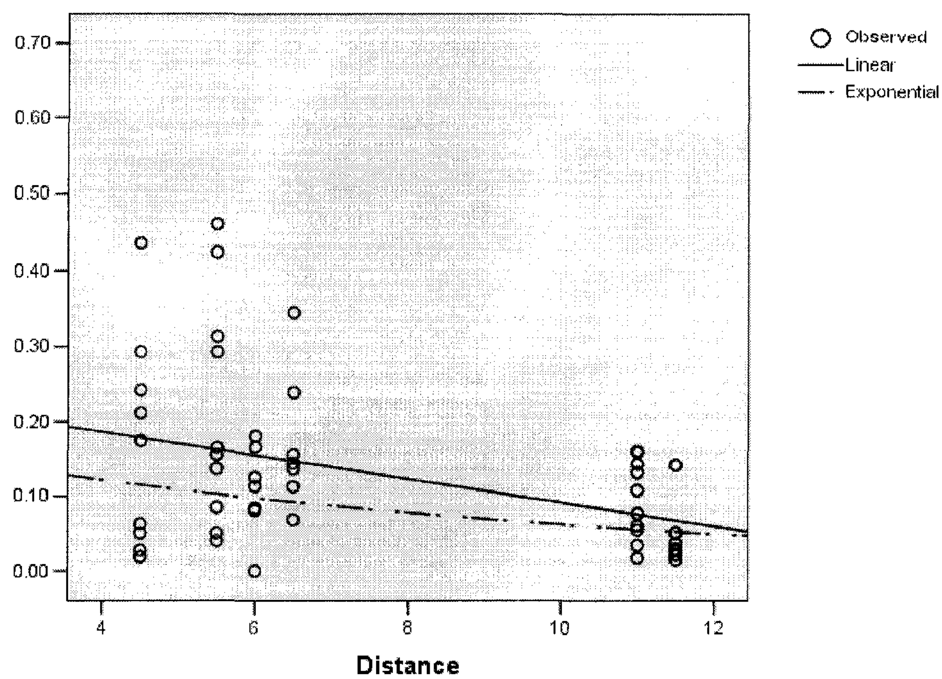

Fig. 3.31. Linear and exponential regressions of 24-hour dry season airborne nickel concentrations vs. distance from the smelter. Linear $r^2=0.158$, $p=0.003$, Exponential $r^2=0.065$, $p=0.063$.

24-hour [Ni], rainy season

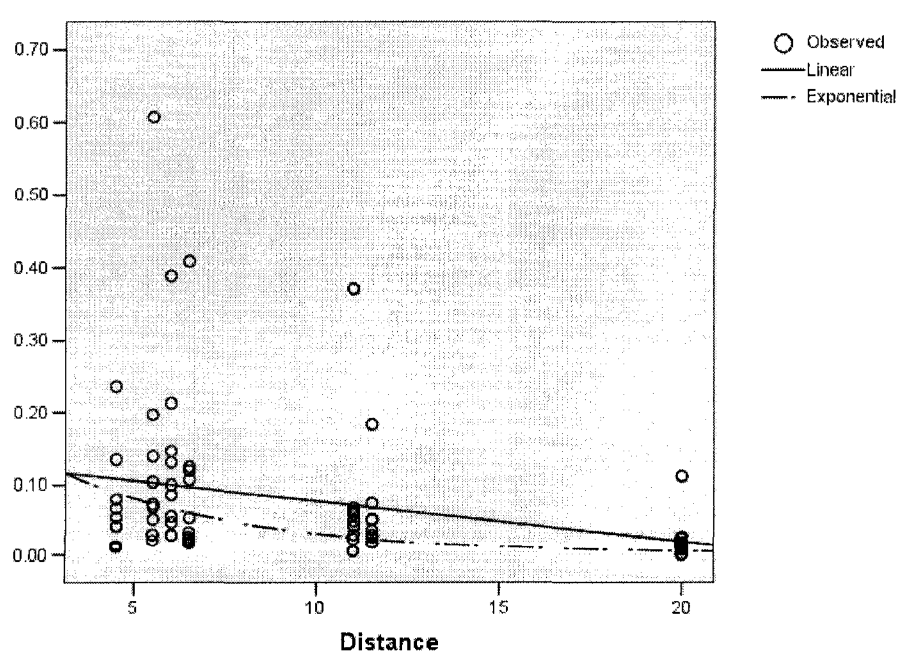

Fig. 3.32. Linear and exponential regressions of 24-hour rainy season airborne nickel concentrations vs. distance from the smelter. Linear $r^2=0.081$, $p=0.016$, Exponential $r^2=0.213$, $p=0.000$.

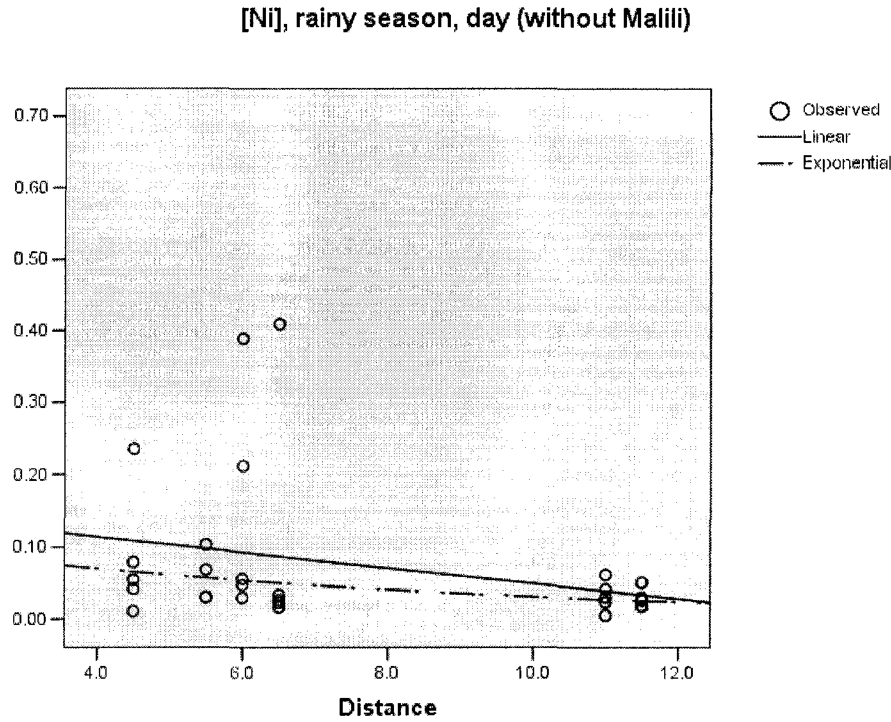

Fig. 3.33. Linear and exponential regressions of rainy season day airborne nickel concentrations (without Malili) vs. distance from the smelter. Linear $r^2=0.085$, $p=0.126$, Exponential $r^2=0.145$, $p=0.041$.

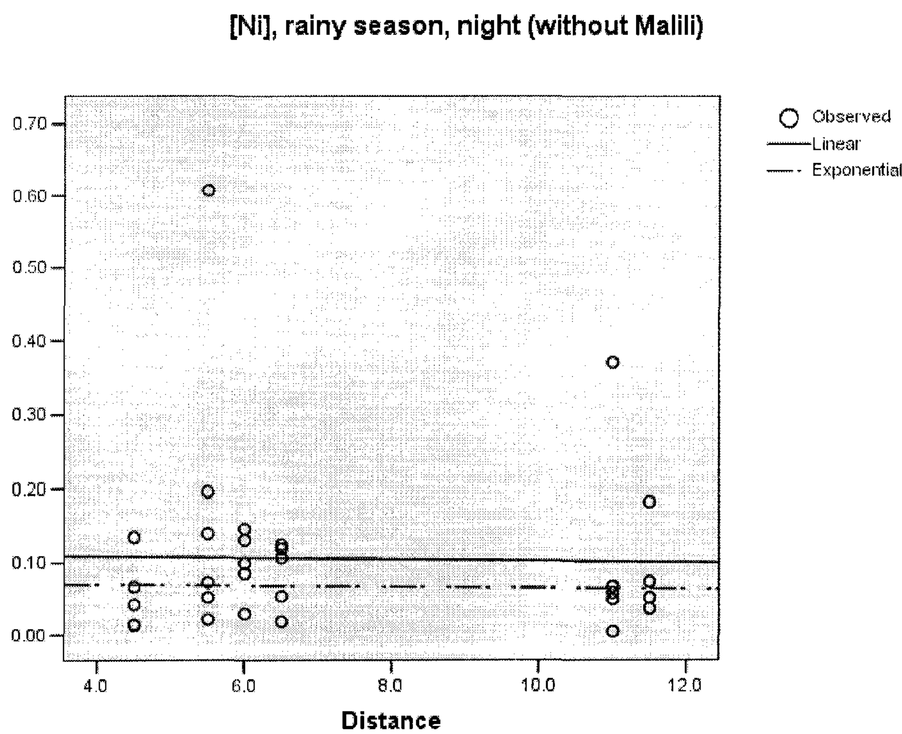

Fig. 3.34. Linear and exponential regressions of rainy season night airborne nickel concentrations (without Malili) vs. distance from the smelter. Linear $r^2=0.000$, $p=0.909$, Exponential $r^2=0.001$, $p=0.874$.

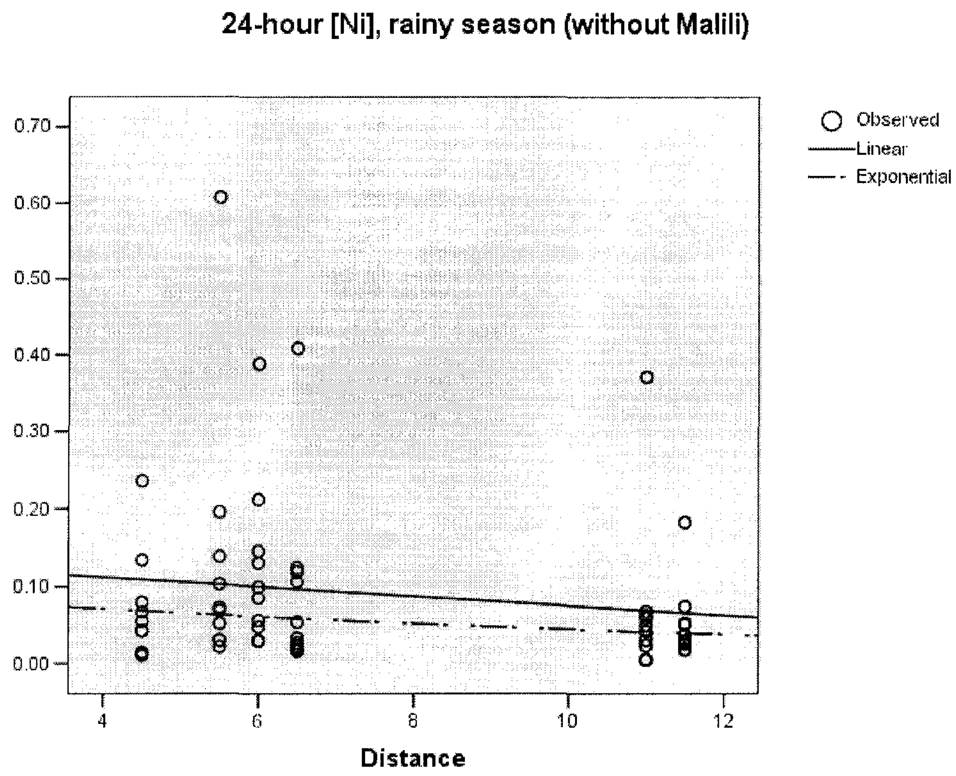

Fig. 3.35. Linear and exponential regressions of 24-hour rainy season airborne nickel concentrations (without Malili) vs. distance from the smelter. Linear r^2=0.081, p=0.016, Exponential r^2=0.213, p=0.000.

Pearson correlation analysis showed that TSP and various heavy metals were significantly positively correlated in some communities but not at all in other communities on a seasonal and diurnal basis (Tables 3.5 and 3.6).

In Desa Nikkel, where smelter fallout is carried with night prevailing winds, TSP was significantly positively correlated with Zn and Si in the dry and rainy season day sample but not in the dry season night sample when TSP was only significantly correlated with airborne Mn. In comparison with Desa Nikkel, TSP was also significantly correlated with airborne Mn in nearby Sorowako in the dry season night sample. TSP was also significantly correlated with airborne Si in Sorowako in the dry season night sample but not in Desa Nikkel.

TSP was significantly positively correlated with airborne Al, Cr, Cu, Fe, Mn, Ni, and Ti in the rainy season day samples in Desa Nikkel. But in contrast to Desa Nikkel, TSP was weakly negatively correlated with several airborne metals in Magani and Sorowako in the rainy season day samples.

TSP was significantly correlated with Al, Co, Cr, Cu, Fe, Mn, Ni, Si and Ti in Magani and TSP was significantly positively correlated with airborne Al, Co, Cr, Fe, Mn and Ni in Sorowako in the rainy season night samples.

In Wawondula, where the prevailing wind blows smelter fallout during the day, TSP was significantly positively correlated with airborne Ni, Co, Mn and Si in the dry and rainy season day samples in Wawondula but not in the dry season night samples. TSP was only significantly correlated with Si and Al in the rainy season night samples in Wawondula. A significant positive correlation between TSP and airborne Ni, Co, and Mn was also observed in the dry season day samples in Kampung Baru but not in the rainy season day samples.

In Wasuponda, located the furthest away from the smelter, TSP was significantly correlated only with Ti in the dry season night samples and Zn in the rainy season day samples.

Common strong inter-metal relationships were: Cr-Fe (21 pairs), Al-Ti (19), Cr-Mn (18), Co-Mn (18), Co-Ni (18), Cr-Ni (16), Cr-Ti (16), Fe-Mn (16), Fe-Ni (16), Mn-Ni (15), Co-Cr (15) and Co-Fe (15). Other common pairs were found but to a lesser degree among the communities. Cu and Zn were the metals generally not associated with other metals.

Table 3.5. Correlation matrices between mean day/night TSP and airborne metal concentrations in each community in 2004 dry season sample.

Magani Day	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.256	1								
Co	0.698	0.85	1							
Cr	0.385	0.98*	0.88	1						
Cu	-0.580	-0.79	-0.83	-0.89*	1					
Fe	0.416	0.98*	0.93*	0.98*	-0.84	1				
Mn	0.719	0.85	0.99**	0.90*	-0.90*	0.93*	1			
Ni	0.547	0.95*	0.97**	0.97**	-0.88	0.99**	0.97*	1		
Si	0.352	0.73	0.65	0.74	-0.47	0.73	0.64	0.73	1	
Ti	0.114	0.99*	0.77	0.95*	-0.74	0.95*	0.77	0.89*	0.69	1
Zn	0.516	0.87	0.83	0.94*	-0.87	0.88*	0.87	0.91*	0.84	0.82

Magani Night	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.30	1								
Co	-0.26	0.92*	1							
Cr	-0.30	0.94*	0.99**	1						
Cu	0.45	-0.15	-0.38	-0.43	1					
Fe	-0.33	0.96*	0.99**	1.00**	-0.39	1				
Mn	-0.31	0.94*	1.00**	1.00**	-0.41	1.00**	1			
Ni	-0.33	0.89*	0.99**	0.99**	-0.52	0.98*	0.99**	1		
Si	-0.60	0.92*	0.87	0.87	-0.20	0.90*	0.88*	0.84	1	
Ti	-0.24	0.98*	0.98**	0.98**	-0.26	0.99**	0.99*	0.96*	0.90*	1
Zn	-0.26	0.36	0.26	0.17	0.58	0.23	0.22	0.12	0.53	0.31

Sorowako Day	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.082	1								
Co	0.106	0.96**	1							
Cr	0.112	0.98**	0.90	1						
Cu	-0.541	-0.24	-0.38	-0.12	1					
Fe	0.121	1.00**	0.96	0.99*	-0.21	1				
Mn	0.086	0.98**	1.00	0.92	-0.35	0.97**	1			
Ni	0.114	0.99**	0.99*	0.96	-0.30	0.99**	0.99**	1		
Si	0.046	0.73	0.89	0.60	-0.56	0.72	0.86	0.81	1	
Ti	-0.049	0.98**	0.92	098*	-0.15	0.97**	0.94	0.96	0.66	1
Zn	-0.640	-0.09	-0.09	-0.16	-0.15	-0.16	-0.08	-0.12	0.02	0.66

Sorowako Night	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.67	1								
Co	0.92*	0.81	1							
Cr	0.67	0.99**	0.80	1						
Cu	-0.32	0.26	-0.34	0.26	1					
Fe	0.74	0.99**	0.83	1.00**	0.22	1				
Mn	0.90*	0.86	1.00**	0.85	-0.27	0.88	1			
Ni	0.88	0.94*	0.95*	0.94*	-0.03	0.96**	0.97*	1		
Si	0.95*	0.65	0.86	0.61	-0.27	0.68	0.84	0.81	1	
Ti	0.37	0.94*	0.58	0.92*	0.46	0.89*	0.65	0.76	0.38	1
Zn	0.63	0.77	0.54	0.81	0.49	0.83	0.58	0.76	0.55	0.65

Desa Nikkel Day	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.93	1								
Co	0.97*	0.91	1							
Cr	0.83	0.97*	0.85	1						
Cu	-0.01	-0.17	0.22	-0.10	1					
Fe	0.88	0.95	0.94	0.97*	0.12	1				
Mn	0.97*	0.95	0.99*	0.89	0.13	0.96*	1			
Ni	0.96*	0.87	1.00**	0.84	0.34	0.94	0.98*	1		
Si	0.98*	0.96*	0.99*	0.91	0.08	0.96*	1.00**	0.96*	1	
Ti	0.90	1.00**	0.90	0.99*	-0.13	0.97*	0.94	0.87	0.953*	1
Zn	0.96*	0.97*	0.98*	0.94	0.06	0.98*	0.99**	0.96*	1.00**	0.97*

Desa Nikkel Night	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.76	1								
Co	0.95	0.77	1							
Cr	0.63	0.40	0.82	1						
Cu	-0.17	-0.20	0.14	0.66	1					
Fe	0.83	0.58	0.95*	0.96*	0.42	1				
Mn	0.95*	0.82	1.00**	0.79	0.09	0.93	1			
Ni	0.76	0.40	0.88	0.97*	0.14	0.98*	0.84	1		
Si	0.60	0.96*	0.69	0.45	0.02	0.56	0.74	0.37	1	
Ti	0.69	0.98*	0.66	0.23	-0.35	0.44	0.72	0.24	0.93	1
Zn	0.09	-0.19	0.33	0.81	0.93	0.61	0.27	0.72	-0.05	-0.36

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Wawondula Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.75	1								
Co	1.00**	0.76	1							
Cr	0.94	0.93	0.95	1						
Cu	-0.88	-0.97*	-0.89	-0.99*	1					
Fe	0.92	0.95*	0.92	1.00**	-1.00**	1				
Mn	0.99**	0.82	1.00**	0.97	-0.93	0.96*	1			
Ni	0.98*	0.87	0.98*	0.99*	-0.96*	0.98*	1.00**	1		
Si	0.99*	0.64	0.99*	0.88	-0.80	0.85	0.96*	0.94	1	
Ti	0.74	1.00**	0.75	0.92	-0.97*	0.94	0.81	0.86	0.62	1
Zn	0.04	-0.63	0.03	-0.30	0.44	-0.36	-0.07	-0.16	0.20	-0.65

Kampung Baru Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.83	1								
Co	0.97**	0.93*	1							
Cr	0.87	0.98**	0.97**	1						
Cu	0.55	0.83	0.65	0.75	1					
Fe	0.86	0.99**	0.95*	1.00**	0.77	1				
Mn	0.95*	0.95*	1.00**	0.98*	0.71	0.97**	1			
Ni	0.95*	0.93*	0.99**	0.97**	0.60	0.96*	0.99*	1		
Si	0.61	0.21	0.53	0.35	0.01	0.29	0.49	0.49	1	
Ti	0.69	0.93*	0.77	0.85	0.90*	0.89	0.81	0.76	-0.06	1
Zn	0.74	0.97**	0.84	0.92*	0.94*	0.94*	0.88*	0.82	0.12	0.97**

Wasuponda Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.72	1								
Co	-0.44	-0.14	1							
Cr	-0.20	0.16	0.95*	1						
Cu	0.35	0.88	0.28	0.54	1					
Fe	-0.27	0.13	0.96*	1.00**	0.53	1				
Mn	-0.22	0.41	0.76	0.87	0.79	0.89	1			
Ni	-0.42	-0.17	1.00**	0.95	0.24	0.95*	0.73	1		
Si	0.34	0.61	0.66	0.84	0.78	0.81	0.77	0.65	1	
Ti	0.46	0.94	-0.07	0.21	0.93	0.20	0.56	-0.11	0.53	1
Zn	-0.64	-0.33	0.97*	0.86	0.14	0.89	0.70	0.97*	0.46	-0.20

Wawondula Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.48	1								
Co	-0.75	0.87	1							
Cr	-0.49	0.92	0.94	1						
Cu	-0.19	0.94	0.65	0.79	1					
Fe	-0.45	0.94	0.93	1.00**	0.82	1				
Mn	-0.64	0.96*	0.98*	0.97*	0.80	0.97*	1			
Ni	-0.72	0.90	1.00**	0.96*	0.70	0.95	0.99*	1		
Si	-0.70	0.96*	0.96*	0.93	0.81	0.93	0.99*	0.97*	1	
Ti	-0.34	0.98*	0.84	0.95*	0.94	0.97*	0.93	0.87	0.91	1
Zn	-0.44	0.90	0.65	0.67	0.92	0.69	0.77	0.68	0.84	0.82

Kampung Baru Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.28	1								
Co	-0.46	0.67	1							
Cr	0.24	0.76	0.96*	1						
Cu	-0.15	0.91*	0.80	0.91*	1					
Fe	0.19	0.70	0.92*	0.89*	0.91*	1				
Mn	0.33	0.79	0.98**	0.74	0.91*	0.91*	1			
Ni	0.49	0.51	0.95*	0.86	0.95*	0.95*	0.90*	1		
Si	0.12	0.909*	0.79	0.76	0.79	0.64	0.88	0.58	1	
Ti	-0.39	0.91*	0.40	0.45	0.66	0.36	0.56	0.15	0.84	1
Zn	0.62	0.23	0.83	0.76	0.80	0.74	0.07	0.91*	0.36	-0.07

Wasuponda Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.90	1								
Co	0.67	0.75	1							
Cr	0.89	0.99**	0.83	1						
Cu	0.80	0.48	0.31	0.46	1					
Fe	0.58	0.61	0.95	0.69	0.24	1				
Mn	0.82	0.85	0.94	0.91	0.53	0.79	1			
Ni	0.43	0.62	0.94	0.70	-0.03	0.93	0.78	1		
Si	0.67	0.81	0.98*	0.88	0.26	0.89	0.95	0.93	1	
Ti	0.95*	0.98*	0.66	0.96*	0.63	0.51	0.82	0.47	0.71	1
Zn	-0.05	-0.23	0.34	-0.15	0.03	0.59	0.08	0.39	0.18	-0.27

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 3.6. Correlation matrices between mean day/night TSP and airborne metal concentrations in each community in the 2004/5 rainy season sample.

Magani Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.326	1								
Co	-0.424	0.991**	1							
Cr	-0.284	0.998**	0.988**	1						
Cu	-0.380	-0.033	-0.063	-0.087	1					
Fe	-0.312	0.998**	0.992**	0.999**	-0.089	1				
Mn	-0.451	0.986**	0.998**	0.982**	-0.052	0.986**	1			
Ni	-0.396	0.995**	0.999**	0.993**	-0.055	0.995**	0.997**	1		
Si	-0.676	0.522	0.621	0.518	-0.281	0.556	0.617	0.586	1	
Ti	-0.225	0.986*	0.965**	0.987**	-0.050	0.988**	0.951*	0.970**	0.497	1
Zn	-0.597	0.837	0.877	0.829	-0.048	0.828	0.902*	0.874	0.560	0.735

Magani Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.932*	1								
Co	0.946*	0.994**	1							
Cr	0.935*	0.999**	0.995**	1						
Cu	-0.925*	-0.988**	-0.971**	-0.988**	1					
Fe	0.939*	0.998**	0.999**	0.998**	-0.979**	1				
Mn	0.947*	0.994**	1.000**	0.995**	-0.970**	0.999**	1			
Ni	0.925*	0.966**	0.987**	0.973**	-0.931*	0.981**	0.987**	1		
Si	0.899*	0.986**	0.989**	0.990**	-0.965**	0.990**	0.989**	0.986**	1	
Ti	0.934*	0.994**	0.982**	0.989**	-0.985**	0.988**	0.982**	0.939*	0.962**	1
Zn	0.820	0.686	0.757	0.707	-0.638	0.728	0.758	0.828	0.730	0.641

Sorowako Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.333	1								
Co	-0.781	0.666	1							
Cr	-0.774	0.739	0.994**	1						
Cu	-0.328	-0.062	0.598	0.509	1					
Fe	-0.898	0.554	0.975*	0.963*	0.567	1				
Mn	-0.750	0.675	0.999**	0.992**	0.612	0.963*	1			
Ni	-0.934	0.361	0.912	0.882	0.624	0.976*	0.895	1		
Si	-0.729	0.861	0.940	0.972*	0.301	0.900	0.937	0.784	1	
Ti	-0.409	0.980*	0.786	0.841	0.139	0.672	0.798	0.493	0.920	1
Zn	-0.077	-0.439	0.241	0.134	0.918	0.237	0.255	0.353	-0.097	-0.252

Sorowako Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.913*	1								
Co	0.904*	0.995**	1							
Cr	0.907*	0.998**	0.991**	1						
Cu	0.385	0.479	0.431	0.524	1					
Fe	0.897*	0.996**	0.988**	1.000**	0.546	1				
Mn	0.854*	0.982*	0.972**	0.988**	0.616	0.991**	1			
Ni	0.889*	0.995**	0.990**	0.999**	0.546	0.999**	0.993**	1		
Si	0.800	0.953*	0.956**	0.955**	0.581	0.959**	0.982**	0.967**	1	
Ti	0.802	0.952**	0.933**	0.963**	0.694	0.971**	0.991**	0.971*	0.969*	1
Zn	0.616	0.611	0.567	0.645	0.943**	0.659	0.709	0.656	0.672	0.756

Desa Nikkel Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.938*	1								
Co	-0.258	-0.001	1							
Cr	0.893*	0.983**	0.123	1						
Cu	0.889*	0.870	-0.452	0.806	1					
Fe	0.882*	0.972**	0.163	0.998**	0.774	1				
Mn	0.952*	0.883*	-0.434	0.838	0.966**	0.818	1			
Ni	0.957*	0.978**	-0.028	0.981**	0.848	0.978**	0.909*	1		
Si	0.916*	0.982**	0.086	0.997**	0.812	0.997**	0.860	0.991**	1	
Ti	0.911*	0.949*	0.067	0.979**	0.784	0.984*	0.863	0.989**	0.989**	1
Zn	0.937*	0.852	-0.494	0.800	0.968**	0.777	0.998**	0.878*	0.822	0.826

Desa Nikkel Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.072	1								
Co	0.575	0.548	1							
Cr	-0.492	0.805	0.081	1						
Cu	-0.489	0.424	-0.522	0.711	1					
Fe	-0.160	0.905*	0.223	0.929*	0.689	1				
Mn	-0.768	0.152	-0.725	0.615	0.920*	0.460	1			
Ni	-0.183	0.807	0.656	0.720	0.068	0.644	-0.014	1		
Si	0.210	0.636	0.404	0.277	0.185	0.344	-0.009	0.483	1	
Ti	-0.180	0.963**	0.373	0.896*	0.557	0.908*	0.360	0.825	0.646	1
Zn	-0.752	0.102	-0.763	0.573	0.914*	0.426	0.998**	-0.078	-0.058	0.305

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Wawondula Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.868	1								
Co	0.932*	0.977**	1							
Cr	0.872	0.964**	0.985**	1						
Cu	-0.100	0.236	0.068	0.134	1					
Fe	0.920*	0.977**	0.999**	0.989**	0.069	1				
Mn	0.938*	0.972**	1.000**	0.982**	0.045	0.999**	1			
Ni	0.919*	0.973**	0.999**	0.991**	0.059	1.000	0.998**	1		
Si	0.912*	0.980**	0.999**	0.990**	0.084	1.000	0.997**	0.999**	1	
Ti	0.851	0.999**	0.975**	0.969**	0.232	0.978**	0.970**	0.974**	0.981**	1
Zn	0.646	0.278	0.456	0.377	-0.814	0.447	0.478	0.455	0.429	0.269

Kampung Baru Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.313	1								
Co	-0.106	-0.068	1							
Cr	-0.131	0.286	0.927*	1						
Cu	-0.236	-0.385	-0.495	-0.707	1					
Fe	-0.035	0.803	0.346	0.669	-0.853	1				
Mn	-0.327	0.587	0.681	0.886*	-0.800	0.868	1			
Ni	-0.228	0.924*	-0.204	0.170	-0.518	0.817	0.565	1		
Si	0.072	0.732	0.444	0.684	-0.551	0.807	0.670	0.531	1	
Ti	-0.248	0.135	0.972**	0.956*	-0.475	0.451	0.764	-0.048	0.575	1
Zn	-0.035	0.436	-0.723	-0.475	-0.162	0.267	-0.041	0.703	-0.171	-0.674

Wasuponda Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.276	1								
Co	0.354	0.526	1							
Cr	0.249	0.495	0.987**	1						
Cu	0.264	0.437	-0.101	-0.243	1					
Fe	0.430	0.469	0.996**	0.978**	-0.095	1				
Mn	0.247	0.654	0.987**	0.974**	-0.027	0.972**	1			
Ni	0.329	0.561	0.998**	0.982**	-0.074	0.990**	0.992**	1		
Si	0.036	0.766	0.899*	0.886*	0.030	0.858	0.942*	0.923*	1	
Ti	-0.112	0.811	0.861	0.881*	-0.056	0.821	0.923*	0.872	0.917*	1
Zn	0.963**	-0.227	0.460	0.360	0.188	0.522	0.350	0.444	0.195	-0.031

Malili Day

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.17	1								
Co	0.46	0.92**	1							
Cr	0.41	0.94**	1.00**	1						
Cu	-0.38	0.79	0.59	0.62	1					
Fe	0.32	0.94**	0.98**	0.99**	0.67	1				
Mn	0.42	0.94**	1.00**	1.00**	0.63	0.99**	1			
Ni	0.47	0.93**	0.94**	0.95**	0.51	0.92*	0.95**	1		
Si	0.21	0.98**	0.91*	0.93**	0.69	0.93**	0.92**	0.96**	1	
Ti	0.19	1.00*	0.94**	0.96**	0.78	0.96**	0.96**	0.94**	0.98**	1
Zn	0.43	0.49	0.89*	0.89*	0.49	0.94**	0.89*	0.71	0.60	0.49

Wawondula Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.950*	1								
Co	0.624	0.767	1							
Cr	0.530	0.681	0.984**	1						
Cu	0.354	0.087	-0.452	-0.556	1					
Fe	0.654	0.793	0.999**	0.980**	-0.429	1				
Mn	0.655	0.780	0.989**	0.988**	-0.433	0.991**	1			
Ni	0.666	0.776	0.992**	0.981**	-0.387	0.992**	0.994**	1		
Si	0.898*	0.925*	0.851	0.821	-0.045	0.871	0.898*	0.890*	1	
Ti	0.814	0.912*	0.729	0.705	-0.140	0.758	0.781	0.735	0.902*	1
Zn	0.632	0.364	-0.097	-0.184	0.904*	-0.072	-0.049	-0.004	0.339	0.153

Kampung Baru Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.692	1								
Co	0.803	0.982**	1							
Cr	0.838	0.962**	0.977**	1						
Cu	0.033	0.042	0.098	-0.091	1					
Fe	0.819	0.959*	0.966**	0.998**	-0.143	1				
Mn	0.793	0.984**	0.998**	0.982**	0.043	0.974**	1			
Ni	0.815	0.958*	0.966**	0.998**	-0.154	0.999**	0.975**	1		
Si	0.318	0.748	0.732	0.577	0.593	0.548	0.713	0.549	1	
Ti	0.833	0.964**	0.975**	0.986**	0.020	0.981**	0.971**	0.975**	0.616	1
Zn	0.734	0.911*	0.899*	0.961**	-0.347	0.974**	0.920*	0.978**	0.430	0.915*

Wasuponda Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	0.619	1								
Co	0.662	0.530	1							
Cr	-0.091	0.209	0.679	1						
Cu	-0.064	0.172	-0.706	-0.803	1					
Fe	0.071	0.399	0.769	0.979*	-0.737	1				
Mn	0.869	0.537	0.938	0.383	-0.531	0.501	1			
Ni	0.196	0.454	0.844	0.954*	-0.748	0.992**	0.607	1		
Si	-0.290	-0.695	0.218	0.457	-0.827	0.302	0.093	0.281	1	
Ti	0.737	0.181	0.858	0.355	-0.696	0.407	0.927	0.507	0.419	1
Zn	0.196	0.750	0.668	0.783	-0.342	0.879	0.450	0.878	-0.188	0.191

Malili Night

	TSP	Al	Co	Cr	Cu	Fe	Mn	Ni	Si	Ti
TSP	1									
Al	-0.06	1								
Co	0.93**	0.09	1							
Cr	0.93**	0.15	1.00**	1						
Cu	-0.82	0.60	-0.70	-0.66	1					
Fe	0.94**	0.11	0.99**	0.99**	-0.71	1				
Mn	0.94**	0.08	1.00**	1.00**	-0.71	0.99**	1			
Ni	0.92*	0.09	1.00**	0.99**	-0.69	0.98**	1.00**	1		
Si	-0.06	0.86*	0.06	0.12	0.43	0.11	0.06	0.05	1	
Ti	0.15	0.96**	-0.26	0.32	0.44	0.27	0.25	0.25	0.75	1
Zn	0.60	0.26	0.60	0.77	-0.37	0.83*	0.60	0.60	0.26	0.54

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

3.3.3. Domestic 24-hour Dust Fall Accumulation

Mean domestic 24-hour dust fall accumulation was significantly higher in Kampung Baru than in other communities (Kruskall-Wallis, $p<0.001$, $F(1,7) = 46.655$). Slightly lower levels of dust fall were recorded in Sorowako, Magani, Malili, and in the homes over Lake Matano, and at slightly higher levels in Wasuponda, Wawondula and Desa Nikkel (Table 3.7; Fig. 3.36). No significant correlation was observed between seasonal day and night mean TSP concentrations and 24-hour dust fall accumulation. Large standard deviations may be caused by different people performing the swipe and by specific environmental conditions at the house sampled. The standard deviation for Kampung Baru may have resulted from the small sampling number and by one household in that community recording a much larger dust fall accumulation rate than the other households. Desa Nikkel also has a relatively higher standard deviation that may be caused by one much larger dust fall accumulation rate than the other households sampled in that community.

Table 3.7. Mean and standard deviation domestic 24-hour dust fall accumulation at the study site ($mg/m^2/day$).

Community	Mean	SD	Max.
Magani, N=15	36.9	25.88	76.33
Sorowako, N=18	64.2	71.90	303.94
Lake Matano, N=18	42.1	30.23	63.26
Desa Nikkel, N=19	146.6	357.40	1596.83
Wawondula, N=14	150.3	156.97	340.0
Kampung Baru, N=7	502.9	530.95	1436.75
Wasuponda, N=19	133.6	137.34	503.53
Malili, N=18	17.5	12.38	40.89

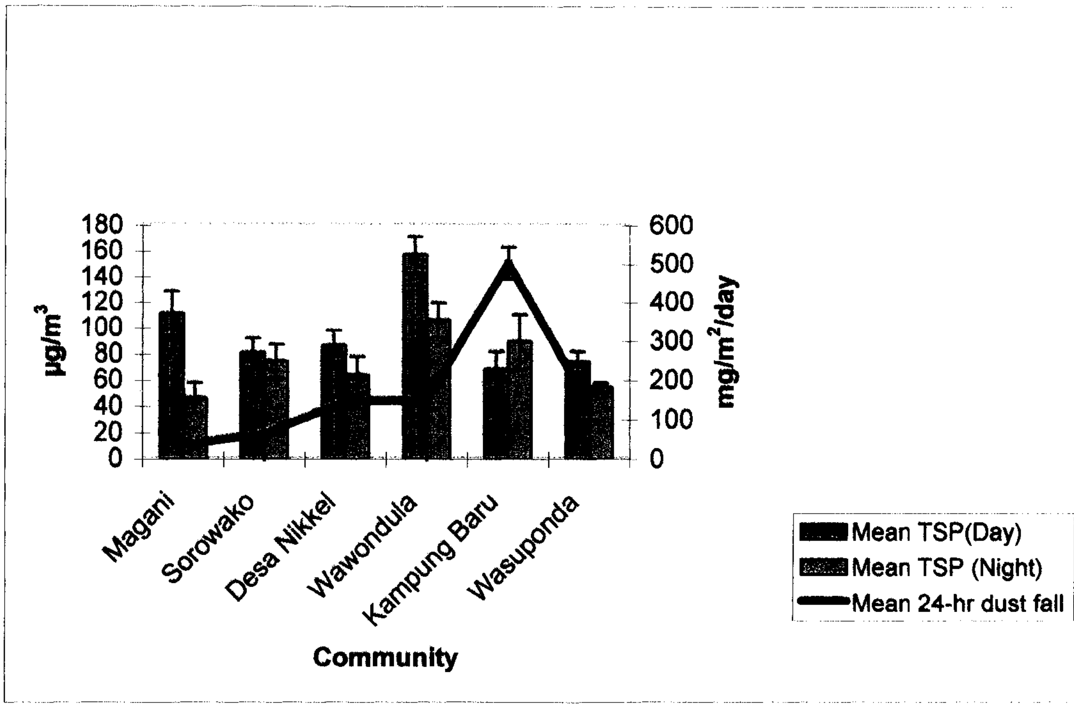

Fig. 3.36. Mean TSP and mean domestic 24-hour dust fall accumulation in 2004 dry season samples.

3.4. Discussion

3.4.1. Spatial and Temporal Variations of TSP and Airborne Metals

TSP and airborne metals distributions were affected by spatial and temporal factors. These factors affect each metal differently due to combined effects of physiochemical properties of metals and environmental conditions (Lee et al., 1994). ANOVA statistical analysis showed that seasonal and diurnal variations were significant among communities.

A small significant regression between TSP values in the day and night rainy season samples was found with distance from the smelter. A small significant regression between Ni concentrations in the day of the dry and rainy season was also found. This indicates that the air in the rainy season may contain more dust from the smelter or re-suspended road dust that also contains nickel and that dust in the dry season may contain other localized sources.

Magani is located immediately Northwest of the smelter in the direction that prevailing winds blow smelter fallout over the community during the night. Wawondula is located immediately Southeast of the smelter and is downwind from the smelter in the day. Mean TSP levels significantly higher in the day than night in Magani and Wawondula in the dry season may be due to the close proximity of Wawondula to the smelter. However, since Magani is located in the opposite direction of prevailing day winds then relatively higher TSP levels in the day could be due to another reason like road dust. In Magani, daytime TSP and airborne nickel concentrations were not significantly correlated like they were in Wawondula, which further suggest another source besides the smelter.

Mean TSP levels during the rainy season were mostly lower than those of the dry season and had less variation between day and night. More rainfall in these months could have dampened roads and reduced road dust, and caused fallout from the smelter to be more localized through the scouring of PM and metals by the rainfall (*c.f.* Browne et al., 1999). Research in Indonesia by Browne et al. (1999) has also shown that TSP levels decrease in the rainy season in Indonesia.

Morodemak, a rural village in Central Java, Indonesia, similar to Sorowako, recorded 90.1 $\mu g/m^3$ as the mean 24-hour TSP value in the dry season (Browne et al., 1999). Comparing this value to the rural communities around the nickel mines and smelter in this study, similar mean TSP values were noted between the low rainy season night mean

TSP value of 72.96 μg/m^3 to the high dry season day mean TSP value of 96.62 μg/m^3. However, in Malili, located 20 km from the smelter and outside the smelter's expected fallout zone, mean TSP values recorded in the rainy season were much lower at 38.58 μg/m^3 in the day and 26.92 μg/m^3 at night. Rural areas tend to have lower TSP levels compared to urban areas in Indonesia that tend to range from 115.5 to 165.8 μg/m^3 where high traffic and leaded gasoline are major sources of TSP (Browne et al., 1999). Urban ambient air pollution in Jakarta, Indonesia has been measured at ranging from 181 to 500 μg/m^3 (Browne et al., 1999; World Bank, 1994).

According to PT Inco, of the 12 stacks in operation, almost all comply with air quality guidelines since the installation of cleaning technologies. For example, electrostatic precipitators (ESPs) installed on the dryers and kilns over a period from 1997 to 2003 reduced air pollution from the smelter. The first furnace stack was equipped in 2005 with the recently developed "bag house hoe-ram" technology and for the first time has met Indonesian air quality guidelines, but the other furnace stacks have not yet been equipped with such cleaning technologies and thus do not comply with guidelines. PT Inco plans to install the cleaning technology on the other furnace stacks in phases (P. Sampetoding, Pers. Comm., 2004; D. Tetradiono, Pers. Comm., 2005). PT Inco's air quality monitoring data was requested but was not forthcoming.

Airborne Ni was higher during the dry season in most communities except in Desa Nikkel (Figs. 3.12-3.13), thus indicating that airborne Ni in these communities may originate from a common source or sources such as the smelter and the re-suspension of nickel deposited onto roads. The slight significant regression between airborne Ni in the day during the day of the dry season with distance from the smelter also reveals that the smelter may be more of a dominant source at this time. Seasonal differences seen in PM and associated metal deposition could have resulted from scouring of particles by rain (*c.f.* Browne et al., 1999) and thus lower levels of Ni.

Pearson correlation analysis wass sed to attempt to differentiate sources, and seasonal and diurnal trends with respect to the levels of TSP and certain metals. Magani, Sorowako and Desa Nikkel, communities adjacent to each other and at similar distances NW from the smelter, showed varying correlations between TSP and metals between seasons, and day and night. This indicates potential localized sources of TSP in each of these communities. In the dry season day samples, only in Desa Nikkel was TSP significantly positively correlated with more than one or two metals; airborne Ni, Co, Mn, Si and Zn. TSP was also significantly positively correlated with airborne Mn in the dry season night samples in Desa Nikkel and Sorowako, and with airborne Si in Sorowako. Based on the smelter fallout and ore composition, and the positive correlations found between TSP and several airborne metals in the day-time for one or both of the seasons, a combination of smelter fallout and road dust seem to be contributing to ambient air pollution in Desa Nikkel. The lack of correlation between TSP and airborne Ti and Si in the day and the presence of a significant positive correlation between TSP and airborne Si in the night in Sorowako was not expected since road dust was expected to be a major source of TSP in the day of the dry season because of higher traffic on dirt roads. There is also evidence of another source of airborne pollution in Magani and Sorowako where airborne Cu was more prevalent in the dry season night samples. Since Cu is not a major component in the smelter fallout or the ore, another local source besides road dust is expected.

More metals were correlated with TSP in the rainy season than in the dry season in all these communities. Desa Nikkel again recorded similar correlations between TSP and airborne metals in the rainy season day samples as in the dry season day samples. However, in the rainy season night samples, TSP was significantly correlated with airborne Ni, Co, Cr, Al, Fe, and Mn in only Magani and Sorowako, but with no metals in Desa Nikkel. This indicates a possible common source of TSP in Magani and Sorowako. Though the metals found in TSP in these two communities are associated with both smelter fallout and road dust, the correlation occurring at night is more consistent with smelter fallout.

In Wawondula and Kampung Baru, communities downwind of the smelter during the day, mean TSP in the dry season was strongly correlated with Ni, Co and Mn in the daytime but not in the dry season night samples. Since these elements are released from the smelter and were correlated with TSP only in the day when smelter fallout is expected in these communities, smelter fallout is a likely source of TSP. Daytime TSP was also correlated with Si in Wawondula but not in Kampung Baru, suggesting that road dust may a factor in the daytime TSP levels in Wawondula. In the rainy season day samples, TSP was significantly positively correlated with airborne Ni, Co, Fe, Mn, and Si in Wawondula. In the rainy season night sample, TSP was significantly positively correlated with airborne Al and Si in Wawondula. Meanwhile, TSP was not significantly positively correlated with any metals in the rainy season day and night samples in Kampung Baru. Since Wawondula is located closer to the smelter, it is possible that the smelter fallout being more localized in the rainy season is having an effect on TSP levels in the day in

Wawondula but not in Kampung Baru as seen in the TSP and airborne metals correlations. The sawmills are also a likely dominant source of dust in Kampung Baru.

Wasuponda recorded fewer correlations between TSP and metals associated with the smelter, which was expected since this community is located the furthest away from the smelter.

Common strong inter-metal relationships such as Ni-Co and Ni-Cr in most communities revealed a potential common source among communities. Other unique strong inter-metal relationships also found in some communities reveal local sources of metals. Ni, Co and Cr are all elements released from the smelter that eventually deposit onto surfaces. In the case of roads, dust and heavy metals that originated from the smelter can become re-suspended. The inter-metal relationships also varied between seasons and time of day. Desa Nikkel recorded significant relationships between Ni-Co and Ni-Cr in both the day and night of the dry season but only recorded a significant relationship between Ni and Co in the day of the rainy season. Aluminum was also found in much higher percentages of the TSP in Malili, which further suggest that smelter fallout affects metal composition of dust in communities closest to the smelter.

3.4.2. Potential Human Health Impacts from TSP and Airborne Metals Exposure

Humans can be exposed to toxic air pollutants originating from mining and smelting activities by direct inhalation. Inhalation of PM has been linked to serious health conditions including cancer and heart disease (Mohanraj et al., 2004). Other routes of exposure include ingestion of contaminated food and water, and skin contact with contaminated soil, water or dust. Contaminants also accumulate in certain plants, which can be thus introduced into the food chain (Yassi et al., 2001).

Smaller particles (2.5 μm and smaller in diameter) tend to originate from anthropogenic sources and appear to have a greater effect on human health than larger particles (Yassi et al., 2001; ESCAP, 2001; ICPS, 1991b). Measuring the extent to which ambient air pollution causes health conditions is currently under debate. The EPA estimates applying a factor between 0.5 to 0.6 to mean TSP levels to derive levels of particulate matter less than 10 μm in diameter (PM_{10}) in order to estimate certain health and mortality effects. Every 10 $\mu g/m^3$ increase in PM_{10} is associated with a 0.07 % increase in mortality and a 3.4 % increase in mortality due to respiratory conditions (Browne et al., 1999; EPA, 1984).

The Wawondula dry season day and night mean TSP values (157.47 $\mu g/m^3$ and 106.55 $\mu g/m^3$ respectively), the Magani dry season day mean TSP value (111.53 $\mu g/m^3$), the Desa Nikkel rainy season day mean TSP value (107.58 $\mu g/m^3$), and the Sorowako rainy season night value (107.23$\mu g/m^3$) all exceeded Indonesia's proposed annual mean TSP guideline of 90 ug/m^3 (Browne et al., 1999). The overall mean of all TSP values in the six sampling sites (96.62 $\mu g/m^3$) also exceeded Indonesia's proposed annual mean TSP guideline. The mean 12-hour TSP concentrations found in this study were compared with the proposed Indonesian annual guidelines because all sites had residential populations chronically exposed to elevated TSP levels.

Potential human health impacts of Ni, Cr and Mn were examined since these metals are in the respirable range and were found in significant amounts in this environment. Airborne Ni has been shown to vary in orders of magnitude depending on anthropogenic sources (European Communities, 2001; WHO, 1991b). Remote areas relatively free of anthropogenic sources typically have airborne Ni concentrations in the range between 0.001 and 0.003 $\mu g/m^3$ (WHO, 1991b; Fishbein, 1985). Airborne Ni concentrations near a nickel smelter site in Harjavalta, Finland (0.102 $\mu g/m^3$) were reported as especially high but were possibly due to disturbances in flue gas cleaning in 1998. In 1999, preliminary data showed that Ni concentrations in Harjavalta area had decreased to 0.02 $\mu g/m^3$. Airborne Ni near the Sudbury smelters was reported to be 0.124 $\mu g/m^3$ in 1986 (WHO, 1991). Elevated airborne nickel and subsequent deposition causes an environmental and human health hazard.

Table 3.8 lists 24-hour airborne Ni, Cr, and Mn concentrations from various sites around the world as well as the average of the day and night 12-hour sites in this study for a comparison of 24-hour levels. The airborne Ni levels were more comparable to the Sudbury smelter concentrations as opposed to the other rural and residential sites listed. Mean Ni concentrations were especially high in the dry season in Sorowako (0.213 $\mu g/m^3$), Magani (0.154 $\mu g/m^3$), Desa Nikkel (0.128 $\mu g/m^3$), and Wawondula (0.181 $\mu g/m^3$). Desa Nikkel also reported elevated Ni concentrations in the rainy season (0.126 $\mu g/m^3$). Peak concentrations in the day suggest that average values from 24-hour sampling tends to underestimate mean metal concentrations in the day and overestimate mean metal concentrations in the night.

Approximately 75-90% of airborne Ni will be found in the PM_{10} fraction (Mohanraj et al., 2004). Ni deposited in the lungs takes longer to be removed from the body than Ni that is ingested but exposure to Ni and Co tends to occur to a greater extent from ingestion (Ontario Ministry of Environment, 2001a; Ontario Ministry of Environment, 2001b). Nickel on particulate less than 1 μm in diameter generally deposits in the alveolar regions of the lung (WHO, 1991). A respiratory rate of 20 m^3/day and air Ni concentrations of 0.005-0.035 $\mu g/m^3$ has been estimated to result in 0.1-0.7 μg/day of Ni entering the human respiratory tract. The range is expected to be greater in the communities surrounding the Sorowako nickel smelters where air Ni concentrations typically exceed 0.035 $\mu g/m^3$. Respiratory health impacts of inhalation of Ni containing particles depend on the concentration, size and speciation of nickel. Skin irritation and allergic sensitization is also indicative of acute Ni exposure. Chronic exposure to Ni can cause asthma and other respiratory health conditions as well as lung and nasal cancers (California Air Resources Board, 2004). The U.S. Agency for Toxic Substances and Disease Registry (1997) associates an air Ni concentration of 0.00385 $\mu g/m^3$ with a 10^{-6} cancer risk (European Communities, 2001). Based on the mean air Ni concentrations observed in the communities around the Sorowako nickel smelter, chronic exposure to current levels of Ni could be associated with an elevated cancer risk.

Air Cr concentrations are generally less than 0.1 $\mu g/m^3$ (WHO, 1988). People living near industries with elevated air Cr concentrations of up to 1 $\mu g/m^3$ did not show elevated lung cancer mortality. Other studies have shown that airborne Cr exposure through inhalation and skin contact can cause health problems especially in workers exposed to large quantities of Cr (WHO, 1988). While the air Cr levels in the study site are all above the other sites listed in Table 3.8, mean air Cr concentrations are not considered to be a major health threat based on dose-response relationships still under formulation (WHO, 1988). The toxicity of Cr also depends on its form; hexavalent Cr has been shown to be more toxic and carcinogenic (WHO, 1988). Smokers and those exposed to second-hand smoke are also exposed to Ni and Cr in cigarettes (WHO, 1988).

Air Mn concentrations are generally in the range of 0.005-0.014 $\mu g/m^3$ in remote areas, 0.040$\mu g/m^3$ in rural areas, 0.065 to 0.166 $\mu g/m^3$ in urban areas and up to 8.0 $\mu g/m^3$ in areas of a manganese point source like foundries (WHO, 1999). It has been estimated that air Mn exposures of 0.035 $\mu g/m^3$ is associated with a 0.7 μg/day intake, assuming a 20 m^3/day respiration rate. This is the estimated amount expected in the communities around the Sorowako smelter that recorded mean air Mn concentrations between 0.026 to 0.083 $\mu g/m^3$. Ingestion of foodstuffs containing Mn is the main exposure route of Mn in humans but workers exposed to elevated airborne Mn also inhale the metal (WHO, 1999) and thus may be at a greater risk of developing health conditions linked to long term exposure of elevated Mn exposure such as developmental deformities, decreased mental capabilities and manganism poisoning. Symptoms of manganism poisoning are similar to Parkinson's Disease. Manganese has also been shown to cause Parkinson's Disease. Welders exposed to elevated levels of manganese over a long time have developed manganism poisoning and Parkinson's Disease (Hine and Pasi, 1975; Bleich et al., 2000).

Differences in metal concentrations across different continents may be due to combined effects of various factors including geographical differences in source and sink processes, and differences in regulatory controls on emissions (Kim et al., 2001).

Table 3.8. Metals concentrations reported at smelter sites and other rural/residential areas over a 24-hour sampling period, and seasonal mean metal concentrations from this study ($\mu g/m^3$).

Sampling location/time	Cr	Mn	Ni
Sudbury smelter, Canada, 1986[1]	-	-	0.124
Chilton, UK, 1971-1986[2]	0.0022	-	-
Kiel Bight, Germany, 1981/83[2]	-	0.015	0.004
Caracas, Venezuela, 1988/89[2]	-	-	0.0099
Alfabia, Spain, 1992[2]	0.0064	0.012	0.0098
Won Ju, Korea, 2001[2]	0.013	0.032	0.015
Magani, dry season, 2004	0.133	0.052	0.154
Magani, rainy season, 2004/5	0.025	0.034	0.07
Sorowako, dry season, 2004	0.044	0.083	0.213
Sorowako, rainy season, 2004/5	0.019	0.029	0.120
Desa Nikkel, dry season, 2004	0.032	0.050	0.128
Desa Nikkel rainy season, 2004/5	0.017	0.014	0.126
Wawondula, dry season, 2004	0.028	0.079	0.181
Wawondula rainy season, 2004/5	0.031	0.040	0.094
Kampung Baru, dry season, 2004	0.016	0.045	0.090
Kampung Baru rainy season, 2004/5	0.015	0.030	0.071
Wasuponda, dry season, 2004	0.021	0.031	0.050
Wasuponda rainy season, 2004/5	0.017	0.026	0.058

([1]WHO, 1991b; [2]Kim et al., 2002).

3.4.3. Domestic 24-Hour Dust Fall Accumulation

The domestic 24-hour dust fall accumulation in terms of the amount of dust that is falling in people's homes provided information that the air sampling did not. On average, significantly more dust falls in Kampung Baru homes compared to homes in other communities. However, the dust fall rates are not normally distributed and range from 28.50 to 1436.75 $mg/m^2/day$. Kampung Baru is located 11 km SE of the smelter where daytime winds often blow smelter fallout and where artisanal sawmills also operate. More dust falls in these homes than what the average airborne TSP concentrations would suggest. This observation may be due to the Kampung Baru air sampling location, which was located near the shore of Lake Towuti where winds off the lake could have reduced ambient air pollution around the air sampler. The homes sampled for dust were further from this shore and effect. The range in dust fall rates also suggest that some homes in Kampung Baru, possibly based on location, are acquiring more dust than others.

People tend to spend much time indoors and thus indoor air quality is a major human health concern but in the study area, people also tend to spend much time outdoors. The health questionnaire results of the community-based research outlined in Chapter 4 found that dust fall amounts were significantly correlated with prevalence of adult asthma, high blood pressure, heart disease and anemia.

Personal exposure to airborne contaminants based on contaminant levels has been difficult because exposure is affected by variable indoor and outdoor airborne contaminant levels, outdoor contaminant fate in the indoors, and the contribution of indoor sources and sinks to total personal exposure (Lioy et al., 1990; NRC, 1999). Several studies show that a significant portion of small indoor particles originate from the outdoors (NRC, 1999). Once inside, particles can deposit on surfaces or react with other particles present inside. Households in the communities sampled for dust fall were relatively open with no air conditioning and thus may be more susceptible to dust fall.

3.5. Conclusions and Recommendations

Results of the community-based monitoring of seasonal TSP and airborne metals concentrations in several communities around the PT Inco nickel mines and smelter in Sorowako, Indonesia showed that TSP and airborne metals levels did not vary significantly between communities alone. However, TSP and airborne metals such as Ni, Co, Cr, and Mn varied significantly between day and night samples in Magani and Wawondula with more variation observed in the dry season between day and night samples.

Major sources of air pollution likely include the smelter, road dust, soot from burn g garbage, and sawmill dust. Correlation between TSP and metals indicate that the smelter may be a dominant source of dust in some communities, such as Magani and Desa Nikkel during the night and Wawondula during both the night and day, but not for others, such as Wasuponda and Kampung Baru.

Dust fall accumulation appears to be more of a problem in Kampung Baru where sawmill operations, smelter fallout, and road dust affect ambient dust levels. Health implications of dust fall were especially noted in this community where dust fall accumulations were significantly correlated with the prevalence of several health conditions including adult asthma, high blood pressure and heart disease. Human health impacts known to be associated with nickel mining and smelting include respiratory diseases and skin conditions. High blood pressure and heart disease has also recently been linked to air pollution (Ibald-Mulli et al., 2004).

Results of the community-based air sampling program serve as foundation for further airborne pollutant analysis and the implementation of a long-term community-based air monitoring program. The community-based component of this research was important for community members in that it provided them with the knowledge and experience to continually monitor, assess, and address environmental and health concerns in their community, and compare their data with that of the industry and the government.

Future recommended studies include:

1) Meteorological analysis linking time specific prevailing winds with TSP and airborne metals concentrations.

2) Assessment of trends of long-term distribution of airborne metals, which could in turn assess the effectiveness of air quality control measures such as cleaning technologies on smelter stacks as well as the effects of a larger than usual amount of emissions.

3) Detailed statistical analysis (PCA or factor) to distinguish source processes affecting metal distributions in the study area.

4) Studying other pathways of exposure to PM like that brought into the home on the clothes of mine and smelter workers.

5) An analysis of Ni concentrations in soil and plants that could demonstrate effects of pollutant dispersion plumes following dominant wind directions. Such an investigation could also determine the impact on agricultural productivity caused by smelter fallout.

Chapter 4: Community-Based Research on the Potential Human Health Impacts of a Laterite Nickel Mine and Smelter in Sorowako, Indonesia

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4.1. Introduction

Nickel mining and smelting are associated with serious toxicological effects in humans including respiratory and skin conditions. These impacts have been studied extensively for nickel sulfide ore mining and smelting in temperate environments such as Canada, Norway and Russia (International Committee on Nickel Carcinogenesis in Man, 1990; Smith-Sivertsen et al., 1997; Ontario Ministry of Environment, 2001a; Norseth, 2003). However, the environmental and human health impacts of mining and smelting of nickel laterite ores in the tropics have garnered less research attention and publication.

Community-based research by Memorial University of Newfoundland and the Indigenous Sorowako Association (KWAS) came about after environmental and health concerns were expressed in communities surrounding a laterite nickel mine and smelter in Sorowako. As was previously stated, Sorowako, located in the centre of the Indonesian island of Sulawesi, is the site of a nearly three-decades old, large-scale laterite nickel mining and smelting operation (Fig. 4.1). The iron and cobalt rich nickel laterite ore is mined on top of hills (Fig. 4.2). The smelter is located on a ridge overlooking the town

(Fig. 4.3). Surrounding the PT Inco nickel mines and smelter are villages, lakes, forest and agricultural areas. Smelter fallout is expected to occur over several sensitive receptor areas including schools, conservation parks and residential areas. Community-based research involved community representatives conducting a health questionnaire in their respective communities.

Smelter fallout creates an environmental and human health hazard through both particulate dust and toxicity, due to the heavy metals in the fallout.

Spatial patterns in self-reported health conditions were examined to determine potential links to contaminant exposure from nickel mining and smelting. Respiratory and skin conditions were expected to be more prevalent in communities closer to and downwind from the smelter. Children were expected to suffer more from respiratory health conditions than adults since children tend to be more susceptible to the adverse health effects of air pollution (NRC, 1999). Respiratory, skin, and parasitic conditions were expected to be more prevalent in households residing in the shanties over the waters of Lake Matano (Figs. 4.1, 4.3).

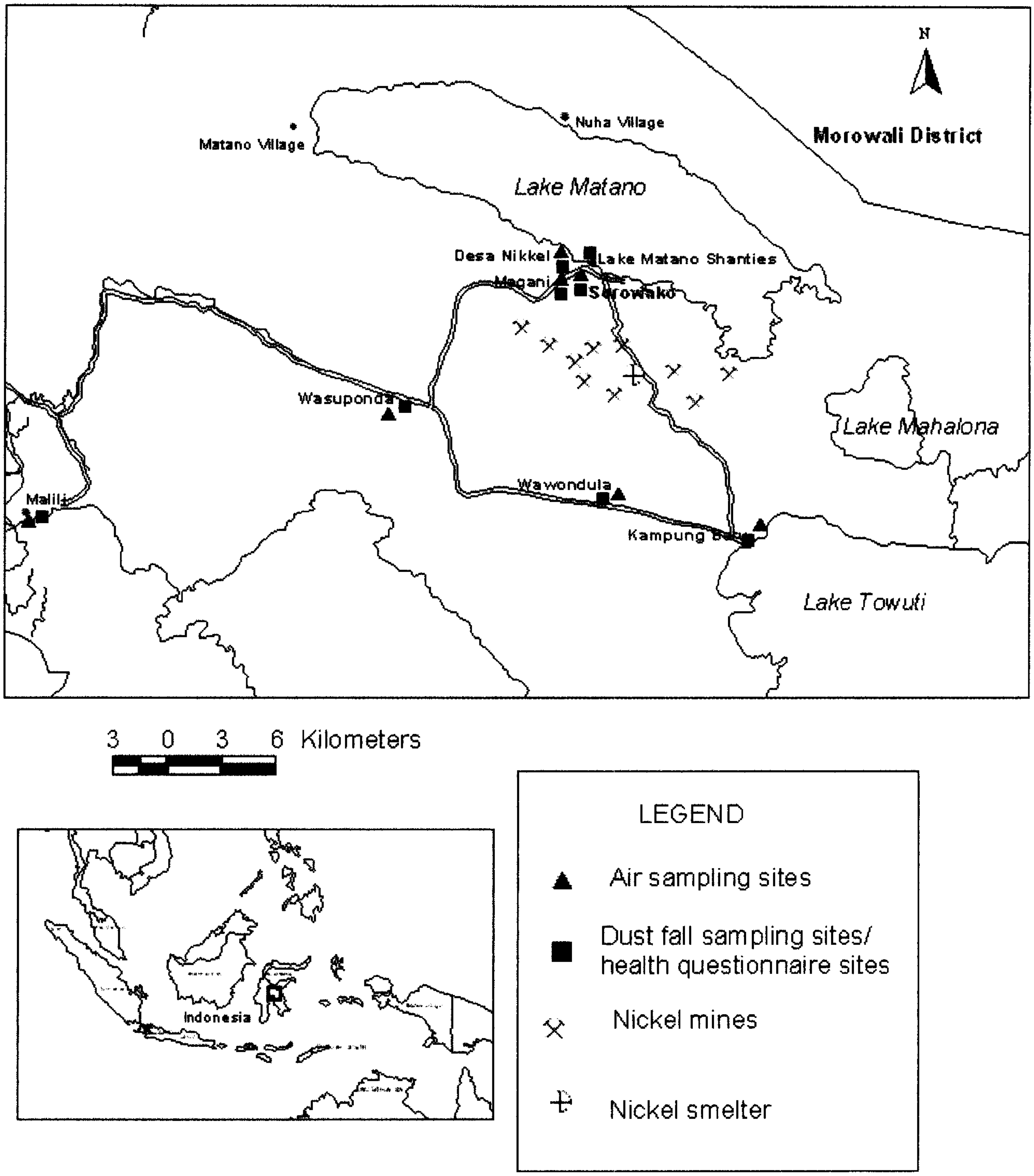

Fig. 4.1. Location of study area.

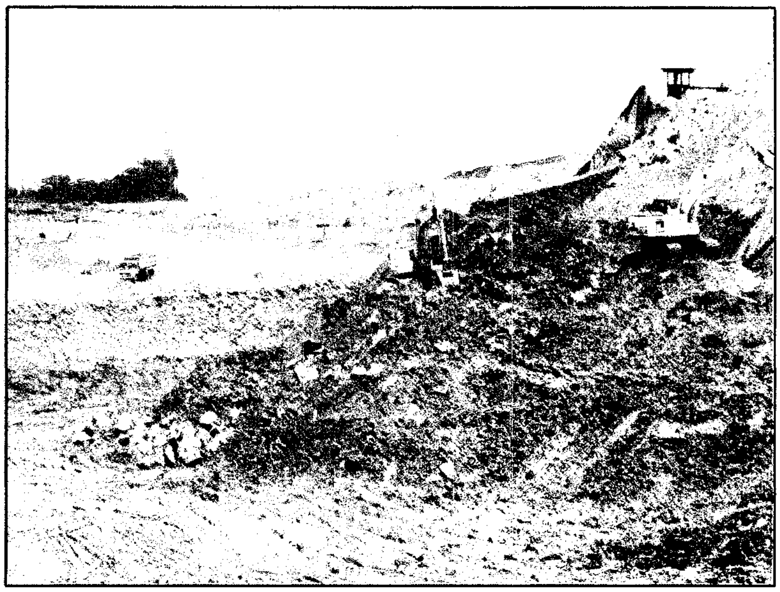

Fig. 4.2. PT Inco laterite nickel mines in Sorowako, August 2004. Credit: Yusri Yusuf.

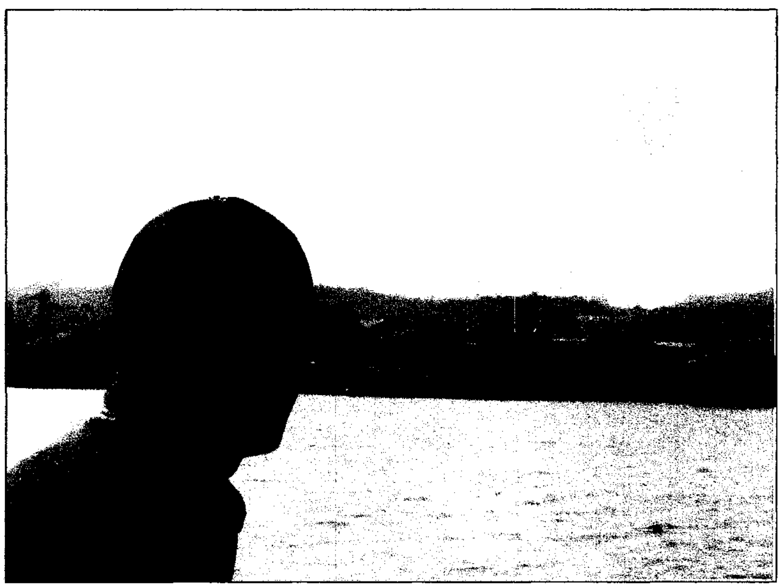

Fig. 4.3. PT Inco nickel smelter in Sorowako, August 2004. Credit: Evan Edinger.

A confidential, anonymous health questionnaire based on a questionnaire conducted in Port Colborne, Ontario, Canada, the site of a former nickel refinery, was adapted to include health concerns specific to the study area (Ventana Clinical Research

Corporation, 2002). Seven of the eight communities selected to participate in the questionnaire were situated 5 to 11.5 km downwind from the smelter. Malili, a community situated 20 km away from the mining and smelting activities, was also chosen as a questionnaire site to compare health conditions in this community with communities closer to the mines and smelter (Fig. 4.1).

Humans are exposed to toxins from nickel mining and smelting mainly through inhalation of contaminated air as well as from skin contact and ingestion of contaminated water, food and other materials (Ontario Ministry of Environment, 2001a; Ontario Ministry of Environment, 2001b). Respiratory and cardiovascular related deaths and hospitalizations have been linked to particulate air pollution (Ibald-Mulli et al., 2004). Epidemiological studies have found an increased risk of human cancers in populations exposed to more than one metal at elevated concentrations (Nordberg et al., 1985). Exposure to both nickel and asbestos has been shown to produce synergistic health effects including cancer (Carson et al., 1986). Metals with long retention times in pulmonary tissues tend to be carcinogenic. The biological half-life of nickel and chromium compounds is positively correlated with respiratory tract carcinogenicity (Nordberg et al, 1985).

Investigations on air and freshwater pollution and its effects on human health are particularly complex in developing countries such as Indonesia where other factors like malnutrition, poor sanitation, overcrowding, and low rates of immunization must also be considered. Exposure to pollution may also have a more severe impact on these already vulnerable populations (ESCAP, 2001). Besides industrial air pollution, common environmental pollution that Indonesian populations are exposed to regularly include indoor air pollution from kitchen smoke as well as active and passive smoking (Nurhaeni, 2001). Those with cardiopulmonary disease and asthma as well as the elderly, infants and children are more susceptible to the harmful health effects of inhaled particulate matter (PM) (NRC, 1999). According to the Indonesian Health Department, respiratory system diseases were the leading cause of death in children under the age of five years (30.8%) in 1995 (Nurhaeni, 2001).

4.2. Materials and Methods

4.2.1. Study Site

There are some 11,000 inhabitants in the Sorowako area (PT Inco, 2005). Table 4.1 summarizes characteristics of each questionnaire site including distance and direction from the nickel mines and smelter. A description of the survey sites can be found in section 3.2.1 on pages 32 and 35.

Environmental health risk factors associated with nickel mining and smelting at the study site includes increased exposure to dust and heavy metals. Table 3.2 on page 43 summarizes the community-based air pollution study results from the dry season, which was performed at the same time as the health questionnaire. A high-volume air sampler took 12-hour samples for total suspended particulates (TSP) and airborne metals over approximately five consecutive days and nights in six of the eight communities surveyed at varying distances and directions from the smelter in the dry season (August-September 2004). Metals composition was analysed by ICP-MS. A Kim wipe swipe measured 24-hour dust fall amounts in each of the households surveyed. TSP was particularly high in Wawondula (157.47 $\mu g/m^3$) and Magani (111.53 $\mu g/m^3$) in the day, communities located near to and downwind from the smelter. Elevated levels of TSP and airborne metals such as nickel were observed in the day of the dry season (see Chapter 3). Dust fall accumulation in households was only significantly higher in Kampung Baru, a site also exposed to sawmill dust (see Table 3.6, page 68).

Many homes in the communities surrounding the smelter have good ventilation systems with open spaces in walls and windows, and no heating or air conditioning systems that are potential sources of air pollution. When there is no wind and the air is still, ambient air pollution and potential human health effects are generally worse (Toogood et al., 1989). Open spaces common in the infrastructure of homes and frequently open doors also allow dust to enter from outside especially in those homes located near dirt roads. Another pathway of particulate matter into the home is from the mine and smelter workers who bring home dust on their clothes.

Table 4.1. Characteristics of study site.

Site	Distance/ direction from smelter	Characteristics of study site
1. Magani	4.5 km, NW	Former PT Inco company housing site. Prevailing night winds blow smelter fallout here. Some paved roads and some limestone roads. Less traffic in daytime compared to Sorowako.
2. Sorowako	5.5 km, NW	Residential area with local shops and markets. Prevailing night winds blow smelter fallout here. Some paved roads with intersecting roads made of slag waste rock. Frequent traffic in daytime.
3. Homes on Lake Matano	6 km, NW	Homes built over Lake Matano, next to Desa Nikkel and Sorowako. Damp and cramped quarters surrounded by garbage and sewage. Prevailing night winds blow smelter fallout here.
4. Desa Nikkel	6 km, NW	Located along the shore of Lake Matano. Prevailing night winds blow smelter fallout here. Roads made of slag waste rock with few paved roads. Frequent traffic in daytime.
5. Wawondula	7.5 km, SW	Settlement area for PT Inco unskilled workforce. Prevailing day winds blow smelter fallout here. Main road is paved and others made of slag waste rock. Less traffic in daytime compared to Sorowako.
6. Kampung Baru	11 km, SE	Artisanal sawmills located along Lake Towuti shore. Prevailing day winds blow smelter fallout here. Main road is paved and others are dirt roads. Less traffic in daytime compared to Sorowako.
7. Wasuponda	11.5 km, SW	District capital. Settlement area for PT Inco workforce. Day winds sometimes blow smelter fallout here. Main road is paved and others made of slag waste rock and backfill. Less traffic in daytime compared to Sorowako.
8. Malili	20 km, SW	Site of local administration office and port. Day winds sometimes blow smelter fallout in this direction but is outside PT Inco's expected smelter fallout zone. Paved roads with only a few roads not paved yet. Frequent traffic in daytime.

Other apparent environmental health risk factors present in the communities include increased re-suspended road dust, sewage and garbage disposal into Lake Matano, heavy metals leaching from roads, and regular burning of garbage. People living in the shanties over the Lake Matano waters were surveyed as a separate group because they may be more at risk for parasite-borne diseases and health conditions that proliferate in damp and unsanitary living conditions.

4.2.2. Methods

Prevalent health conditions in the communities surrounding the nickel mines and smelter were assessed in a cross-sectional design with a confidential, anonymous health questionnaire. It was hypothesized that (1) health conditions linked to exposure of airborne PM and metals from the nickel mine and smelter such as respiratory health and skin conditions would be more prevalent in areas closer to and downwind from the nickel mines and smelter; (2) children, a vulnerable sub-population to the effects of air pollution, would suffer more respiratory health conditions than adults in the same communities; and (3) health conditions linked to damp and unsanitary conditions would be more prevalent in households living over Lake Matano.

The health questionnaire was developed based on a similar health questionnaire conducted in the Port Colborne Community Health Assessment Project (Ventana Clinical Research Corporation, 2002). Port Colborne, Ontario was home to a nickel and cobalt refinery that operated from 1918 to 1984. The health questionnaire in this study was further adapted to address health concerns in Sorowako. The health questionnaire focused on doctor diagnosed respiratory and skin conditions suffered either over the past month or year but also asked questions on other illnesses and health determinants such as age, gender, employment status, income, and education levels. This information is needed to assess relationships between prevalence of health conditions, exposure to contaminants from nickel mining and smelting, and several health determinants. The likelihood of adverse responses to pollution not only depends on the degree of exposure but also on individual traits, personal habits and other environmental and health determinants (NRC, 1999).

The questionnaire received approval from Memorial University's Interdisciplinary Committee on Ethics in Human Research (ICEHR). Interviewers, representatives from KWAS or other local community organisations, participated in a training session before administering the questionnaire in August 2004. The training included information on how to conduct the questionnaire ethically. Confidentiality and informed consent were especially highlighted. Interviewers selected, explained the study in detail (without stating potential health implications of smelter fallout), obtained informed consent, and administered the health questionnaire to consenting members of twenty households in eight different communities using a convenience sampling. Efforts to minimize biased results were taken such as making an effort to select households as randomly as possible from different areas of the community. It was explained to participants that they could stop filling out the questionnaire at any time if they so wished. To ensure confidentiality, the questionnaire was anonymous and participants were asked not to write their names on the questionnaire. Data was encoded, entered and presented in a way that ensured individuals or households were unidentifiable.

Persons over the age of 18 years answered their own health questionnaire, while members of the household under the age of 18 years had an adult in their household answer a health questionnaire for them specifically designed for children and adolescents. Community representatives were present to answer any questions but the participant's answers were kept confidential to the participant. After completing the questionnaire, study participants placed their questionnaire in an envelope then sealed it and gave it to the community representatives for secure storage and later data entry.

4.2.3. Data Analysis

Initial data compilation and analysis of the health questionnaire results was done with community representatives in August 2004. Relationships among reported health conditions, environmental risk factors, and other health determinants like socioeconomic factors were assessed using Pearson correlation analysis.

4.2.4. Focus Group Discussion on Mining and Health

A community review session of a draft book chapter pertaining to mining and health from the "Community Guide to Environmental Health" by the Hesperian Foundation was held on August 25, 2004 at the KWAS secretariat in Sorowako after the health questionnaires were completed and returned earlier that month. The review session was coordinated and facilitated by the community-based research team. People were invited to attend from Sorowako and nearby areas including Wawondula, Wasuponda, and Kampung Baru. Participants included: four Sorowakan women including a doctor who works at the Wawondula community health clinic; three Sorowakan men; one Karonsi'e Dongi woman; six men from Wawondula; and four men from communities near Lake Towuti. Participants were also given information on nickel and an update on the community-based research. These materials as well as sections of the chapter most relevant and of concern to citizens such as dust and water contamination were translated into Bahasa Indonesian and discussed in the review session.

4.3. Results

4.3.1. Health Questionnaire Results

4.3.1.1. Demography of Health Questionnaire Participants

Table 4.2 summarizes characteristics, which are also health determinants, of adults surveyed (Health Canada, 1997). The mean age of each community surveyed was similar and ranged from 34 years old in the Kampung Baru community to 43 years old in the Wasuponda community. Gender balance of respondents was mostly observed with the greatest differences observed in Wawondula and Magani, where more males completed the questionnaire than females (60.9% and 61.8% respectively). Most people who completed the questionnaire were residents of the area for at least five years. Most reported being married as their marital status in each community. Wawondula had the highest single status rate of 41.8%.

More residents living on top of Lake Matano and in Sorowako reported the lowest levels of education (97.8% and 97.2% respectively with high school or less) while more in Wawondula, Wasuponda, and Malili reported higher levels of education (22.7%, 21.6% and 20% respectively with college/university education) (Fig. 4.4).

Full-time employment was low in all communities with a high of 34.2% in the community living over Lake Matano and a low of 3.8% in Desa Nikkel. Full-time work status is not linked to higher incomes in the community living over Lake Matano where more people reported being employed full-time but generally had lower family incomes. The Sorowako, Magani, Wasuponda, and Wawondula communities reported having more people employed either part-time or as housewives. Unemployment was the highest in Desa Nikkel (22.6%), Malili (24.1%) and Kampung Baru (19.4%) and the lowest in Magani (3.1%). Magani was once the PT Inco company housing site (Fig. 4.5).

Table 4.2. Characteristics of adults surveyed at each study site, %.

Characteristic	Sorowako N=35	Lake Matano N=45	Desa Nikkel N=52	Magani N=39	Kampung Baru N=40	Wawondula N=47	Wasuponda N=37	Malili N=46
Average age, years								
Age (Mean, years)	393P NP v 9	9	37	38	34	35	43	35
Gender, %								
Male	47.5	53.3	45.3	61.8	43.2	60.9	44.7	53.3
Female	52.5	46.7	54.7	38.2	56.8	39.1	55.3	46.7
Resident of area, %								
< 5 yrs	80.8	83.3	93.5	87.2	100	87.0	100	100
Education, %								
Below high school	80.5	77.8	75.0	69.6	72.9	70.5	59.4	45.7
High school	16.7	20.0	9.6	18.2	16.2	6.8	18.9	34.3
College/University	2.8	2.2	15.4	12.1	10.8	22.7	21.6	20.0
Family Income, %								
< US$ 292	14.3	5.7	0	3.4	0	16.7	18.2	0
US$ 97-292	46.4	2.8	21.1	13.8	0	28.6	42.4	19.2
US$ 49-73	7.1	31.4	17.3	10.3	8.3	9.5	9.1	26.9
US$ 24-49	3.6	8.57	13.5	3.4	8.3	0	0	3.8
US$ 10-24	0	0	3.8	3.4	22.2	2.4	3.0	0
> US$ 10	0	0	7.7	3.4	8.3	0	0	7.7
Declined to answer.	28.6	51.4	36.5	62.1	52.8	42.8	27.3	42.3
Work Status, %								
Full-Time	24.4	34.2	3.8	21.9	8.3	20.0	13.5	10.3
Part-Time	34.1	18.4	24.5	25.0	30.6	53.3	48.7	27.6
Retired	2.4	0	1.9	12.5	0	2.2	2.7	10.3
Unemployed	7.3	7.9	22.6	3.1	19.4	11.1	2.7	24.1
Student	2.4	2.6	9.4	3.1	8.3	0	2.7	10.3
Housewife	29.3	34.2	24.5	34.4	25.0	11.1	29.7	17.2
Marital Status, %								
Single	2.7	2.3	28.8	19.4	23.7	41.8	13.5	16.7
Married	97.2	93	65.4	77.4	65.8	58.1	83.8	75.0
Divorce/Separated	0	2.3	0	0	2.6	0	2.7	2.8
Widowed	0	2.3	5.8	3.2	7.9	0	0	5.6
Smoking, %								
Often	32.4	9.1	25	32.1	18.2	38.5	6.1	24.1
Sometimes	8.8	33.3	16.7	18.5	21.2	15.4	9.1	20.7
Never	58.8	57.6	58.3	48.1	60.6	46.1	84.8	55.2

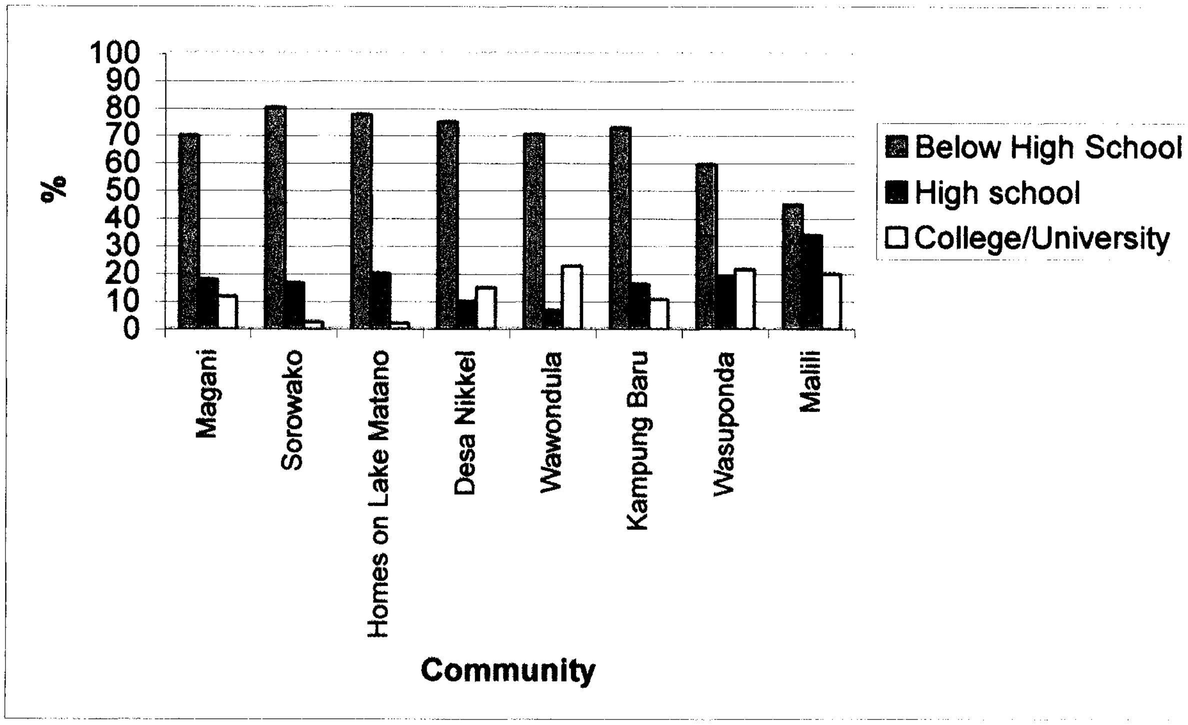

Fig. 4.4. Percentage of reported education levels adults in the study.

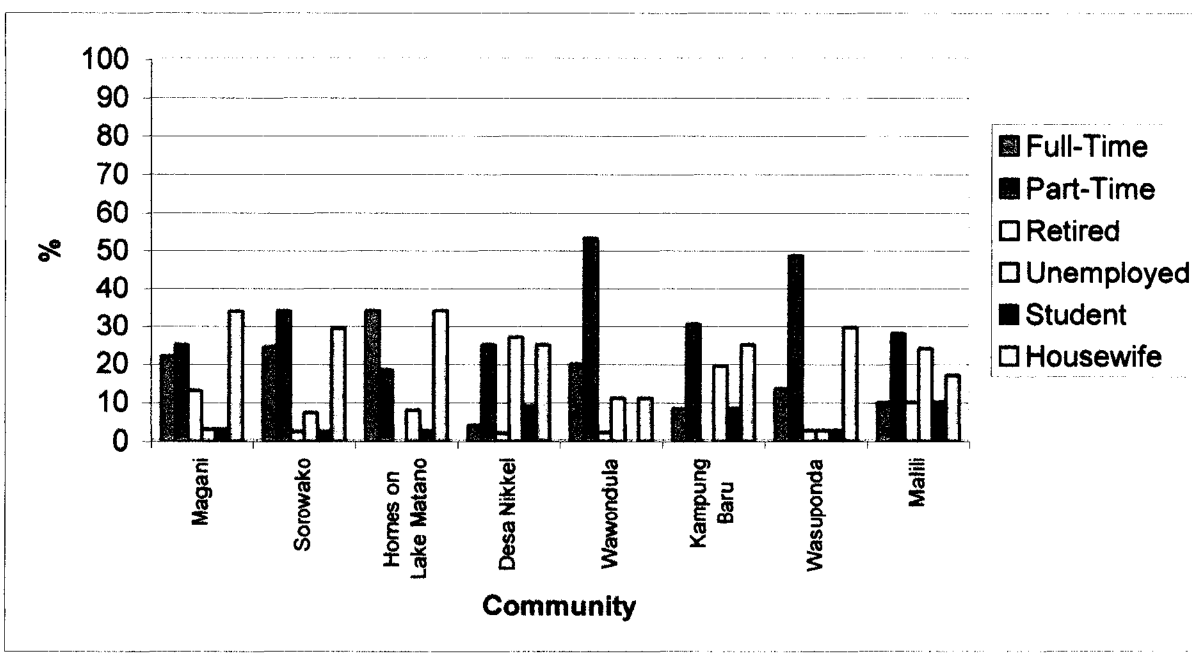

Fig. 4.5. Percentage of reported work status of adults in the study.

Monthly family income brackets of US$ 97 (Rp. 1 million) and higher was reported more in Wawondula (75.3%), Sorowako (60.7%), and Wasuponda (60.4%). Monthly family income brackets of US$ 24 (Rp. 250,000) or less were reported in Kampung Baru (30.5%) and Desa Nikkel (11.5%) (Fig. 4.6). The Indonesian Health Department reported a national per capita monthly household income of approximately US$ 33 (Rp. 350,000) (Nurhaeni, 2001).

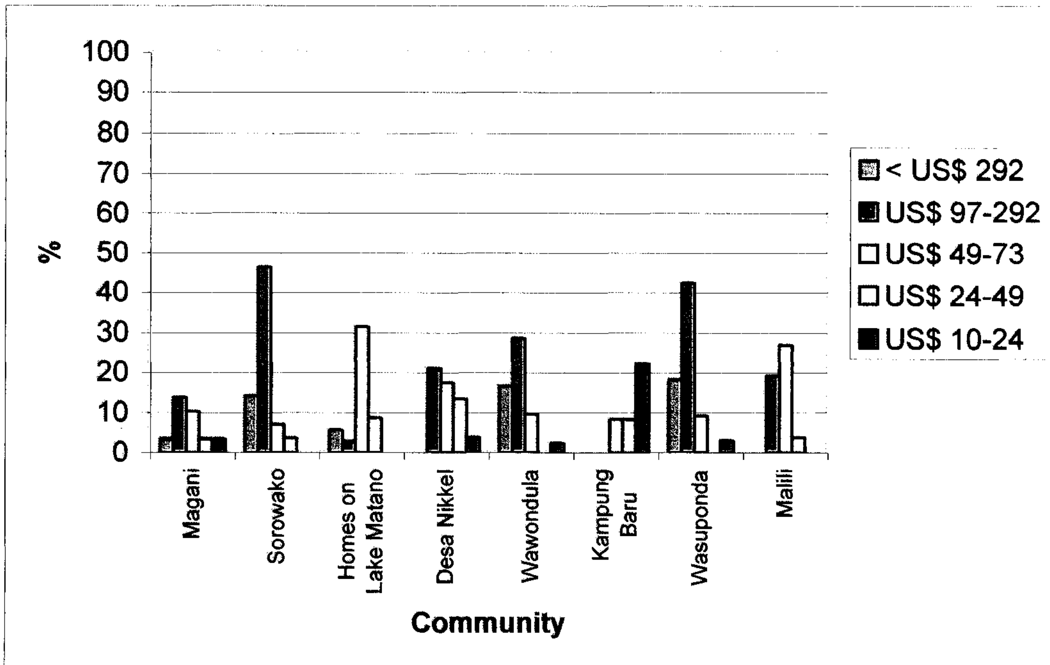

Fig. 4.6. Percentage of reported monthly family income brackets in the study.

On average, more people reported never smoking with a high of 84.8% in Wasuponda. Over one third of respondents reported smoking often in Wawondula (38.5%), Sorowako (32.4%), and Magani (32.1%) (Fig. 4.7). Most everyday smokers were men ranging from 80% of smokers in Desa Nikkel to 100% in Sorowako, Wawondula, Kampung Baru and Wasuponda (Fig. 4.8). Prevalence of those reporting that they never smoked was also significantly positively correlated with females (R=0.71) and significantly negatively correlated with males (R=-0.71) (Table 4.10).

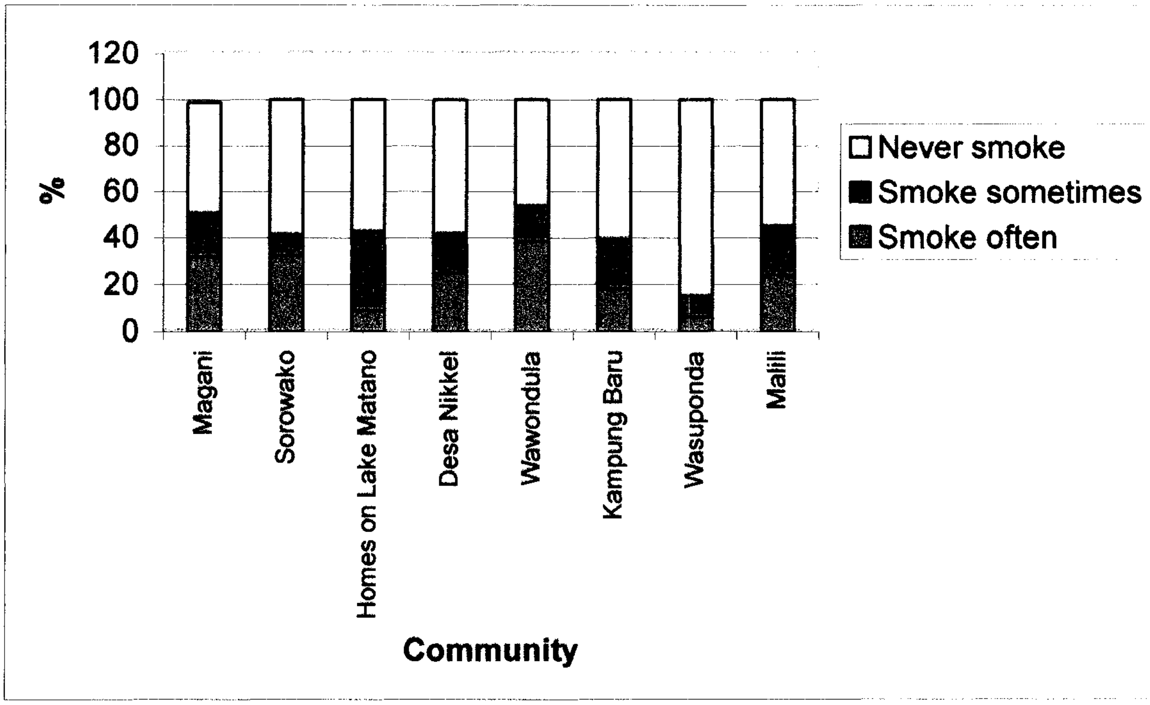

Fig. 4.7. Percentage of adults reporting smoking often, sometimes and never in the study.

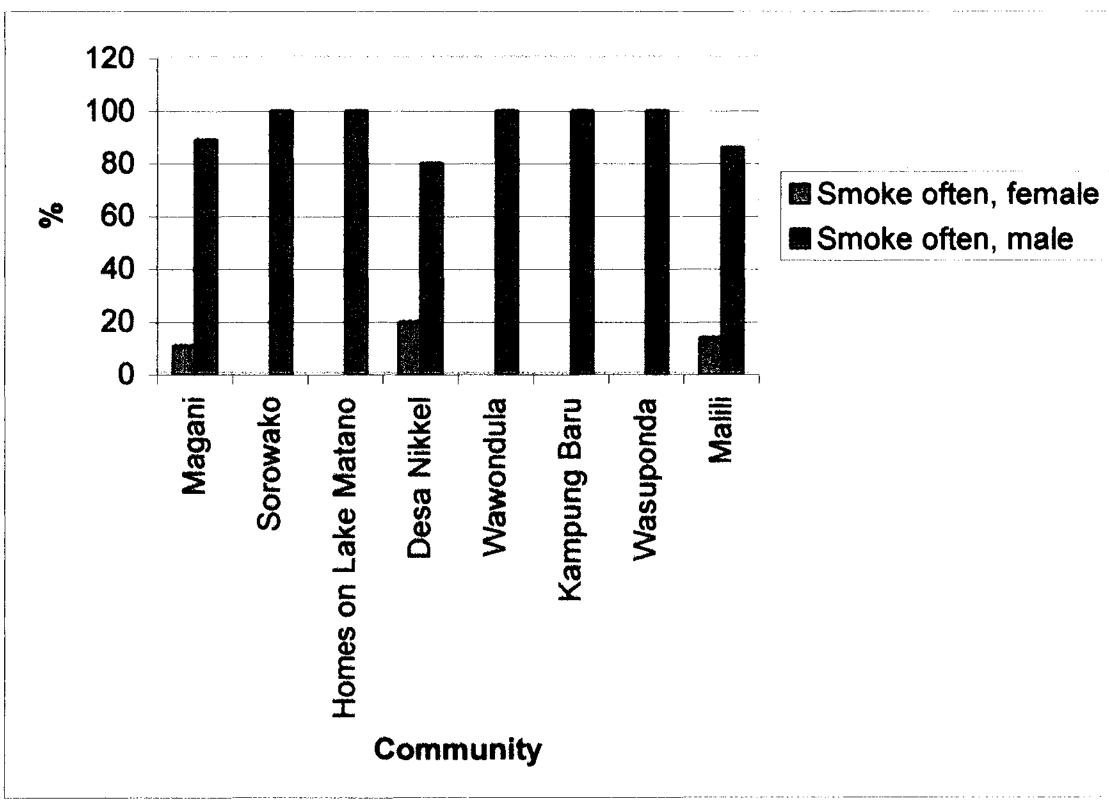

Fig. 4.8. Percentage of everyday smokers in the study who are male and the percentage who are female.

4.3.1.2. Respiratory Health Conditions

More adults suffer from asthma than children except in Magani where child asthma was the highest at 33.3% (Fig. 4.9). Adult asthma diagnosed by a doctor was more prevalent in Kampung Baru (33.3%) than Malili (5.4%). Tables 4.4 and 4.5 summarize the prevalence of asthma symptoms, asthma and asthma medication usage in adults and children respectively. Prevalence of diagnosed asthma in adults by a doctor was associated with domestic 24-hour dust fall accumulation (r=0.78), prevalence of wheezing (0.73), emotional health problems (r=0.77), and anemia (r=0.87) (Table 4.9). Tables 4.3 and 4.4 summarize asthma symptoms in adults and children respectively. Prevalence of asthma symptoms was generally reported more than diagnosed asthma. Prevalence of wheezing was higher in Kampung Baru adults and children than in Wasuponda. Prevalence of wheezing in adults was strongly associated with mean night TSP concentrations (r=0.86) and prevalence of emotional health problems (r=0.91), physical health problems (r=0.85) and asthma as previously mentioned (Tables 4.9-4.10).

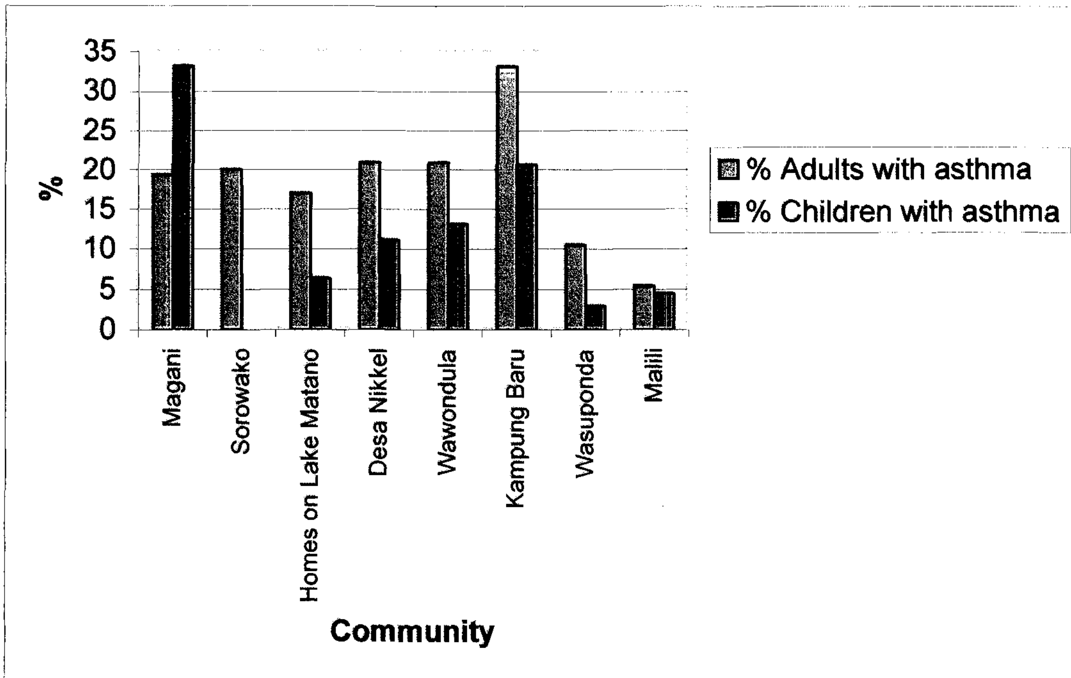

Fig. 4.9. Percentage of adults reporting asthma diagnosed by a doctor in the study.

All asthma sufferers in Desa Nikkel and 88.9% asthma sufferers in Kampung Baru also smoked or had a smoker in their household. But the majority of asthma sufferers in Sorowako (57.1%) did not have a smoker in their household. The only respiratory condition correlated with smoking was prevalence of wheezing in children, which was strongly associated with prevalence of occasional smoking (r=0.77) and negatively strongly associated with high monthly family income (r= -0.92).

Table 4.3. Prevalence of asthma symptoms, asthma, and asthma medication use in adults, %.

Symptom/ medication use	Site, prevalence (%), N=initial sample							
	Sorowako N=40	Lake Matano N=45	Desa Nikkel N=52	Magani N=39	Kampung Baru N=40	Wawondula N=47	Wasuponda N=37	Malili N=46
Wheezing	16.2	20.9	15.2	8.6	27.0	21.0	8.1	11.9
Breathless when wheezing	20.0	33.3	26.7	8.3	40.7	43.5	8.7	18.5
Chest tightness	25.0	25.0	21.3	24.3	19.4	30.0	14.3	13.5
Nocturnal shortness of breath	25.7	23.2	14.9	18.9	20.7	29.3	31.4	13.9
Nocturnal cough	41.7	43.2	38.3	32.4	51.4	39.0	31.4	25.7
Diagnosed asthma	20.0	17	20.9	19.4	33.3	20.9	10.5	5.4
Asthma medication	14.3	13.3	17.4	27.3	47.6	11.8	33.3	14.3

Table 4.4. Prevalence of asthma symptoms, attacks, and medication use among children, %.

Symptom/ medication use	Site, prevalence (%), N=initial sample							
	Sorowako N=18	Lake Matano N=31	Desa Nikkel N=47	Magani N=19	Kampung Baru N=35	Wawondula N=50	Wasuponda N=42	Malili N=31
Wheezing	11.8	35.3	16.7	33.3	42.3	12.8	7.5	25.0
Asthma	0	6.3	11.1	33.3	20.6	13.1	2.9	4.5
Asthma medication	0	0	11.1	45.4	44.4	9.1	0	20

Rhinitis, a reaction of the eyes, nose and throat to irritants like pollen, dust, and fumes, that was diagnosed by a doctor was more prevalent in areas closer to the smelter and in the direction of prevailing night winds; Magani (26.7%), Desa Nikkel (24.5%), and Sorowako (20.0%) compared to Malili (5.6%) (Fig. 4.10).

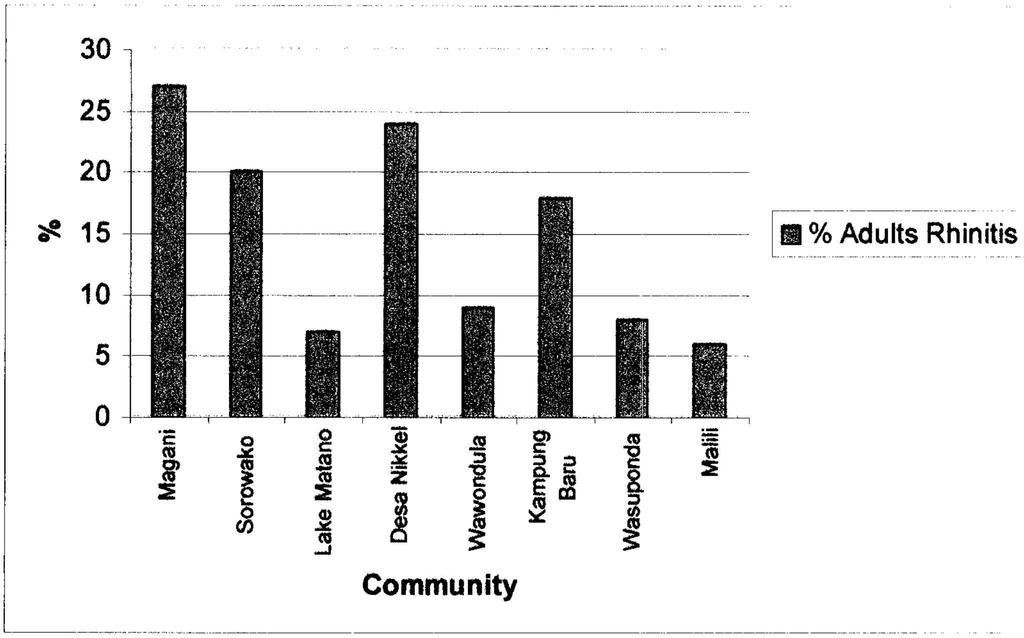

Fig. 4.10. Percentage of adults reporting rhinitis diagnosed by a doctor in the study.

4.3.1.3. Skin Conditions

Table 4.5 and 4.6 summarizes prevalence of eczema symptoms and doctor diagnosed eczema among adults and children respectively. Diagnosed eczema in adults was the highest in Wawondula (9.3%) and the lowest in Wasuponda (2.6%) (Fig. 4.11). Desa Nikkel reported high percentages of several eczema symptoms including itchy skin (24.0%), sensitive skin (28.0%), and rashes (22.9%). Magani, Kampung Baru and Wawondula communities also reported high percentages of eczema symptoms. Diagnosed eczema in children was reported the highest in Magani (25.0%) but was not reported at all in Wasuponda, Desa Nikkel and Lake Matano (Fig. 4.11). However, an eczema symptom of rashes on the folds of skin, ears, and throat were the highest in children living over Lake Matano (66.7%), Kampung Baru (58.3%), Malili (57.1%) and

Wawondula (42.8%). However, numerous skin parasites can cause various skin conditions that resemble eczema symptoms.

Table 4.5. Prevalence of eczema symptoms and diagnosed eczema among adults, %.

Symptom/illness in last year	Site, prevalence (%), N=initial sample							
	Sorowako N=40	Lake Matano N=45	Desa Nikkel N=52	Magani N=39	Kampung Baru N=40	Wawondula N=47	Wasuponda N=37	Malili N=46
Itchy skin	10.5	6.8	24.0	28.1	23.5	22.5	16.7	9.8
Sensitive skin	17.1	15.6	28.0	25.8	20.0	22.5	6.3	12.8
Rash	10.3	4.5	22.9	6.7	-	5.1	3.0	7.7
Diagnosed eczema	2.7	4.5	6.4	3.2	3.2	9.3	2.6	5.0

Table 4.6. Prevalence of eczema symptoms and diagnosed eczema among children, %.

Symptom/ illness in last year	Site, prevalence (%), N=initial sample							
	Sorowako N=18	Lake Matano N=31	Desa Nikkel N=47	Magani N=19	Kampung Baru N=35	Wawondula N=50	Wasuponda N=42	Malili N=31
Recurring rash	5.9	20.0	6.3	18.2	37.1	26.5	13.9	20.0
Rash on folds of skin, ears, throat	37.5	66.7	-	22.2	58.3	42.8	11.1	57.1
Diagnosed eczema	11.1	-	-	25.0	3.1	2.6	-	15.0

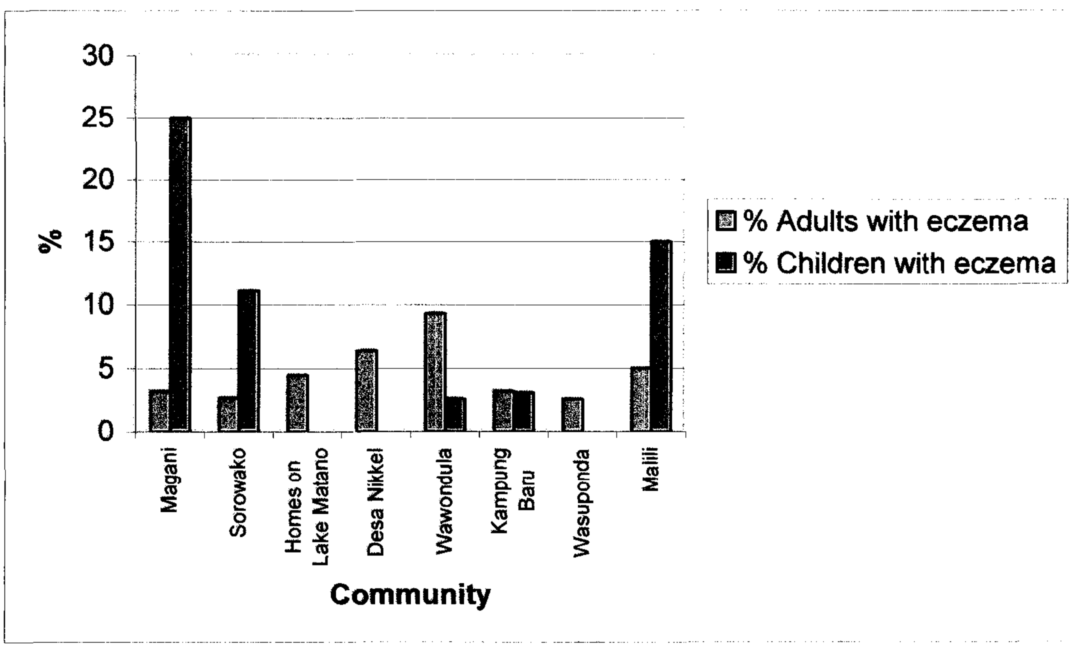

Fig. 4.11. Percentage of adults and children reporting doctor diagnosed eczema in the study.

Skin tumours diagnosed by a doctor were more prevalent in Sorowako and Magani residents (22.2% and 18.8% respectively) and those living over Lake Matano (15.9%) compared to Wasuponda (3.0%) and Malili residents (5.3%) (Fig. 4.12).

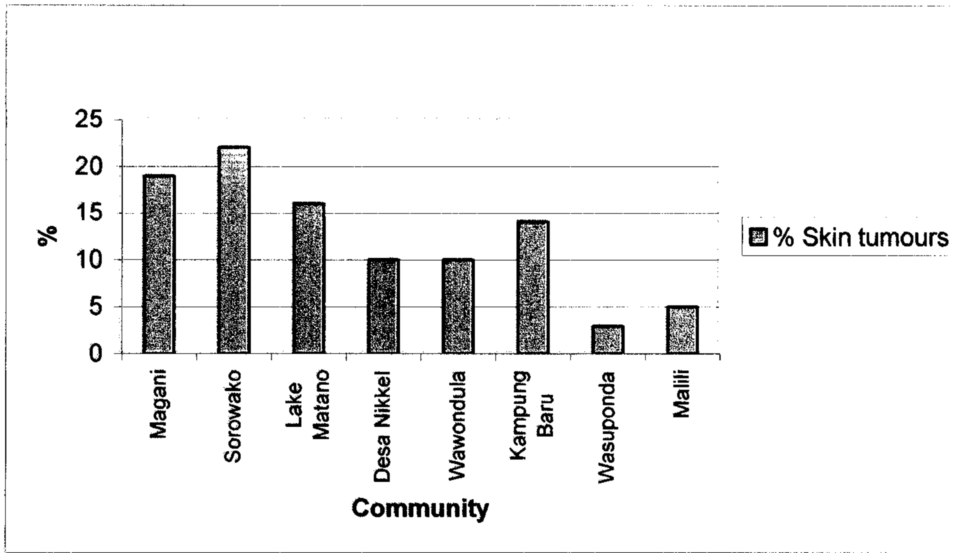

Fig. 4.12. Percentage of adults reporting doctor diagnosed skin tumors in the study.

4.3.1.4. Miscarriages and Birth Deformities

The percentage of pregnant women who have miscarried at least once was the highest in Wasuponda (35.0%) and Sorowako (27.8%) and the lowest in Desa Nikkel (5.6%) (Fig. 4.13). Miscarriages were not significantly correlated with environmental risk factors and health determinants in this study.

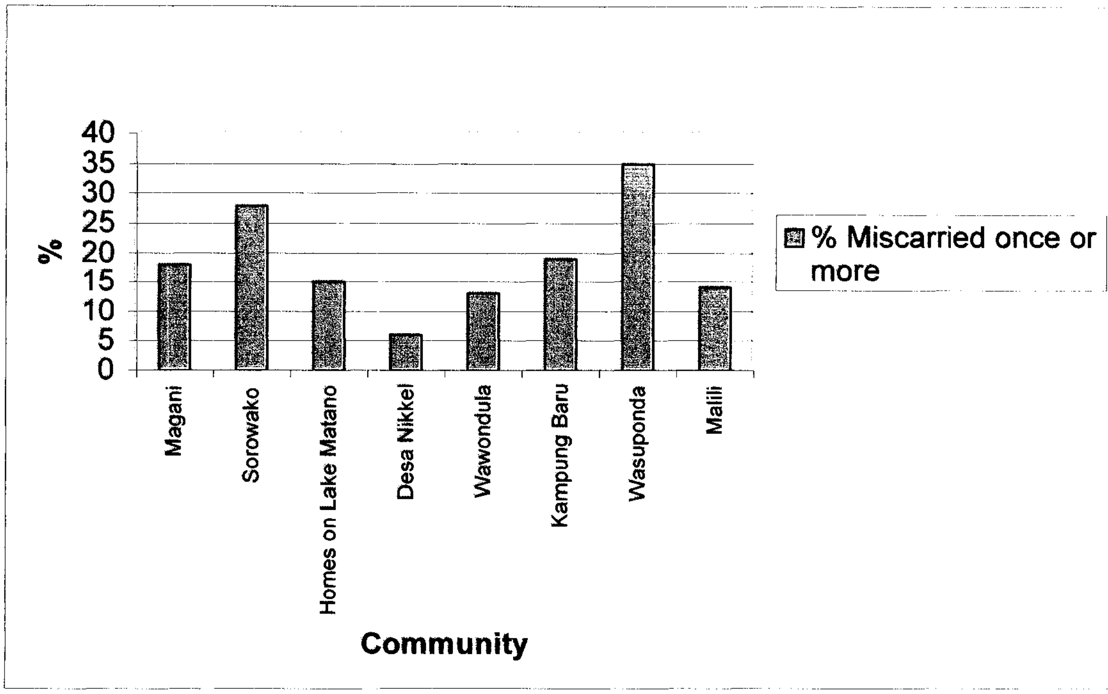

Fig. 4.13. Percentage of women who miscarried at least once in the study.

The percentage of mothers who gave birth to at least one child with a deformity is also greater in Wasuponda (13.9%) whereas other communities had 5.3% or less reporting giving birth to a child with a deformity.

4.3.1.5. Other Prevalent Illnesses

Tables 4.7 and 4.8 lists several prevalent illnesses reported in adults and children respectively in the last month or year. Over half of the people surveyed living over Lake Matano and in Kampung Baru reported their physical and emotional health as affecting their work in the last month. Adults who reported that they worry often to all the time in the last month was similar in all communities ranging from 30.0% in the Sorowako community to 16.0% in the Desa Nikkel community. More adults reported feeling depressed in Sorowako (28.2%) and Wawondula (26.3%) compared to Malili (7.5%).

Bone and joint pain in adults was reported in more than 50% of respondents from Sorowako (56.4%) and Desa Nikkel (51.0%). Bone and joint pain was reported less in the community over Lake Matano (17.8%) and Malili (18.4%). Prevalence of bone and joint pain was strongly associated with night air chromium levels ($r=0.83$).

Incidence of diagnosed high blood pressure in adults was the highest in Kampung Baru (40.0%), Wasuponda (37.8%) and Desa Nikkel (34.1%) and the lowest in Malili (11.4%). Diagnosed adult heart disease ranged from 20.6% in Kampung Baru to 2.4% in the community living over Lake Matano. Prevalence of diagnosed high blood pressure and heart disease was found to be strongly associated with 24-hour domestic dust fall accumulation ($r=0.74$ and $r=0.84$ respectively) but was negatively associated with the day mean air nickel, chromium and manganese concentrations in the communities sampled for airborne metals.

Diagnosed stomach ulcers and intestinal problems was the most prevalent in Wasuponda (18.9%) and the least prevalent in the community living over Lake Matano (2.3%).

Over one third of study participants in Desa Nikkel (39.6%), Wasuponda (38.9%) and Wawondula (34.1%) reported suffering migraine headaches.

The Wawondula community reported the highest prevalence of diagnosed diabetes (10.5%) and kidney disease (13.2%). Besides diagnosed heart disease, prevalence of diagnosed diabetes was strongly associated with prevalence of diagnosed kidney disease (r=0.95) and anemia (r=0.73) as well as part-time employment (r=0.83) and mean night airborne TSP (r=0.89). Prevalence of diagnosed kidney disease was strongly associated with part-time employment (r=0.90). Prevalence of diagnosed anemia was strongly associated with mean night airborne TSP (r=0.81) and domestic 24-hour dust fall accumulation (r=0.77).

A maximum of three people reported having hepatitis diagnosed by a doctor in Kampung Baru, Magani and Malili. Hepatitis A and B were the most common types of hepatitis reported with Hepatitis E and C also reported. Reports of parasitic conditions were generally low in all communities.

In terms of prevalent health conditions in children, learning difficulties were prevalent in all communities except Malili with peaks in Desa Nikkel (59.6%) and Wawondula (40%). Learning difficulties was not correlated with other variables. Seasonal allergies in children was also prevalent with peaks in Wawondula (47.5%) and Kampung Baru (45.2%). Prevalence of seasonal allergies in children was strongly associated with mean night airborne TSP (r=0.92).

Table 4.7. Prevalence of other illnesses surveyed in adults, %.

	Site, prevalence (%), N=initial sample							
Illness in last year	Sorowako N=40	Lake Matano N=45	Desa Nikkel N=52	Magani N=39	Kampung Baru N=40	Wawondula N=47	Wasuponda N=37	Malili N=46
Physical health affects work in last month	30.0	53.3	34.7	22.8	55.6	36.6	31.4	21.6
Emotional health affects work in last month	35.7	51.1	43.8	22.6	67.7	34.2	14.7	25.6
Worried often to all the time	30.0	19.6	16.0	22.8	25.0	26.7	22.9	20.5
Depression	28.2	20.9	19.6	13.0	16.7	26.3	22.9	7.5
Bone/joint pain	56.4	17.8	51.0	28.6	38.7	21.6	30.6	18.4
High blood pressure	21.2	11.9	34.1	23.3	40.0	25.0	37.8	11.4
Heart disease	5.9	2.4	4.4	3.6	20.6	16.7	8.6	5.7
Stomach ulcers	5.6	2.3	4.2	9.7	3.4	5.7	18.9	10.8
Hepatitis (type)	-	5.7 (A, E)	2.2 (A)	12.5 (B, B, C)	12.5 (A, B, B)	5.3 (B)	2.9 (B)	14.3 (A, A, E)
Migraines	22.9	17.4	39.6	25.8	3.6	34.1	38.9	22.2
Diabetes	5.6	-	2.1	-	6.9	10.5	5.4	-
Anemia	11.8	2.2	10.6	3.3	17.8	12.8	2.8	-
Kidney disease	5.7	2.2	2.1	-	7.1	13.2	8.3	2.8

Table 4.8. Prevalence of other illnesses surveyed in children, %.

	Site, prevalence (%), N=initial sample							
Illness	Sorowako N=18	Lake Matano N=31	Desa Nikkel N=47	Magani N=19	Kampung Baru N=35	Wawondula N=50	Wasuponda N=42	Malili N=31
Learning difficulties	27.8	9.7	59.6	26.3	31.4	40.0	28.6	-
Seasonal allergies	17.6	31.3	18.2	14.3	45.2	47.5	15.0	22.2

Table 4.9. Correlation matrix depicting significant correlations between diurnal mean TSP and airborne metal concentrations and prevalent health conditions.

	Day TSP	Night TSP	Day airborne Ni	Night airborne Ni	Day airborne Cr	Night airborne Cr	Day airborne Mn	Night airborne Mn	Day airborne Zn	Night airborne Zn	Domestic 24-hour dust fall accumulation
Adult asthma	-0.11	0.53	-0.06	0.38	-0.11	0.23	-0.11	0.36	-0.22	0.56	0.78
Adult Eczema	0.80	0.62	0.28	0.24	0.13	0.11	0.45	0.22	0.92	0.45	-0.07
Child wheezing	-0.19	0.01	-0.04	-0.18	-0.08	-0.28	-0.20	-0.24	-0.17	0.17	0.38
Child seasonal allergies	0.40	0.92*	-0.04	0.22	-0.35	-0.02	0.10	0.36	0.20	0.68	0.61
High blood pressure	-0.57	-0.03	-0.96**	-0.36	-0.92**	-0.33	-0.94**	-0.31	-0.33	0.67	0.74
Heart disease	0.14	0.81	-0.29	0.06	-0.61	-0.15	-0.17	0.26	-0.07	0.68	0.84*
Diabetes	0.35	0.89*	-0.08	0.32	-0.39	0.13	0.15	0.55	0.30	0.49	0.53
Kidney Disease	0.40	0.78	-0.12	0.13	-0.44	-0.03	0.12	0.38	0.33	0.41	0.39
Anemia	-0.02	0.81*	-0.11	0.69	-0.18	0.53	-0.04	0.72	0.09	0.73	0.77
Bone/joint pain	-0.62	-0.16	-0.14	0.70	0.23	0.83*	-0.21	0.56	-0.11	0.07	0.25
Physical health problems	-0.28	0.62	-0.57	0.20	-0.67	0.07	-0.50	0.30	-0.22	0.85*	0.65
Emotional health problems	-0.26	0.55	-0.29	0.48	-0.26	0.37	-0.30	0.46	-0.14	0.74	0.69

*Significant at the 0.05 level.
**Significant at the 0.01 level.

Table 4.10. Correlation matrix depicting significant correlations between health determinants and prevalent health conditions.

	Full Time	Part Time	Low income	Single status	Married	Smoke often	Smoke some	Smoke never
Adult asthma	-0.08	-0.07	0.65	0.29	-0.33	0.21	0.08	-0.26
Adult Eczema	-0.10	0.32	-0.11	0.76*	-0.67	0.48	0.12	-0.54
Child wheezing	-0.08	-0.67	0.62	-0.12	0.21	0.36	0.77*	-0.22
Child seasonal allergies	0.04	0.27	0.32	0.50	-0.55	0.13	0.35	-0.35
High blood pressure	-0.60	0.39	0.50	-0.42	-0.42	-0.18	-0.47	0.49
Heart disease	-0.34	0.55	0.41	-0.60	-0.60	0.14	-0.16	-0.01
Diabetes	-0.13	0.83	-0.03	-0.39	-0.39	0.29	-0.50	0.07
Kidney Disease	-0.07	0.90**	-0.20	0.48	-0.35	0.15	-0.42	0.15
Anemia	-0.28	0.25	0.53	-0.43	-0.43	0.36	-0.25	0.18
Bone/joint pain	-0.31	-0.06	0.30	0.13	0.13	0.21	0.57	0.17
Physical health problems	0.17	-0.17	0.50	-0.04	-0.05	-0.44	0.55	0.08
Emotional health problems	-0.04	-0.39	0.75	0.05	-0.18	-0.11	0.52	-0.22

*Significant at the 0.05 level.
**Significant at the 0.01 level.

4.3.1.6. General Perceptions on Health and Health Care

Table 4.11 summarizes the percentage of adults surveyed who felt their health problems are related to nickel mining and smelting in their area. Sorowako, Wawondula, Kampung Baru and Malili strongly reported feeling that their health concerns were related to nickel mining and smelting whereas Magani reported this feeling less.

Table 4.11. Respondents who Feel their Health Concerns are Related to Nickel Mining and smelting, (%)

Community	% feel health concerns related to nickel mining and smelting
Desa Nikkel	52
Sorowako	86
Magani	43
Lake Matano	64.7
Wasuponda	66.7
Wawondula	97
Kampung Baru	92.6
Malili	86

The percentage of those answering that they had a special concern for their health was quite high in all communities including 100% in Kampung Baru, 94% in Sorowako, and 93% in Wasuponda. This sentiment was expressed less in the community living over Lake Matano (43%).

Common comments on health in all communities included: PT Inco should provide greater access to community for health services (not only to employees); dust and air pollution affect health and PT Inco should take measures to reduce this pollution; and health services need to be improved. People living in Kampung Baru and over Lake Matano, considered to be perhaps more socio-economically marginalized of all the survey sites, reported no access to healthcare in greater numbers (12.8% and 11.1% respectively) while other communities mostly reported that access to healthcare was easy to difficult.

4.4. Discussion

4.4.1. Spatial Patterns of Respiratory Health Conditions

The spatial pattern of prevalent respiratory health conditions and mean TSP and domestic 24-hour dust fall amounts suggests that exposure to airborne PM and metals from the nickel mine and smelter are having an effect on some respiratory health conditions. Prevalence of asthma in adults was associated with domestic 24-hour dust fall accumulation. Adult asthma was more prevalent in Kampung Baru, Wawondula, Desa Nikkel, Magani and Sorowako, all communities located closer to the mines and smelter. Adult rhinitis was also more common in Magani, Desa Nikkel, Sorowako and Kampung Baru. Allergic rhinitis often precedes asthma onset (Linna et al., 1992). Both adult asthma and rhinitis was less prevalent in Malili, the community located furthest away from the smelter.

Prevalence of seasonal allergies in children was strongly associated with elevated mean night airborne TSP. Allergy-like symptoms are noted precursors to asthma (Toogood et al., 1989, 80 p.). Asthma symptoms such as wheezing, nocturnal loss of breath, chest tightness and coughing were generally reported in greater numbers than diagnosed asthma. Prevalence of wheezing in adults was strongly associated with mean night TSP concentrations. Asthma has been difficult to diagnose due to similarities with other illnesses like chronic bronchitis (Toogood et al., 1989) and thus may be misreported in this study.

Various active agents present in air pollution are known asthma triggers. These active agents include sulfur dioxide, silica, nickel, vanadium, iron, copper, organic residues and biological matter (Bush, 2001). Asthma is also triggered by cold air, exercise, certain medications, respiratory viral infections, and active and passive smoking (Toogood et al., 1989; Bush, 2001; Koening, 1998).

Unexpectedly, no health conditions were significantly correlated with people who smoke often. The only health condition correlated with smoking occasionally was wheezing in children. Studies have consistently found that parental smoking is linked to increased prevalence of wheezing in children (EPA, 1992). The reported number of men who smoke often in the health questionnaire was much lower than expected based on observed smoking behaviors in the community. Women generally were not observed smoking but many are exposed to cigarette smoke. Smokers are exposed to nickel and chromium in their cigarettes (WHO, 1988).

Acute respiratory diseases are the second leading cause of death in children in Indonesia (Browne et al., 1999). It was predicted that children would suffer more respiratory health conditions than adults due to children being a vulnerable sub-population to the effects of air pollution (Bush, 2001) but this was not the case for asthma with more adults suffering asthma than children in all communities except Magani. Asthma can first appear at any age (Toogood et al., 1989) and is usually not diagnosed until at least four years of age (Bush, 2001). However, the most common form of asthma is linked to environmental conditions with studies showing that 15% of adult asthma may be due to occupational exposure (Bush, 2001). Metal ions such as nickel, chromium, sulphate and platinum are noted components in occupational exposures linked to asthma (Toogood et al., 1989). Asthma symptoms such as wheezing were reported more in children than in adults in almost all communities with a high of 42.3% of Kampung Baru children. The number of children diagnosed with asthma in the surveys may be deflated due to delayed diagnosis. Asthma has often been mistaken for other common respiratory conditions. A more in depth study could look at how many cases of upper respiratory infections commonly reported at Community Health Services (PUSKESMAS) are actually asthma since people with asthma or prone to asthma are also prone to upper respiratory tract infections.

Asthma and other respiratory diseases expected to be more prevalent in households residing on the waters of Lake Matano due to damp living conditions showed similar levels seen in other communities. Lower respiratory system illnesses including coughing, phlegm and wheezing are prevalent in homes with mold and mildew (Bush, 2001; Dales et al., 1991). Mold and mildew was not restricted to households over Lake Matano but also found in households of other communities.

4.4.2. Spatial Patterns of Skin Conditions

Nickel exposure is associated with adverse skin health effects (Carson, 1986) especially a particular dermatitis known as hand eczema or 'nickel rash'. Hand eczema consists of itching, swelling, scales and cracks, and is more prevalent in women than in men but has been shown to vary depending on contact with jewellery and occupational exposure (Vahter et al., 2002). No significant correlation was found between eczema and mean airborne nickel concentrations. Continuous itchy skin symptoms were reported over twice as much in Magani and Desa Nikkel, communities closer to and downwind from the smelter than in Malili, a community further away from the smelter. There are also several skin conditions caused by parasites such as scabies that are difficult to diagnose and thus may not have been reported in this study.

4.4.3. Spatial Patterns of Parasitic Conditions

It was expected that internal parasitic conditions would be most prevalent in households living over Lake Matano. This, however, was not the case. Similar levels of malaria, diarrhea, dysentery, giardia, cholera, typhoid fever, and parasitic worms were observed in all communities.

4.4.4. Spatial Patterns of Health Determinants and other Health Conditions

Besides air pollution data from each community, other health determinant data examined in this study included education, income, work status, marital status, smoking and access to health services. Other factors that also interact to produce health effects but not encompassed in this study include social status, social support networks, working conditions, biology and genetic endowment, personal health practices and coping skills, and healthy child development (Health Canada, 1997).

Lower levels of education, high school or less, was more prevalent in Sorowako and in households over Lake Matano, while higher levels of education including university and college were more prevalent in Wawondula and Malili. Of the major health conditions reported, none were found to be associated with education levels. Higher levels of education are associated with better health since education increases employment opportunities, which in turn may lead to less stress, greater satisfaction, and increased sanitary conditions. Health education in particular is important to prevent and mitigate potential health problems (CSGS Associates, 2004).

No significant correlations were found in this study between prevalence of health conditions and unemployment. High levels of unemployment, underemployment and economic instability are linked to mental illness and adverse physical health effects in not only the unemployed and underemployed but also in their families and community (Health Canada, 1997).

The only health condition significantly correlated with low income was emotional health problems that affected work in the last month (R=0.75). The Kampung Baru community reported the highest prevalence of households in the lower monthly family income bracket of Rp. 250,000 and less. Emotional problems affecting work were also the highest in this community at 67.7% and access to health services was the most limited with 12.8% reporting no access at all. Higher incomes are generally associated with improved health because of a greater ability to pay for medical services, safe and clean housing, and sufficient and nutritious food (Health Canada, 1997).

Most of the adults interviewed in each community were married and many identified social support networks in their community as what they liked most about their community. The only health condition correlated to being single was eczema (r=0.76). Eczema flares have been linked to emotional stress (American Family Physician, 1999). Emotional support garnered from social relationships is important in preventing and overcoming health conditions (CSGS Associates, 2004).

No significant correlations were found between health conditions and those reporting that they worry often. Worries of contamination and unsafe surrounding environments cause stress levels to increase to a level that may also compromise immune systems (CSGS Associates, 2004).

The Sorowako smelter emissions have been linked to increased incidences of respiratory illnesses in surrounding communities (Ballard, 2001). At a Venezuelan laterite nickel mine and smelter opened in 2001, residents are currently complaining that pollution from the mine and smelter has affected their crops and health. Increased incidences of asthma and respiratory problems in children and dermatitis have been noted (Medina, 2005). In this study, there was a higher prevalence of several health conditions in communities closer to and downwind from the nickel smelter compared to Malili, a community further away from the nickel smelter and outside the smelter fallout zone estimated by the company (PT Inco, 1995).

Poor air quality in Indonesia caused by forest fires, and poor industrial and transportation emission regulations has seriously affected public health. Respiratory tract inflammation, one condition linked to poor air quality, was the sixth leading cause of death in Indonesia after accidents, diarrhea, cardiovascular disease, tuberculosis, and measles (EIA, 2004). In addition to the host of pollutants mentioned above, humans can also be exposed to toxic air pollutants that originate from nickel mining and smelting activities. Routes of exposure include inhalation, ingestion of contaminated food and water, and skin contact with contaminated soil, water or dust. Certain contaminants also accumulate in certain plants and can be passed up the food chain in elevated concentrations (Yassi et al., 2001).

Particles that are 0.25 μm and smaller in diameter tend to originate from anthropogenic sources and appear to have more significant effect on human health than larger particles (Yassi et al., 2001; ESCAP, 2001; ICPS, 1991a). Currently disputed, the E.P.A. estimates

PM_{10} levels and associated health and mortality effects by applying a factor of 0.5 to 0.6 to mean TSP levels. Every change of 10 $\mu g/m^3$ in PM_{10} is associated with a 0.07 % change in mortality and a 3.4 % increase in mortality due to respiratory conditions (Browne et al., 1999; EPA, 1984). The E.P.A. conservative factor of 0.5 was applied to the range of mean TSP levels found in the dry season. During the day of the dry season, the mean TSP level in Wawondula was 89.10 $\mu g/m^3$ (PM_{10} 43.06) higher than in Kampung Baru. The difference in TSP concentration between Wawondula and Kampung Baru translates into an estimated increase of 3.0% in mortality for all causes of death and of 14.6% increase in mortality due to respiratory causes for those living in Wawondula. During the night of the dry season, the mean TSP level in Wawondula was 59.76 $\mu g/m^3$ (PM_{10} 29.88) higher than in Magani. The difference in TSP concentration between Wawondula and Magani translates into a 2.1% increase in mortality for all causes of death and a 10.2% increase in mortality due to respiratory causes for those living in Wawondula.

Humans require a number of metals including nickel to maintain their health. Generally, humans are regularly exposed to a complex mixture of metals at low concentrations but mobilization of trace quantities of various toxic metals can lead to excessive exposure and potential health effects. Metal interactions and effects on human health are currently under investigation, and dose-response relationships are being reviewed as a result. Nickel interacts with other compounds to produce either an additive, synergistic or antagonistic effect (Eisler, 1998). Rabbits that inhaled both nickel and trivalent chromium had more severe respiratory effects than those exposed to nickel alone (USPHS, 1993;

Eisler, 1998). Nickel has a synergistic effect on the carcinogenicities of asbestos and various PAHs (Carson, 1986; USEPA, 1980). Manganese has been shown to reduce nickel toxicity (USPHS, 1993; WHO, 1991b; Eisler, 1998) and nickel accumulation in some organs (Murthy et al., 1979; Eisler, 1998).

Approximately 75-90% of airborne nickel is found in the PM_{10} fraction (Mohanraj et al., 2004). Mean airborne nickel concentrations were especially high in the dry season in communities closest to the nickel smelter; Sorowako (0.213 $\mu g/m^3$), Magani (0.154 $\mu g/m^3$), Desa Nikkel (0.128 $\mu g/m^3$), and Wawondula (0.181 $\mu g/m^3$). Desa Nikkel also reported elevated airborne nickel concentrations in the rainy season (0.126 $\mu g/m^3$) (see Chapter 3).

Indications of acute exposure to elevated nickel levels include skin irritation and allergic sensitization. Indications of chronic exposure to nickel include asthma and other respiratory health conditions as well as lung and nasal cancers (California Air Resources Board, 2004). Adverse reproductive health effects and birth defects were found in rats and mice eating or drinking large amounts of soluble nickel (ATSDR, 1995).

Various forms of nickel have demonstrated different carcinogenic, mutagenic, and teratogenic effects on organisms such as fish, rats and humans (Nordberg et al., 1985). Health investigations conducted at the Falconbridge nickel refinery in Norway in the 1960s and conclusions made by nickel toxicologist Sir Richard Doll in 1989 confirmed soluble nickel as a carcinogen at concentrations in excess of 1 mg/m^3 and less soluble nickel as a carcinogen at concentrations in excess of 10 mg/m^3 (Norseth, 2003). Nickel dust, nickel subsulfide, nickel oxide, and nickel carbonyl are noted as causing the more serious health conditions such as acute pneumonitis, central nervous system disorder, skin disorders such as dermatitis, and lung and nasal cavity cancers (Eisler, 1998). Human carcinogenicity has also been shown in exposure to nickel metal (Merian, 1984). Epidemiological studies including a study at a nickel refinery in 1990 found that workers had 5 times higher the risk of developing lung cancer and 150 times higher the risk of developing nasal cavity cancer (Lin et al., 1990; Sunderman, Jr., 1985). Very few people in the health questionnaire reported working at the nickel smelter and thus no links could be made between occupational exposure and health conditions.

Prevalence of high blood pressure and heart disease reported in the health survey was strongly associated with domestic 24-hour dust fall accumulation. Reported incidences of high blood pressure were more common in communities closer to the smelter and the lowest in Malili, the community furthest from the smelter. However, significant negative correlations between prevalence of high blood pressure and the concentration of numerous heavy metals like nickel, chromium and manganese found in this study suggests other causes of high blood pressure than airborne particulate. Cardiovascular-related deaths and hospitalizations have been linked to particulate air pollution (Ibald-Mulli et al., 2004). Air pollution affects a part of the nervous system that controls blood pressure, which possibly increases the risk of heart attacks and other cardiac conditions (Ibald-Mulli et al., 2001). Recent research suggests that particulate matter affects cardiovascular health by altering the autonomic nervous system (Ibald-Mulli et al., 2004;

Dockery, 2001), causing systemic and local inflammatory events (Ibald-Mulli et al., 2004; Liao et al., 1999; Seaton et al., 1995), and altering blood coagulability (Ibald-Mulli et al., 2004; Peters et al., 2000; Pekkanen et al., 2000). Asthma has also been linked to cardiovascular disease and increased blood pressure (Toogood et al., 1989, 103 p.).

Prevalence of reported learning difficulties and children with deformities could have been deflated due to the cultural taboos associated with these diseases. However, prevalence of learning difficulties in children was reported more than expected. No significant correlations were found between these health conditions and environmental risk factors such as airborne metal concentrations, and socio-economic factors such as income and employment.

The percentage of those answering that they had a special concern for their health was quite high in all communities including 100% in Kampung Baru, 94% in Sorowako, and 93% in Wasuponda. However, satisfaction to healthcare services was generally also reported as high. This could be attributed to recent developments of more open access to PT Inco healthcare services that before the year 2000 were restricted for non-employees. Also, many respondents may come from rural areas and may be used to fewer services and thus have lower expectations (CSGS Associates, 2004). There also may be a level of complacency and some may not want to threaten PT Inco by being critical because they are a potential source of employment. People have also expressed their concerns of an increased military presence if they protest too much.

Besides nickel, chromium is another metal of concern at the study site. Trivalent chromium is an essential element for humans and animals (Fishbein, 1985) but hexavalent chromium, which is usually the form found in industrial wastes, is more toxic (Mutti et al., 1985, Merian, 1985; WHO, 1988; Fishbein, 1985). Common health problems associated with chromium exposure include ulcerations, dermatitis, and respiratory cancers (WHO, 1988). Mean airborne chromium concentrations were below amounts commonly found in non-industralized areas of 0.1 $\mu g/m^3$ (WHO, 1988).

The health questionnaire results did not show any significant correlation between air chromium concentrations and prevalence of health conditions commonly associated with elevated chromium exposure. Prevalence of bone and joint pain was the only health condition associated with mean night air chromium concentrations.

Smelter emissions were brought down to air quality guidelines in the late nineties when Electro-Static Precipitators were placed on several smelter stacks in phases. One furnace stack was equipped with a recently developed cleaning technology in 2005. For the first time, the furnace stack complied with guidelines but other furnace stacks still exceed air quality guidelines. There are plans to install the newly developed cleaning technologies on the other stacks (D. Tetradiono, Pers. Comm., 2005). Compliance with environmental quality guidelines does not mean no adverse health effects. Previous decades of non-compliance also could mean that communities were exposed to acute levels of pollution and therefore possibly suffer long-term adverse health effects as a result. Also, chronic exposure to slightly elevated levels of heavy metals could also be a health risk for communities located around the nickel mines and smelter. The potential environmental and human health effects of PT Inco's scheduled increased annual nickel production from 150 million pounds to a record level of 200 million pounds by 2009 must also be assessed.

Of the most common illnesses reported during July 2004 at the PT Inco Wasuponda health clinic and at community health services in Desa Nikel, Wasuponda, and Timampu (near Kampung Baru), upper respiratory tract infections, also known as the common cold, was generally the most common ailment treated. Diarrhea, and skin, stomach, muscle and bone conditions were other common illnesses reported in the communities. Table 4.12 lists percentage breakdown of the top five most common illnesses treated in each clinic. Health data is not available from Malili. In this study, the highest prevalence of adults suffering often from respiratory infections in the last year was from Kampung Baru (21.1%) while the lowest rate was reported in Malili (4.76%).

Table 4.12. Percentage breakdown of the five most common illnesses reported at Community Health Services and the PT Inco health clinic in the study site in July 2004.

Community Clinic	1	2	3	4	5
Sorowako Community Health Services, N=769	Upper respiratory tract infections, 66.4%	Muscle-bone conditions, 15.9%	Skin conditions, 8.3%	Diarrhea, 5.9%	Hypertension, 3.5%
Wasuponda Community Health Services, N=266	Diarrhea, 22.6%	Skin conditions, 20.3%	Upper respiratory tract infections (same as #4), 19.2%	Gastritis (same as #3), 19.2%	Accidents, 18.8%
Wasuponda PT Inco Clinic, N=473	Upper respiratory tract infections, 55.8%	Digestive system condition, 16.9%	Accident, 10.0%	Skin condition, 9.1%	Maternal planning, 8.2%
Wawondula Community Health Services, N=710	Upper respiratory tract infections, 34.4%	Post natal care, 24.0%	Skin conditions, 15.1%	Diarrhea, 13.7%	Muscle-bone conditions, 13.0%
Timampu Community Health Services, N=492	Upper respiratory tract infections, 39.0%	Gastritis, 19.1%	Post-natal care, 16.1%	Diarrhea, 13.0%	Skin conditions, 12.8%

Malnutrition, poor sanitation, overcrowding, and low immunization coverage are other factors influencing community health in Indonesia. Health impacts of air pollution may be more severe on people exposed to such conditions as well as those with compromised immune systems, diseases, and the elderly, infants and children (ESCAP, 2001; NRC, 1999).

4.4.5. Focus Group Discussion on Mining and Health

The focus group discussion was attended mostly by village leaders who were very knowledgeable about environmental issues concerning nickel mining and smelting.

However, concerns were expressed regarding a lack of information or consultation on details of the mine and smelter's environmental monitoring and management such as the effectiveness of the Electro-Static Precipitators in reducing air pollution.

Regarding the chapter review, community members noted that practices to minimize dust exposure outlined in the chapter were not being done. For example, PT Inco plant workers do not change their clothes or shower after leaving the mining location as suggested. It was also noted that contractors for mining companies usually have less stringent safety standards for their employees compared to the mining company's employees, and thus may be more likely to suffer health and safety problems. For example, PT Inco workers are given masks but not all contract workers are provided with masks that would reduce their dust exposure.

Participants in the discussion mentioned that PT Inco should inform community members about ways to reduce dust exposure at home and at work to the community. There are some in the community who take precautions to avoid dust exposure like wearing masks while driving motorcycles but many, like security employees at the PT Inco plant site, which is a very dusty area, were observed only wearing dust masks occasionally. The chapter also discussed closing doors and windows to reduce dust accumulation in the household but many responded that this would be difficult because open doors and convening in open spaces are significant parts of their culture.

Community members were also concerned about the company's air quality monitoring. PT Inco's air sampler in Wasuponda is located under a tree at the PT Inco clinic, which does not follow air sampling protocol of being far enough away from obstructions to ensure a representative sample.

Water was a major concern for the Sorowako and surrounding communities. The discussion focused on promises made in the company's contract of work with the government of Indonesia to provide drinking water to the community. PT Inco has only recently begun providing treated drinking water to most of the population of Sorowako but many still bathe, wash and play in the lakes, which may pose potential health risks. Sources of water contamination in Lake Matano include mining and smelting runoff containing various heavy metals as well as domestic sewage and garbage disposal along the inhabited lakeshore.

Community representatives from Wawondula, a settlement established especially for PT Inco's unskilled workforce, discussed their concerns with one of their district's drinking water source. The primary drinking water source was described as insufficient to meet the needs of the community. The secondary drinking water source was described as having high levels of organic matter and suspended sediment. It was agreed that the community-based research team would take water samples from these two drinking water sources. The secondary drinking water source had elevated concentrations of nickel (136.9 μg/L), cobalt (10.8 μg/L), chromium (17.6 μg/L), manganese (112.5 μg/L), aluminum (80.7 μg/L) and titanium (2.58 μg/L) compared to the primary drinking water source.

Many participants felt that health officials should be responsible for providing information about how health conditions are related to the nickel mining and smelting operations in their area. According to Dr. Hasmin, a local doctor who attended the focus group discussion, Community Health Services may not have resources to do this task. Many participants agreed that a more extensive community health assessment is needed in the form of an epidemiological study.

4.4.6. Limitations

The community-based research provided many advantages in terms of building community capacity but also posed several limitations. The community-based research had limited financial and human resources and a short time frame to complete the data collection. The relatively small sample size and convenience sampling method was useful in giving an overview of health conditions and concerns but provided less precise measurements of health conditions and health determinants.

Since a health condition may be caused by a complex interaction of health determinants and environmental exposures, isolating a possible cause or measuring its effect can be arduous. Exposure characterization, dose estimation, effects characterization and dose-response assessments are factors to consider in an appropriate human health risk assessment (Norseth, 2003).

Other factors that should be included when exploring the prevalence of conditions like asthma, rhinitis and eczema are differences in humidity, climatic conditions, air quality, and exposure to house dust mites, mold and cockroaches (Habbick et al., 1999).

The health questionnaire did not address spiritual well being that also affects health (CSGS Associates, 2004). The health questionnaire also did not explore several personal health practices like alcohol consumption, physical activity and exercise, eating habits, sexual practices, coping skills, and genetic make-up/pre-deposition to disease due to either cultural reasons or it was beyond the scope of this questionnaire. This information would have been useful in linking other factors that may be affecting health.

4.4.7. Importance of Community-Based Research

Besides baseline data collected by PT Inco for their environmental impact assessment and environmental monitoring reports, no other human health research has been published at the relatively isolated study site. Community-based research is important because it informs the communities involved of pertinent environmental health issues and involves community training and participation in as many aspects of the research from sampling to analysis to interpretation of results. Communities are then able to continue the environmental and health monitoring independently. The monitoring results and analysis give communities information on how to critique and inform public policy decision-making on such items as environmental assessment processes, mining regulations, and community health.

4.5. Conclusions and Recommendations

The health questionnaire results revealed that some health conditions such as adult and child asthma, rhinitis and skin tumours were more prevalent in communities closer to and downwind from the nickel mines and smelter compared to Malili, a community located further away from the mines and smelter. Correlations between domestic 24-hour dust fall accumulation and mean night TSP suggest a potential human health risk associated with nickel mining and smelting in nearby communities. Mean night TSP was strongly correlated with prevalence of diabetes and seasonal allergies in children. Domestic 24-hour dust fall accumulation was strongly correlated with prevalence of adult asthma, high blood pressure, heart disease, and anemia.

Epidemiological studies and human health risk assessments are recommended to identify health problems and determine causes. Blood, hair and fingernail sampling would be useful in determining heavy metal levels in the population. Future recommended research questions in such a risk assessment could include: 1) What risks are associated with exposure to Lake Matano waters, in particular along the shore line at Sorowako?; 2) What are the health risks to and the conditions found in workers at the mine and smelter sites, and their families?; 3) Are there any dangers associated with eating fish or shellfish from local lakes, in particular from mine and smelter runoff areas that have high heavy metal concentrations?; and 4) What are the effects of socio-economic class attitudes, and differences in income on community health?

Assessing pollution and its effects on human health is very complex. Assessing the total intake and uptake of particulate matter and associated metals and other components from the combined exposures can more adequately describe whether there is a human health risk associated with the various pollutant levels that exist in an environment.

The community-based component of this research was important for community members in that it not only provided them with baseline community health data but it also gave them knowledge and experience to continually monitor and address environmental and health concerns in their community.

Chapter 5: History and Peoples of Sorowako, Indonesia

5.1. Sorowako Before Colonialism

Historically, mountains and impassable rivers kept the Sorowako area on the Indonesian island of Sulawesi in relative isolation, which led to several sparse populations and high linguistic diversity throughout the area. Before the twentieth century, Sorowakans were shifting cultivators and jungle foragers. Sorowakans then came under the influence of the Bugis people, famous across continents for their maritime trade and devotion to Islam (Robinson, 1986).

5.2. Sorowako During the Dutch Colonialism Period

The Dutch colonized Indonesia from the 1600s to 1945. In 1905, the Dutch launched a military offensive in Sulawesi, and by 1908 established a Dutch civil administration in South Sulawesi, the province where Sorowako is located. Colonialism brought restrictions on the lives of Indonesians including the Sorowakans. A number of customary practices like headhunting and warfare were banned. Some of these restrictions were regarded as beneficial in bringing peace to the area, but the prohibition against secondary burials and the erection of village shrines were met with more resistance. The colonial government also passed regulations that forced communities like Sorowako to establish rice paddies. This was an attempt by the government to gain greater control of the people by bringing them down from the hills and into settlements (Robinson, 1986).

Nickel mining has been noted in the Sorowako/Lake Matano area as early as the Majapahit Kingdom era of 1364 (Sangaji, 2003). The Lake Matano area became the focus for Dutch mineral exploration in the 1930s. During the 1930s, two Dutch companies held contracts for nickel mining in the Sorowako area; Mijnbouw Maatschappij Celebes and Mijnbouw Maatschappij Toli Toli. Mijnbouw Maatschappij Celebes began mineral exploration of nickel, chrome, iron, and cobalt in the Sorowako area in 1941 but did little mining as it was taken over by Japanese companies during the Japanese invasion of Indonesia in 1942. During the Japanese occupation from 1942 to 1943, nickel reserves exploited in the area were supplied to Japan and used in their war effort (ter Braake, 1977). From 1942 to 1945, Sumitomo Metal Mining Co. from Japan took over the Mijnbouw Maatschappij Toli Toli mine in Southeast Sulawesi, where it also built a nickel processing plant. Nickel production reached 27,000 tons in 1942 and 58,000 tons in 1944 (Sangaji, 2003).

5.3. Sorowako After Indonesian Independence

Indonesia gained independence in 1945. Islamic rebellions against the central government aimed at achieving an Islamic state known as the DKI/TII Kahar Muzzakar followed independence from 1950 to 1965. This was a period of hardship for the Sorowako community, especially the mostly Christian indigenous Karonsi'e Dongi community (see Sec. 5.6) who fled to different parts of Sulawesi to escape the conflict. The Islamic rebellion ended with the change of government from the nationalist Sukarno regime to the "New Order" regime of General Suharto in 1967 (Robinson, 1986).

5.4. Nickel Mining and Processing in Sorowako

The Suharto regime made foreign investment and economic development as its main priorities and began signing joint ventures with multinational companies. Indonesia signed its second contract of work with a foreign mining investor in 1968, with the Canadian nickel mining company, Inco Ltd., to develop the nickel mining operation in Sorowako. Inco's contract provided varying levels of royalties, and stipulated the conversion of 20% equity to Indonesia within the first ten years of the project. PT Inco's contract allowed for an exploration area of 6.6 million hectares that covered three provinces on the island of Sulawesi; South, Central, and Southeast Sulawesi (Sangaji, 2002). In 1973, the project was deemed feasible and Inco proceeded with building a processing plant, roads and a wharf (Robinson, 1986).

Members of the Sorowakan community, many who just returned home after self-imposed exile during the time of the Islamic State, stumbled upon a large-scale nickel mining operation where once they lived and where their crops grew just some years before (Robinson, 1986).

The oil price rise in 1973 led PT Inco to search for a way to power its plant. PT Inco decided to build a hydroelectric dam on the Larona River. In order to make this project feasible, the plant had to be expanded. PT Inco was granted approval from the Indonesian government in 1975 for an expansion of their operations. The expansion led to the increased capacity of the plant from 35 million pounds of nickel matte per year to 100 million pounds, making it one of the largest low-cost nickel producers in the world. The dam flooded nearby villages, coconut groves, rice fields and a mosque. The dam also prevented the migration of native eels that was a major source of food and protein for the local communities (Robinson, 1986). In 1980, 95 families from the shores of Lake Towuti filed a compensation suit against PT Inco in the Makassar court. The community demanded Rp. 750 million (approximately US$ 375,000 at an exchange rate of Rp. 2000 for US$1) in compensation for the damaged mosque, rice fields, gardens and homes caused by the flooding. The case was resolved out of court with PT Inco agreeing to build a new mosque and pay the compensation (Aditjondro, 2001).

PT Inco opened its nickel smelter in 1977 in a ceremony attended by the Indonesian President Suharto. PT Inco blamed low world nickel prices for various cost saving measures it implemented like laying off workers, restructuring the labour force and cutting costs not directly linked to nickel production. These cuts included the town bus, clean water for the village residents, and personnel training (Robinson, 1986).

Australian anthropologist Kathryn Robinson published a book about Sorowako in 1986 called: "Stepchildren of Progress: The Political Economy of Development in an

Indonesian Mining Town." Robinson used the popular Indonesian metaphor in the title of her book to describe how Sorowakans felt being the original inhabitants of the area but not the prime beneficiaries of the nickel development. Sorowakans felt pushed aside and treated like stepchildren while newcomers e ceived the "fruits" of development. Villagers complained that PT Inco's contributions to community development were only being given to PT Inco employees of a certain rank. Robinson quoted one villager as saying: "We are given the bones while others eat the meat" (Robinson, 1986).

The fundamental change and grievance that Robinson (1986) observed was the loss of the community's most productive agricultural land for the mining project that included an airport, sports oval, golf course and staff housing sites (Robinson, 1986; Ballard, 2001). Robinson (1986) noted a resulting paradox where in pre-colonial times, indigenous Sorowakans were once well known master blacksmiths, smelting iron ore to create knives and agricultural tools, but had become unskilled labourers in a multi-million dollar nickel mining operation.

Sorowakans were force to free land in 1972 (Sangaji, 2003). The total land bill paid by PT Inco in 1974 was US$100,000, while Inco's total investment in the PT Inco nickel project was US$850 million. Sorowako landowners were not involved in the land negotiations (Ballard, 2001). PT Inco paid another US$80,000 in land compensation to silence criticisms but 75% of the community still refused the land payment into the 1980s (Ballard, 2001). Land compensation in most cases did not account for loss of crops and livelihoods or accounted very little for standing crops and commercial trees (Ballard, 2001). For most, the land compensation was inadequate to establish an alternative source of income like building a house to rent or opening a small business. Most refused to accept the compensation that they felt was inadequate. Military and police attempted to coerce the community into accepting the compensation. Andi Baso, long-time leader of the Indigenous Sorowako Community Association (KWAS), refused to accept the compensation and was jailed for eight days for his action that was considered an 'anti-development' act by the State (Sangaji, 2002). Two hundred farmers were forced to accept the compensation of two cents per square metre (Aditjondro, 1982). Those who accepted the compensation had trouble getting it due to corruption and mismanagement of funds at the regional government office. Village leaders could not protest too much for fear they would be detained by provincial governments (Robinson, 1986). The risk of being labelled a dissident and potential communist held grave consequences during the Suharto regime that ended in 1997.

With Suharto gone, a wider window of political freedom was opened, and KWAS continued to make land claims over the Old Camp area, which is currently a PT Inco company housing site (Fig. 5.1). The issue was brought to courts in Palopo and the provincial capital Makassar in 1999 but the community was denied their claims (Sangaji, 2001a; Sangaji, 2001b). From 1999 to 2005, community demonstrations have been held in Sorowako calling for a renegotiation of the original land sale (Ballard, 2001). The most recent action occurred on September 15, 2005 when eight community representatives were joined with over 300 university students and NGO representatives from Makassar in a demonstration that demanded a meeting with the President Director of PT Inco (Daya, Pers. Comm., September 15, 2005).

As the mining operations developed, rural Sorowako was transformed into a small town that soon became overcrowded with people from all around Sulawesi and Indonesia seeking work at the mining operation. PT Inco applied poor infrastructure development planning by developing next to the lakeshore where an already settled population would become overcrowded and lake pollution would result (Ballard, 2001). It is estimated that less than one third of the Sorowako area's population who do not work at the mine are indigenous Sorowakans (Ballard, 2001).

Training and employment at the PT Inco nickel mines and smelter for local people were very limited during the early years of the project. Only 12% of the original construction workforce was from the local district. The local production phase workforce increased from 39% in 1978 to 58% in 1985 but 22% of this amount represented employment as casual labourers (Ballard, 2001). PT Inco contractors tend to hire more local people than the company (Ballard, 2001). Foreign employees were employed at professional and managerial positions with few Indonesians in these positions (Robinson, 1986). In 1998, KWAS released a statement requesting that Sorowako citizens be given priority in employment at the mining operations, access to education and trainings, and permanent employment as opposed to contract work (Sangaji, 2002). Today, community members are still upset over dismal employment opportunities. Employment opportunities for women have also been very limited (Ballard, 2001).

Working conditions were precarious especially in the early years of the mining operation. In 1990, ten workers were killed in a smelter accident (Marr, 1993). In 2000, Hamzah Baso died when the truck he was driving while depositing slag tipped over a cliff into the valley of molten slag (Sangaji, 2002).

Labour relations at the nickel mine and smelter are regulated by the government. There is a house union for PT Inco managers and workers. Regional military commanders acting on the side of the company have intervened in several labour disputes (Ballard, 2001). On July 29, 2005, 250 former PT Inco employees held a demonstration in Sorowako demanding a meeting with PT Inco to discuss a resolution to worker severance and other labour issues. Labour problems persist today (Tribun Timur, 2005).

Agricultural production did remain the main source of livelihood for some in the community. However, loss of paddy fields meant it was difficult to maintain this livelihood. Rice farmers also sought paid work to supplement their family income (Robinson, 1986). Cocoa, beans, tomatoes, copra, rice, cassava, yams, tobacco, spices, and various tropical fruits are planted by people living in and around Sorowako (Sangaji, 2002). Before the mining operations, most of the population were farmers and all had access to land that they could cultivate. The farmers were dependent on labour exchange with others. If there was a surplus of rice or another harvest, there was a kinsmen obligation to provide for the less fortunate in the village (Robinson, 1986; Manata, 2003).

Robinson (1986) observed that there was a shortage of labour that was never experienced before, especially at planting and harvesting time.

The mining operations monopolized large tracts of land. PT Inco strip-mined seven hills behind the Sorowako plain by the mid 1980s. Tracts of community forest resources like dammar and rattan were destroyed. Those who collected jungle resources and farmed had to travel further because these areas were either destroyed or the company prohibited access to these areas. There was confusion over who was in charge, the government or the company, because company security guards dictated where the villagers traveled. PT Inco banned the keeping of buffalo because they said buffalo had destroyed gardens in the town site. Hunting dogs were shot by company personnel because of a rabies scare. PT Inco prohibited the slash and burn cultivation of the slopes along the town site, claiming it was a fire hazard (Robinson, 1986).

Robinson (1986) observed the disparity of living conditions between the PT Inco managers, and staff, and the villagers not employed at the mining operations. These disparities changed significantly in 2000 and 2004 but still persists in some forms today. The expatriate staff still live in an enclave with spacious weatherboard bungalows, wide streets, manicured lawns and gardens (Fig. 5.1). Supermarkets, golf courses, tennis and badminton courts, running water, electricity, telephones, and air-conditioning are facilities once only available to this privileged community.

Fig. 5.1. Housing of PT Inco employees, June 2002.

The expatriate general manager of the nickel mine and smelter still lives in seclusion in a quiet bay on the shore of Lake Matano. The employee's status generally determined which company housing site and its amenities that they inhabited. Company housing sites B and C were built for senior management staff. Company housing sites D and F were built for PT Inco staff and contractors. The company housing sites, with the exception of company housing site F or Magani, was off limits to native Sorowakans until 2000. In contrast to the company housing, the houses of villagers were, and still are, smaller, simpler in construction and built closer together. Many streets still are narrow, and dusty or muddy, depending on the weather. Tiny shops and stalls still compete for space alongside the main road (Robinson, 1986) (Fig. 5.2).

Fig. 5.2. Sorowako market, August 2004.

Newcomers from various parts of Sulawesi as well as the other islands of Indonesia came to Sorowako seeking employment at the nickel mines and smelter. PT Inco's decision to only house the upper half of the workforce and the land acquisition for the mining operations caused land alienation and squeezed the population into a small area where overcrowding and the building of illegal shanties on top of Lake Matano occurred (Fig. 5.3).

Fig. 5.3. Shanties over Lake Matano, August 2004 (Credit: Evan Edinger).

The immigrants and Sorowakans mingled in daily lives at work but there was a tendency for segregation with Sorowakans living in the Old Village and immigrants living in the New Village. The indigenous Sorowakans found themselves in intense competition with the immigrants for water supply, jobs, housing land, and scarce resources. Sorowakans felt dispossessed and saw the immigrants being favoured by their own, for example in hiring practices (Robinson, 1986).

Today, nearly 1000 people live in unsanitary and unhealthy living conditions in houses over the water of Lake Matano. Lake water once used untreated for household needs, bathing and drinking water became quickly fouled with domestic sewage. With no garbage disposal system, garbage quickly piled up in this part of the lake found along Sorowako (Fig. 5.4). Three samples taken for *E. Coli* by Robinson (1986) were above

2400 MPN, an order of magnitude higher than the acceptable Australian standard of 200 MPN. These high levels of bacteria were found also at a time when raw sewage had been reduced from the town site. Bacterial levels in the 1970s were probably worse. Villagers also expressed concern over the silt in the water that made it impossible to wash and bathe, and linked increase in incidences of illnesses, in particular stomach ailments and itching after bathing, to germs in the water (Robinson, 1986, p. 205). The community asked PT Inco repeatedly to take responsibility for the problem. PT Inco eventually installed standpipes that provided access to clean water but then there were problems in access to the standpipes so the people used this water only for drinking but still bathed and washed clothes in the lake (Robinson, 1986).

Fig. 5.4. Garbage along Lake Matano shore, August 2004 (Credit: Tracy Glynn).

Lake Matano is the source of drinking water for both the PT Inco company housing areas and for the Sorowako and Desa Nikkel communities. Prior to PT Inco's commencement of operations in the late 1970's, Desa Nikkel residents accessed water directly from the lake. In the late 1970's, PT Inco put pipestands in Desa Nikkel to provide outdoor water sourced directly from the lake to village residents, the source was not far from the sewer outfall (Fig. 5.5). The PT Inco housing sites were provided with a separate treated water system. Many Sorowako residents were irritated by this "separate and not equal" access to water (Edinger In Press). Severe coliform bacterial contamination of both the lake water and the water delivered through outdoor pipestands was found in water testing 2002 (Edinger In Press). In 2002, PT Inco began extending the treated water system to the houses of Sorowako and Desa Nikkel residents. It was only in 2004 that most of the community gained access to the same treated drinking water supply as PT Inco staff but those living over the lake waters are still observed to be in direct contact with the lake water through washing and recreation. Before the year 2000, unpolluted lake recreational areas in the PT Inco housing area were off limits to native Sorowakans.

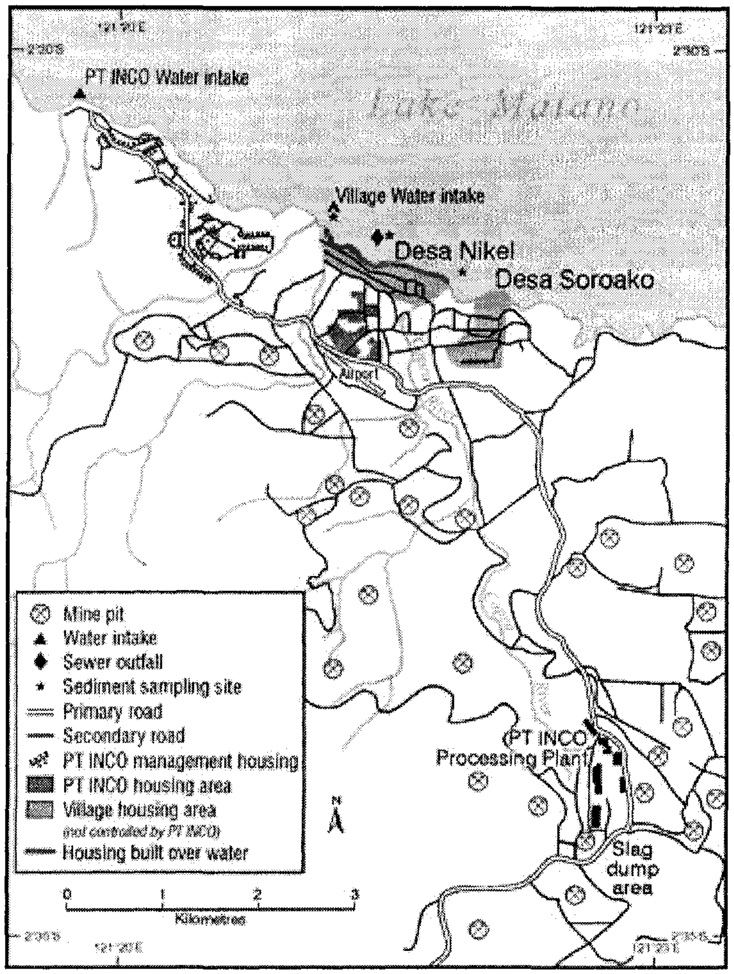

Fig. 5.5. Sorowako area showing separate village and PT Inco water intake (Source: Edinger, in press).

A new settlement is planned just off the shores of the southeast portion of Lake Matano. Villa Lake Matano is the current name of the new settlement to be established. There are brochures in the community of the several options of duplex homes that will be available. From a 2004 price list, the homes ranged in price from 98,582,000 Rupiah (approximately $12,824 CAD) to 127,611,000 Rupiah (approximately $16,600 CAD). Facilities planned for Villa Lake Matano include a sport club, volleyball and basketball courts, a church and mosque, a restaurant/café, market and lake recreational facilities (PT Waraindo Property, 2004). PT Inco company staff will have priority over the homes in this new settlement area and it is expected to alleviate crowing in Sorowako. It has been suggested that a small percentage of those living over Lake Matano will be re-located there as well. Despite promises made in the last decade to move the community, those living over Lake Matano appear less than optimistic about moving soon with several additions being made to the shanties on the water.

Staff at the company health clinics reported high incidences of stress after the mining development operations began. The stress was linked to the adaptation to a new culture of work, uncertain employment, and the possibility of retrenchments. The 'coping mechanism' was also observed in Sorowako as seen in third world countries where as many family members as possible seek work in both the formal and informal sectors because a single source of income is not enough to provide for their family. In most cases, the women farmed, fished and kept boarders and this supplemented the men's waged labour. Children and elderly helped in the fields, fished and sold vegetables (Robinson, 1996).

New roles for women also emerged mostly as company wives and mining town prostitutes (Ballard, 2001; Robinson, 1998). The 'contract wife phenomenon' was observed that is common in many mining towns where immigrant workers tend to marry local women but the marriage lasts as long as the worker's contract with the company then the husband returns home to a first wife (Robinson, 1998).

The community remained unaffected by corporate advertising of breads and baby formula and still purchased similar foods they would have produced like green leafy vegetables, rice, and fish with the exception of Coca Cola. The most potentially harmful change in their diet was the increased consumption of sugar (Robinson, 1986).

Robinson (1986) noted that racism was important in legitimizing the ideology of Western colonial expansion and domination. Racist assumptions about relative capacities of Indonesians and expatriates permitted the company to hire many expatriates for upper level positions that had more generous pay and benefits. In contrast, the unskilled workers were cheap labour and deemed replaceable. Cultural differences were used to justify unequal distribution of status, privilege and power. Indonesians were regarded as less competent in the work place than the expatriates. PT Inco's top managers were expatriates or tended to be from West Java, the junior management and skilled labourers tended to be from Java or Sumatra, and the unskilled workers from Sulawesi. The people of rural areas were regarded as backward and in need of uplifting. The Indonesian Women's Association in Sorowako organized functions for local women to learn modern and urban roles but few local women attended (Robinson, 1986).

Segregation in the company's facilities was noted as reinforcing ideas of white superiority. The PT Inco hospital had separate Indonesian and expatriate clinics and waiting rooms. Doctors consulted patients of their own race. The expatriate waiting room was air conditioned and less crowded with more comfortable seating. In the Indonesian waiting room, patients waited for hours, sitting on hard benches. The hospital was inaccessible to the community because of fees that they could not afford. The company store was segregated and was accessible only to employees of skilled status and above. The company supermarket sold food staples at cheaper prices than the local market. Schools were also segregated. Only children of parents employed at the skilled labour status or above could attend the company school (Robinson, 1986).

Racial and working class segregation in such services as education and healthcare ended in 2000. Perhaps a catalyst to this change was when Andi Baso, leader of KWAS and Arianto Sangaji, a long-time vocal critic of PT Inco's operations and community organiser from Palu, Central Sulawesi, visited Canada and attended the annual shareholders' meeting of PT Inco's parent company, Inco Ltd. In Canada, they voiced their concerns to Canadian government officials and public about the impacts of the development on Sorowako and met with the Innu and Inuit indigenous people in Labrador also dealing with a large-scale nickel development on their land (Sangaji, 2002).

The mining company exerts a dominant political and economic force that is found in most towns with a multinational corporate citizen. PT Inco's nickel mining contract was renewed in 1996 and is set to expire on December 28, 2025. PT Inco's activities focus on 3% of their original contract of work area, 218,529 hectares, which is divided into fourteen separate blocks (PT Inco, 2005). The blocks cover land in three provinces of Sulawesi; South Sulawesi, Southeast Sulawesi and Central Sulawesi. The contract of work allows PT Inco to excavate 150 million pounds per year for 20 years. PT Inco's total assets were US$1,309,805,000 in 2000. PT Inco's parent company Inco Ltd. reported total assets of US$9.5 billion in 2001. PT Inco employed 2360 staff in 2000 (YTM, 2003).

Theœontract of work has been criticized as outdated and unfair, made at a time during Suharto's foreign investor-friendly era. Communities were not involved in the contract of work negotiations and have been paid no royalties (Ballard, 2001). From 1988 to 1998, PT Inco paid royalties, land rent and water levies to the Indonesian government in the amount of $US 25.7 million or 4% of PT Inco's gross profits (Mizwar, 2003). PT Inco and the government have been criticized by local community organizations and local governments for the cheap sell off of minerals in the way of inadequate royalties and land rent. In the original contract of work with the government, PT Inco is obligated to pay 0.015% of the price of every kilogram of nickel sold and US$1 per hectare per year in land rent to the Indonesian government. The new contract of work signed in 1996 did not change the amount of royalties that PT Inco had to pay but land rent was increased to US$1.50 per hectare per year (Mizwar, 2003).

Another criticism with the contract of work system is that it allows foreign companies to control majority shares in operations in Indonesia. PT Inco is owned 80% by foreign investors including 58.7% by the Canadian mining multinational company Inco Ltd, 20% by Japan's Sumitomo Metal Mining Co., 0.54% by Tokyo Nickel Company Ltd., 0.36% by Mitsui & Co. Ltd., 0.14% by Nissho-Iwa Ltd., and 0.14% by Sumitomo Shoji Kiasha. The remaining 20% of shares are owned by the public (Mizwar, 2003). Government officials from the three provinces where PT Inco operates have requested that the contract between PT Inco and the government of Indonesia be reviewed. In 1999, PT Inco threatened international arbitration against the government if such an action was taken (Mizwar, 2003). There has been almost no talk by local government officials to renegotiate the contract since this threat was made.

Regional autonomy laws that came into place in Indonesia in October 2001 that would among other items decentralise government authority and benefits over natural resource management has in some cases benefited and in other cases harmed the situation of local peoples, natural resources and the environment. Some regional governments are implementing community-based natural resource plans. However, in other areas, there are problems of corruption and lack of transparency in regional governments. Some local government officials have approved a large increase in natural resource extraction in their areas with apparent short-term economic gain motivation and placed less consideration on sustainable management and potential land conflicts. Local governments are also tempted by offers of contributions to local coffers that are in most cases cash strained.

Today, Sorowako's population was approximately 11,000 (Inco, 2005). In the villages, there are few paved roads with dirt roads intersecting the major roads. There are many shops, a large market, community health centres, an Internet café, mosques, churches, and a hotel. People get around by driving cars but mostly by motorcycles and walking. The fish market mostly sells marine fish from Malili but there is also some freshwater fish sold from the nearby lakes. Besides pollution from the mining and smelting operations, open sewers and garbage are still major environmental problems. Burning of garbage and littering is frequent. Areas of the shores of Lake Matano, especially where the community lives atop its waters, are filled with garbage and raw sewage (Figs. 5.4-5.5).

To the north of Sorowako and across Lake Matano is the small Nuha settlement (Fig. 1.1). Nuha has a population of about 300 people. Nuha inhabitants are mostly farmers with gardens on the hilly outskirts of the settlement. These gardens include cocoa, rice paddies, and vegetables. Some people work at PT Inco and move back and forth from Sorowako to Nuha.

On the western side of Lake Matano is the Matano Village (Fig. 1.1). Surrounding Matano Village today are test pits/exploration areas for PT Inco. Mining occurs around the shores of the lakes including Matano Village. Bits of charcoal were found several hundred meters from the shore at Matano Village. Matano was once the site of blacksmithing. An access road is planned to connect Sorowako and Matano.

Concerns in the Sorowako community have been expressed about an increasing military presence. The historical military conflict that has occurred around Indonesia's first and still operating multinational mining operation in Papua is infamous throughout Indonesia. Conflicts between security officers and community members Sorowako have recently occurred. On September 2, 2003, some members of the Sorowako community burned the local police station after a police officer physically attacked a member of the community during a community gathering. The community asked that the police discipline the police officer but when no action was taken, the community members felt they had to take the matter in their own hands and burned down the police station. Fifty people connected to the incident were later detained by the police (Franky, 2003).

In May 2004, security forces guarding PT Inco were increased to approximately 200 after warnings were issued by the Canadian and Australian governments of possible terrorist targets directed at foreigners. PT Inco relocated their Canadian and Australian staff to other parts of Indonesia following this threat (Mining Journal, 2004). The threat turned out to be a hoax by a disturbed dentist who feared he would lose his job to a foreigner. The foreign staff returned and the numbers of security guards were decreased. However, security forces maintain a presence at community gatherings such as the Independence Day festivities in August 2004.

5.5. The Karonsi'e Dongi Story

The Karonsi'e Dongi is an indigenous ethnic group of Sorowako. Karonsi'e is the name of the indigenous people, which was derived from Karo and Si, which means rice barn. Karonsi'e land was formerly known as Witamorini land, which is today located on the North Western side of Wasuponda (Fig. 1.1). Witamorini means peaceful and fertile land The area where the Karonsi'e lived produced lucrative rice yields so much so that the area was known as "Lembo Moboo" or the valley where the harvest rotted. The

Karonsi'e Dongi would give away the rice to those less fortunate in their community as well as to those in nearby communities (KRAPASKAD, 2003).

The Witamorini people left the area in 1870 during a time of war during the Dutch colonialism period. In 1910, a new settlement was built by the community called Dongi Village (Fig. 5.6). Today, this village is known as the Old Dongi Village (KRAPASKAD, 2003).

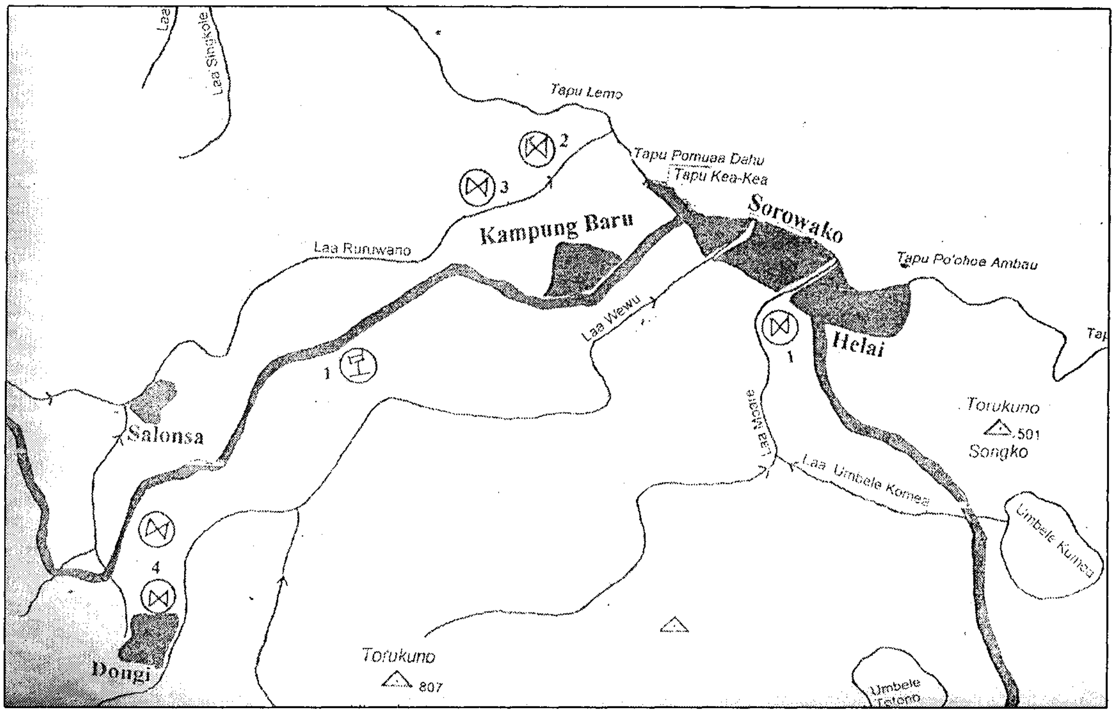

Fig. 5.6. Location of Dongi Village (Scale: 1:25,000). Credit: Community map, July 2000.

The people who came to live in the Dongi Village became known as Karonsi'e Dongi. Dongi was the name of a tree with a shrivelled fruit and used to grow abundantly around the village. Besides Karonsi'e Dongi, two other Karonsi'e sub-ethnic groups also exist, Karonsi'e Pae-Pae and Karonsi'e Sinongko. Some other Karonsi'e Dongi moved to the shores of Lake Matano near Tapu Lemo and surrounding areas (Fig. 5.6) (KRAPASKAD, 2003).

Christian missionaries came to the Nuha and Malili Districts in 1918. The Karonsi'e Dongi people then converted to Christianity. After the Christian missionaries left, the Karonsi'e Dongi people came together including those living in Dongi Village and along the shores of Lake Matano to form a new settlement under the orders of the Nuha District Head in 1920. This settlement became known as the New Village and would later become PT Inco's company golf course (KRAPASKAD, 2003).

The social and political chaos that broke out in South Sulawesi in the late 1950s forced the Karonsi'e Dongi people to flee to other parts of Sulawesi including Malili, Central Sulawesi, and Southeast Sulawesi. In 1959, seventeen Dongi families returned to the New Dongi Village. In 1965, the Dongi were further marginalized and fled to Central Sulawesi. From 1969 to 1976, when it was safe to return, the Dongi began returning to where they once lived and found that the land where they once lived and grew crops was now a large nickel mining operation (KRAPASKAD, 2003). The Karonsi'e Dongi received either little or no compensation for their lost lands and crops, as little as less than the local price for a plate of rice for one square metre of land (Sharma, 2003).

When the community went to the government for support and compensation, one government official told the community that it was better to get rid of one village at a time than to get rid of PT Inco. The Karonsi'e Dongi with no choice, moved again. Some members of the community moved to Wasuponda. Members of the Karonsi'e Dongi and some members of the Sorowako community, who were predominately Muslims, did not receive compensation for the lost lands and livelihoods (KRAPASKAD, 2003). Members of the village compensation committee, all members of the village elite class, were detained for four days in Palopo for refusing to accept the land compensation offer in 1975. This was done to stop the resistance from the entire community to the land compensation offer. Some were forced to take the land compensation offered while others continued to reject it. PT Inco responded to complaints launched by Sorowakans over the land compensation in 1975 by stating that since the community rejected the amount offered, it was the government's problem now and no longer the company's (Robinson, 1986, p.182) and such has been PT Inco's response since when the Karonsi'e Dongi demand a resolution to the land compensation issue. On July 29, 2005, over 100 community members took at least one dozen PT Inco foreign employees and their vehicles hostage in order to get a meeting with PT Inco to discuss the land compensation issue (Tribun Timur, 2005). On September 15, 2005, the community held a sit-in protest at the PT Inco regional office in Sulawesi where they said they would wait until a meeting with the PT Inco President Director (Daya, Pers. Comm., September 15, 2005). As of today, the community are still waiting for a resolution to various problems. A plan to relocate the community to part of Wasuponda has several community members upset that they will leaving their new settlement in the Kuratelawa area.

The Dongi feel that ethnocide is being committed against them in the form of occupation of their lands that once provided a way to make a living for their community. Land currently occupied by PT Inco that was once Karonsi'e Dongi includes: 1) New Village (now PT Inco's golf course); 2) rice fields in Kopatea and Pontadaa (now PT Inco's staff housing site); 3) coconut groves and other fruit trees (now PT Inco's concession area); 4) rice fields at the western side of the foot of Buton Mountain, Kuratelawa (now impacted by PT Inco mining); 5) part of the graveyard of the New Dongi Village (now PT Inco's staff housing site, the dormitory D area) (Fig. 5.7) (KRAPASKAD, 2003).

The Dongi people, recognizing that their survival as a community was under threat, formed a Karonsi'e Dongi community organization called KRAPASKAD in May 2000. Their goal was to communicate their community's problems to PT Inco and government bodies, and to achieve a solution to their problems (KRAPASKAD, 2003). Ibu Naomi Manata, general secretary of KRAPASKAD, has been a vocal member of the community and is working with non-governmental organizations and indigenous alliances throughout Indonesia, the Southeast Asia region and internationally, attempting to raise awareness of the Karonsi'e Dongi plight in an effort to resolve the problems plaguing her community (Fig. 5.7) (Franky, 2003). The community completed a participatory community-mapping project with the assistance of a NGO from Palopo, South Sulawesi called the Sawerigading Earth Foundation (YBS) in 2000. The community is currently identifying members of their community in Nuha, Malili and Towuti and other areas, and consolidating and formulating position statements to give to PT Inco and the local governments (KRAPASKAD, 2003).

Fig. 5.7. Ibu Naomi Manata, Karonsi'e Dongi leader at her mother's grave in the community's traditional graveyard, part of which was transformed into a PT Inco housing site, August 2004.

In October 2002, land not being used by PT Inco any longer was freed south of Salonsa in the Kopatea area (Fig. 5.6). Seventy Karonsi'e Dongi families began preparing the land and built huts just south of the PT Inco golf course in an abandoned mining area known as Kuratelawa (Fig. 5.8) in October 2002. This land was once known as Kopatea and was the site of the Karonsi'e Dongi rice paddies before PT Inco began mining there. The Karonsi'e Dongi people complained of the various name changes that they feel were part of the alienation efforts to disconnect the people from their land. In December 2002, the community celebrated Christmas and the New Year with sweet corn from gardens that they had planted (Manata, 2003).

Fig. 5.8. Kuratelawa settlement, abandoned mining area and recent settlement of Karonsi'e Dongi community, August 2004 (Credit: Tracy Glynn).

Not long after the first few families established huts in the Kuratelawa area, the community feels that several acts of intimidation were committed against them in 2003. Community members were escorted to the PT Inco's Government Relations Office by security officers for questioning (YTM, 2003). PT Inco security guards and the Nuha Police Chief visited the community to ask for a halt to all activities on the land. PT Inco and the government sent a patrol of security guards and Brimob, Indonesia's notorious elite police force, to the community almost daily after a community leader sent a letter of complaint. A blockade was also established by security officers and the Brimob in May 2003 attempted to stop community members from going back to their settlement. Also in May 2003, PT Inco security guards practiced shooting at the foot of Buton Mountain, not far from the settlement, in an act considered by the community to be a scare tactic directed at the community. During this time, several of the community's livestock disappeared. The community felt that methods were being used to provoke strife within their community (Manata, 2003; Franky, 2003).

Tensions escalated to the burning of farmers' homes at the edge of Lake Matano on May 3, 2003 (Manata, 2003; Hajramurni, 2003). Thirteen units were burned down by PT Inco security. Two months after the burning incident, the Nuha police chief sent a letter to Ibu Naomi Manata threatening to report her to the police and evict the community from their huts at Kuratelawa. On July 14, 2003, the Nuha police chief summoned two members of the community to their headquarters and threatened to burn down their huts if they did not leave. The pair refused to leave (Manata, 2003).

Despite the presence of the repressive Brimob and Indonesian Army Battalion 712, the Karonsi'e Dongi continue to live in their newly established settlement, and make a living from their vegetable gardens and fruit trees (Franky, 2003).

Today, there are approximately 1000 Karonsi'e Dongi people. The Karonsi'e Dongi are still returning to Sorowako from other parts of Sulawesi in the hopes of finding a way to make a living. In Kuratelawa, the Karonsi'e Dongi have established approximately twelve homes made of wood and built on stilts (Fig. 5.8). Approximately, 50 people live there. Besides Kuratelawa, Karonsi'e Dongi populations are found concentrated in Wasuponda, a town south of Sorowako that was established to house PT Inco company staff. Other Karonsi'e Dongi people live around Sorowako and some still live in other parts of Sulawesi. Some live on other islands of Indonesia including Papua and

Kalimantan, and in Indonesia's capital, Jakarta. Three Karonsi'e Dongi families live in Taiwan and two Karonsi'e Dongi families live in the U.S. (Franky, 2003; Karunsi'e Dongi community listing, 2004).

The Karonsi'e Dongi community currently want a community settlement established and assistance with setting up a crop that would sustain the community before an access road is built to Matano, a site of PT Inco exploration. The Karonsi'e Dongi people feel that once the access road is built that it will be easier to take away lands if they do not have any entitlement to the land (Manata, Pers. Comm., 2004).

According to Peter Sampoetoding from PT Inco (Pers.Comm, 2004), over 200 complaints were made to the Canadian Embassy in Indonesia in 2004 regarding PT Inco, many of which requested a resolution to the problems faced by the Karonsi'e Dongi people.

The Karonsi'e Dongi indigenous people, PT Inco mine workers, university students, and several human rights and environmental non-governmental organizations based in the provincial city of Makassar formed the Mine Victims' Solidarity Forum (FSMT) in September 2005, which marked the beginning of a series of actions including the occupation of the regional PT Inco office for five days and a three day hunger strike (Fig. 5.9). The actions were aimed at getting a meeting with PT Inco to resolve several issues of land compensation and the termination of employees. The September actions ended with a blockade in Sorowako when police fired a warning shot and detained three people temporarily. PT Inco and the local governments have promised meetings to resolve the issues. At the time of this writing in early 2006, little progress has been made on any of these fronts.

Fig. 5.9. Yuliana, a 70 year old Karonsi'e Dongi woman participating in a hunger strike during an occupation of the PT Inco regional office in Makassar, South Sulawesi, Indonesia in September 2005 (Credit: Daya).

Chapter 6: Conclusions and Recommendations

Investigations on air pollution and human health were carried out in the community-based monitoring program between Memorial University of Newfoundland and the Indigenous Sorowako Association (KWAS) at Sorowako, Indonesia. Sorowako is the site of an operating three decades-old nickel mining and smelting operation.

Results of the community-based monitoring of seasonal TSP and airborne metal level in several communities around the PT Inco nickel mines and smelter in Sorowako, Indonesia showed elevated levels of TSP, Ni, Co and Cr in the dry season samples taken in the day and significant differences of these concentrations between day and night samples in Magani and Wawondula, communities most near to and downwind from the smelter. Several significant positive correlations among the metals, except Cu and Zn, further suggest a common source in Magani and Wawondula that could at least be partially attributed to the smelter. Other patterns of metal concentrations and correlations between TSP and airborne metals suggest the effect of localized sources in Magani, Desa Nikkel and Desa Sorowako. These three communities recorded different patterns but all are located next to each other and exposed to approximately similar levels of smelter fallout. Fewer correlations between metals found in the smelter fallout and TSP were found in Kampung Baru and Wasuponda. Kampung Baru's sawmill operations likely contribute to the dust while Malili, located furthest away from the smelter, recorded smaller concentrations of TSP and nickel, suggesting that this community is less affected by smelter fallout. Re-suspended road dust and the burning of garbage are possibly other major sources of ambient air pollution in the areas.

Results of the community-based air sampling program serve as foundation for further airborne pollutant analysis and the implementation of a long-term community-based air monitoring program.

Future recommended studies include:

1) Meteorological analysis linking time specific prevailing winds with TSP and airborne metals concentrations.

2) Assessment of trends of long-term distribution of airborne metals, which could in turn assess the effectiveness of air quality control measures such as cleaning technologies on smelter stacks as well as the effects of a larger than usual amount of emissions.

3) Detailed statistical analysis (PCA or factor) to distinguish source processes affecting metal distributions in the study area.

4) Studying other pathways of exposure to PM like that brought into the home on the clothes of mine and smelter workers. This investigation did not distinguish between two type of exposures, the smelter fallout and transportation via the worker.

5) An analysis of Ni concentrations in soil and plants that could demonstrate effects of pollutant dispersion plumes following dominant wind directions. Such an investigation could also determine the impact on agricultural productivity caused by smelter fallout.

The health questionnaire results revealed that some health conditions such as adult and child asthma, rhinitis and skin tumours were more prevalent in communities closer to and downwind from the nickel mines and smelter compared to Malili, a community located further away from the mines and smelter. Correlations between domestic 24-hour dust fall accumulation and mean night TSP suggest a potential human health risk associated with nickel mining and smelting in nearby communities. Mean night TSP was strongly correlated with prevalence of diabetes and seasonal allergies in children. Domestic 24-hour dust fall accumulation was strongly correlated with prevalence of adult asthma, high blood pressure, heart disease, and anemia.

Asthma was more prevalent in the adults surveyed than the children, which was not expected since children are vulnerable to the effects of air pollution. However, asthma symptoms were generally more prevalent than diagnosed asthma in children, which indicate a possible delay in the diagnosis of asthma in children.

The community that lives on top of Lake Matano live in conditions that may compromise their bodies' ability to respond to heavy metal exposure and dust from nickel mining and smelting. Water in Lake Matano is contaminated with raw sewage and garbage but is still used by members in this community for washing and recreation. Reported incidence of respiratory, and skin conditions, and infection by parasites, expected to be more prevalent in this community, were comparable to other communities surveyed.

Epidemiological studies and human health risk assessments are recommended to identify health problems and determine causes. Epidemiological studies on the occurrence of respiratory disease in the vicinity of the nickel mines and smelter and heavy metals in blood, hair and fingernails in order to examine health effects of air and freshwater pollution. Future recommended research questions include: 1) What risks are associated with exposure to Lake Matano waters, in particular along the shore line at Sorowako?; 2) What health risks and conditions are found in workers at the mine and smelter sites, and their families?; 3) Are there any dangers associated with eating fish or shellfish from lakes, in particular from mine and smelter runoff areas that have high heavy metal concentrations?; and 4) What are the effects of socio-economic class attitudes, and differences in income on community health?

The effects of mining and smelting pollution, in particular air pollution, on human health are often very difficult to assess. Examining the total intake and uptake of particulate matter and associated metals and other components of combined exposures can more adequately describe whether there is a human health risk to the various pollutant levels that exist in an environment.

Improvements have been made to the environment in Sorowako in recent years including scrubbers on smelter smokestacks that have reduced ambient air pollution, and revegetation that has also reduced air pollution and erosion. All communities in Sorowako were finally provided with clean drinking water sources from the mining company in 2004. Further reductions on pollution could be achieved if the local and central governments were more forceful in implementing more stringent environmental planning and monitoring regulations. The community must be informed of best available technology and consulted meaningfully, which frequently is not done in communities where foreign owned developments are active.

People in the Sorowako communities continue to demand land compensation and access to local employment opportunities at the mines and smelter. Increased access to clean drinking water and education has only recently been made available but issues of concern in these areas continue to be heard.

Results of this community-based research serve as foundation for further needed environment and health analysis and possibly the implementation of a long-term community-based monitoring program. Besides providing baseline data on environmental and health conditions in the community, the community-based component of this research also imparted knowledge and experience to community members on how to continually monitor and address environmental and health concerns in their community, and compare their data with that of the industry and government.

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Appendix A: Adult Health Questionnaire

INSTRUCTIONS

Each adult (18 years of age or older) in the household should complete the questionnaire.

Fill in the code number at the top of the first page of the health questionnaire as provided by the interviewer. This must be the same code number that appears on the envelope that the completed questionnaires are to be placed. Do you write your name on the questionnaire.

Please answer each question as accurately as possible.

- Most questions can be answered by marking **X** in the appropriate box, OR by circling the number beside the most appropriate answer. For example:

1. What is your sex?

[ ] Male [X] Female

2. In general, how would you describe your health?

1 Excellent

2 Very good

3 Good

4 Fair

5 Poor

- Some questions may require more than one response. Be certain to mark all that apply, where appropriate. For example:

3. Have you had wheezing or whistling in your chest at any time in the last 12 months?

[X] Yes [ ] No [ ] Don't Know

If **Yes,** have you been at all breathless when the wheezing noise was present?

[X] Yes [ ] No [ ] Don't Know

Have you had this wheezing or whistling when you did not have a cold?

[X] Yes [ ] No [ ] Don't Know

- Some questions will require numerical answers. Please write your answer clearly within the space provided. For example:

4. How many months or years have you lived at your current address? [1][1] Months [ ][ ] Years

- For some answers, you may need to provide <u>an approximate</u> numerical answer (i.e.: How old you wer e when you were first told you had a specific medical condition?).

If you have any questions regarding the questionnaire, please contact the KWAS or KRAPASKAD office.

CODE # (Provided by interviewer) ☐☐☐☐☐

HOUSEHOLD INFORMATION

1. How many people usually live in your household in total? ☐☐

   a) How many of these people are 18 years or older? ☐☐

   b) How many of them are under the age of 18? ☐☐

2. In what year did you first live in Luwu Regency? ☐☐☐☐

3. How long have you lived in Luwu Regency? ☐☐ years **OR** ☐☐ months

4. How long have you lived at your current address? ☐☐ years **OR** ☐☐ months

5. Please answer the following questions while using the enclosed map of Sorowako as a reference:

   a) Which area corresponds to your current primary place of residence?

☐ Lamoare ☐ Desa Nikel ☐ On top of Lake Matano ☐ Desa Sorowako

☐ Matano ☐ Wasuponda ☐ Wawondula ☐ Timampu

   b) Which area corresponds to your current primary place of work?

☐ Lamoare ☐ Desa Nikel ☐ Lake Matano ☐ Desa Sorowako

☐ Matano ☐ Wasuponda ☐ Wawondula ☐ Timampu

☐ PT Inco plant ☐ Other: ____________

INDIVIDUAL INFORMATION

6. Where were you born? ______________________________

   Village/City Regency

   ____

   District Province Country

7. What is your date of birth? ☐☐/☐☐/☐☐☐☐

   M M D D Y Y Y Y

8. What is your sex?

   ☐ Male ☐ Female

9. What is your height? [ ][ ][ ] Centimetres

10. What is your weight? [ ][ ][ ] Kilograms

GENERAL HEALTH

Please answer every question by circling the number as indicated (refer to the Instructions sheet for an example). If you are unsure about how to answer a question, please give the best answer you can.

11. In general, how would you describe your health?

1 Excellent
2 Very good
3 Good
4 Fair
5 Poor

12. Compared to 1 year ago, how would you rate your health in general now?

1 Much better now than one year ago
2 Somewhat better now than one year ago
3 About the same as one year ago
4 Somewhat worse now than one year ago
5 Much worse now than one year ago

13. The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
a) Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports.	1	2	3
b) Moderate activities, such as moving a table, cleaning house.	1	2	3
c) Lifting or carrying food.	1	2	3
d) Climbing one flight of stairs.	1	2	3
e) Bending, kneeling or stooping.	1	2	3
f) Walking more than a mile.	1	2	3
g) Walking one block.	1	2	3
h) Bathing or dressing yourself.	1	2	3

14. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	Yes	No
a) Cut down on the amount of time you spent on work or other activities.	1	2
b) Accomplished less than you would like.	1	2
c) Were limited in the kind of work or other activities	1	2
d) Had difficulty performing the work or other activities (for example, it took extra effort).	1	2

15. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	Yes	No
a) Cut down on the amount of time you spent on work or other activities.	1	2
b) Accomplished less than you would like.	1	2
c) Did work or activities less carefully than usual	1	2

16. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

1 Not at all
2 Slightly
3 Moderately
4 Quite a bit
5 Extremely

17. How much bodily pain have you had during the past 4 weeks?

1 None
2 Very Mild
3 Mild
4 Moderate
5 Severe
6 Very Severe

18. During the past 4 weeks, how much did pain interfere with your normal work (including both outside the home and housework)?

1 Not at all
2 A little bit
3 Moderately
4 Quite a bit
5 Extremely

19. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

1 All of the time
2 Most of the time
3 Some of the time
4 A little of the time
5 None of the time

These questions are about how you feel during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling.

20. How much of the time during the past 4 weeks …

	All of the time	Most of the time	Good bit of the time	Some of the time	A little of the time	None of the time
a) Did you feel full of energy?	1	2	3	4	5	6
b) Have you been very nervous?	1	2	3	4	5	6
c) Have you felt persistent sadness?	1	2	3	4	5	6
d) Have you felt serenity?	1	2	3	4	5	6
e) Did you feel worn out?	1	2	3	4	5	6
f) Have you been happy?	1	2	3	4	5	6
g) Did you feel tired?	1	2	3	4	5	6
h) Did you not get enough sleep or rest?	1	2	3	4	5	6
i) Have you worried?	1	2	3	4	5	6

21. How TRUE or FALSE is each of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
a) I seem to get sick a little easier than other people.	1	2	3	4	5
b) I am as healthy as anybody I know.	1	2	3	4	5
c) I expect my health to get worse.	1	2	3	4	5
d) My health is excellent.	1	2	3	4	5

MEDICAL HEALTH STATUS

Please answer every question by marking the appropriate box or filling in the requested information (refer to the Instructions sheet for examples). If you are unsure about how to answer a question, please give the best answer you can.

We are asking about certain chronic conditions and/or recent symptoms that you may have. Chronic or 'long-term' conditions are those that have lasted for six months or more, and have been diagnosed by a health professional.

Respiratory

22. Have you had wheezing or whistling in your chest at any time in the last 12 months?

☐ Yes ☐ No ☐ Don't Know

If **Yes,** have you been at all breathless when the wheezing noise was present?

☐ Yes ☐ No ☐ Don't Know

Have you had this wheezing or whistling when you did not have a cold?

☐ Yes ☐ No ☐ Don't Know

23. In the past 12 months, have you experienced any of the following symptoms affecting your chest?

	Yes	No	Don't know
a) Waking up in the night with a feeling of tightness in the chest	☐	☐	☐
b) Difficulty breathing	☐	☐	☐
c) Shortness of breath made worse by exercise, which is more than other people your own age	☐	☐	☐
d) Being awakened in the night with an attack of shortness of breath	☐	☐	☐
e) Being awakened in the night with a coughing attack	☐	☐	☐

24. In the rainy season, do you usually cough first thing in the morning?

☐ Yes ☐ No

25. In the rainy season, do you usually cough during the day, or at night?

☐ Yes ☐ No

If **Yes**, for how many days of the year do you usually cough? ☐☐☐ Days

26. Do you usually bring up any phlegm from your chest first thing in the morning in the rainy season?

☐ Yes ☐ No

27. Do you usually bring up any phlegm from your chest during the day, or at night, in the rainy season?

☐ Yes ☐ No

If **Yes**, for how many days of the year do you usually bring up phlegm in this manner?

☐ Yes ☐ No

28. Have you ever had asthma?

☐ Yes ☐ No → **(Go to Question 33)**

↓

If **Yes:** Was this confirmed by a doctor?

☐ Yes ☐ No

How old were you when this was first confirmed? ☐☐ Age in years

How old were you when you had your first asthma attack? ☐☐ Age in years

How old were you when you had your most recent asthma attack? ☐☐ Age in years

Only complete Questions 29 through 32 if you answered **Yes** *to Question 28.*

29. During which months of the year do you usually have asthma attacks? *Mark all that apply.*

☐ January / February ☐ July / August

☐ March / April ☐ September / October

☐ May / June ☐ November / December

30. Have you had any asthma symptoms or asthma attacks in the past 12 months?

☐ Yes ☐ No ☐ Don't Know

31. In the past 12 months, have you taken any medicine for asthma such as inhalers, nebulizers, pills, liquids, injections or natural medicine?

☐ Yes ☐ No ☐ Don't Know

32. How many times in the past 12 months have you visited a hospital emergency room because of your asthma?

☐☐ Number of times ☐ Don't Know

33. Do you have any nasal allergies?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, how old were you when you first had nasal allergies?

☐☐ Age in years

34. Have you ever had a problem with sneezing, or a runny or a blocked nose when you did not have a cold or the flu?

☐ Yes ☐ No ☐ Don't Know

If **Yes:** Have you had a problem with sneezing or a runny or blocked nose when you did not have a cold or the flu in the last 12 months?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, has this nose problem been accompanied by itchy or watery eyes?

☐ Yes ☐ No ☐ Don't Know

In which month(s) of the year did this nose problem occur?
Mark all that apply.

☐ January	☐ April	☐ July	☐ October
☐ February	☐ May	☐ August	☐ November
☐ March	☐ June	☐ September	☐ December

35. Do you often have respiratory infections?

☐ Yes ☐ No ☐ Don't Know

36. Have you ever been told by a doctor that you have any of the following respiratory conditions? If **Yes**, please provide the age when you were first told about this condition.

	Yes	No	Don't know	If Yes, Age When Told
a) Chronic Bronchitis	☐	☐	☐	☐☐
b) Emphysema	☐	☐	☐	☐☐
c) Sinusitis (sinuses that are infected or inflamed)	☐	☐	☐	☐☐
d) Rhinitis (eyes, nose and throat reaction to irritants like pollen, dust, or fumes)	☐	☐	☐	☐☐
e) Pneumonia	☐	☐	☐	☐☐
f) Whooping cough	☐	☐	☐	☐☐
g) Any other condition(s) related to the lungs, chest, nose or throat	☐	☐	☐	☐☐

If **Yes**, please specify:

____

____

Skin

We are asking about chronic conditions and/or symptoms that you may have which are related to your skin.

37. In the past 12 months, have you experienced any of the following symptoms on the skin?

	Yes	No	Don't know
a) Persistent itching	☐	☐	☐
b) Skin redness or inflammation	☐	☐	☐
c) Tenderness of skin	☐	☐	☐
d) Localized swelling	☐	☐	☐
e) Scaling of the skin or appearance of dry skin	☐	☐	☐
f) Rash	☐	☐	☐
g) Scabies	☐	☐	☐
h) Pyoderma	☐	☐	☐

If you answered **Yes** to any of the above symptoms, have any of these skin reactions limited your daily activity (e.g. days missed from work, restricted participation in sports, avoided other daily routines such as washing) ☐ Yes ☐ No

38. Please answer the following questions about your skin.

	Yes	No	Don't know
a) Do you have a tendency toward dry, flaky, itchy skin when exposed to detergent?	☐	☐	☐
b) Do you have a tendency toward dry, flaky, itchy skin when exposed to hot weather?	☐	☐	☐
c) Are you easily irritated by new products (e.g. new detergents, soaps, creams, etc.)?	☐	☐	☐

39. Have you ever been told by a doctor that you have Eczema (i.e. a long lasting rash that itches in one or more of the following regions: face, hollow of the knee, elbow bends, ankles or wrists)?

☐ Yes ☐ No ☐ Don't Know

If **Yes**: Was this confirmed by a doctor?

☐ Yes ☐ No

How old were you when this was first confirmed? ☐☐ Age in years

How old were you when you were first told about this? ☐☐ Age in years

How old were you when this rash last appeared? ☐☐ Age in years

40. Have you ever been told by a doctor that you have a Metal Contact Allergy or Dermatitis?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, on what part of your body? *Mark all that apply.*

☐ Hands ☐ Face ☐ Hollow of knee/elbow bends

☐ Back/chest ☐ Legs/arms ☐ Other (please Specify):___________

How old were you when you were first told about this? ☐☐ Age in years

41. Do you get Eczema or a skin rash after wearing earrings, a watch, metal buttons or other jewelry? ☐ Yes ☐ No ☐ Don't Know

42. Have you ever been told by a doctor that you have any of the following conditions? If **Yes**, please provide the age when you were first told about this condition.

	Yes	No	Don't know	If **Yes**, Age When Told
a) Psoriasis (red, thickened areas of the skin with silver scales)	☐	☐	☐	☐☐
b) Rosacea (redness and swelling of the face)	☐	☐	☐	☐☐

Endocrinology/Rheumatology

43. In the past 12 months, have you experienced any of the following symptoms?

	Yes	No	Don't know
a) Weight gain	☐	☐	☐
b) Weight loss	☐	☐	☐
c) Dry skin	☐	☐	☐
d) Sensitivity to cold	☐	☐	☐
e) Thin, brittle hair	☐	☐	☐
f) Thin, brittle fingernails	☐	☐	☐
g) Hoarse throat	☐	☐	☐
h) Constipation	☐	☐	☐
i) Irregular or heavy menstrual periods	☐	☐	☐
j) Depression	☐	☐	☐
k) Slow speech	☐	☐	☐
l) Joint, bone or muscle stiffness/pain	☐	☐	☐
m) Puffy face, hands and feet	☐	☐	☐
n) Poor memory	☐	☐	☐
o) Increased sleepiness	☐	☐	☐
p) Difficulty swallowing	☐	☐	☐
q) Fatigue	☐	☐	☐

44. Have you been told by a doctor that you have Chronic Fatigue Syndrome?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, how old were you when you were first told about this? ☐☐ Age in years

45. Do you have fatigue that is not due to ongoing exertion and has lasted more than 6 months?

☐ Yes ☐ No ☐ Don't know

If **Yes**, does this fatigue restrict your activity levels?

☐ Yes ☐ No ☐ Don't know

If **Yes**, have you had any of the following symptoms within the past 6 months?

	Yes	No	Don't know
a) Sore throat	☐	☐	☐
b) Sensitive lymph nodes	☐	☐	☐
c) Headaches (different from previous headaches in quality, severity or pattern)	☐	☐	☐
d) Unrefreshing sleep	☐	☐	☐
e) Pain in your joints with no joint swelling	☐	☐	☐
f) Fatigue that lasts at least 24 hours after exercise	☐	☐	☐
g) Difficulties with memory or concentration	☐	☐	☐
h) Muscle pain	☐	☐	☐

46. Have you ever been told by a doctor that you have a thyroid problem?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, what type of thyroid problem?

☐ Hypothyroidism (under active thyroid)

☐ Hyperthyroidism (over active thyroid)

☐ Other (please specify): ____________________________

At what age were you first told about this? ☐☐ Age in years

Heart and Circulatory System

47. Have you ever been told by a doctor that you have any of the following heart or circulatory system conditions? If **Yes**, at what age were you first told about this?

	Yes	No	Don't know	If **Yes**, Age When Told
a) High Blood Pressure (sometimes called hypertension)	☐	☐	☐	☐☐
b) Heart disease or abnormalities (including blood vessels)	☐	☐	☐	☐☐
c) Heart Attack (damage to the heart muscle, sometimes called a myocardial infarction (MI))	☐	☐	☐	☐☐
d) Angina (chest pain, chest tightness)	☐	☐	☐	☐☐
e) Congestive Heart Failure (inadequate heart beat, fluid build-up in the lungs or legs)	☐	☐	☐	☐☐
f) Cardiomypathy (disease of heart muscle, loss of ability to pump blood, sometimes heart rhythm disturbed causing irregular heartbeats)	☐	☐	☐	☐☐

Stomach and Liver

48. Have you ever been told by a doctor that you have any of the following conditions? If **Yes**, at what age were you first told about this?

	Yes	No	Don't know	If **Yes**, Age When Told
a) Stomach or Intestinal Ulcers	☐	☐	☐	☐☐
b) Gastroenteritis (diarrhea associated with nausea or vomiting)	☐	☐	☐	☐☐
c) Jaundice (yellowing of the skin and eyes)	☐	☐	☐	☐☐
d) Cirrhosis (liver damage)	☐	☐	☐	☐☐
e) Other stomach conditions	☐	☐	☐	☐☐

Neurological Conditions

49. Have you ever been told by a doctor that you have any of the following conditions? If **Yes**, at what age were you first told about this?

	Yes	No	Don't know	If **Yes**, Age When Told
a) Peripheral Neuropathy (also called numbness or tingling in the fingers or toes, or weakness of one or more extremities)	☐	☐	☐	☐☐
b) Parkinson's Disease	☐	☐	☐	☐☐
c) Alzheimer's Disease	☐	☐	☐	☐☐

Reproductive Health

*If you are male, please go to Question 52. Do **not** complete Questions 50 and 51.*

WOMEN

50. About how old were you when you had your first menstrual period? ☐☐ Age in years

51. Have you ever been pregnant?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, how many times have you been pregnant? (Include live births, miscarriages, still births, and abortions). Number of times pregnant: ☐☐

How many of your pregnancies were live births? ☐☐ Live births

If applicable, how old were you when you had your first live birth? ☐☐ Age in years

WOMEN AND MEN

52. Have you ever had a child that was born with a birth defect?

☐ Yes ☐ No ☐ Don't Know

Other Health Questions

53. Have you ever been told by a doctor that you have Cancer?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, at what age were you first told about this? ☐☐ Age in years

What type of cancer was it? ______________________________

If it was skin cancer, where was it on your body? ____________________

54. Have you ever been told by a doctor that you have any of the following conditions? If **Yes**, please provide the age when you were first told about this condition.

	Yes	No	Don't know	If **Yes**, Age When Told
a) Food Allergies	☐	☐	☐	☐☐
b) Glaucoma	☐	☐	☐	☐☐
c) Multiple Chemical Sensitivities	☐	☐	☐	☐☐
d) Migraine Headaches	☐	☐	☐	☐☐
e) Bowel disorder (such as Crohn's Disease or Colitis)	☐	☐	☐	☐☐
f) Bladder control problems	☐	☐	☐	☐☐
g) Diabetes	☐	☐	☐	☐☐
h) Arthritis or Rheumatism	☐	☐	☐	☐☐
i) Fibromyalgia	☐	☐	☐	☐☐
j) Anemia	☐	☐	☐	☐☐
k) Kidney condition	☐	☐	☐	☐☐
l) Bone, joint, muscle condition	☐	☐	☐	☐☐
m) Any other long-term condition(s) ______________________________	☐	☐	☐	☐☐

If **Yes**, please specify:

____

____

____

55. Have you ever been hospitalized or had any surgeries?

☐ Yes ☐ No

If **Yes**, please specify: ______________________________

LIFESTYLE FACTORS

56. In your lifetime, have you smoked a total of 100 or more cigarettes (about four packs)?

☐ Yes ☐ No ☐ Don't Know

If **Yes**, how many years did you smoke? ☐☐ Years

How many cigarettes per day did you smoke? ☐☐ Cigarettes/Day

57. At the present time do you smoke cigarettes daily, occasionally or not at all?

☐ Daily ☐ Occasionally ☐ Not at all

58. Does anyone in your household smoke regularly inside the house?

☐ Yes ☐ No ☐ Don't Know

59. On <u>average</u>, how many hours in a day are you exposed to the tobacco smoke of others?

On Working Days: ☐☐ Hours per Day

On Non-Working Days: ☐☐ Hours per Day

60. Do you now or have you ever worked for **2 years or longer** in one of the following industries/occupations? *Mark all that apply.*

☐ Metal refining	☐ Plumbing	☐ Welding
☐ Smelting	☐ Metal Refining	☐ Sintering
☐ Boiler maker/repairer	☐ Electrician	☐ Ceramics/pottery
☐ Metal plating/ Electroplating	☐ Lumberyard/sawmill	☐ Metal cutting and grinding
☐ Heavy equipment Operator	☐ Truck driver	☐ Other: ____________

61. Does your household members now or have worked for **2 years or longer** in one of the following industries/occupations? *Mark all that apply.*

- ☐ Metal refining
- ☐ Plumbing
- ☐ Welding
- ☐ Smelting
- ☐ Metal Refining
- ☐ Sintering
- ☐ Boiler maker/repairer
- ☐ Electrician
- ☐ Ceramics/pottery
- ☐ Metal plating/ Electroplating
- ☐ Lumberyard/sawmill
- ☐ Metal cutting and grinding
- ☐ Heavy equipment
- ☐ Truck driver
- ☐ Other: _______________

62. If you are employed in the smelter? If **No**, go to question 67.

a) Does your employer provide you with a dust mask? ☐ Yes ☐ No

b) Does your employer provide you with a respirator? ☐ Yes ☐ No

c) Does your employer provide you with gloves? ☐ Yes ☐ No

d) Does your employer provide you with coveralls? ☐ Yes ☐ No

e) Are your clothes visibly dirty at work? ☐ Yes ☐ No

f) Do you shower at work before you return home? ☐ Yes ☐ No

g) Do you change your clothes to clean clothes before you return home? ☐ Yes ☐ No

63. Do you have any concerns about your health?

☐ Yes ☐ No

If **Yes**, do you feel that any of your health concerns are related to where you live?

☐ Not at all ☐ Somewhat ☐ Definitely ☐ Don't Know

64. Has a doctor ever told you, or any member of your household, that a health problem was due to living in the Sorowako area? ☐ Yes ☐ No

If **Yes**, please specify: ______________________________________

GENERAL INFORMATION

65. What is your current marital status?

- ☐ Married
- ☐ Living Common-law
- ☐ Widowed
- ☐ Separated
- ☐ Divorced
- ☐ Never Married

The following **TWO** *questions deal with your level of education.*

66. What is the highest grade that you completed?

- ☐ SD
- ☐ SMA
- ☐ SMP

67. What is the highest degree, certificate or diploma that you have obtained?

- ☐ No postsecondary degree, certificate or diploma
- ☐ Trades certificate or diploma from a vocational school or apprenticeship training
- ☐ Non-university certificate or diploma from a community college, school of nursing, etc.
- ☐ University certificate below bachelor's level
- ☐ Bachelor's degree (S1)
- ☐ University certificate or diploma above bachelor's degree

68. At present, are you:

- ☐ Employed full-time outside the home
- ☐ Employed part-time outside the home
- ☐ Attending school full or part-time
- ☐ Unemployed and not looking for work (e.g. disabled)
- ☐ Unemployed and looking for work
- ☐ Homemaker
- ☐ Retired
- ☐ Other (please specify): ______________________________

69. Please estimate in which of the following groups your monthly household income falls?

- ☐ Greater than Rp. 3 million
- ☐ Rp. 1- 3 million
- ☐ Rp.750,000 to less than Rp. 500,000
- ☐ Rp. 500,000 to less than Rp. 250,000
- ☐ Rp. 250,000 to less than Rp. 100,000
- ☐ Less than Rp. 100,000
- ☐ Prefer not to answer

70. Which best describes to your dwelling?

- ☐ Sago-leaf thatch constructed house on stilts
- ☐ Wooden house on stilts with sago-leaf thatch roof
- ☐ Wooden house on stilts with corrugated iron roof
- ☐ Wooden house with corrugated iron roof
- ☐ House made of concrete with corrugated iron roof

71. Do you have and use air conditioning regularly? ☐ Yes ☐ No

72. Do you have any animals in the household? ☐ Yes ☐ No

73. What is the source of your bathing and washing water? ______________________________

74. What is the source of your drinking water? ____

75. How many glasses of water do you consume daily? _________________________________

76. Do you swim in local rivers and lakes? ☐ Yes ☐ No

77. Do you consume fish caught in local rivers and lakes? ☐ Yes ☐ No

If **Yes**, how many fish do you consume in one week? ___________

The following questions are about your community.

78. How would you describe your sense of belonging to your local community?

1 Very strong
2 Somewhat strong
3 Somewhat weak
4 Very weak

79. What do you like most about your community?_____________________________________

____

____

____

80. What do you dislike most about your community? __________________________________

____

____

____

81. As a Sorowako resident, do you have any other health concerns that you feel may be related to the environmental exposures you may experience within your community? ______________

82. Is there any comment that you would like to make in relation to your health?

83. Please indicate who helped you complete this questionnaire:

Name Organization (KWAS or other)

Name Organization (KWAS or other)

Date Questionnaire completed: ______________
Day Month Year

Thank you for your participation in this study!

Appendix B: Child/Adolescent Health Survey

Code # (as provided by the interviewer) ☐☐☐☐☐

• One parent or guardian in the household should answer the following questions for all members of the household who are younger than 18 years of age.

• Please indicate the number of child/ adolescent questionnaire booklets being completed:

☐ 1 (for one to four children) **OR** ☐ 2 (for five to eight children)

• Please ensure that all responses to questions correspond to each child's assigned number.
• For some answers, you may need to provide an approximate numerical answer (for example, when we ask you how old your child was when you were first told about a specific medical condition)

	Child/Adolescent 1	**Child/Adolescent 2**	**Child/Adolescent 3**	**Child/Adolescent 4**
GENERAL INFORMATION				
1. What is this child's date of birth?	D D / M M / Y Y Y Y	D D / M M / Y Y Y Y	D D / M M / Y Y Y Y	D D / M M / Y Y Y Y
2. Place of birth	______	______	______	______
3. Who is answering these questions for this child?	☐ Mother ☐ Father ☐ Other: Please specify (e.g. brother, sister, grandmother) ______	☐ Mother ☐ Father ☐ Other: Please specify (e.g. brother, sister, grandmother) ______	☐ Mother ☐ Father ☐ Other: Please specify (e.g. brother, sister, grandmother) ______	☐ Mother ☐ Father ☐ Other: Please specify (e.g. brother, sister, grandmother) ______
4. Please indicate child's gender.	☐ Male ☐ Female	☐ Male ☐ Female	☐ Male ☐ Female	☐ Male ☐ Female
5. How long has this child lived at this address?	☐☐ years ☐☐ months	☐☐ years ☐☐ months	☐☐ years ☐☐ months	☐☐ years ☐☐ months

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
6. What is this child's weight in kilograms?	☐☐☐ Kg	☐☐☐ Kg	☐☐☐ Kg	☐☐☐ Kg
7. In what grade and at what school is this child currently attending?	Grade ☐☐ School: ________ ________ ☐ **Not** currently enrolled	Grade ☐☐ School: ________ ________ ☐ **Not** currently enrolled	Grade ☐☐ School: ________ ________ ☐ **Not** currently enrolled	Grade ☐☐ School: ________ ________ ☐ **Not** currently enrolled
GENERAL HEALTH				
8. Compared to one year ago, how would you say this child's health is now?	☐ Much better now than 1 year ago ☐ A bit better now than 1 year ago ☐ About the same ☐ A bit worse now than 1 year ago ☐ Much worse now than 1 year ago	☐ Much better now than 1 year ago ☐ A bit better now than 1 year ago ☐ About the same ☐ A bit worse now than 1 year ago ☐ Much worse now than 1 year ago	☐ Much better now than 1 year ago ☐ A bit better now than 1 year ago ☐ About the same ☐ A bit worse now than 1 year ago ☐ Much worse now than 1 year ago	☐ Much better now than 1 year ago ☐ A bit better now than 1 year ago ☐ About the same ☐ A bit worse now than 1 year ago ☐ Much worse now than 1 year ago
9. Over the past three months, how often has he/she been in good health?	☐ Almost all the time ☐ Often ☐ About half the time ☐ Sometimes ☐ Almost never	☐ Almost all the time ☐ Often ☐ About half the time ☐ Sometimes ☐ Almost never	☐ Almost all the time ☐ Often ☐ About half the time ☐ Sometimes ☐ Almost never	☐ Almost all the time ☐ Often ☐ About half the time ☐ Sometimes ☐ Almost never

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
10. How physically active is this child compared to other children the same age and sex?	☐ Much more ☐ Moderately more ☐ Equally ☐ Moderately less ☐ Much less	☐ Much more ☐ Moderately more ☐ Equally ☐ Moderately less ☐ Much less	☐ Much more ☐ Moderately more ☐ Equally ☐ Moderately less ☐ Much less	☐ Much more ☐ Moderately more ☐ Equally ☐ Moderately less ☐ Much less
11. Does this child have any long-term condition(s) or health problem(s) that limit(s) his/her participation in school, at play, sports or in any other activity for a child of his/her age?	☐ Yes ☐ No If **Yes**, please specify: ____________ ____________ ____________	☐ Yes ☐ No If **Yes**, please specify: ____________ ____________ ____________	☐ Yes ☐ No If **Yes**, please specify: ____________ ____________ ____________	☐ Yes ☐ No If **Yes**, please specify: ____________ ____________ ____________
RESPIRATORY HEALTH				
12. In the last 12 months, has this child had wheezing or whistling in the chest at any time?	☐ Yes ☐ No (Go to question 19)	☐ Yes ☐ No (Go to question 19)	☐ Yes ☐ No (Go to question 19)	☐ Yes ☐ No (Go to question 19)

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
13. In the last 12 months, how many attacks of wheezing or whistling has this child had?	☐☐☐ Attacks	☐☐☐ Attacks	☐☐☐ Attacks	☐☐☐ Attacks
14. In the last 12 months, how often, on average, has this child been awakened due to wheezing?	☐ Never woken with wheezing ☐ One to three nights/month ☐ One or more nights/week	☐ Never woken with wheezing ☐ One to three nights/month ☐ One or more nights/week	☐ Never woken with wheezing ☐ One to three nights/month ☐ One or more nights/week	☐ Never woken with wheezing ☐ One to three nights/month ☐ One or more nights/week
15. In the last 12 months, has wheezing ever been severe enough to limit this child's speech to only one or two words at a time between breaths?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
16. In the last 12 months, has this child's chest sounded wheezy during or after exercise?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
17. In the last 12 months, has this child had a dry cough at night, apart from a cough associated with a cold or chest infection?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
ASTHMA				
18. Has this child ever had asthma diagnosed by a health professional?	☐ Yes ☐ No (Go to question 27)	☐ Yes ☐ No (Go to question 27)	☐ Yes ☐ No (Go to question 27)	☐ Yes ☐ No (Go to question 27)
19. Has he/she had an asthma attack in the last 12 months?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
20. Does asthma prevent or limit this child's participation in school, at play or any other activity normal for a child of his/her age?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
21. At what age was this child diagnosed with asthma?	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years

	Child/Adolescent 1	**Child/Adolescent 2**	**Child/Adolescent 3**	**Child/Adolescent 4**
22. How many times in the past 12 months has this child visited a doctor because of his/her asthma?	☐☐ Number of times	☐☐ Number of times	☐☐ Number of times	☐☐ Number of times
23. Does this child use inhalers or puffers prescribed by a doctor for asthma?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
24. Does this child take any other prescribed medication for his/her asthma?	☐ Yes ☐ No, If No go to question 27 If **Yes**, please specify: ________ ________ ________ ________	☐ Yes ☐ No, If No go to question 27 If **Yes**, please specify: ________ ________ ________ ________	☐ Yes ☐ No, If No go to question 27 If **Yes**, please specify: ________ ________ ________ ________	☐ Yes ☐ No, If No go to question 27 If **Yes**, please specify: ________ ________ ________ ________

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
25. How was this child told to take medication for asthma?	☐ As needed ☐ Before exercise or exposure to asthma triggers ☐ Regularly, but only at certain times of the year ☐ Regularly throughout year ☐ Other? Please specify: ____________ ☐ Don't know ☐ Refused	☐ As needed ☐ Before exercise or exposure to asthma triggers ☐ Regularly, but only at certain times of the year ☐ Regularly throughout year ☐ Other? Please specify: ____________ ☐ Don't know ☐ Refused	☐ As needed ☐ Before exercise or exposure to asthma triggers ☐ Regularly, but only at certain times of the year ☐ Regularly throughout year ☐ Other? Please specify: ____________ ☐ Don't know ☐ Refused	☐ As needed ☐ Before exercise or exposure to asthma triggers ☐ Regularly, but only at certain times of the year ☐ Regularly throughout year ☐ Other? Please specify: ____________ ☐ Don't know ☐ Refused
SKIN				
26. Has this child ever had an itchy rash, which was coming and going for at least 6 months?	☐ Yes ☐ No (Go to question 33)	☐ Yes ☐ No (Go to question 33)	☐ Yes ☐ No (Go to question 33)	☐ Yes ☐ No (Go to question 33)
27. Has this child had this itchy rash at any time in the last 12 months?	☐ Yes ☐ No (Go to question 33)	☐ Yes ☐ No (Go to question 34)	☐ Yes ☐ No (Go to question 33)	☐ Yes ☐ No (Go to question 33)

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
28. Has this itchy rash at any time affected any of the following places: the folds of the elbows, behind the knees, in front of the ankles, under the buttocks, or around the neck, ears or eyes?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
29.At what age did this itchy rash first occur?	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years
30. Has this rash cleared completely at any time during the last 12 months?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
31. In the last 12 months, on average, how many nights per week has this child been kept awake by this itchy rash?	☐ Nights per week	☐ Nights per week	☐ Nights per week	☐ Nights per week

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
32. Has this child ever had childhood eczema that was diagnosed by a health professional?	☐ Yes ☐ No (Go to question 35)	☐ Yes ☐ No (Go to question 35)	☐ Yes ☐ No (Go to question 35)	☐ Yes ☐ No (Go to question 35)
33. At what age was this childhood eczema first diagnosed?	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years
34. Has this child ever had another skin disorder that was diagnosed by a health professional?	☐ Yes ☐ No (Go to question 37)	☐ Yes ☐ No (Go to question 37)	☐ Yes ☐ No (Go to question 37)	☐ Yes ☐ No (Go to question 37)
35. At what age was this other skin disorder first diagnosed?	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years	☐☐ Age in years
OTHER HEALTH CONDITIONS				
36. How many times in the past 12 months did this child have a bad cold, tonsillitis or the flu?	☐☐ Number of times	☐☐ Number of times	☐☐ Number of times	☐☐ Number of times

	Child/Adolescent 1	Child/Adolescent 2	Child/Adolescent 3	Child/Adolescent 4
37. Does this child have any seasonal allergies?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
38. Has this child ever had any of the following conditions? *Mark all that apply.*	☐ Learning problem ☐ Epilepsy ☐ Cystic Fibrosis ☐ Cerebral Palsy ☐ Tumor or cancer ☐ Down's Syndrome ☐ Other (please specify): ____________ ☐ None of the above	☐ Learning problem ☐ Epilepsy ☐ Cystic Fibrosis ☐ Cerebral Palsy ☐ Tumor or cancer ☐ Down's Syndrome ☐ Other (please specify): ____________ ☐ None of the above	☐ Learning problem ☐ Epilepsy ☐ Cystic Fibrosis ☐ Cerebral Palsy ☐ Tumor or cancer ☐ Down's Syndrome ☐ Other (please specify): ____________ ☐ None of the above	☐ Learning problem ☐ Epilepsy ☐ Cystic Fibrosis ☐ Cerebral Palsy ☐ Tumor or cancer ☐ Down's Syndrome ☐ Other (please specify): ____________ ☐ None of the above

39. Is there any comment that you would like to make in relation to the health of this person? Please include whether it is child/adolescent 1, 2, 3 or 4.

____

____

Date questionnaire completed: ____
Day Month Year

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY! If you have any questions regarding this questionnaire, please contact:
KWAS (Sorowako Indigenous Association), Sorowako, South Sulawesi, Indonesia