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Passive sampling of SO_2 and NO_2 ambient air concentrations in Zambia

September 1998

Cristina Guerreiro and Bjarne Sivertsen

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Summary

As part of a screening study to develop a plan for ambient air pollution monitoring in Zambia (Guerreiro and Sivertsen, 1998), 20 SO_2 and 10 NO_2 passive samplers were placed inside the cities of Lusaka and Ndola, and around industries in the Copperbelt area. The passive samplers were installed in field to measure ground level concentrations as a result of emissions from traffic and industry. SO_2 is particularly a problem in the Copperbelt area, due to the high industrial activity that characterises this area. The World Health Organisation's (WHO) air quality guideline for SO_2 is exceeded in Luanshya, Mufulira and Nkana, downwind from the smelters. While in Luanshya and Mufulira these concentrations can have a very serious impact on both vegetation and population leaving downwind from the smelters, in Nkana the population is less often exposed to extremely high SO_2 concentrations, since the townships are not located on the prevalent downwind direction from the industry. The measured NO_2 concentrations are well below the WHO air quality guideline and do not represent presently a motive of concern.

Passive sampling of SO2 and NO2 ambient air concentrations in Zambia

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1. Introduction

NILU was asked by Norwegian State Pollution Control Authority (SFT) for support in defining the ambient air pollution component of the Industrial Pollution Prevention Programme (IPPP) operated by the Environmental Council of Zambia (ECZ).

As part of a screening study to develop a plan for ambient air pollution monitoring in Zambia, 20 SO_2 and 10 NO_2 passive samplers were placed inside Lusaka, Ndola and around industries in the Copperbelt area. The passive samplers were installed in field to measure ground level concentrations as a result of emissions from traffic and industry.

2. The passive samplers

A sensitive diffusion sampler for sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in ambient air has been used in several investigations to undertake a screening of the spatial concentration distribution.

The sampler was developed by the Swedish Environmental Research Institute (IVL) and has been used in several cases by NILU. The sampler includes an impregnated filter inside a small plastic tube. To avoid turbulent diffusion inside the sampler, the inlet is covered by a thin porous membrane filter. Gases are transported and collected by molecular diffusion.

The samplers are very easy to manufacture. For example, the samplers used by NILU are produced from commercially available 50 mm long polypropylene tubes. The tubes are cut to the desired length and then fitted with a solid cap containing the impregnated filter at one end, and an open cap containing the anticonvection mesh/membrane at the inlet end (as shown in Figure 1).

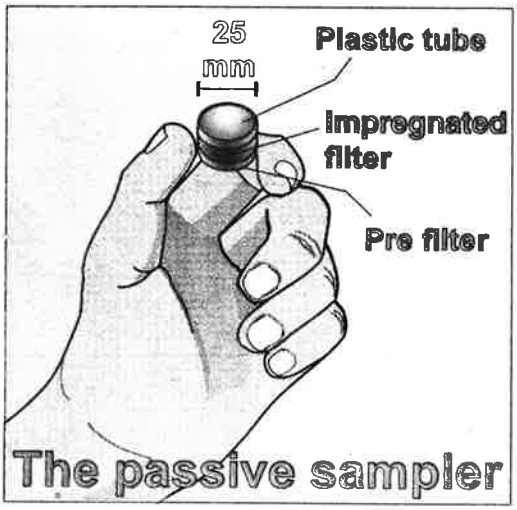

Figure 1: The passive sampler.

All components, except the impregnated filter can be reused. They have many other advantages as well for use in the field. For example they are small, light (~2 g), and require no electricity.

It should be emphasised that they provide time integrated concentrations with continuous time coverage, with the averaging time determined by the period they are exposed to ambient air (which can be daily, weekly, monthly, etc.). They are obviously not well suited for monitoring temporal variations over short time intervals, or for detection of individual peak values, or when real time measurements are needed.

2.1 The basic principle

The sampling technique is based on the property of molecular diffusion of gases, hence the term passive (also referred to as diffusive) sampling. The gas molecules diffuse into the sampler where they are quantitatively collected on an impregnated filter or an absorbent material. Thus they achieve a time-integrated (or average) concentration. No electricity, pumps or other supporting equipment are needed.

If the sampling efficiency is sufficiently high, then the sampling rate can be calculated from the cross sectional area perpendicular to the transport direction and the distance that the gas has to diffuse using Fick's first law of diffusion.

To work properly (and quantitatively) it is essential that the transport occurs solely by molecular diffusion and that no gas is lost to the walls of the sampler. Under these conditions then the sampling rate, and thus the concentration range of the sampler, is directly proportional to its cross sectional area and inversely proportional to its length.

Inorganic gases are absorbed by chemical reaction on a filter impregnated with a solution specific to each pollutant measured. The reaction product, which is washed out of the filter prior to analysis, is specific to the particular gas in question. When species do not react sufficiently fast with other chemicals (e.g., organics) they are instead trapped on an absorbent material. Such gases are then desorbed from the adsorbent during analysis.

2.2 Uptake rates and analyses

The uptake rate is only dependent upon the diffusion rate of the gas. The collection rate is 31 *l*/24h for SO_2 and 36 *l*/24h for NO_2. Also NH_3 can be collected at a rate of 59 *l*/24h.

For SO_2 the measuring ranges are approximately 0,1-80 ppb for a sampling period of one month. The corresponding range for NO_2 is 0,02-40 ppb. The passive samplers are assembled and made ready for use at NILU. After exposure the samplers are usually returned to NILU where concentrations of SO_2 are determined as sulphate by ion chromatography. NO_2 and NH_3 is determined by spectrophotometry.

The average concentration at the measurement site over the time period that the sampler is exposed to ambient conditions is determined by chemical analysis of the filter. Analysis consists of removing the impregnated filter and leaching the reaction product, typically using de-ionised water. The leachate is then analysed using an appropriate analytical technique. The highest concentration that can be measured depends on the amount of sorbent on the impregnated filter. This is typically estimated by the stoichiometric amount of the impregnate reduced by a safety factor (typically a factor of 2).

The lower detection limit of the samplers is determined by the use of blanks. As soon as a filter is impregnated it will begin to measure ambient levels. A filter kept in the laboratory will measure laboratory levels, while field blanks will measure the integrated exposure during the transport and storage periods.

The samplers are impregnated shortly before sent to the field, samplers labelled for batch number, a few filters checked immediately, and then filters identified for lab and field blanks. The laboratory blanks are stored in the lab and periodically tested. The field blanks are kept in their containers and accompany the samplers to the field and are returned after the filters are exposed. The field blanks are analysed along with the exposed samples. The concentrations determined from the exposed filters are then corrected using the blanks. The lower detection limit is commonly defined as 2 to 3 times the standard deviation of the blanks. The repeatability of the results is quantified and checked by use of duplicate samples.

3. Sampling sites in Zambia

Passive samplers were used to measure NO_2 and SO_2 concentrations at selected sites in Lusaka, Ndola, Luanshya, Mufulira and Nkana (Kitwe).

In Lusaka two sites were selected to measure NO_2 and SO_2; one in the city background area, inside the Norwegian embassy; and the other in the city business centre, near the main street. In Ndola two sites measured NO_2 and SO_2, one in the main street and the other in the Mukuba hotel, downwind from the INDENI Petroleum Refinery.

In Luanshya five sites were chosen to measure the SO_2 ambient air concentrations inside townships around the Roan Antelope Mining Corporation smelter. Four sites were located downwind at different distances from the smelter, and one site was located 1 km upwind from the smelter. In this last site both NO_2 and SO_2 were measured.

In Mufulira four sites measured the SO_2 and two sites measured the NO_2 ambient air concentrations around the ZCCM Mufulira smelter. Three of the sites were located inside townships, downwind (SW and NW) and at different distances from the smelter. The 4th site was located 2,5 km upwind from the smelter in a residential area inside the city and measured both NO_2 and SO_2.

In Nkana seven sites were chosen to measure SO_2 ambient air concentrations and three sites NO_2 around the ZCCM Nkana smelter and the Scaw Zambia Ltd. foundry. The Central Shaft site was located inside the smelter area, about 1 km down wind from the smelter. The Fire brigade site was located about 500 m south from the smelter, on the border between the industrial area and Wusakili township. In these two sites only SO_2 was measured. The Wusakili hospital site is located about 750 m upwind from the smelter, and the Nkana hospital site is located inside the city 1,5 km north of the smelter. These two sites measured both NO_2 and SO_2. No residential area is located in the main downwind direction from the industrial area, instead there is a golf court 2-3 km west for the industries. In the golf court area two sites measured SO_2. The last site was placed in a township 4 km north-north-west from the industries.

Table 1 describes the sampling sites in terms of location, main emission sources, position in relation to the emission sources, measured compounds and sampling periods. The maps in Appendix A give a picture of the spatial distribution of the sampling sites and residential areas in relation to the main sources, for each city.

Table 1: Sampling sites for the SO_2 and NO_2 passive samplers.

City/ Town	Site name (position)	Area	Emission source	Position to emission source	UTM co-ordinates		Passive samplers		Sampling period
					X	Y	SO_2	NO_2	(days)
Lusaka	Embassy of Norway	City backg.			640, 3	295, 3	1	1	11.13
Lusaka	Featex building	City centre	Traffic	20m W from main road	637, 3	295, 0	1	1	7.24
Ndola	Buteko Avenu	City centre	Traffic	Main road			1	1	5.78
Ndola	Mukuba Hotel	City/ Ind.	INDENI	≈1,5 km WNW			1	1	5.10
Luanshya	Phiri office	Township/ Industrial	RAMCZ	≈1 km NE	651, 9	548, 4	1	1	4.00
Luanshya	Section 5 clinic	Township/ Industrial	RAMCZ	≈1 km W	650, 0	548, 3	1	-	3.96
Luanshya	14 shaft clinic	Township/ Industrial	RAMCZ	≈2 km WNW	649, 1	549, 2	1	-	3.96
Luanshya	Section 9 clinic	Township/ Industrial	RAMCZ	≈3 km W	647, 8	549, 0	1	-	3.96
Luanshya	Section 25 clinic	Township/ Industrial	RAMCZ	≈8 km W	642, 8	550, 5	1	-	3.96
Mufulira	Clinic 5	Township/ Industrial	ZCCM	≈ 1 km NW	633, 2	614, 8	1	1	2.73
Mufulira	Clinic 7	Township/ Industrial	ZCCM	≈ 4 km NW	630, 5	616, 2	1	-	2.73
Mufulira	Clinic 3	Township/ Industrial	ZCCM	≈ 1 km SW	633, 0	613, 8	1	-	2.70
Mufulira	47 Entebbe street	City/ Industrial	ZCCM / Traffic	≈ 2,5 km SE	636, 0	612, 6	1	1	2.68
Nkana	Central shaft	Industrial	ZCCM/ Scaw	≈ 1 km NW	630, 0	580. 9	1	-	2.05
Nkana	Fire brigade	Industrial/ Township	ZCCM/ Scaw	≈ 0,5 km S	630, 9	579, 9	1	-	2.04
Nkana	Wusakili hospital	Township	ZCCM/ Scaw	≈ 0,75 km E	631, 6	580, 2	1	1	2.05
Nkana	Nkana hospital	City	ZCCM/ Scaw	≈ 1,5 km N	630, 7	581, 8	1	1	2.00
Nkana	Golf - club house	Leisure	ZCCM/ Scaw	≈ 3 km W	627, 7	581, 8	1	-	1.99
Nkana	Golf - club 900m east	Leisure	ZCCM/ Scaw	≈ 2,1 km W	628, 6	581, 5	1	-	1.98
Nkana	Miseshi shop	Township	ZCCM/ Scaw	≈ 4 km NNW	629, 3	585, 3	1	1	1.92

4. Measured concentrations

The passive SO_2 and NO_2 samplers were brought to NILU for analysis. The

Table 2: Measured ground level daily concentrations, averaged over the sampling period.

Sampling period				Site name (position)	UTM coordinates		Concentration (µg/m3)	
From:		To:			X	Y	SO_2	NO_2
date:	hr:	date:	hr:					
21.9.98	10:00	2.10.98	13:00	Lusaka, Nor Embassy	640,3	295,3	2	7
21.9.98	11:20	28.9.98	17:00	Lusaka, Featex build.	637,3	295,0	4	14
22.9.98	13:45	28.9.98	08:30	Ndola, Buteko Avenue			10	18
22.9.98	16:00	27.9.98	18:30	Ndola, Mukuba Hotel			38	2
23.9.98	13:55	27.9.98	13:55	Luanshya, Phiri office	651,9	548,4	14	6
23.9.98	15:10	27.9.98	14:13	Luanshya, Section 5 clinic	650,0	548,3	194	-
23.9.98	15:15	27.9.98	14:17	Luanshya, 14 shaft clinic	649,1	549,2	107	-
23.9.98	15:25	27.9.98	14:25	Luanshya, Section 9 clinic	647,8	549,0	167	-
23.9.98	15:45	27.9.98	14:40	Luanshya, Section 25 clinic	642,8	550,5	91	-
24.9.98	16:20	27.9.98	09:58	Mufulira, Clinic 5	633,2	614,8	382	7
24.9.98	16:40	27.9.98	10.10	Mufulira, Clinic 7	630,5	616,2	19	-
24.9.98	16:55	27.9.98	09:50	Mufulira, Clinic 3	633,0	613,8	672	-
24.9.98	17:20	27.9.98	09:40	Mufulira, 47 Entebbe street	636,0	612,6	6	7
25.9.98	11:35	27.9.98	12:47	Nkana, Central shaft	630,0	580.9	1493	-
25.9.98	11:45	27.9.98	12:40	Nkana, Fire brigade	630,9	579,9	385	-
25.9.98	11:55	27.9.98	13:00	Nkana, Wusakili hospital	631,6	580,2	19	10
25.9.98	12:10	27.9.98	12:05	Nkana hospital	630,7	581,8	55	11
25.9.98	12:20	27.9.98	12:00	Nkana Golf - club house	627,7	581,8	80	-
25.9.98	12.25	27.9.98	11:50	Nkana, golf club 900m east	628,6	581,5	107	-
25.9.98	13.25	27.9.98	11:35	Nkana, Miseshi shop	629,3	585,3	44	11

5. Air quality guidelines

The air quality guidelines for SO_2 and NO_2 from the Norwegian Pollution Control Authority (SFT, 1992) and World Health Organisation (WHO) are given in Table 3.

Table 3: Air quality guidelines for SO_2 and NO_2

Component	Effect	24 hour average	
		SFT	WHO
SO_2	Health	90 µg/m³	125 µg/m³
	Vegetation	50 µg/m³	
NO_2	Health	75 µg/m³	150 µg/m³

6. Discussions and conclusions

The SO_2 concentrations measured at 2 locations in Lusaka indicate low background concentrations, while the measured NO_2 concentrations indicate traffic emissions, specially at the site "Featex", in the city business centre.

In Ndola city centre the measured SO_2 concentration indicate that there are emissions of SO_2 in the area. The background concentration in the Copperbelt area is expected to be higher than in Lusaka, due to the industrial activity that characterises this area, but not as high as 10 µg/m³. The concentration measured at the Mukuba hotel, located 1,5 km west-north-west from the INDENI Petroleum Refinery, indicate that there are emissions of SO_2 in the area and that there may occur episodes with high SO_2 concentrations. The NO_2 concentration measured in Ndola main street, Buteko Avenue, is relatively high due to the traffic, but it is still well bellow the air quality guidelines. The NO_2 concentration measured in Mukuba hotel was very low. This site is not exposed to traffic, but a higher NO_2 concentration was expected due to the Petroleum Refinery.

In Luanshya the SO_2 concentrations measured indicate that there are large emission sources in the area. The measured concentrations inside townships, west and west-north-west from the smelter, are close or above the WHO air quality guideline of 125 µg/m³ for 24 hours. Specially the sites west from the smelter, on the prevalent downwind direction (see wind roses in Appendix B), measure very high SO_2 concentrations, decreasing with the distance from the source, as expected. The site in Phiri office is located upwind from the source, as a reference to the downwind measurements. Here the measured SO_2 concentration is down to 14 µg/m³ and the NO_2 concentration is 6 µg/m³.

In Mufulira the measured SO_2 concentrations indicate that there are very large emissions of SO_2 in the area. The sites located 1 km from the source in the north-west and south-west directions measured 382 and 672 µg/m³ SO_2, respectively. These concentrations are measured inside townships and are 3 and 5 times higher than the WHO air quality guideline for health. From the wind rose of Mufulira (September 1998, in Appendix B), it is expected that even higher SO_2 concentrations have occurred in the township west from the smelter, since this was probably the prevalent downwind direction during the measuring period. The SO_2 concentration dropped considerably between 1 and 4 km from the source along north-west direction. This is probably due to the importance of the fugitive emissions for the measured concentrations close to the source, and to the fact that

the wind only blows from south-east 10-15 % of the time. The 47 Entebbe street site is located upwind from the smelter, giving the background concentrations of SO_2 and NO_2 for Mufulira. From the comparison of the NO_2 concentrations measured at 47 Entebbe street and at Clinic 5 sites, one can conclude that the smelter's emissions of NO_x are relatively low, and its impact on the NO_2 ambient air concentration is not visible, compared to the impact of the SO_2 emissions.

In Nkana, as opposed to Luanshya and Mufulira, there are no townships in the main downwind direction from the industrial area. The measured SO_2 concentration in the Central shaft site, inside the smelter's area, is extremely high (1493 µg/m^3), due both to the proximity to the smelter and to the fact that the wind blew more often to its direction, than to the Fire Brigade site or to the Wusakili hospital site. These measurements indicate that in the periods the wind blows from south or from north-west, Nkana West and Wusakili, respectively, will be exposed to very high concentrations of SO_2. This was not the case during these 2 days of measurements. Nevertheless, during the measuring period, the Fire Brigade site, located on the border between Wusakili township and the smelter's area, registered a very high SO_2 concentration (385 µg/m^3), due to its proximity to the smelter. The two measuring sites located in the Golf camp, in the main downwind direction, 2,1 and 3 km from the smelter, registered high SO_2 concentrations of 107 and 80 µg/m^3, respectively. The measured NO_2 concentrations indicate some NO_x emissions in the area, but these concentrations are presently well below the WHO air quality guideline and do not represent a motive of concern.

7. References

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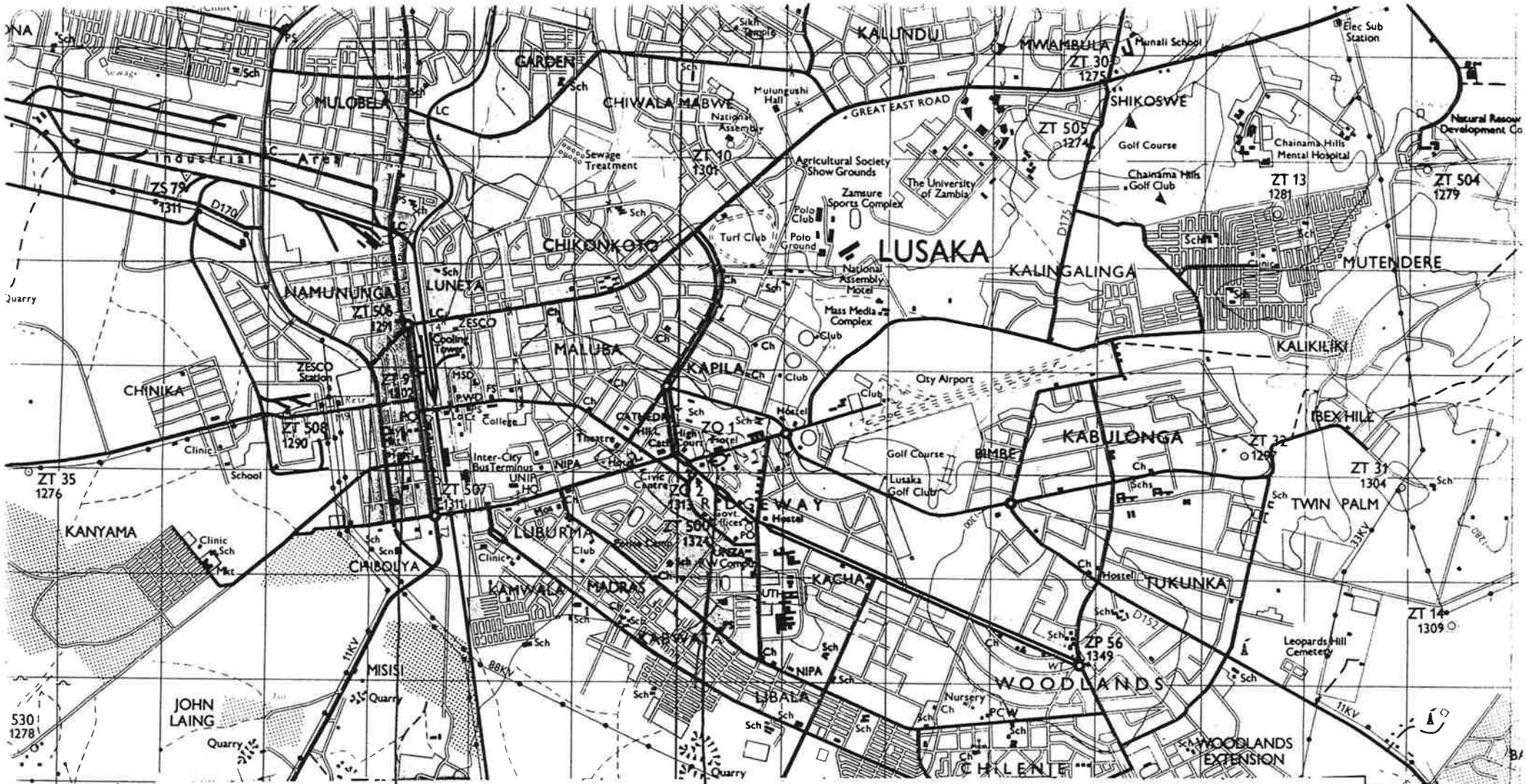
Robertson S., Kirsten (1996) Environmental impact statement, Mufulira division, Mufulira mining licence area - ML 15. Volume 4.2: Appendices E-K. Environmental Engineering Studies. Zambia Consolidated Copper Mines Ltd.

SFT (1992) Virkninger av luftforurensinger på helse og miljø - anbefalte luftkvalitetskriterier. Oslo, Statens forurensningstilsyn (SFT-rapport 92:16).

Appendix A

Location of sampling sites



Featex build.

Northegian Embassy

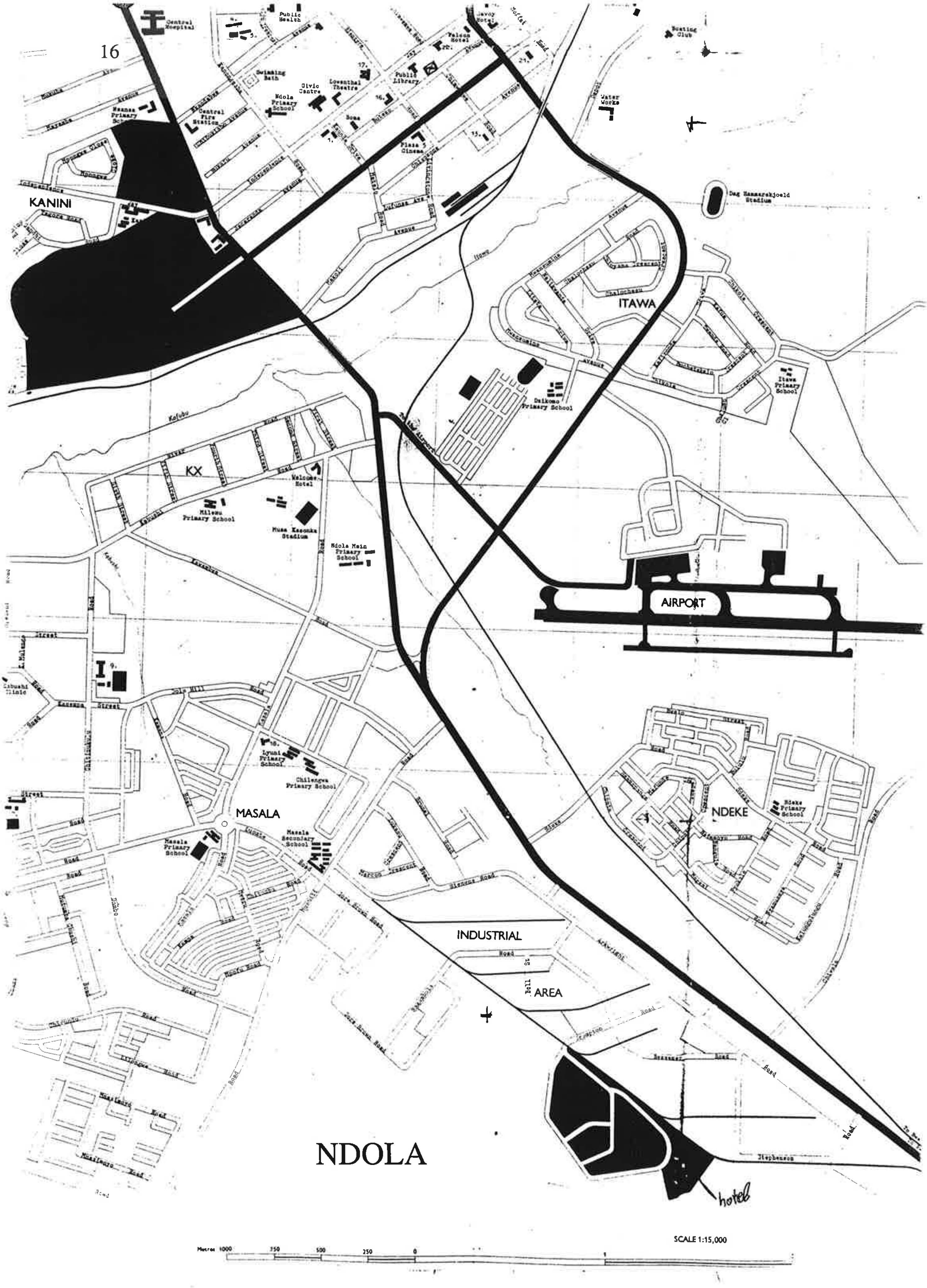
MAP OF GREATER LUSAKA

SCALE 1: 50,000

METRES 1000 0 1 2 3 4 5 6 7 8 KILOMETRES

MILE 1 0 1 2 3 4 5 6 MILES

FEET 5000 2500 0 5000 10000 15000 20000 25000 30000 FEET


Central Hospital
Public Health
Boating Club
Savoy Hotel
Falcon Hotel
Swimming Bath
Civic Centre
Lowenthal Theatre
Public Library
Ndola Primary School
Central Fire Station
Boma
Plaza Cinema
Water Works
Dag Hammarskjoeld Stadium
KANINI
ITAWA
Itawa Primary School
KX
Welcome Hotel
Ndola Main Primary School
AIRPORT
MASALA
Masala Primary School
Masala Secondary School
NDEKE
Ndeke Primary School
INDUSTRIAL
AREA
NDOLA
hotel
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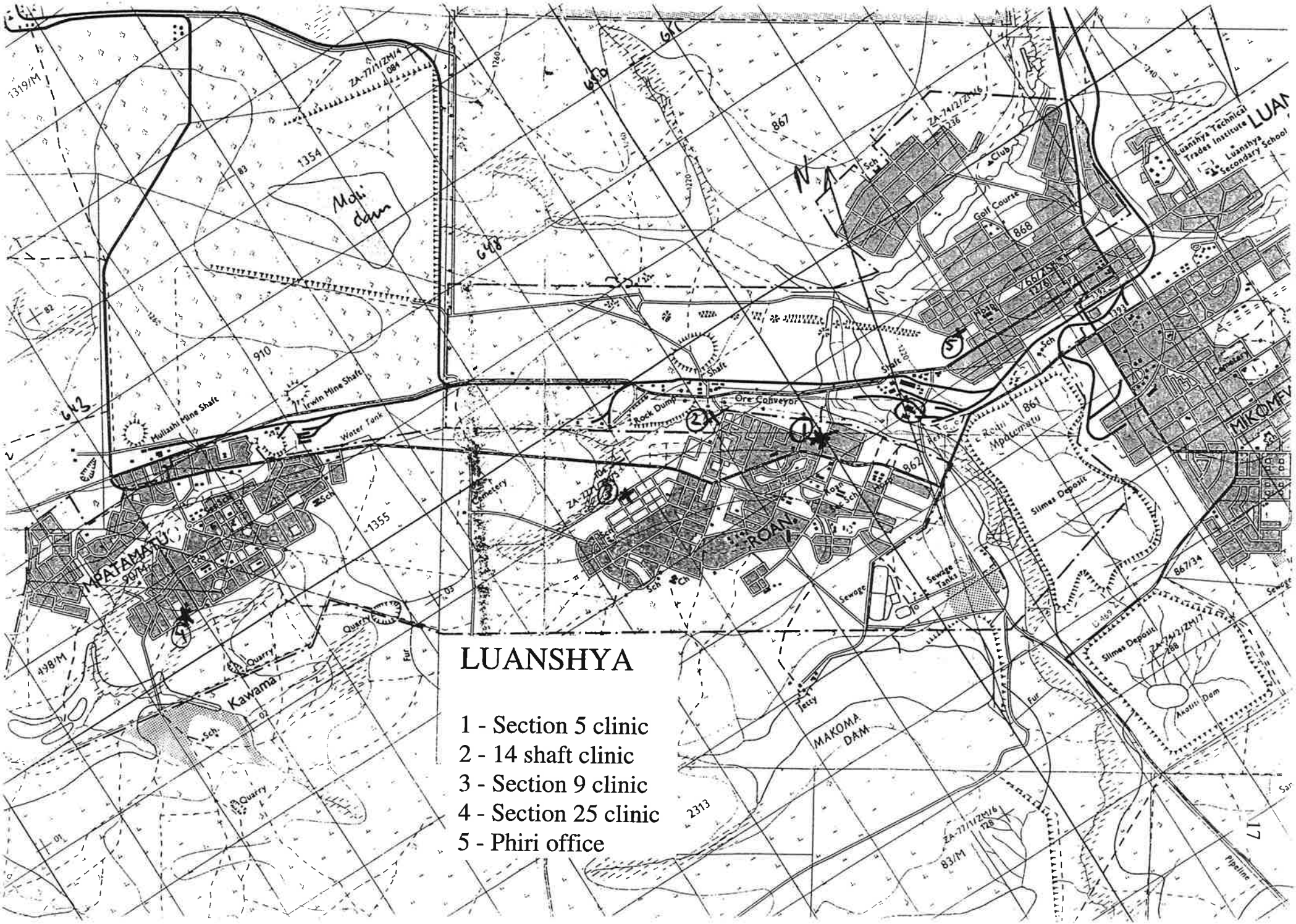
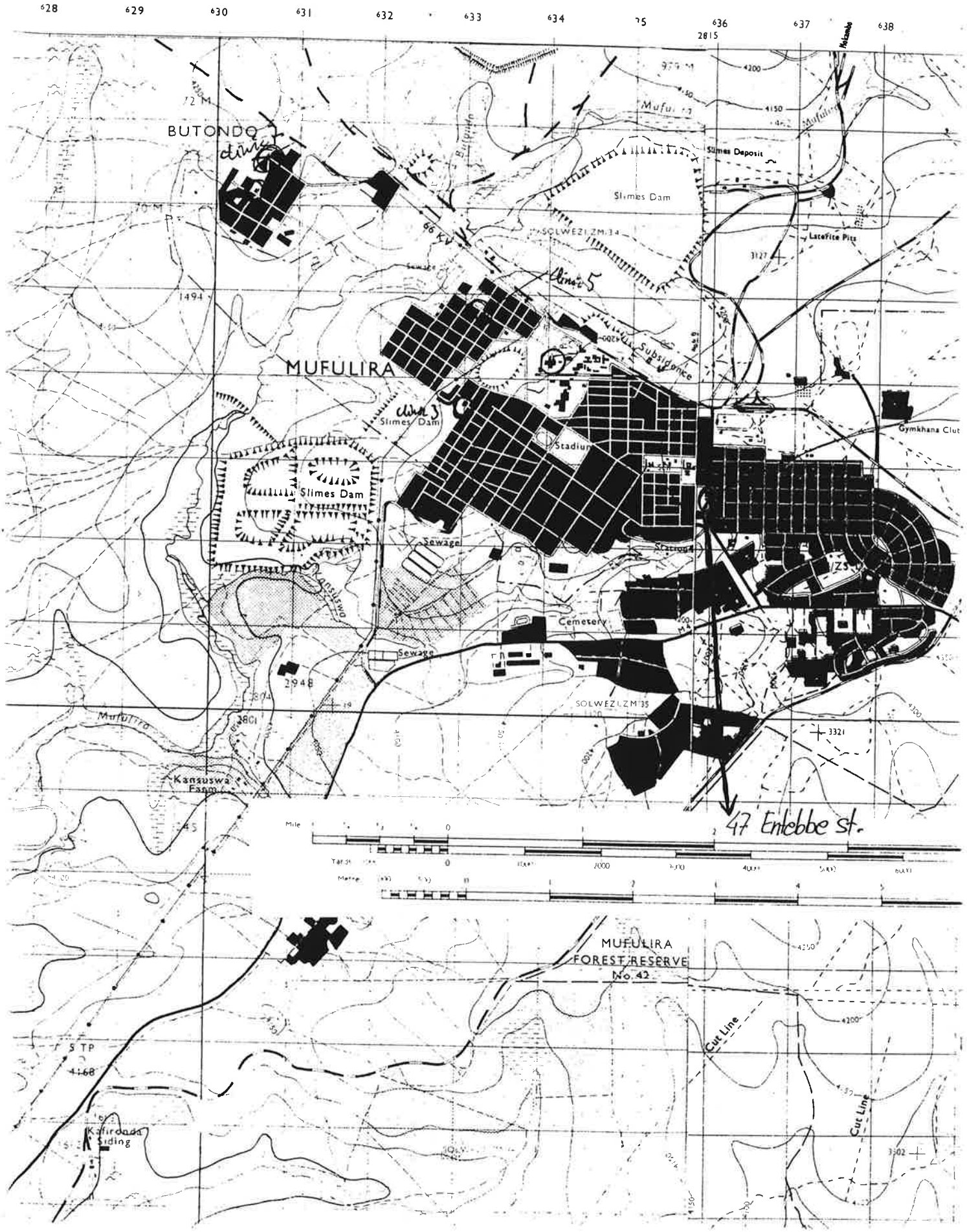
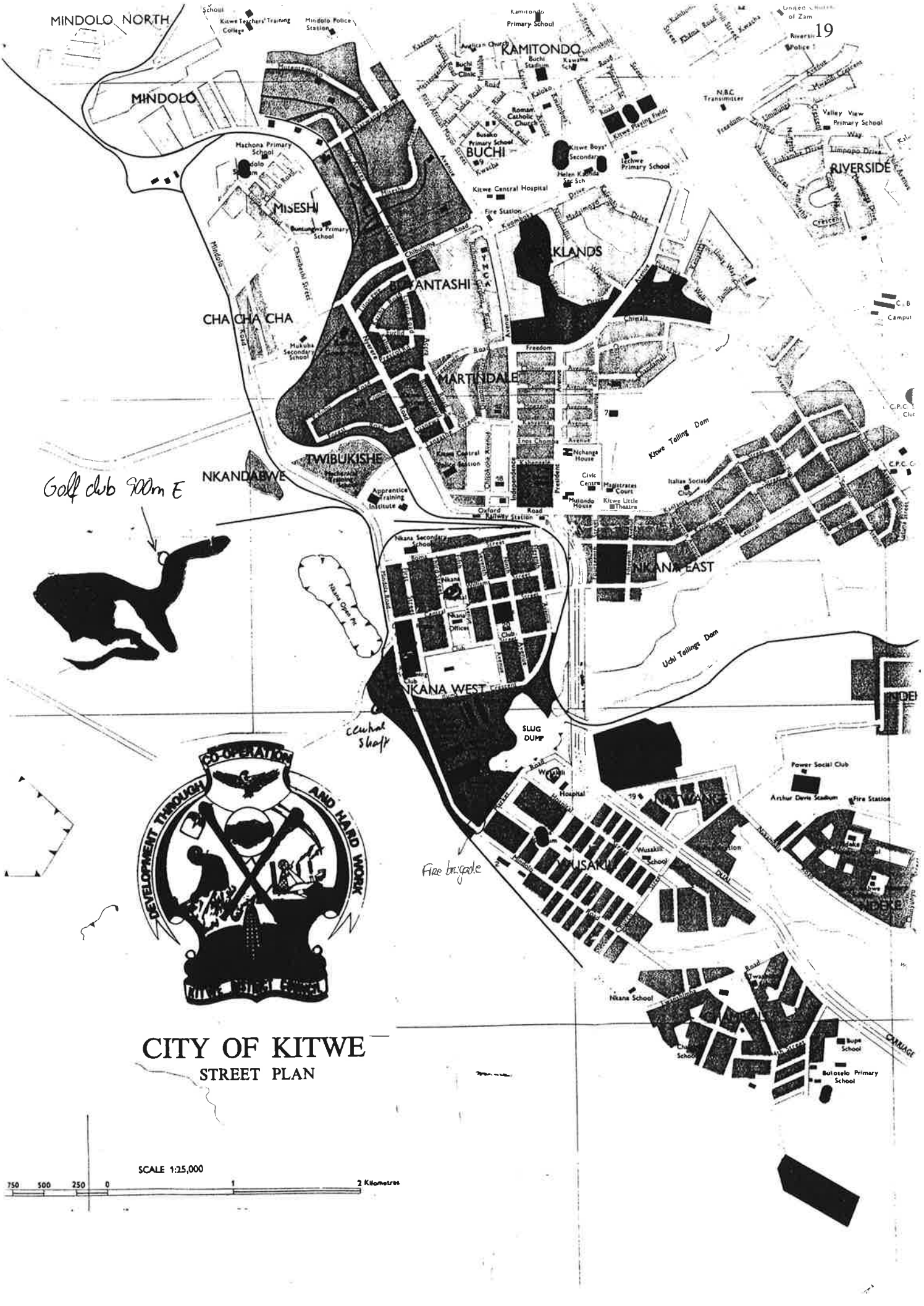

LUANSHYA
1 - Section 5 clinic
2 - 14 shaft clinic
3 - Section 9 clinic
4 - Section 25 clinic
5 - Phiri office
MPATAMATU
ROAN
MAKOMA DAM
Kawama
Mulashi Mine Shaft
Irwin Mine Shaft
Water Tank
Rock Dump
Ore Conveyor
Cemetery
Golf Course
Club
Sewage Tanks
Slimes Deposit
Quarry
Jetty
Pipeline

SHEET 1228 C SCALE 1:50,000

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MINDOLO
KAMITONDO
BUCHI
MISESHI
CHA CHA CHA
ANTASHI
KLANDS
MARTINDALE
TWIBUKISHE
NKANDABWE
RIVERSIDE
NKANA EAST
NKANA WEST
SLUG DUMP
Golf club 900m E
Kitwe Tailing Dam
Udzi Tailings Dam
Fire brigade
DEVELOPMENT THROUGH CO-OPERATION AND HARD WORK
CITY OF KITWE
STREET PLAN
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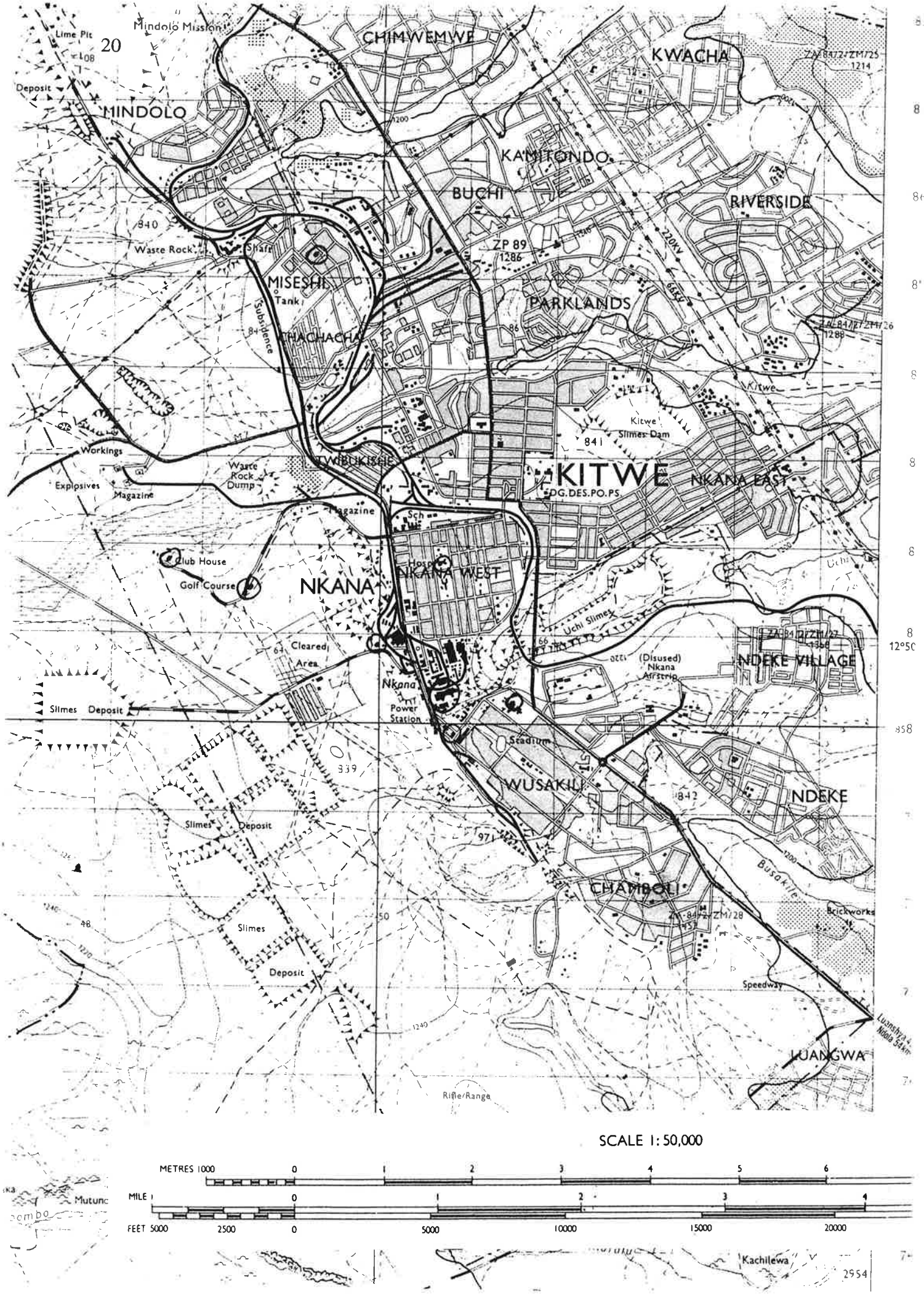
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Mindolo Mission
CHIMWEMWE
KWACHA
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Deposit
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BUCHI
RIVERSIDE
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Waste Rock
Shaft
ZP 89
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MISESHI
Tank
PARKLANDS
Subsidence
THACHACHA
ZA/8472/ZM/26
1288
Kitwe
Kitwe
Slimes Dam
841
Workings
TWIBUKISHE
KITWE
DG.DES.PO.PS.
NKANA EAST
Waste
Rock
Dump
Explosives
Magazine
Magazine
Sch
Club House
Golf Course
NKANA
NKANA WEST
Hosp
Uchi
Uchi Slimes
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1356
Cleared
Area
(Disused)
Nkana
Airstrip
NDEKE VILLAGE
Slimes Deposit
Nkana
Power
Station
Stadium
WUSAKILI
842
NDEKE
Busakile
Slimes
Deposit
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Brickworks
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Deposit
Speedway
Luanshya
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LUANGWA
Rifle Range
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SCALE 1: 50,000
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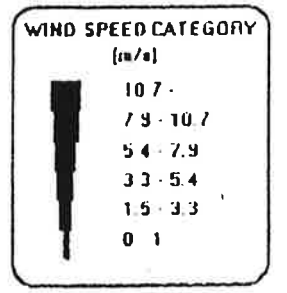
Kachilewa
2954

Appendix B

Wind roses

Wind roses for 1995 at Mufulira Smelter



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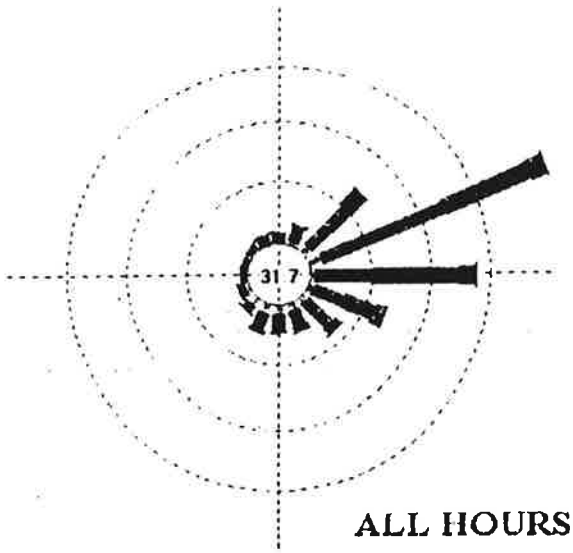
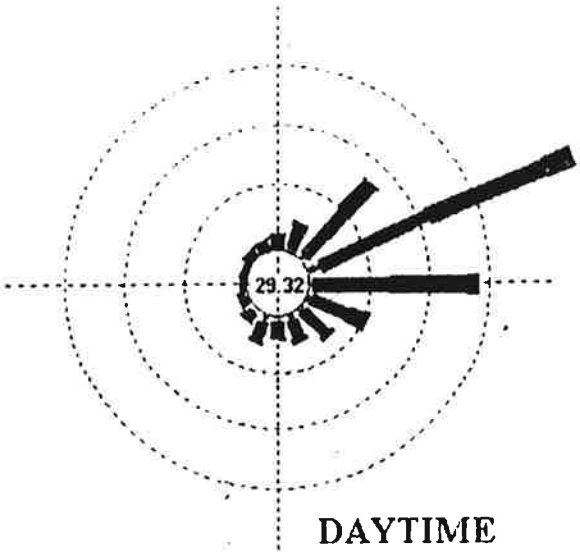


ALL HOURS



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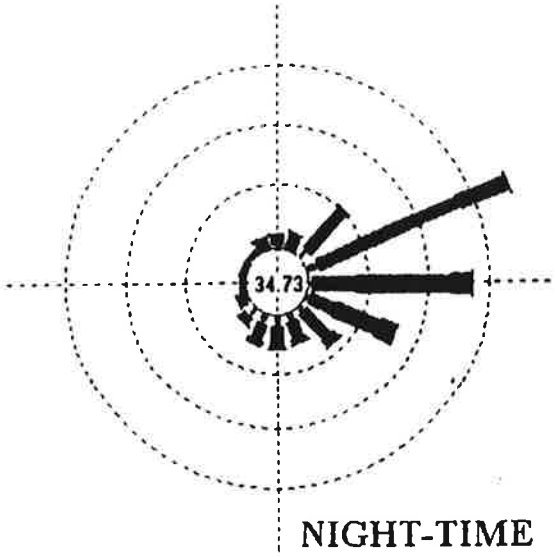
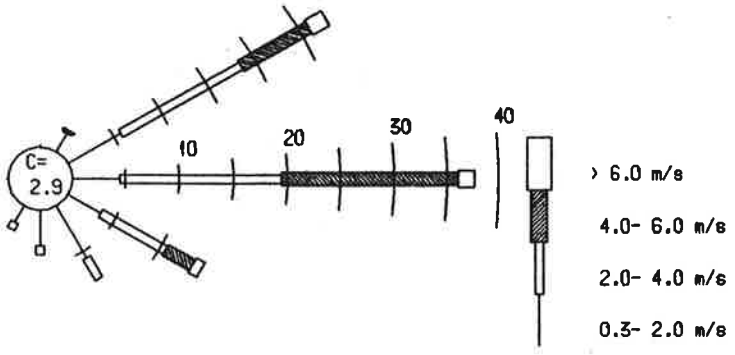


NIGHT-TIME

Wind rose for 01.09.98 - 24.09.98 at Mufulira Smelter



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Passive sampling of SO2 and NO2 ambient air concentrations in Zambia September 1998	Bjarne Sivertsen NILU PROJECT NO. O-98101
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REPORT PREPARED FOR:
Environmental Council of Zambia (ECZ)

ABSTRACT
As part of a screening study to develop a plan for ambient air pollution monitoring in Zambia, 20 SO_2 and 10 NO_2 passive samplers were placed inside Lusaka, Ndola and around industries in the Copperbelt area. The passive samplers were installed in field to measure ground level concentrations as a result of emissions from traffic and industry. SO_2 is particularly a problem in the Copperbelt area, due to the high industrial activity that characterises this area. The World Health Organisation's (WHO) air quality guideline for SO_2 is exceeded in Luanshya, Mufulira and Nkana, downwind from the smelters. While in Luanshya and Mufulira these concentrations can have a serious impact on both vegetation and the populations leaving downwind from the smelters, in Nkana the population is less often exposed to extremely high SO_2 concentrations, since the townships are not located on the prevalent downwind direction from the industry. The measured NO_2 concentrations are well below the WHO air quality guideline and do not represent presently a motive of concern.

NORWEGIAN TITLE
Passiv prøvetaking av SO_2 og NO_2 luftkonsentrasjoner i Zambia. September 1998.

KEYWORDS		
Passive sampling	Zambia	Screening study

ABSTRACT (in Norwegian)

* *Classification*
- *A Unclassified (can be ordered from NILU)*
- *B Restricted distribution*
- *C Classified (not to be distributed)*