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FACTORS AFFECTING THE SPATIAL AND TEMPORAL VARIATION IN TEMPERATURE PATTERNS IN LUSAKA AND ITS ENVIRONS

BY

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GEO 474 RESEARCH REPORT

UNZA, LUSAKA

APRIL 2000

DEDICATION

Dedicated to my relatives and friends without whom this journey would have been unbearable. I love you all.

DECLARATION

I, *DUPXA CHIKOMBORERO. D*, do solemnly declare that this work has been solely composed by me, and that the work recorded is my own. The maps and tables were compiled by me and all sources of information have been appropriately acknowledged. This work has not been previously presented in any form for any academic or other award.

Signed: ....

ACKNOWLEDGEMENTS

First of all I would like to acknowledge Dr. Mark. C. Mulenga for encouraging me to take on this study. I am indebted to him for supporting me through the initial stages of its formulation.

I would also like to thank the Zambia Meteorological Department and the Cartographic Office of UNZA for availing to me data and equipment, and base maps, respectively.

I would also like to thank my family and friends for the support they rendered me, material and otherwise.

Special gratitude goes to *Mr. J. Volk* for agreeing to take on me as his student. I am forever grateful for the constructive criticism that has helped shape this report.

Finally, I wish to thank the whole Department of Geography at the University of Zambia - both lecturers and supporting staff and all my companions in GEO 474 for making my stay at UNZA a memorable experience.

TABLE OF CONTENTS

Chapter **Page**

TABLE AND ILLUSTRATIONS

ABSTRACT

Global temperature patterns have been reported to have been significantly altering. Climate change has become a topic of great importance and problems of temperature calamities of both small and large scales have increased. Human beings have been intruding on the natural temperature patterns, altering surfaces and replacing them with ones with high thermal capacities. Aerosol generation has increased resulting in an emphasis on the green - house effect. Unfortunately, however, the dynamics of these operations in developing countries have not been well documented and there is a need for more information in these areas. This study set out to investigate the possibility of human - induced change in temperature patterns in a developing world city like Lusaka and to describe the factors that cause such a scenario. Both primary and secondary data were used to achieve the objectives, with the use of isotherms to help define the heat island and identify the main areas that influence it. The results showed that there is a possibility of the heat island occurring in Lusaka, though it may be of smaller proportions compared to those in developed world cities. Heavy industrial and high-density residential areas were shown to be the main areas of influence and time was also seen to be a significant factor in influencing the intensity of the heat island. The building of concrete surfaces, removal of vegetation, generation of heat from domestic and industrial sources and of aerosols in the urban area were identified as being the probable causes of the situation obtaining. Options for reducing the impact include the increase in green areas, increased use of renewable resources, and the control of population dynamics.

CHAPTER 1

1.0 INTRODUCTION

The state of the atmosphere has been one of the most pertinent issues of this and immediately preceding decades. The heightening of concern has been indicated by global bodies such as the World Meteorological Organisation (WMO) who indicate problems and issues concerning the state and dynamics of climate and weather. Problems of temperature and rainfall calamities of both small and large scales have increased in incidence and intensity. The Intergovernmental Panel on Climate Change (IPCC) was consequently formed to spearhead research on climate issues in order to better understand these phenomena so as to effectively deal with them (U.N, 1997)

Climate change conventions have increasingly highlighted the 'human factor' in natural processes and how dynamics of natural processes have been greatly altered by human beings (IPCC, 1996). Particularly observed in urban areas, human activity has altered land surfaces, with consequent modifications on atmospheric elements such as precipitation, winds and temperature.

In developed world cities such as Hamilton in Canada and Paris in France, the characteristics of the 'heat island' have been well documented

(Oke, 1987; Goudie, 1997). The state of the phenomenon of heat island in developing countries, however, is scantily reported. There are a number of indications in developing countries that point towards the occurrence of the heat island.

In Lusaka, for instance, there are a number of human activities that have taken place such as the rapid construction of concrete buildings, industrial establishments, roads, pavements, houses and other structures. These, undoubtedly, have had a considerable impact on natural temperature and wind patterns of the area. Few research work, such as that by Punabantu (1987), attempts an enlightenment of the occurrence of the urban heat island and their presence in Lusaka. There is therefore a need to identify these factors which create the heat island and to explain the dynamics of their processes, such as the passage of time and the differing location impacts on their operations.

The significance of such a study would best be understood by drawing on the knowledge that temperature patterns have a significant effect on the biophysical environment (Handerson - Sellers and McGuffie, 1987). They affect, either directly or indirectly, both animate and inanimate matter. Relatively stable temperature patterns, spatially and temporally, are therefore of importance to the stability and ecology of Lusaka and its environs. Unanticipated or abrupt changes in temperature patterns can have adverse impacts on human, plant and animal life. Biodiversity loss can become a major problem. There could also be higher heat stress to humans in Lusaka's already warm environment and an increase in vector borne diseases such as malaria could threaten the city's people's health.

In industrialised areas of North America, North Africa and East Asia, for instance, there have been a higher number of heat waves per year and this has significantly raised mortality and morbidity amongst urban populations (IPCC, 1996). Increases in rates of infectious diseases and in spatial and temporal occurrence of vector organisms of infectious diseases, like the anopheles mosquito, can in total increase mortality in a city which is plagued by problems of inadequate health facilities and has a large but ever-growing population. Non-vector borne diseases such as cholera can also increase because of rise in temperature. Hunger and malnutrition may also increase due to the effect that temperature change can initiate on agricultural, animal and farming productivity.

Many first world cities have experienced gradual, and at times abrupt, alterations in the coverage of their terrestrial surfaces. Concrete structures and surfaces have replaced natural vegetation. Establishment of industries and the congregation of humans in high densities in these areas has led to intensification of activities that generate heat and aerosols, that trap heat, are being generated. Research in these cities has shown that these activities have a great potential to alter natural temperature patterns (Oke, 1987).

In Lusaka, from the early 1900s to the present. there has also been a dramatic alteration in the surface of the land area. The formerly vegetated surface has increasingly been replaced by an area comprising buildings and other concrete surfaces. Lusaka has grown rapidly both in spatial extent and in population size. The growth of its areal extent has been documented and is shown in the table below:

Table 1: **Population Density of Lusaka's Built-Up Area**

Year	Area (km2)	Population Estimate	Population Density (No./km2)	Source
1955	17.25	66 467	3 853	Williams, 1983b
1967	32.63	147 493	4 520	"
1975	72.63	425 079	5 853	"
1981	85.62	542 572	6 337	Williams, 1983b
1998	-	1 543 000	-	C.S.O., 1998
2000	-	1 641 694	-	C.S.O., 1998

1.1 Statement of the Problem

Like in the developed world cities, inhabitants of Lusaka Urban have intruded on the formally natural weather patterns that existed in the area, and this is the basic problem. Paving and construction of concrete structures have increased the thermal capacity as vegetation, which has a

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moderating effect on temperature, has been eliminated. Buildings have exerted a fictional drag on winds, which have a ventilating effect on temperatures. There is a great potential for natural temperature patterns in Lusaka being altered significantly in contrast to the surrounding environs. The problem is not evenly distributed but rather has some core areas that experience greater changes within the built-up area than others. Seasons also have an influence on the temperatures obtaining.

1.2 Rationale

There is a scarcity of literature relating to the human impact on weather elements in Zambia in general and in Lusaka in particular. In addition, it is important to conscientise the inhabitants of Lusaka and other urban areas on the need for environmental awareness in their development activities. The study was also important because of the need to identify and provide responsive and relevant mitigation options. It is also hoped that the study will stimulate further and more in-depth research into changes in weather elements due to human influence.

1.3 Main Objective

The broad objective of the research was to establish the possibility of human - induced change in temperature patterns in the urban area, and to contrast these with temperature patterns in the surrounding countryside.

1.3.1 Specific Objectives

The specific objectives of the research were to:

(a) Establish the prescence of a heat island and its spatial extent;

(b) Identify the core areas of heat island effect;

(c) Investigate the shifting of the boundary with time; and

(d) Identify the factors responsible for temperature pattern variability.

CHAPTER 2

LITERATURE REVIEW

The pace for the research can be set by a citation of some interesting facts given by Killham (in the Globe, 1995, p7) who contends that:

> 'The scope and impact of human activity on the dynamics of natural processes is a relatively recent phenomenon, which may interrupt or change natural climatic variation. Climate change is not just about increases in global mean temperatures. The most immediate serious effects of climate change for humans are felt through changes to the occurrence and severity of climatic events'.

In light of the above, it is worthy to note that the bulk of human activity that has an overbearing influence on temperature patterns is epitomised in urban areas. "The city is the quintessence of man's capacity to inaugurate and control changes in his habitat' (Detwyer and Marcus, 1972 in Goudie, 1988). Activities such as industrial production and consumption are manifested in towns.

Humans therefore influence weather patterns and this has far-reaching effects on the biophysical environment. Alteration of the city environment has led to significant temperature differences between the city and the surrounding countryside. Reasons proposed for this include the actuality that city surfaces significantly absorb more heat than the rural environs. Much of the reflected radiation is retained by the high walls and dark coloured roofs of city streets, and the concrete surfaces have a high thermal capacity and conductivity to store heat by day and release it by night (Oke, 1978). The tall buildings also exert a frictional drag on the ventilating effect of winds thus leading to higher temperatures in the city than the surrounding countryside which has plant cover that insulates from heat and whose cooling effect is enhance by evapotranspiration. Thermal changes in cities caused by artificial heat generation, by industrial domestic, and commercial activity, also raises city temperatures (Goudie and Viles, 1997; Oke, 1978).

The impact of city activities on weather patterns, if left unchecked, can be similar to that of volcano or a desert in destruction of the natural environment (Changnon, 1973, in Goudie, 1988). This phenomenon where the built up areas experience significantly higher temperatures than the surrounding rural areas has been termed the 'urban heat island' (Oke, 1987). There is a steep temperature gradient between rural and urban areas, with urban temperatures appearing as a plateau of warm air, with a steadily rising gradient towards the city center, and the urban core representing peak maximum temperatures (Goudie and Viles, 1997).

Research on Paris has revealed that outlying weather stations have mean annual temperatures of 10.6 - 10.9°C, while in central Paris temperature was 12.3°C (Goudie and Viles, 1997). Goudie (1988) also showed that cities can generally raise annual mean temperatures by 0.7°C, and raise the winter maximum by 1.5°C. Inquiries in Hamilton, Ontario and Montreal, Quebec revealed temperatures changes of 3.8°C and 4.8°C, respectively, per kilometer (Oke, 1978). The difference between the peak value at the urban core and the background rural temperatures specifies the intensity of the heat island (T u-r max). He gives the intensity of one night in Upssala, Sweden as being between 5°C and 6°C.

Goudie (1988) has also given some mean urban-rural temperature differences for some cities as follows:

- Chicago, 0.6°C;
- Moscow, 0.7°c;
- Berlin, 1.0°C; and
- London, 1.3°C.

In France, research has shown that urban temperatures are significantly higher during the week days when there is intense industrial activity than over the weekend which has less activity (Goudie and Viles, 1997). The magnitude of change varies spatially and temporally, a function of locational characteristics. Isotherms closely follow the built up form of the city (Oke, 1987). Intensity increases rapidly around and just after sunset because the urban area is slow to warm. During midday, rural temperatures may actually be higher than in the city.

These changes in temperature patterns have an influence on human activity. Crop yield models have indicated that food production depends on weather and thus any change in its elements has consequential implications on the yields of a particular area and its production methods (see Table 2).

Table 2: **High Temperature Effects on Key Development Stages of Major Crops**

Crop	Effect
Wheat	Temperature > 30°C for more than 8 hours can reverse vernalisation
Maize	Pollen begins to lose viability at temperatures > 36°C
Potato	Temperatures > 20°C depress tuber initiation and bulking
Soyabean	Great ability to recover from temperature stress; critical period in its development unknown

Source: IPCC (1996, p.433)

The temperature change margins can also alter the general atmospheric circulation and precipitation patterns, among other things. It must be noted that these temperature changes are not the result of one extreme event that can alter temperature. On the contrary, apart from extreme events such as droughts, there are many isolated and seemingly insignificant events, such as aerosol generation from industry and construction, that alter the natural heat balance.

Attention may also be drawn to the view propounded by some scholars that the perception that this change is due to human influence is a rather superficial one. They contend that these changes in weather patterns can be explained by the fact that weather is a dynamic phenomenon and that the warmer temperatures being experienced are part of a general movement into warmer years on a cycle in the geological time scale. One, however, is inclined to undermine this view because if indeed it is true that the changes are due to processes operating on the geological time scale, then the apparent differences between rural and urban temperatures would be small or non - existent, since both areas are subjected to the same factors. That therefore cities experience temperatures different from the countryside is indicative of an influential role that altering factors in the city must have on the atmosphere.

In the formulation and implementation of strategies, the United Nations Environment Programme (UNEP) has recognised the important role that developing countries like Zambia play in climate change and mitigation options (Hadley Centre for Climate Prediction and Research, in The Globe, 1995). The need for more efficient conversion of carbon fuels and increased use of renewable source of energy in Global Environmental Change (GEC) policy can thus only effectively succeed with an increasingly greater contribution from developing countries. Lack of information from developing countries prevents effective global modelling. Thus more researches in such areas need to be complemented.

CHAPTER 3

3.0 Description of the Study Area

This chapter schemes through the characteristics of the study area.

(See fig.1).

3.1 Physical Characteristics

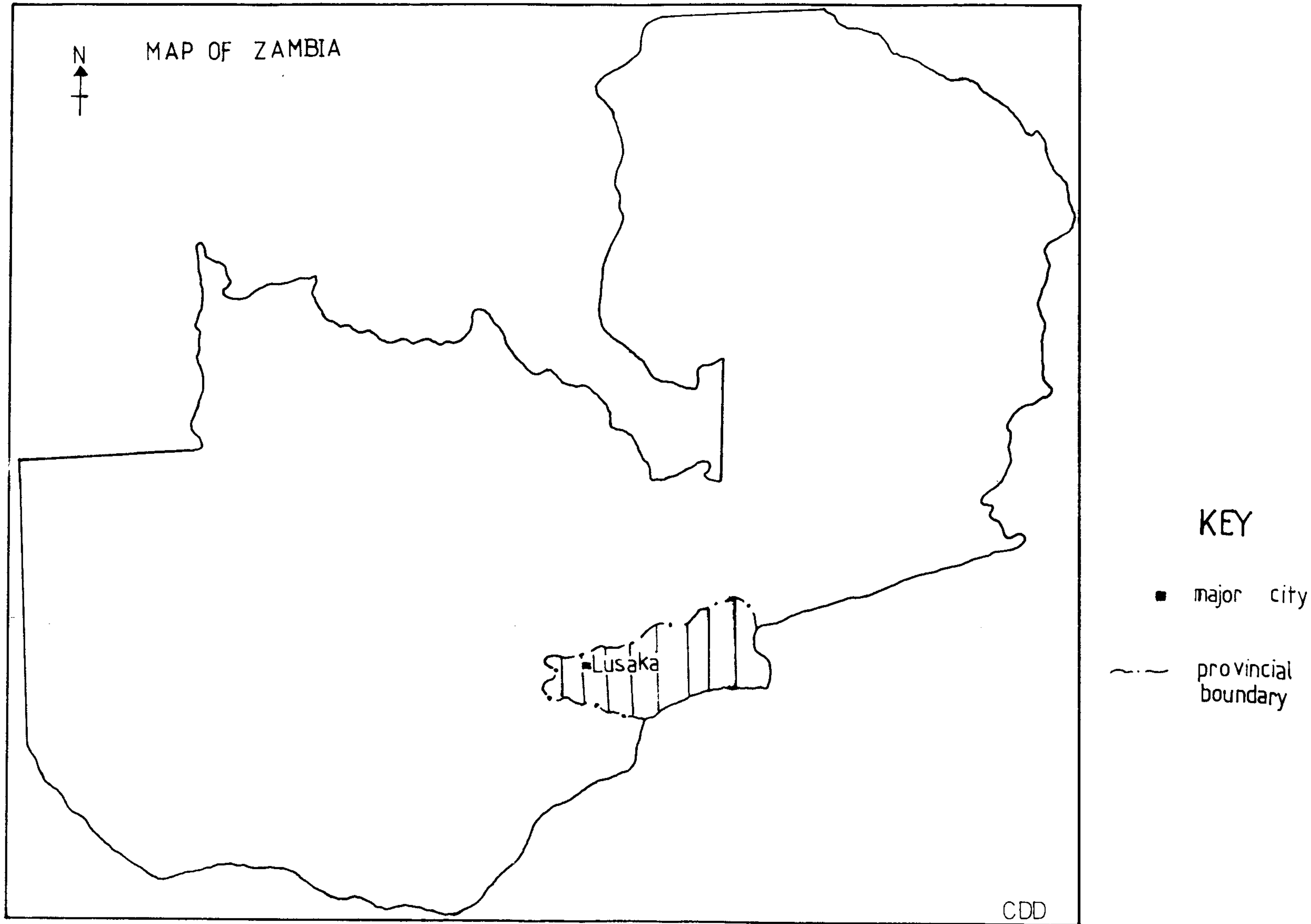
3.1.1 Relief

Lusaka is located at approximately 1300m above sea level on the Central African Plateau (Williams, 1983b). It covers an area spanning from longitudes 28°E to 29°E, and latitudes 15°S to 16°S (see fig. 1). It covers approximately 360 sq.km of almost flat relief, except in some parts in the north and east, where land forms escarpments ending in the Luangwa valley (Agyemong et. Al., 1997).

3.1.2 Geology

Lusaka comprises a Pre-Cambrian basement complex overlain by more recent limestones and dolomites. The basement complex consists of granites and quartzites.

FIG.1. LOCATION OF STUDY AREA



source: Agyemong et al (1997)

3.1.3 Drainage

The junction of the basement complex on one hand, and the limestone and dolomites, on the other, provides the sources for the city's streams. The two major ones are the Ngwerere, flowing northeastwards and the Chunga, that flows southeastward to join the Mwembeshi that in turn joins the Kafue River.

3.1.4 Climate

As in most parts of Zambia, Lusaka's climate is punctuated by three district seasons namely:

- The wet season (November – April)
- The cool season (May – July); and
- The hot dry season (August – October).

Average temperature is about 20°C, with a mean minimum of 20°C and mean maximum of 26°C (Agyemong et. Al., 1997). Rainfall is heaviest in December, with an average of 220mm.

3.1.5 Vegetation

Dominant vegetation in the Lusaka area is 'open' decidous woodland (miombo), accounting for about 80% of the forested area in the north and east of the city, while in the south and west the 'munga', a savanna woodland dominates.

3.1.6 Soils

Underlying geology influences the soils. Those on limestone and dolomite outcrops are generally varied in texture and depth, from red-brown clays to dark loamy soils. Those over quartzite and other sandstone formations are light, sandy and well drained. In Lusaka Province as a whole, soils are also divided into two, but those developed over exposed dolomite and limestone outcrops tend to be more acidic.

3.2 History

Lusaka has grown from being a railway siding in 1905, to the metropolitan city it is today. The Adshead Plan of 1930 proposed the development of Lusaka on the 'garden city' principle, with tree-lined avenues, detached houses in spacious grounds and complete barring of polluting industries, and it was to be strictly an administrative center (Agymong et. Al., 1997). In 1952, the Adshead Plan was discarded for a 'Lusaka Town Planning Scheme' (LTPS). The Doxiadis Plan, in 1968, also replaced the LTPS, which assumed a motorised resident population and has, since then, not been revised.

3.3 Population

The growth of Lusaka's population is shown in the table below:

Table 3: Population Size and Growth Rates, Lusaka Province, 1969, 1980 and 1990

Year	Population	Annual Growth Rate (%) Period	Rate
1969	353 975	1969 – 80	6.3
1980	691 054	1969 - 90	3.6
1990	987 106	-	-
***2000**	1 641 694	Estimated for 1990 - 2000	3.1

Source: C.S.O (1990) Census of Population Housing and Agriculture Vol.5, Lusaka Province Analytical Report.

*Project population at a growth rate of 3.1% (C.S.O, 1998)

CHAPTER 4

4.0 Methodology

This chapter explains the major sources and choices of data, sampling procedure, size and points. It also looks at limitations of the quality of data and possible sources of error.

4.1 Data Sources

4.1.1 Secondary Data Sources

Meaningful analysis of climatic variables frequently calls for use of data acquired over a long time period. This data, for different stations, was obtained from the Zambia Meteorological Department (Z.M.D.). Data for each station was obtained as far back as records began spanning up to 1991. The stations for which data was collected were:

- → Lusaka Hydro - (LH)
- → International Airport - (IA)
- → City Airport - (CA)
- → UNZA - (UZ)
- → Kafue Polder - (KFP)
- → Chalimbana - (CH)

→ Kafironda Forest Reserve - (KFR)

→ Mount Makulu - (MTM)

→ Lusaka North Plantation - (LNP)

These stations were selected because they more or less cover most parts of the city and temperature records can be used to draw isotherms.

4.1.2 <u>Primary Data</u>

Temperatures were read in the field by the researcher using a mercury thermometer. At each point the reading was taken approximately 1.25cm from the ground in the shade, with the thermometer covered to minimise the effect of re-radiation – inflation on the atmospheric temperature readings. Five (5) observations were made for each sample point from the late September to early November 1998. It is during this period, in Zambia, that temperatures are at some of their highest and standard deviation shows the least variations in temperature values for each station (Chipungu, 1994). It may be deducted therefore that the observed variations are attributed to other extraneous factors. Readings were taken between 15:00 hours and 16:00 hours, as insolation by this time has sufficiently heated the atmosphere for a long enough period.

4.2 Choice of Study Area

Lusaka was chosen for the following reasons:

- The larger availability of archival temperature data;
- The larger number of meteorological stations, unlike in other cities;
- Accessibility to the researcher–travelling and accommodation expenses in the study area were reasonable; and
- The greater contrast between urban built up land and the surrounding unbuilt up land here than in other towns.

4.3 Sample Size and Sampling Procedure

Nine stations, most of which more or less cover portions of the city were used so as to have a reasonable number of stations to allow interpolation of isotherms.

For primary data, a stratified random sampling survey was used in order to ensure that, as far as possible, the samples would be representative of the different strata identified in the study area. This was in order to facilitate identification of the core-areas of heat – island effect.

The defined strata, identified from a street map of Lusaka, and based on relatively homogenous classes of areas, which were sampled to represent the area, were areas of:

- Heavy Industrial Activity - (HIA)
- Light Industrial Activity - (LIA)]
- High Density Residences - (HDR)
- Low Density Residences - (LDR)
- Urban Unbuilt Land - (UUL)

The points were chosen on the basis of their representation of each area. A six – figure grid was superimposed on the maps and used as a sampling frame from which points were chosen. In ideal conditions, a much larger sample would have been desirable as it approximates reality.

CHAPTER 5

5.0 DATA ANALYSIS AND RESULTS

This chapter presents the findings of the study. The data obtained to achieve each objective are also analysed.

5.1 The Presence of the Heat Island and its Spatial Extent

To achieve this, secondary data were mainly used and the seasonal or annual means for each of the selected stations were calculated and used to construct isotherms by interpolation.

Seasonal means were also used to show the spatial extent of the heat island. As shown in fig.2, temperature apparently increases as one moves from the non built-up area towards the city center, from 19°C to 21°C on average. Lusaka urban and Kafue urban show distinctly higher temperatures than the surrounding countryside.

The 20°C isotherm defines a shift to a relatively consistent lower temperature value of 19°C. The October means, which have the least standard deviation also show a steady temperature increase towards the city centre from about 20°C to about 24°C. (See fig.3).

fig.2 seasonal means

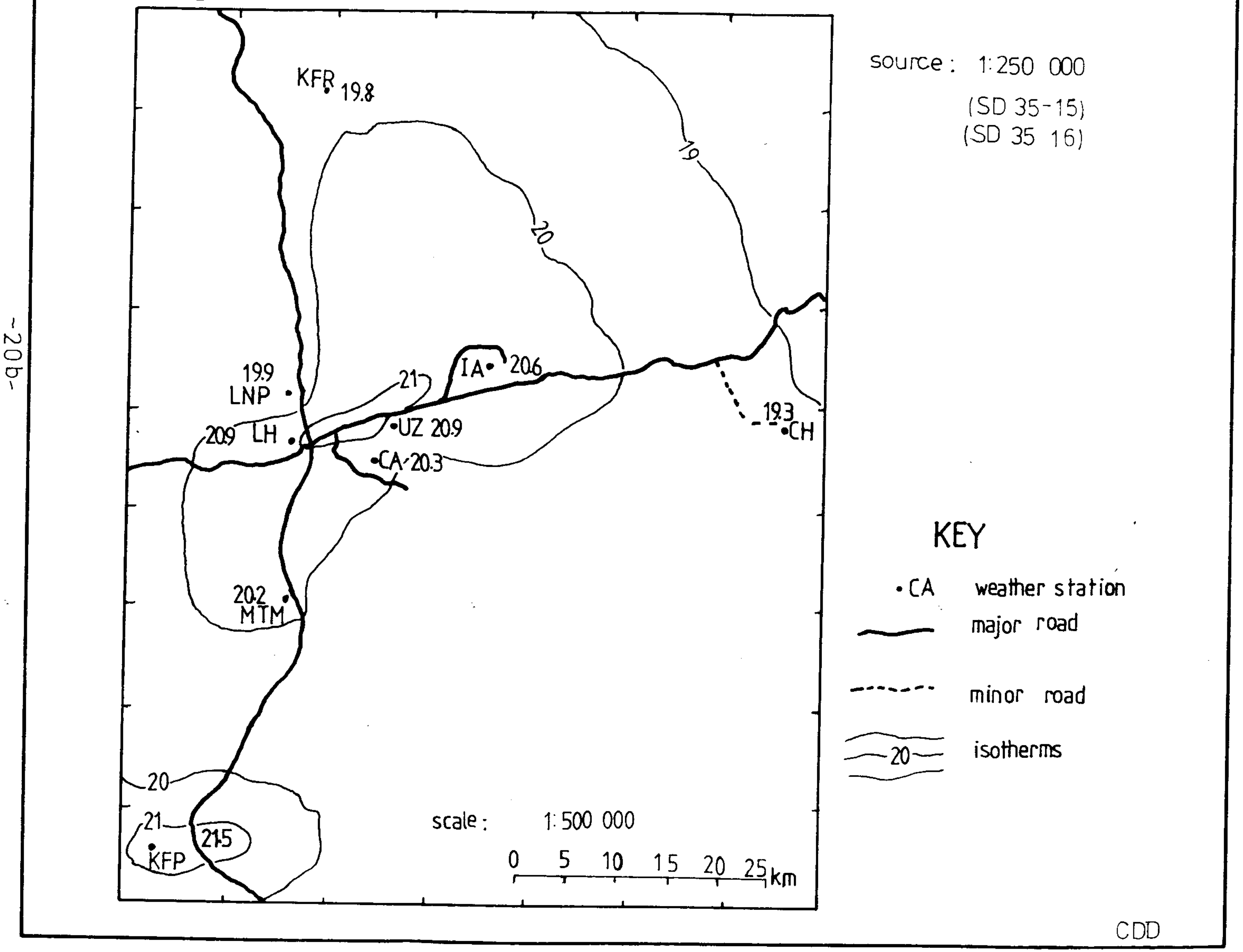
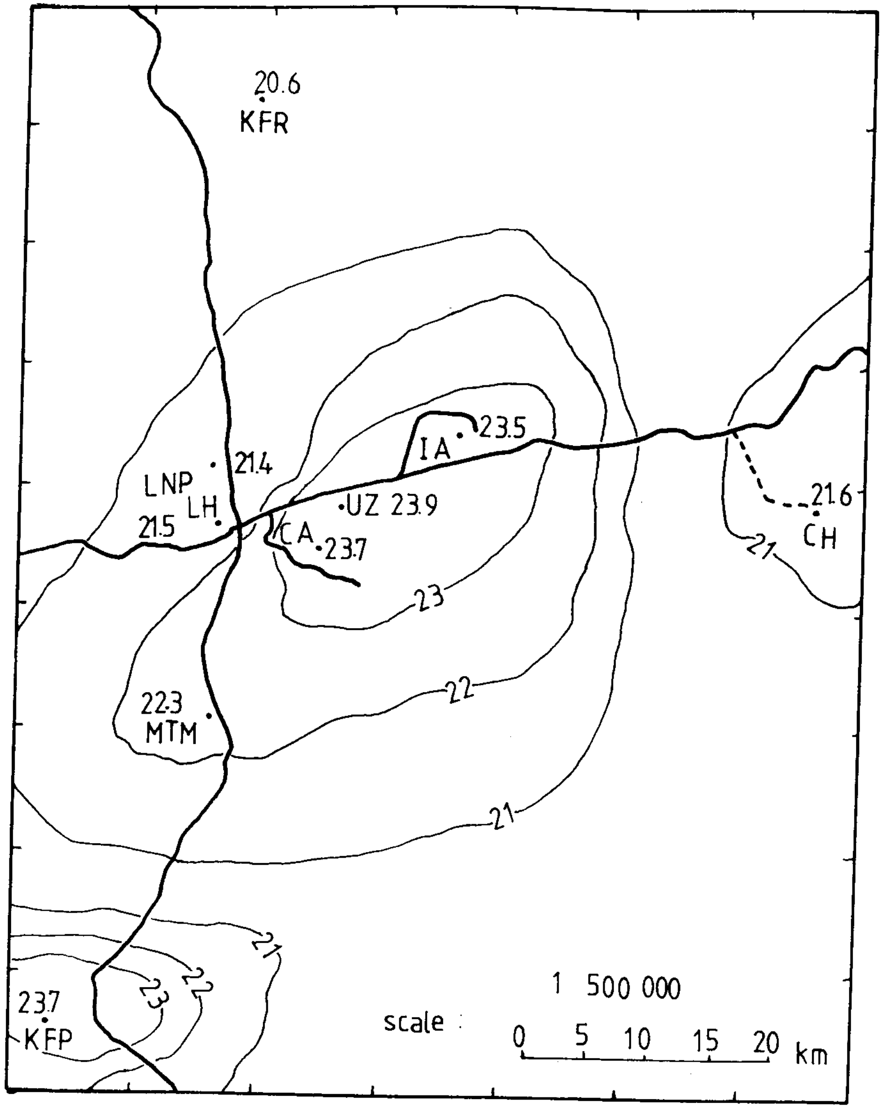


Fig.3 OCTOBER MEANS



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KEY

CA ------ station

---- major road

---- minor road

23 ---- isotherms

CDD

5.2 Identification of the Core Areas of Heat Island Effect

Primary data collected in the field was used to identify spots in the urban area where the factors causing change are most active. The mean values for each sampled area were determined and are presented in Table 3.

The unbuilt land had the lowest temperatures (20.7°C) while the heavy industrial area had the highest temperature mean (26.2°C).

Table 4: Observed Means of 15:00 hours Shade Temperature

Sampled Area	**(T max) Mean Temp (°C)**
Heavy Industrial	26.2
Light Industrial	22.9
High Industrial	25.3
Low Density Residences	22.2
Unbuilt up Land	20.7

The means for each of the study areas sampled were tested for significance using the Chi – square (X^2) Test for significance. This required conversion of each value observed in each area to a nominal scale (Kethuria and Bless, 1998). To do this, temperature values were classified as either warm or cool according to whether the value was above or below the average for the whole set of temperature values (23.5°C). The contingency tables for the observed and expected frequencies are shown in Appendix I.

The testable and null hypotheses adopted were:

H_o There is no significant difference between the means of the populations from which the samples were taken.

H_1 There is a significance difference between the means of the populations from which the samples were taken.

Results from the Chi – square are shown in Appendix II.

Despite loss of internal information, the application of the test statistic to the data verified, to an extent, the differences in the values than the otherwise arbitrary differences that would have been expected without a test of the values (Barnaby and Cleves, 1997).

The null hypothesis was rejected in favour of the alternative one. That is, the difference in means between the areas is statistically significant. The temperatures in the heavy industrial area and high density residential area are significantly higher than those in the other three sampled areas (see fig.4).

Fig. 4 CORE AREAS OF EFFECT

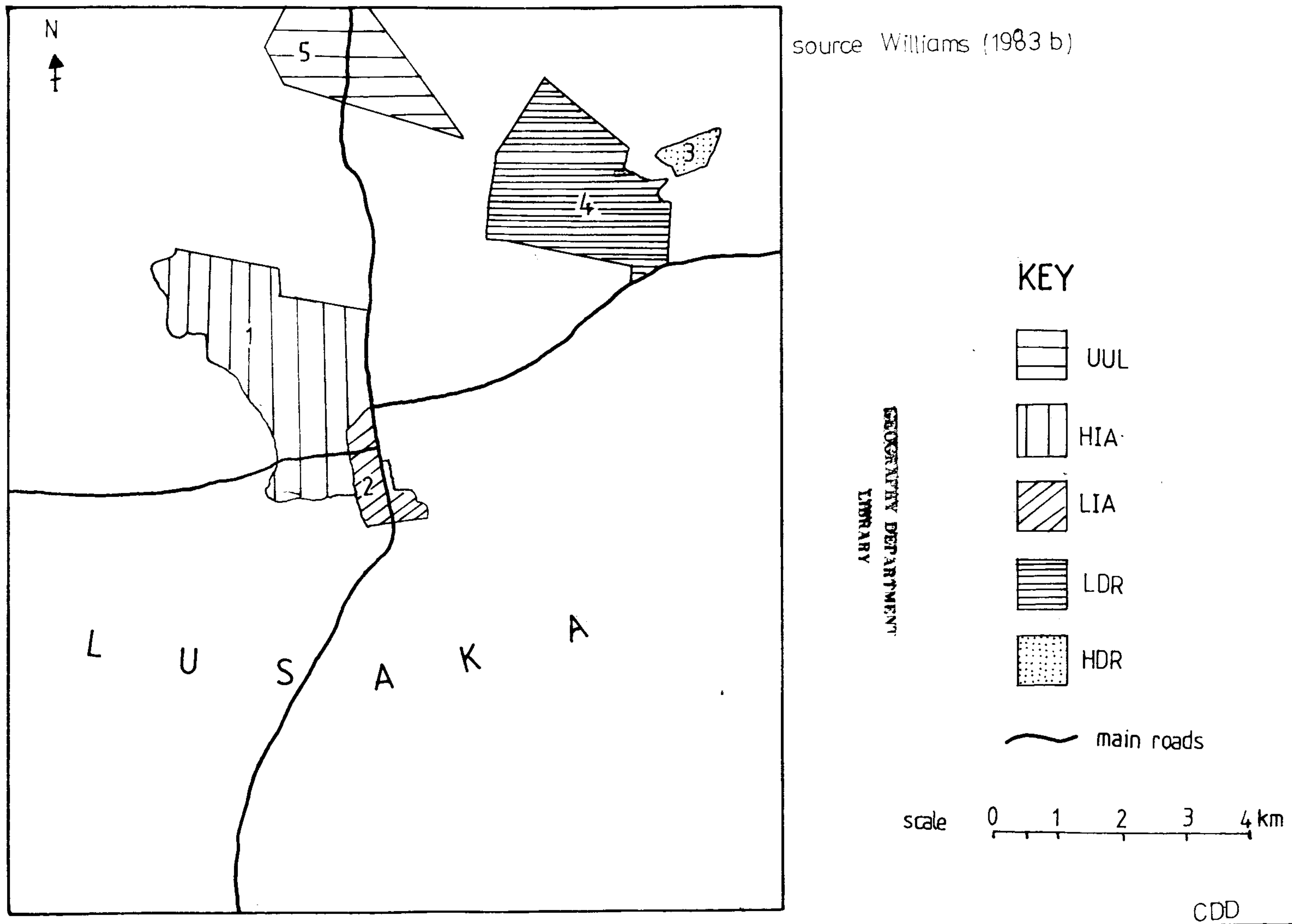

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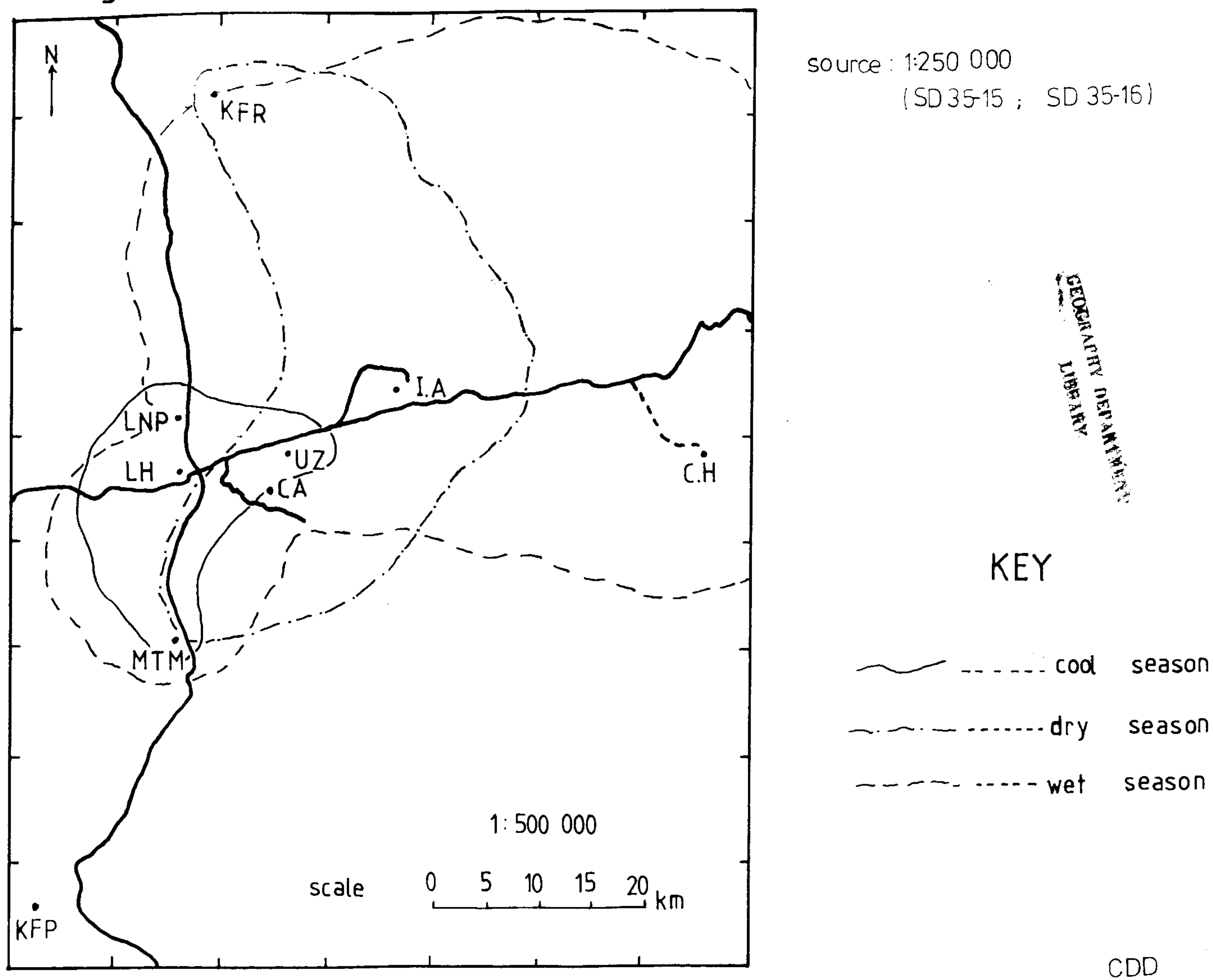
Fig. 5 SHIFTS IN BOUNDARY



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5.3 Temporal Shifting of the Boundary

As shown in fig.5, seasons influence the spatial extent of the heat island boundary. The boundary covers a smaller area during the cool season and has a wider extent during the dry and wet seasons. The boundary thus expands and contracts with the passage of time.

CHAPTER 6

6.0 Discussion

This chapter discusses the results found in Chapter 5 and explains the factors influencing the scenarios described.

6.1 Presence of the Heat Island and Its Spatial Extent

The alteration of the surfaces in the city, coupled with the presence of activities which involve production and consumption and generation of heat and gases have led to higher temperatures in this area than in the surrounding countryside which experiences predominantly natural conditions. The presence of tall structures also exerts a drag on the ventilating effect of wind leading to higher temperatures in the urban area than the rural countryside.

The October averages in the city center are as high as 23.9°C compared to 20°C – 21°C in the rural country (See fig.3). Reasons for this could include the ever – increasing generation of aerosols from both domestic and industrial sources. When these aerosols are emitted into the atmosphere above the urban area, they have been known to create a heat – retention 'blanket', usually resulting in higher temperatures there than the surrounding natural environment (Oke, 1987; Goudie and Viles, 1997). Together, water vapour, the oxides from industrial pollutants and chlorofluorocarbons (CFCs) trap heat around the urban areas resulting in higher temperatures – heat island.

The 20°C isotherm in fig.3 defines the spatial extent of the head island. Notably, this isotherm closely follows the extent of the built up area in the urban environment. This is similar to what Oke (1987) found in Hamilton, Ontario and Montreal, Quebec. This shows the roles that heat generation from industrial and domestic sources, its retention by higher absorbent urban surfaces and compounds of carbon combustion, and the clearing of vegetation have played in altering the heat budget of the area.

The scenario in Lusaka can also be seen in Kafue urban (see fig.2). The same factors also enhance the heat island effect. Here industries such as Nitrogen Chemicals of Zambia (NCZ) and Kafue Textiles of Zambia (KTZ) emit sulphur dioxide (SO_2) and water vapour into the atmosphere (Chipungu, et al., 1994), and these act as aerosols to form a heat – retention blanket above the urban area.

6.2 <u>Identification of the Core Areas of Heat Island Effect</u>

The heavy industrial and high density residential areas were identified as the core areas of heat island effect since their mean maximum temperatures (T-Max) of 26.2°C and 25.3°C, respectively, exceeded the average for the whole set of values (23.5°C) which was set as the threshold - see Table 3.

The causes for this increase in temperature could be the result of the growing urban population and its increased demands for energy, industries and resultant modification of the surfaces through deforestation, characterised in these two areas.

In the industrial area, there is high heat generation from industrial processes while aerosols like smoke, dust, and carbon – dioxide are emitted into the air.

In the high density residential area of N'gombe there are many people engaged in activities that generate heat while the unpaved dust surfaces are a source of aerosols into the atmosphere. Prevalent use of fuelwood, charcoal and presence of dust, due to high population densities are important factors that cause higher temperatures there than in other areas. There are more activities which alter the natural heat budget such as deforestation and more combustion of carbon based fuels for lighting and energy.

In Sub-Saharan Africa the occurrence of droughts is endemic. Activities that can potentially increase the incidence and intensity of droughts are thus a great threat to food production and security.

6.3 Temporal Shifting of the Boundary

During the cool season, the effect of human induced heat on temperature patterns is greatly reduced by the predominance of low temperatures in the months from May to July. The dry and wet seasons (August to April) are characterised by high temperature values. These high values can enhance the effect of increases caused by human activities and thus enlarge the boundary.

6.4 Conclusion

This study has established that the temperatures in the built up areas of Lusaka are significantly higher than those of the surrounding countryside. The boundary of this heat island closely approximates the extent of the built up urban environment.

Within the heat island, the heavy industrial and high density residential areas were identified as being the main source areas responsible. High emissions of heat and gases per unit area in the heavy industrial area, and high densities in the high density residential area (and their associated activities) are probably the major causes of the problem.

It was also discovered that the boundary of the heat island generally shifts with seasons. During the cool season, it is contracted to a small area around the built up city center. In the dry and wet seasons, the boundary expands outwards to areas beyond the built up area. This emphasises the effect of human activity on temperature patterns.

The impacts resulting from these slight changes in temperature are diverse and they affect resources, ranging from forests and water to humans themselves. Studies by the IPCC (1996) have shown that small but sustained increases of 1°C in mean seasonal temperature can change the growth and regeneration capacity of various species of vegetation. This is undesirable since a good number of Lusaka's farming community lies on the fringes of the area affected by these gradual increases in temperature.

6.5 Recommendations

I recommended that the number of people entering into Lusaka be reduced so as to reduce the pressure of the population on the environment. This can be done by ensuring that other cities and rural areas are also developed so as to reduce or reverse migration trends towards the capital city. It is also recommended that the use of renewable resources and sources of energy be increased. Solar, biomass, wind and hydro energy are environmentally friendly sources that produce little to no aerosols. Green areas should also be increased and recent media reports have shown that planting of trees on the tops of roofs can reduce the temperature over the urban area by 1°C.

Finally, it may be reiterated that our environment, which is our heritage, is slowly being degraded. We the peoples of the developing world have an advantage in that the impact of change factors is still low. Efficiency of the mitigation options ultimately depends on the will of the government and people concerned to recognise the urgency of the situation, and to adopt options that are practical for our socio-economic situation.

APPENDIX I

Mean Temperature: 23.5°C

(a) **Nominal Classification of Observed 15:00 Hours Shade Temperatures**

	UUUL	HDR	LDR	LIA	HIA
COOL	48	29	37	8	7
WARM	2	21	13	2	43

(b) **Observed Frequencies**

	COOL	WARM	TOTAL
UUL	48	2	50
HDR	29	21	50
LDR	37	13	50
LIA	8	42	50
HIA	7	43	50
TOTAL	**129**	**121**	**50**

(c) **Expected Frequencies**

	COOL	WARM	TOTAL
UUL	25.8	24.2	50
HDR	25.8	24.2	50
LDR	25.8	24.2	50
LIA	25.8	24.2	50
HIA	25.8	24.2	50
TOTAL	**129**	**121**	**50**

APPENDIX II

CHI – SQUARE (X^2)

X^2obs = 104.00.

Degrees of freedom (df) = (2 – 1) x (5 – 1) = 1 x 4 = 4 at 0.05 level of significance.

X^2crit with four degrees of freedom at 0.05 level of significance = 9.49.

X^2obs > X^2crit

- At 0.05 significance level, with four degrees of freedom, the critical value of X^2 is less than the observed value. The null hypothesis (H_o) is therefore rejected.

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