THE MICROCLIMATIC CHARACTERISTICS WITHIN THE URBAN CANOPY OF IBADAN

BY

YINKA ROTIMI ADEBAYO
B.Sc. Hons., M.Sc., Geog. (Ibadan)

A Thesis in the Department of
GEOGRAPHY

Submitted to the Faculty of Science in Partial Fulfilment of the Requirements for the degree of

DOCTOR OF PHILOSOPHY

of the

UNIVERSITY OF IBADAN

January, 1985

Abstract

This study analyses the spatial, diurnal and seasonal characteristics of some climatic parameters within the urban canopy of Ibadan. These climatic parameters are global radiation, surface albedo, net long wave radiation and latent and sensible fluxes of energy. The analysis is based on data collected on a daily basis (0600 - 1800 hrs. GMT) for one year at twenty stations located all over the city. Furthermore, twenty-year data (1961-80) on the characteristics of maximum and minimum temperatures, relative humidity and rainfall are analysed with the aim of analysing the effect of urbanization on climate over that period.

This study makes a departure from earlier studies which were concerned mainly with the rural/urban dichotomy in climatic parameters by actually looking into the intra-urban pattern of the climatic parameters. In this regard the city surface was classifed into six land use categories on the basis of their components of buildings, water, tarred roads, untarred roads, paved surfaces, bare ground, lawns and trees. The land-uses identified are 'high density' built-up areas, 'medium density' built-up areas, 'low

density'built-up areas, 'commercial' areas, 'open spaces' and 'rural' areas. These land-uses were used as the basis for setting up the climatic stations and explaining results of the variation in climatic parameters.

Results of the investigation show that components of radiation and energy budgets vary considerably from the rural areas to the urban centre. Global radiation values for the different land-uses range between 0.62 and 0.64 ly min^{-1} in the rural surroundings to between 0.56 and 0.58 ly min^{-1} in the urban centre. This shows a decrease of about 14%. Albedo mean values range between 15% and 18% in the rural area to between 8% and 10% in the city centre. The net radiation at the urban centre is about 15% higher than that at the rural area; the mean values for the different land-use surfaces being between 0.200 and 0.215 ly. min^{-1} in the rural area and between 0.225 and 0.245 ly. min^{-1} in the urban centre. Net long wave radiation increases from between -0.21 and -0.22 ly. $min.^{-1}$ in the rural area to between -0.18 and -0.19 ly min^{-1} in the urban centre. The increase in the city centre over the rural area is by about 16.7%.

Mean values of temperature urban 'heat island' vary between 1.0°C and 1.5°C, and 2.5°C and 3.0°C during the wet and harmattan periods respectively. The extreme value of temperature 'heat island' is as high as 11.7°C. The relative humidity in the urban centre is 6.3% lower than in the rural surroundings during the wet season and 24.3% lower than the harmattan season.

From the temporal analysis of climatic data over a 20-year period, it is found that temperature has increased significantly over time. Maximum temperature increased by as much as 0.7°C. Rainfall increase over time has also been related to urban effects. All these confirm that urbanization is changing the climate of Ibadan.

Finally, land-use components and climatic parameters are correlated and the relationships between them are found to be statistically significant at 5% level of significance.

Acknowledgement

I sincerely thank my Supervisor, Professor J.S. Oguntoyinbo, who initially encouraged me to work in the area of urban climatology. He extended his intrinsic kindness to me not only through his thorough supervision of this work but also by his moral, financial and material assistance in course of my graduate training. I also appreciate the vital expertise contributions of Dr. J O. Ayoade at various important stages of the project

My thanks go to the entire members of staff of the department. I am particularly grateful to Professor A. Faniran , whose assistance as the then Head of Department, contributed to the successful take-off of the project in 1982. I thank Dr. O.O. Areola, for his criticisms at different stages; Dr. F.O. Akintola, for his material assistance; Dr's. S.I. Okafor, A.O. Aweto, C.O. Ikporukpo, B.F. Iyun and I Megbolugbe for their concern about the project; Mrs. A. Aderogba who, with the assistance of Mrs. Uthman, mobilized other cartographers to produce all the maps; the entire members of staff of Climate Office, who assisted me during the fieldwork; Mr. Awoyemi and Mrs. Akinboade for their general assistance and Messrs Omuta and Kassim, who typed different drafts of the project.

Offprints of relevant publications given by the following experts were helpful: Professor R.D. Bornstein, San Jose State University, California U.S.A.; Professor K.D. Hage, University of Alberta Edmonton Canada; Professor H.E. Landsberg, University of Maryland U.S.A ; Professor J.E. Lewis, McGill University Montreal Canada; Dr. D.L. Morgan, California State University Fresno U.S.A.; Professor S.O. Ojo, University of Lagos, Nigeria; Professor T.R. Oke, University of British Columbia Vancouver Canada; Professor P.O. Oluwande, University of Ibadan, Nigeria, and Professor W.H. Terjung, University of California Los Angeles U.S.A. The suggestions of Professor T.J. Chandler, County London, and Dr. O.J. Olaniran, University of Ilorin Nigeria, are appreciated Professor S.O. Ojo gave out some University of Lagos equipment .

My profound gratitude goes to my highly enduring parents, Mr. and Mrs. M.A. Adebayo, who spent so much on my education. The understanding of my brothers and sister is also acknowledged. I thank the following friends: Messrs. Godwin Mebitaghan, Wale Dipeolu, Tokunbo Jegede, Biodun Sanni and Dr. Niyi Gbadegesin, for their various assistance during my fieldwork. I thank Mr. Yinka Osinubi for his assistance during the period of the analysis and for going through a draft of this thesis. I am grateful to Bola Ogundein and all members of BAN, Alora Sea Lords, for their contributions towards the success of the work.

Finally, to God Almighty, from whom all blessings flow.

Certification

I certify that this work was carried out by Mr. Y.R. Adebayo in the Department of Geography, University of Ibadan.

(Supervisor)

J.S. Oguntoyinbo, B.A. (Durham), M.Sc. (McGill), Ph.D (Ibadan), F.R. Met Soc. (London).
Professor in the Department of Geography, University of Ibadan, Nigeria.

Table of Contents

Table of Contents (Contd.)

Table of Contents (Contd.)

Table of Contents (Contd.)

List of Figures

List of Figures (Contd.)

CHAPTER 1

1.0 INTRODUCTION

1.1 The Dilemma of Climatic Modification

Man's cultural advancement leads to a great deal of unpleasant changes within the socio-physical environment. The process of urbanization is one of the most unfortunate and perhaps the most horrible phenomenon, accruing from this cultural advancement. The so-called social and technological sophistications of the contemporary world, coupled with the process of urbanization, resultsin the alteration, misuse and inadvertent over-utilization of the atmospheric resources by man. These are done through the continuous replacement of the highly beneficial and aethestically pleasing rural green spaces and trees by bricks, concretes, asphalts, bare grounds and the ejection of various types of poisonous pollutants to the atmosphere. These cause a change from the precious, homogeneous country-side climate characterized by clear air and water to the city's gloomy, highly polluted, unpleasant, noisy, more heterogeneous and unpredictable atmospheric condition. The situations are worse in the tropical areas where cities are mostly characterized by dreary atmospheric environments and shanty layouts owing to planlessness.

Unless something positive is done, the misuse, and therefore depletion of the atmospheric resources are likely to continue. This is so because according to WMO (1983) more than one-third of the world's people already live in towns and there is the likelihood of an even larger scale of urbanization whereby cities coalesce into immense continuous built-up areas perhaps occupying one hundred thousand square kilometres or more and having total population exceeding one hundred million.

Improvement in technological know-how leads to a lot of changes within the environment. For example, sophisticated tools are used to destroy the natural environment and inject a great deal of dangerous gases into the atmosphere. Smith (1975) is of the opinion that man is becoming more vulnerable to atmospheric hazards because of, rather than in spite of, his present social sophistication and technological strength. This is evident in the unabated changes and subsequent problems, being effected on climates by modern tools which have not been effectively used to protect mankind against climatic hazards. With the aid of modern technology, man is capable of installing multitudes of air conditioners while cognizance is not taken of their resultant impact on outdoor microclimates.

*/Peculiar characteristics of the twentieth-century urban atmospheric environments include reduction in relative humidity, evapotranspiration, increases in noise pollution, air pollution, cloud cover, rainfall and temperature. Others include hazards like urban floods, frequent and serious fog (smog) cover, reduction in visibility on highways, amongst others. Both negative and positive feedbacks result from these attributes. Indeed, there is no gainsaying that they have considerable effects on health, energy, comfort and socio-economic activities of the city dwellers.

For instance, the increase in city temperature, compared with the surrounding rural environments, is advantageous in the temperate region where the winter heating bills are reduced but disadvantageous in tropical areas where the high temperature constitutes the heart of climatic discomfort. The increase in the total amount of rainfall would be of some advantage in areas of scarce precipitation but likely to be otherwise for places where excess rainfall disrupts daily activities. Notable urban pollutants like oxides of sulphur, nitrogen and carbon have serious effects on visibility, the health and comfort of the city dwellers (Ayoade, 1977).

* Climatic modification, through urbanization, is not limited to the urban areas alone. According to Oke (1977b) an urban climate can affect areas as far as two hundred kilometres down-wind. This means that areas of urban megalopolis could have their regional climates significantly altered through urban effects.

*Considering the problems earlier enumerated with respect to the inadvertent modification of climate, the dilemma faced by man arises from the inevitable growth of cities and activities therein vis-a-vis the need to effectively manage the highly valuable atmospheric resources. * This problem of man-environment relationship could be summarized in the words of Pearse, et al (1976) who stressed the fact that the production of a more hospitable climate, while minimising the man-made energy impact is a key environmental challenge facing mankind. Understanding the fundamentals of urban climates would definitely go a long way in solving this problem. This study is a step towards this direction.

1.2 Rationale of the Study:

This study was chosen in order to help contribute towards the understanding of the climatic conditions of the fast-growing tropical cities; result of which could help guide against the occurrence of serious climatic problems resulting from urbanization. These problems are imminent in tropical areas because of:

(i) the continued misuse and inadvertent over-utilization of their cities' atmospheric resources;

(ii) rapid growth of their cities as a result of the influx of rural-urban migrants in large numbers owing to lack of basic rural infrastructures; and

(iii) the apparent indifference of the policy makers which further puts the fast-depleting resources in serious danger.

There is no doubt about the fact that the fundamental causes of urban micro-climates are yet to be fully understood. This problem is further complicated by the poor knowledge of the variability of climatic parameters which could help in the full understanding of the causal factors of the urban microclimatic conditions. This scarcity of information is more pronounced in cities located in the tropical and polar regions. Because of this, several people have emphasized the need for further investigations into the climatic conditions of these areas. Investigations about the effect of climate on human settlements in low latitudes are highly necessary (Jaurequi-C' stos, 1982).

Oke (1977b) is of the view that serious, urgent attention need be focussed on the climatic problems of the fast-growing tropical cities in order to rescue them from the sad, serious western experience. The radical differences between the regional climates of the tropical and temperate areas dictating the climates of the cities in these areas further support this call. The WMO is aware of this, hence the November 1984 Mexico City Conference on the urban climates of tropical cities. Referring to the work of Nakamura (1967) on the city of Nairobi as one of the few examples, Ojo (1980) emphasized the dearth of knowledge on the climatic conditions of African cities in particular.

In realization of the fact that cities are one of the few remaining surfaces awaiting satisfactory energy balance analysis, Kalanda, et al (1980) and Mabogunje (1981) stress the need for the studies of urban atmospheric conditions to be able to monitor the changing levels of pollution.

From all of the above, it is clear that this present study, which tries to contribute its quota to the understanding of the behavioural pattern of microclimatic characteristics of a tropical pre-industrial city, will certainly advance our knowledge of urban climatology. Results of an investigation of this nature will further enable us compare, effectively, the microclimates within a tropical city with those of other tropical cities and also the cities of the temperate region. In the process, the writer becomes familiar with, and exposed to, the various methods and equipment being employed in the studies of urban climate in particular and microclimatology in general. These are the vital inspirations behind the choice of this study.

1.3 Aims and Objectives

An assessment of the characteristics of the climatic parameters within the urban canopy of Ibadan, a tropical city, is the main focus of this work. The detailed objectives of the study are to:

(i) determine the city-surface characteristics for the purpose of knowing the urban textural characteristics which play a significant role in modifying the climate;

(ii) estimate spatial patterns of radiation and energy budgets;

(iii) examine the spatial patterns of temperature and relative humidity, and

(iv) analyse the temporal variations in characteristics of temperature, relative humidity and rainfall.

From the foregoing, it could be said that the study revolves around the understanding of urban climatic conditions in relation to urban surface land cover. Climatic stations were set-up in accordance with the land-use pattern. The land-use pattern also served as a basis for analysing and describing the climatic data collected.

Climatic conditions within the urban canopy were analysed as follows:

(i) by explaining the essence of the research and describing the study area in Chapter One, presenting the conceptual framework and the literature review in Chapter Two, and dealing with the method of approach in Chapter Three;

(ii) through the recognition, in Chapter Four, of the pattern of city-surface infrastructures which is fundamental to the understanding of the surface variation in the exchange of energy, mass and momentum;

(iii) by estimating, in Chapter Five, the spatial patterns of radiation and energy budgets, on diurnal and seasonal basis with emphasis on the urban-rural differences;

(iv) following the above, in Chapter Six, is the analysis of the urban-rural differences, diurnal and seasonal patterns of temperature and relative humidity;

(v) the temporal variations in temperature, relative humidity and rainfall over a period of twenty years were examined in Chapter Seven. This is for the purpose of knowing the impact of urbanization on these climatic parameters, and

(vi) the work was concluded in Chapter Eight by (a) drawing out the relationships between land-use, building density, aerodynamic roughness of building and trees on one hand, and the micro-climatic parameters on the other; (b) relating the outcomes of all of the above to the results of similar investigations carried out in tropical countries in particular and the other parts of the world in general, and (c) looking into areas necessary for future considerations and recommendations as regards the possible use of the project for planning purposes.

With all of the above, meaningful information about the climatic characteristics within the urban canopy of Ibadan is obtained.

The urban canopy could be referred to as the area below the building roof level and the ground surface (see Fig. 2.2). The scope is limited to the analyses of microclimatic conditions within the urban canopy for three reasons. Firstly, it is the area occupied by human beings. An understanding of the variability of the climatic conditions therein would therefore be of important help to finding lasting solutions to the serious atmospheric hazards like low-level atmospheric pollution, human physiologic discomfort and economic losses accruing from climatic variations. This will also aid architects and city planners in their exercises. Secondly, the available equipment are only suitable for the collection of microclimatic data within this level. To deal with conditions above roof level, it is necessary to employ costly and sophisticated means like the installation of equipment on tall masts, the use of radiosondes and balloons, helicopters and sophisticated remote sensing equipment. Thirdly, the vailable archival records are mostly on climatic conditions within the urban canopy.

1.4 Study Area

1.4.a Location and site characteristics

Ibadan is the study area (Fig. 1.1). This tropical city is located in the south western part of Nigeria. Its exact location is 7°23'N and 3°54'E. The city is situated in the forest zone close to the boundary between the forest and the savanna. It has secondary bush and derived savanna surrounding it as a result of human interference with the original natural forest.

Oyelese (1970) describes Ibadan as a city of hills and valleys which lies within an area consisting of different erosion surfaces separated by area of active erosion and youthful landscape forms. It is located on a rugged topography with a central ridge traversing the city. The hills in Ibadan range in elevation from 160m to 275m above sea level. Generally speaking, the average elevation is about 210 metres above sea level. According to Faniran (1982), despite the fact that they make up less than five per cent of the total area, the hills are the most striking features around (Fig. 1.2).

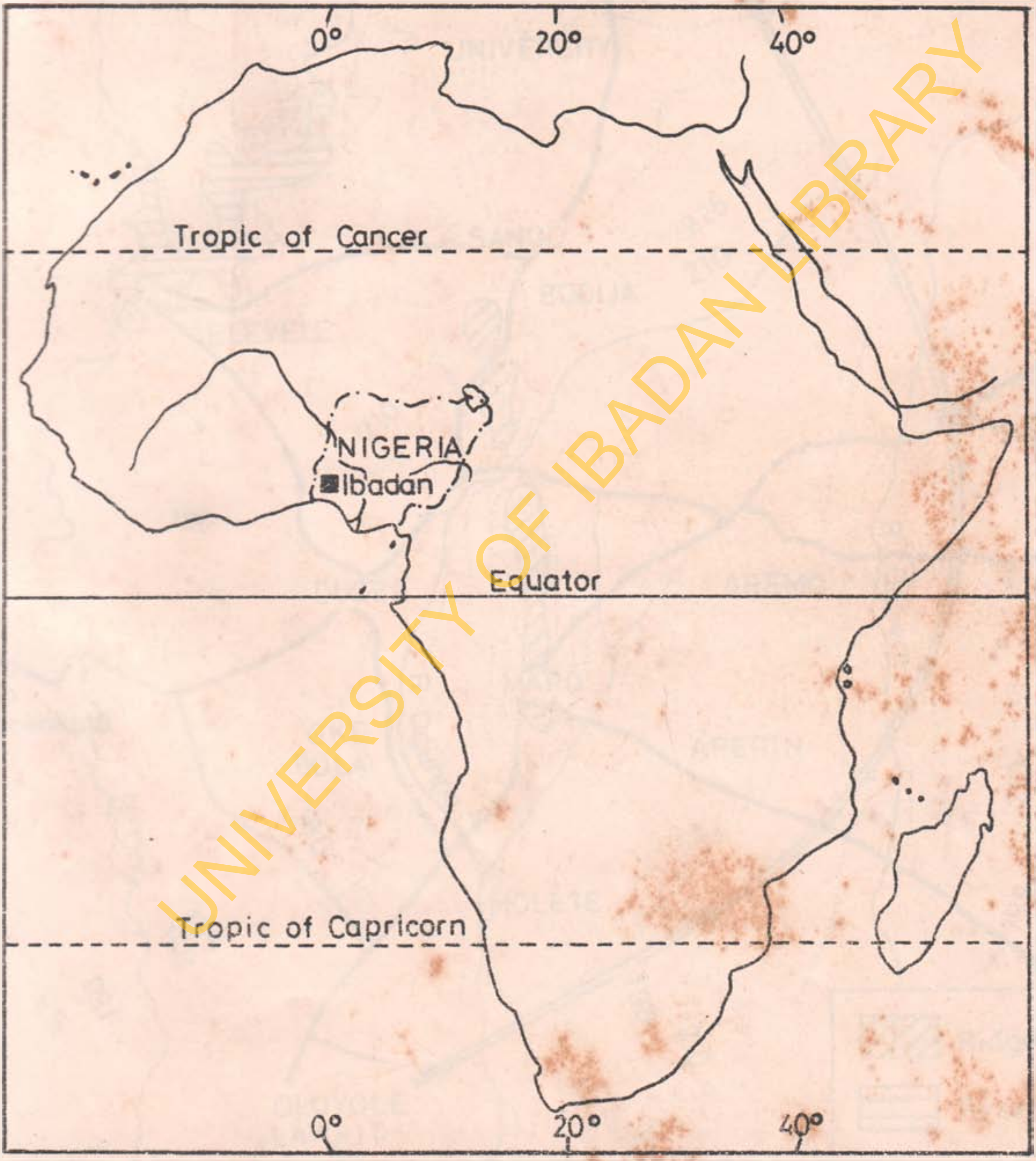
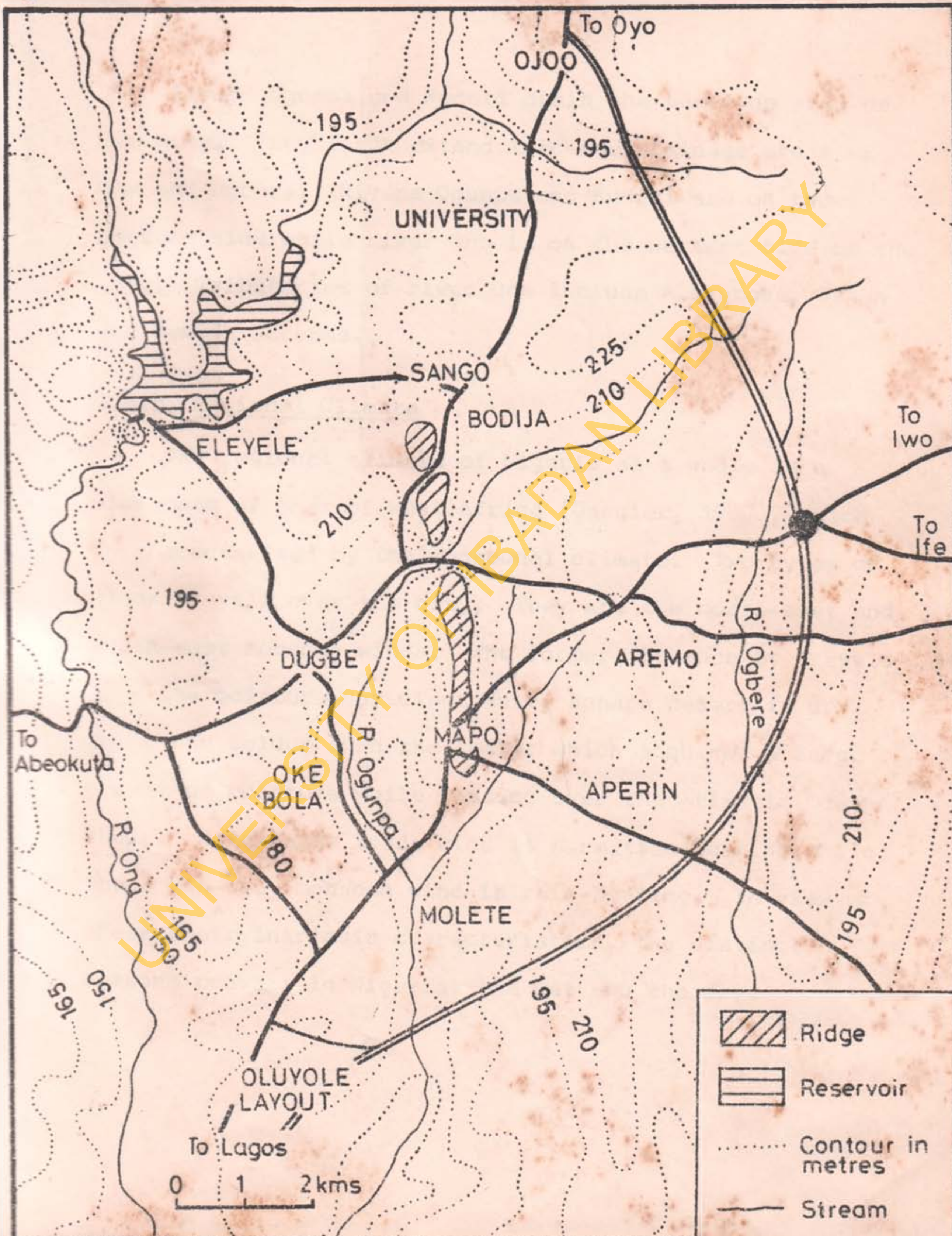


Fig.1·1 Africa showing the Study Area, Ibadan, Nigeria.

Fig.1·2 Ibadan, Site Characteristics.



Rivers Ogunpa and Kudeti drain the built-up area of the city. They later extend into the drainage areas of Ona and Ogbere. Rivers Ogunpa and Kudeti are on the eastern side while river Ona is on the western side of the city. Tributaries of river Ona include Alalubosa, Oshun and Yemoja streams.

1.4.b Regional Climate

The regional climate of Nigeria as a whole is a microcosm of that of West Africa (Garnier, 1957), which is characterized by the monsoonal climate. Two types of winds prevail over the city. They are the north-east and south-west monsoon winds. The former, because it travels from the moisture-deficient dusty Sahara desert is dry, dusty and colder than the latter which acquires a large amount of moisture while passing over the Atlantic Ocean route. North-east trade wind is harmattan-bearing while the south-west monsoon wind is rain-bearing. In view of these their intrinsic characteristics, two distinct seasons prevail in Nigeria: the wet and the dry.

In the northern part of the country, longer period of dry season prevails than in the south. Because Ibadan is situated in the south western part of the country, it is under the influence of the rain-bearing winds from late March to October, and the dry north-easterly winds from November to early March.

Oguntoyinbo (1982b), gave a broad description of the seasonal variability of weather over the city of Ibadan as follows:

1. For a period of four to six weeks by late December to part of January, the harmattan winds are strongest. The period is mostly characterized by early morning mist and high diurnal range of temperature, due to an absence of cloud cover.

2. Late February to March when the surface winds are south-westerly with north easterly winds prevailing aloft. There are usually occasional rains or thunderstorms and marked increase in night temperatures and humidities.

3. The months of April or part of March to around July are marked by growth of cumulus cloud and short, sharp showers of rain. There is potent thunderstorm activity and generally high relative humidity but small diurnal range of temperature.

4. In late July and part, or all of August there is low stratus cloud, high humidity and relatively low and constant temperature with continuous drizzle or rainfall. This is the period of reduction in quantity of rainfall giving the characteristic "August break" or "little dry season". From this period onwards rainfall conditions are repeated in a reversed order because the moist maritime air mass retreats and the dry Saharan air begins to predominate.

5. Conditions from late August to end of October or early November are similar to (3) above.

6. Briefly, November and early December conditions are similar to (2) above.

7. At the end of December to early January, the conditions merge into those of (1) above.

Mean day length of this latitude is 12 hours, ranging from a minimum of 11.5 hours in December to a maximum of 12.7 hours in June. Maximum values of global radiation are recorded in April (391 cal cm^{-2} day-1) while the minimum values are recorded in August/September due to dense cloud cover. Mean annual rainfall value is 1262.3mm. In Ibadan the relative humidity is generally high, with the months of June to October having daily means of about 86%.

1.4.c Socio-economic Activities

A lot of activities take place in Ibadan. Although it grew up as an administrative centre, trading and industry also contributed greatly to the early growth of the city. It is the most cosmopolitan city in Yoruba land (Udo, 1982). Business activities are promoted by the passage of important transport routes, like all road traffic from Lagos to the Northern States through Abeokuta and Shagamu which converge on Ibadan before proceeding to their destinations and the railway to the northern states which alsorenders important services to the city. Ibadan is, therefore, not just a business station for its immediate region, but also for the different parts of the country, including the east.

The central business district (C.B.D) covering an area of one hundred and forty-two hectares is located west of the traditional city close to the railway station. Apart from this, there is also the older market, called Oja'ba, which is the traditional business centre. With the C.B.D. and Oja'ba, there emerged twin commercial centres. Apart from these two major centres, various trading activities are carried out along the main streets of the city with several pockets of mini-markets like the Oke-Ado, Beere, Agodi Gate, Sango, Mokola and Ojoo markets.

There are a number of industries like the Nigerian Tobacco Company, Lafia Canning Factory, Nigerian Bottling Company, Odutola Tyre Retreading Company, Africana, Standard and the Nigerian Breweries, Sanyo Electronics Plant, Leyland Motor Assemblying Plant, among others. Small scale industries are also numerous.

Numerous intra-city transport routes linking and fuelling the various business activities exist. According to Filani and Osaymwese (1979), the average daily traffic along various routes range from less than 8,000 in some areas through 8,000 - 10,000 to 15,000 along others. Resulting from this heavy traffic is the emission of smoke that pollutes the atmosphere.

1.4.d <u>Choice and Suitability of Study Area</u>

Many reasons account for the choice of this African city as the study area. These qualifying factors range from those that have to do with the intrinsic attributes of the city to those that could assist in the carrying out of this project. The reasons are as follows:

1. The city with an estimated population of 1.8 million (Ayeni, 1982) is regarded as the largest truly

indigenous urban centre in Africa south of the Sahara. Its urban characteristics are like an amalgam of traditional and modern types. The study should therefore provide some useful information that could advance knowledge about the relationship existing between land-use characteristics of such cities and their atmospheric conditions.

2. Ibadan is a tropical city and there is the need to know more about the microclimatic conditions of cities in this part of the world.

3. Several information on the site characteristics of Ibadan, that are important to this investigation, are more readily available for the city as compared with those existing about many other Nigerian towns and cities. These include: (a) topographical maps of Ibadan published in different scales viz, 1:100,000, 1:63,360, 1:50,000, 1:12,500 and 1:1,250; (b) recently flown aerial photographs of scales 1:25,000 (1974,75) and 1:12,500 (1977) which are available to update the information supplied by those flown in 1965 (scale 1:40,000). Air photographs are important sources of information about the cultural characteristics of any area; (c) several studies from which materials could be gathered for this research have

been carried out on the physico-human attributes of the site. They include the works of Mabogunje (1962, 1968), Akinola (1966), Oyelese (1970), Akintola (1974), Ayeni (1982), Faniran (1982), Oguntoyinbo (1982) and Udo (1982) amongst others.

4. The appreciable size of Ibadan metropolis, which is about twenty five kilometres in diameter makes the design of an urban-oriented experiment reasonable.

5. The familiarity of the writer with the city which was envisaged would, and did, enhance both the choice of experimental sites and the whole process of data collection.

6. Proximity of the site to the Department of Geography, University of Ibadan, from where the research was carried out. This aided easy consultations with the Department for expert advice.

7. Having known a lot about the regional climate of Nigeria as a whole and considering the phenomenal growth of the Nigerian urban centres, a detailed study of the microclimates of the important towns and cities like Ibadan is undoubtedly a worthwhile exercise.

CHAPTER 2

2.0 THE BASIS OF URBAN CLIMATES, LITERATURE REVIEW AND HYPOTHESES

2.1 The Basis of Urban Climates

2.1.a Scope and Extent of Climatology

The supply of solar radiation to any place on the earth's surface is the main determinant of the characteristics of its climate. Diurnal, seasonal and annual variations in atmospheric conditions are mainly caused by the fluctuations in the receipt of radiant energy. Variation in the supply of radiant energy combined with the non-uniformity in surface physical conditions is the factor causing spatial variation in climatic conditions.

Spatial uniformity in climatic conditions could be broadly identified at three different levels as exemplified in Fig. 2.1. There are macroclimate, mesoclimate, and microclimate. Macroclimate, is global climate and it is the broadest of the three classifications. This, according to Malone (1951), is the case of the important climatic phenomena at the global level. Examples of these are the mass energy transfer from low latitudes where there is surplus to high latitudes where there is deficit, the upper-air movement of the Rossby waves and jet streams, hemispheric variation in day length and period at which sun is overhead and so on (Fig. 2.1).

Mesoclimate or regional climate is the climatic condition within a defined region, essentially having some important climatic phenomena in common. Ojo (1977) defined it as a fundamental unit of climate within an area or a sub-region. The areal extent starts from beyond 10 km^2 and 50m above the ground level. Regional weather phenomena like the monsoons, tropical and extra-tropical cyclones and anticylcones operate at this level.

Microclimate is the branch with the most limited scope. According to Munn (1966) it is the atmospheric condition within limited areas, say about 10 km^2 and below 50 metres above the ground surface. Local weather features like katabatic and anabatic winds, land and sea breezes, humidity, visibility, cloud cover and rainfall are features of microclimates. Microclimate is a function of surface characteristics. Urban climates fall within the scope of mesoclimates. At the local level, an amalgam of surface features like vegetation

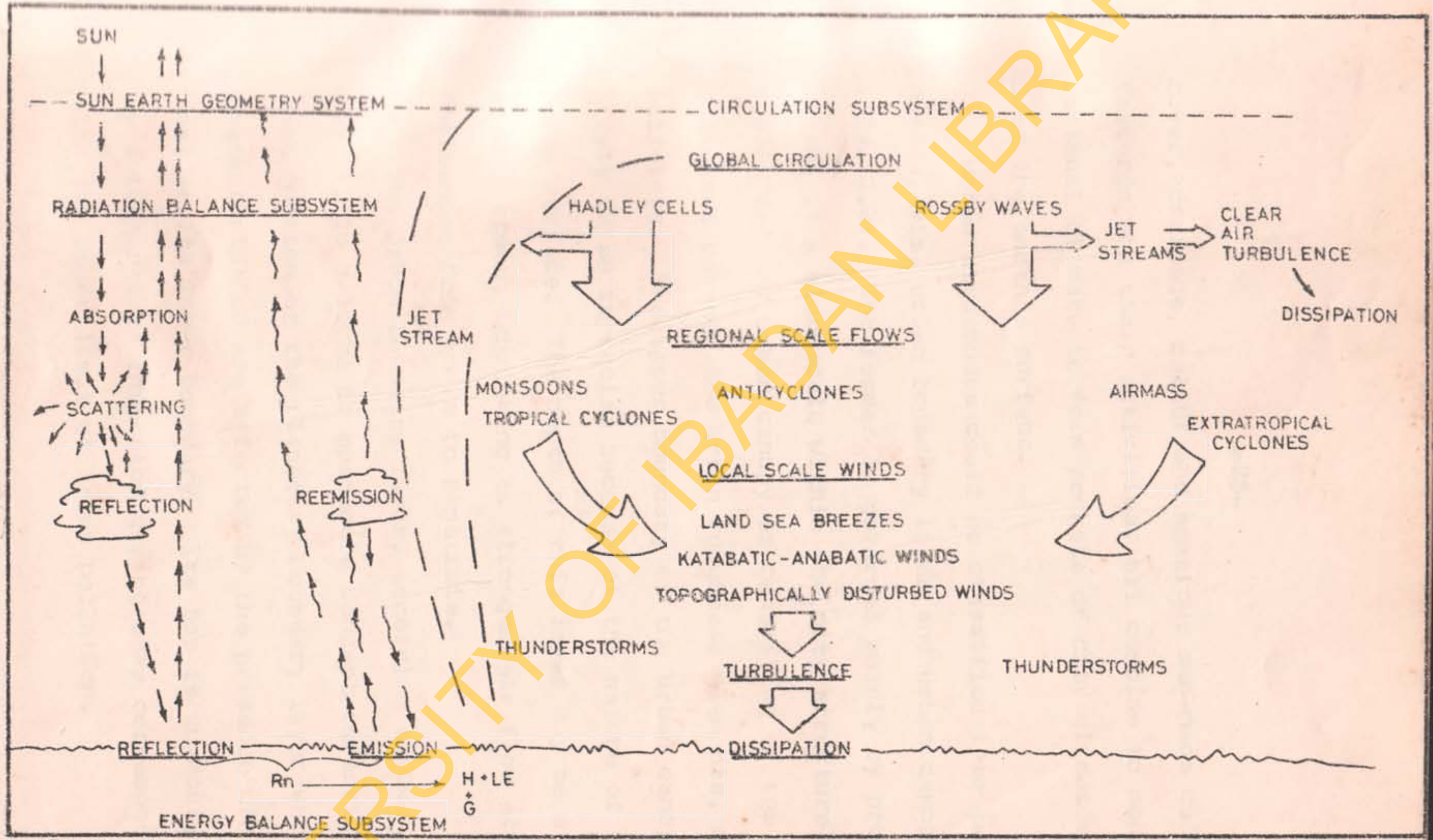


Fig. 2·1 Atmospheric Heat-Engine System (After Myrup and Morgan 1972) cover, drainage, relief and numerous man-made cultural features and their activities, all combine to modify the regional climate to form pockets of city climates all over the earth's surface.

Urban atmosphere could be classified into two categories, viz, urban boundary layer and urban canopy (Fig. 2.2). The former is governed mainly by processes acting at a microscale within the city structure. Oke (1976) defines urban canopy as consisting of the air contained between the urban roughness elements, mainly buildings. The upper boundary of the urban canopy is likely to be imprecise because of the nature of the urban surface. The depth of this layer may be a function of wind speed, shrinking as stronger air flow allows the influences from above to penetrate.

The urban boundary layer, according to Oke and East (1971), is a local or mesoscale concept referring to that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lower boundary. Its top is commonly capped by a temperature inversion giving some correspondence with the upper limit of urban pollution.

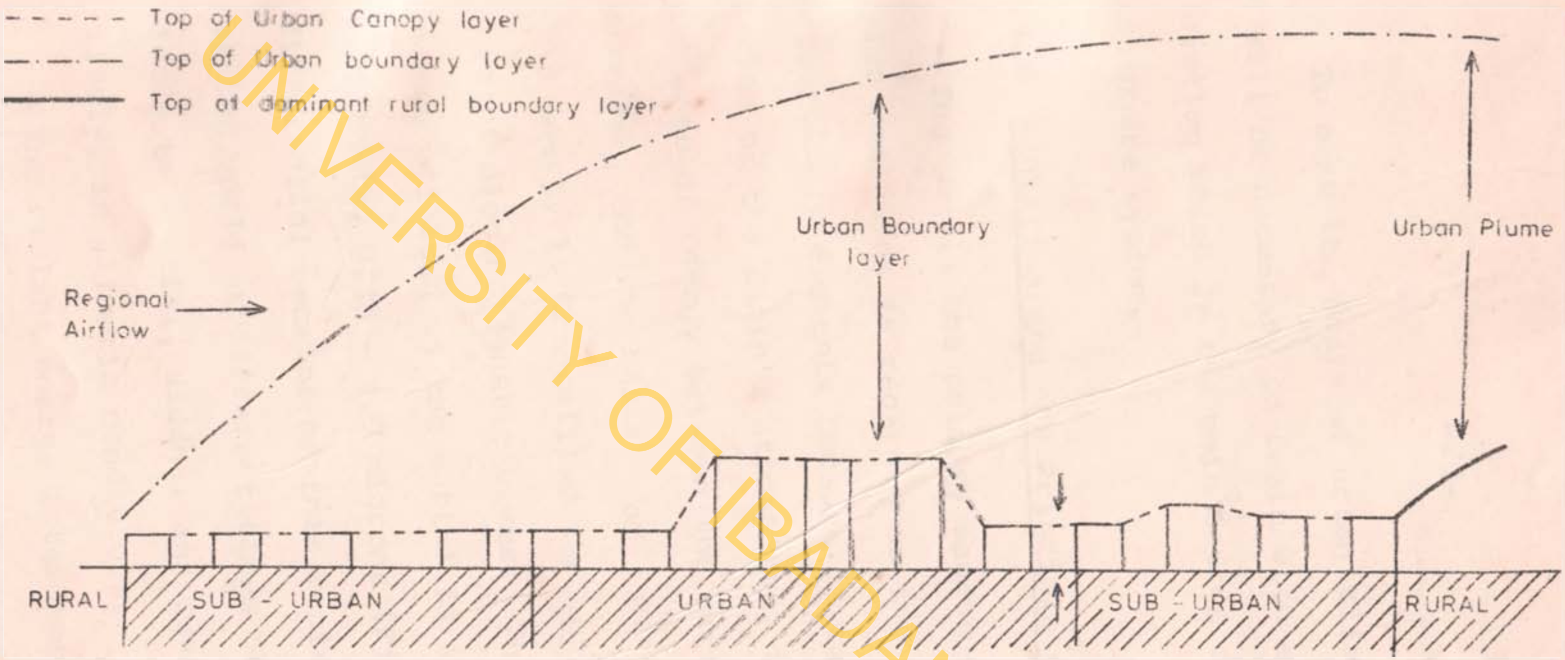


Fig. 2.2: Schematic representation of urban atmosphere illustrating a 2-layer classification of thermal modification (After Oke, 1976)

To make the basis of urban climate very explicit, it will be necessary to begin with a discussion on solar radiation which is the main source of energy for the earth-atmosphere system.

2.1.b Radiation and the Principle of Energy Conservation

The sun is the primary source of energy to the earth. Solar radiation is regarded as the most important of all meteorologic elements because it fuels the general circulation of the earth's atmosphere; it is the sole means of exchange of energy between the earth and the rest of the universe, and the basis of man's day-to-day activities. This energy is transmitted through the atmosphere in the form of electromagnetic waves. The input (over 95% of the energy utilized on the earth) is in the form of short-wavelength, 0.15 - 4.0 microns (Fig. 2.3). It is the differential receipt of this radiation in different parts of the world at different times of the day and year that leads to spatial, diurnal and seasonal variations respectively, in climatic conditions.

The radiant energy intercepted by the earth undergoes different effects. It could be reflected and scattered back to space, or in the alternative be absorbed by clouds,

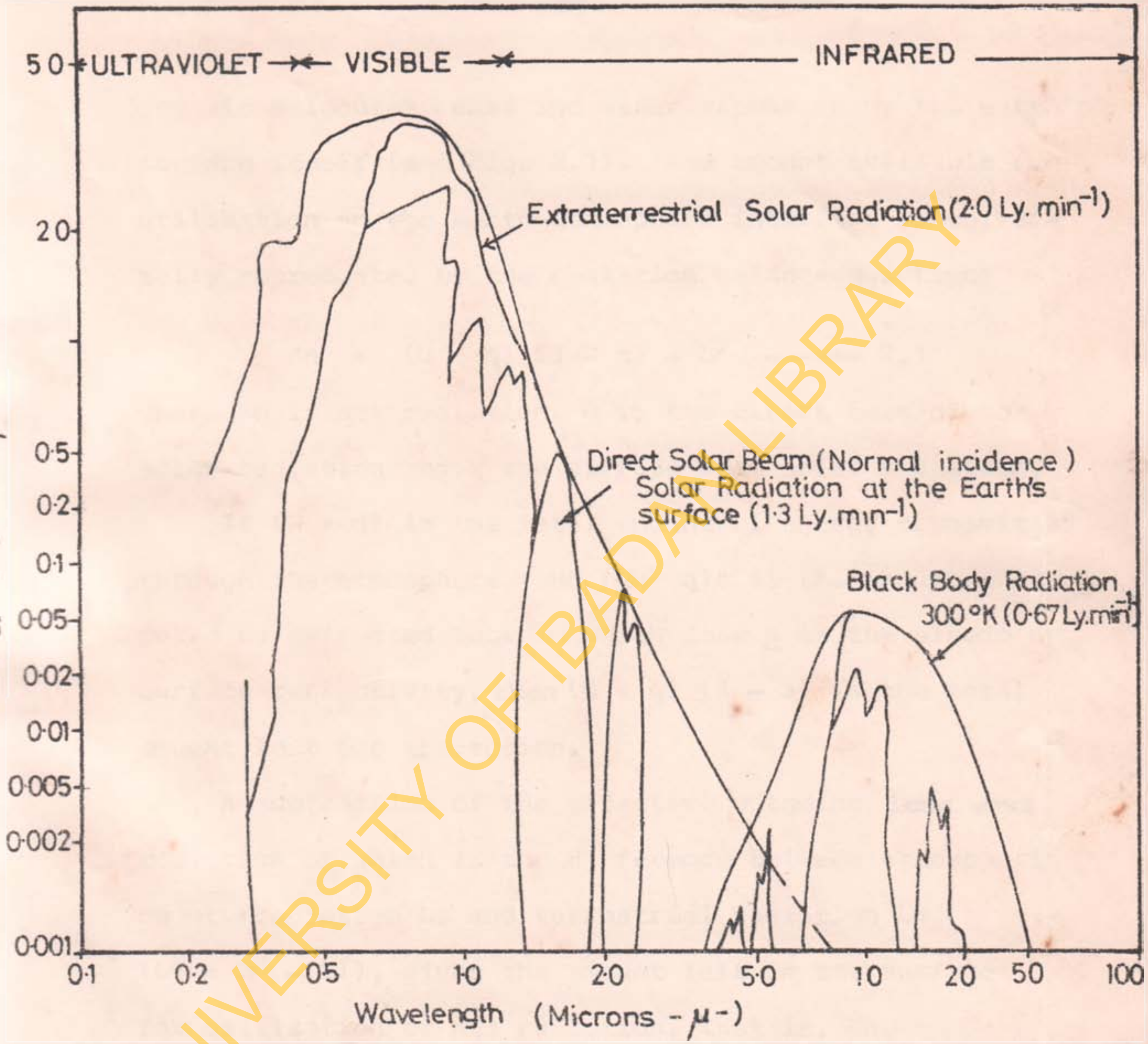


Fig. 2·3: Electromagnetic Spectra of Solar and Terrestrial Radi
(After Sellers 1965)

dry air molecules, dust and water vapour or by the earth's surface itself (see Fig. 2.1). The amount available for utilization on the earth-atmosphere interface is universally represented by the radiation balance equation:

$$Rn = (Q + q)(1 - a) - L^{*} \quad \text{------} \quad 2.1$$

where Rn is net radiation, Q is the direct beam of the solar radiation and q the diffuse beam solar radiation.

If (Q + q) is the total amount of energy transmitted through the atmosphere, (Q + q)a is the amount that could be reflected back in which case a is the albedo or surface reflectivity, then (Q + q) (1 - a) is the total amount left for absorption.

A subtraction of the effective outgoing **long wave** radiation L* which is the difference between atmospheric counterradiation $L\downarrow$ and terrestrial radiation $L\uparrow$ ($L^{*} = L\uparrow - L\downarrow$), gives the amount left on the surface for utilization or net radiation, that is, Rn.

The manner in which Rn is utilized on the surface could be represented by the energy budget equation:

$$Rn = LE + H + G + \Delta P \quad \text{----------} \quad (2.2)$$

where LE is the latent heat flux, H the sensible heat flux, G the flux of heat into the ground, and ΔP the energy utilized for photosynthetic activity.

Equations 2.1 and 2.2 represent what obtains during the day. At night, the situation differs (Fig. 2.4). There is a net loss of radiation by the surface, balanced by the upward flow of heat through the ground, downward flow from the air and on some occasions from condensation. The primary source of radiation at night is the outgoing long wave radiation.

The principle of conservation of energy, which states that, all gains and losses of energy at the earth's surface must balance, could be applied to the equations 2.1 and 2.2 with the former representing energy gain and the latter energy loss. From this, another equation could be written as

$$(Q + q)(1 - a) - L^{*} = LE + H + G + \Delta P \text{ ----- } (2.3)$$

Different components of the foregoing equation vary over space and time. The attempt to understand the microclimates of an area therefore revolves around the direct and indirect estimations of these components.

2.1.c <u>The City Surface, its Energy, Mass and Momentum</u>

The inadvertent modification of 'natural', homogeneous climate to city's heterogenous types through urbanization makes the atmospheric environment difficult to

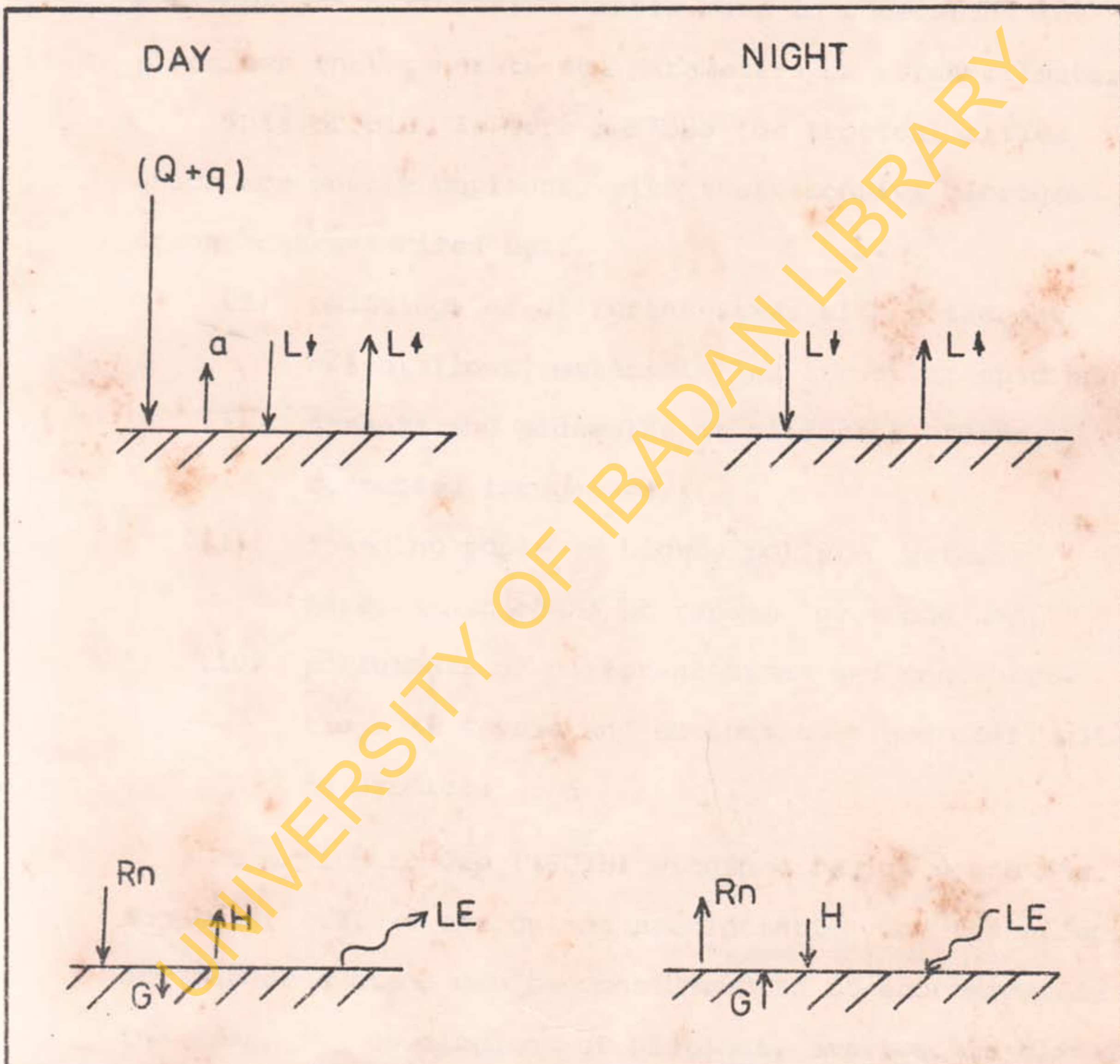


Fig. 2·4 Schematic Representation of the fluxes at the Earth's Surface by Day and by Night (after Munn 1966) understand. Indeed, the nature of various surfaces and materials in cities constitutes a formidable barrier to numerous and different attempts made to understand the processes that generate the parameters of urban climates.

This problem is more serious for tropical cities which are mostly unplanned with their complex microgeography characterized by:

(i) buildings of different sizes with different orientations, materials and irregular spacings;

(ii) streets and sidewalks of different widths, connected irregularly;

(iii) standing pools of highly polluted water, parks and gardens at random locations and,

(iv) pollutants of different types and concentrations at levels and extents that are difficult to predict.

According to Oke (1977b) within a region where the supply of radiant energy and precipitation and the effects of weather systems can be considered to be approximately the same, the development of distinct, small-scale climate is the result of the unique mix of surface and atmospheric properties possessed by a specific site (Fig. 2.5). These properties control the direction and the amount of energy

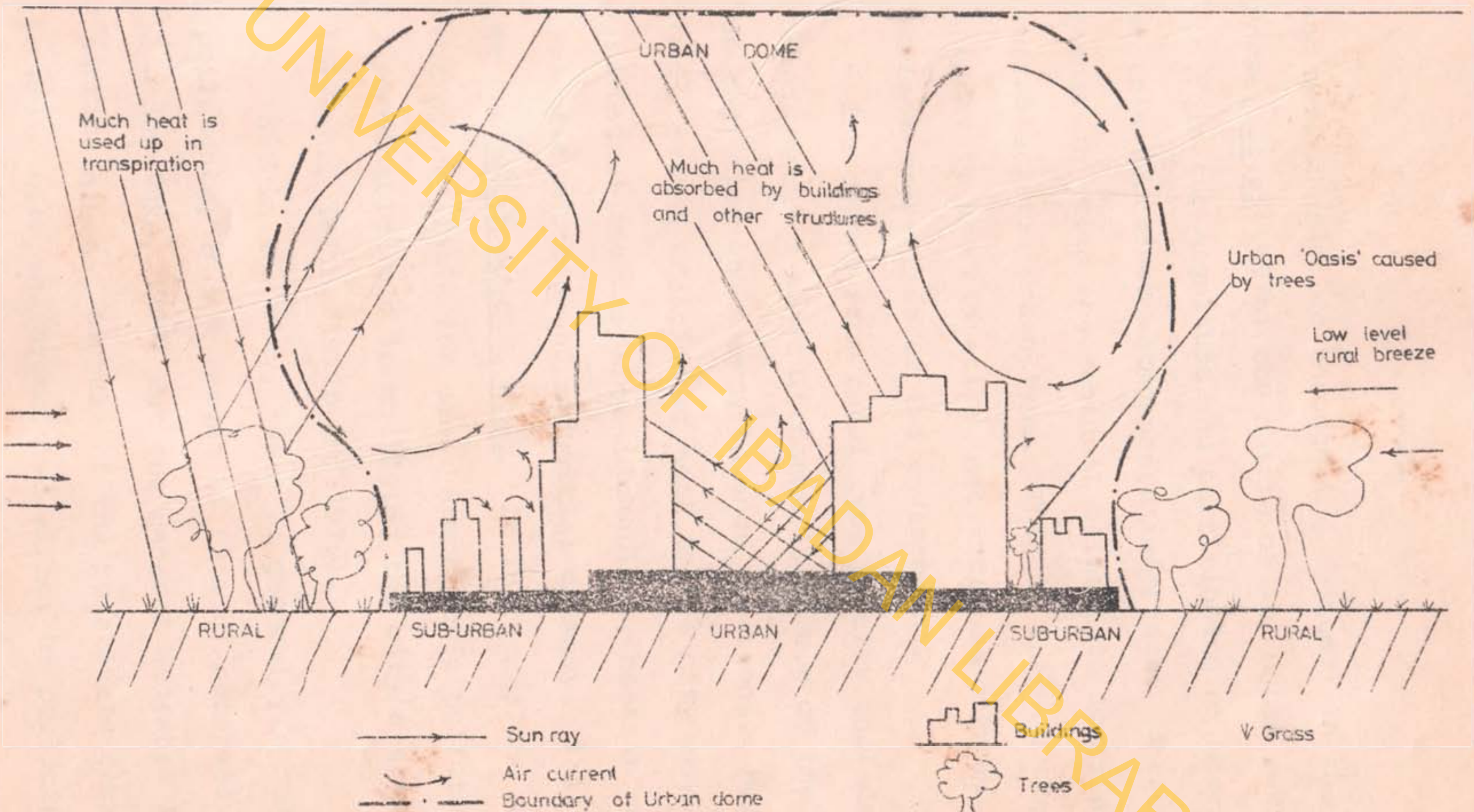


Fig.25: Hypothetical view of urban-rural Characteristic Microclimatic Condition
(Modified after Oke 1977 and WMO 1983).

and mass channelled through the system. In the words of Pease, et al (1976) the nature of the urban surface controls the magnitude and partitioning of energy at the earth's surface-to-atmosphere interface. There is a manner in which the regional climate is modified to the characteristic urban type. This is through the changes brought to the radiative, moisture, aerodynamic and thermal properties of the environment.

The change from rural type to city surface properties brings about a radical change in values of the components of radiation and energy balance equations. Moreover, there is the addition of heat to the city atmosphere via artificial sources like automobiles, heat of metabolism, domestic sources and industrial chimney. This is known as the anthropogenic heat. It increases the amount of energy available for use. Atmospheric pollution plays a formidable role in modifying the city's atmosphere (Atwater, 1971a, 1971b and 1975).

Within the city, there is generally a reduction, by pollutants, in the amount of (Q + q) received by about 2 - 10% (Oke, 1979) but the general decrease in the surface albedo, because of the relatively darker surface coupled with the protective effect of pollution veil over the city reduces the amount of energy (Q + q)a thrown back therefore leaving more of (Q + q) (1 - a) for absorption.

The incoming atmospheric counterradiation L↓ is increased by pollution veil while there is little or no change in the outgoing terrestrial long wave radiation L↑. There is a decrease in the effective outgoing long wave radiation L* due to:

(i) increase in incoming atmospheric counterradiation, and

(ii) reduction in sky view factor by canyon geometry. The canyon geometry also contributes to increase in net radiation by absorbing more of the short wave radiation.

On the city hydrology, the surfaces are concretized and therefore are less impervious than the rural environments. There is channelling of water into sewers, which leaves little water on the surface for evaporation except immediately after heavy downpours. A lower amount of energy is therefore utilized for evapotranspiration (LE) while more is converted to sensible heat (H). This means that the urban temperature is increased compared to that of the rural environment. The higher city temperature is generally referred to as "urban heat island" effect.

The amount, frequency and intensity of rainfall is increased in the city. Huff and Changnon (1972) advanced the reasons for these characteristics: (i) atmospheric destablising from the output of the well-established 'heat island'; (ii) modification of microphysical and dynamic process from industrial discharge; (iii) increase in low-level mechanical turbulence from urban-created obstruction to airflow, and (iv) modification of the low-level atmospheric moisture content by addition from stacks and towers along with changes in natural evapotranspiration processes in central urban areas.

Aerodynamic characteristics of the city are such that regional low windspeeds are accelerated while the regional high windspeeds are decelerated, the former because of its turbulence tendency and the latter owing to the frictional effect. In most cases this turbulent behaviour makes the prediction of energy and mass transfers within the urban canopy and boundary layer a difficult exercise. Turbulence in the urban air is as a result of individual eddies created mostly by buildings and vehicles. The city also acts as a single block, therefore exercising formidable frictional effect on high-velocity regional winds, 'Urban 'heat island' effect is a well-known attribute of urban climates. Its major causes are identified by Bornstein and Oke (1979) as: (i) anthropogenic heat from building sites; (ii) greater absorption of short wave radiation due to canyon geometry; (iii) decreased outgoing long wave radiation due to reduction in the sky view factor by canyon geometry and the effect of pollution veil; (iv) greater daytime sub-surface heat flux due to thermal properties of building materials; (v) greater sensible heat flux due to reduced heat flux from removal of vegetation, and (vi) conveyance of sensible heat flux due to a reduction of windspeed within the canopy. These factors retard the nocturnal cooling of urban surfaces between sunset and mid-night, therefore affecting both the city's vertical and horizontal temperatures. This has been proved by Duckworth and Sandberg (1954) and Fowler and Sandberg (1954).

In summary, the major factors controlling the climatic properties of an urban system could be identified as presence of pollutants, replacement of rural soil and vegetation with paved surfaces and buildings, roughness of the surface and the poor permeability of the urban ground to water. It is the complex interactions between these factors that accounts for the variability of urban microclimates. The results of these are the increases in net radiation, sensible heat flux, cloudiness, rainfall, temperature, reduction in global radiation, albedo, evaporative heat flux, relative humidity, sunshine and impaired visibility in the city compared with the country-side. All these also lead to a temporal impact the city growth, on climates (Chandler, 1964).

2.2 Literature Review

The desire to learn more about the fundamentals of city climates has generated a lot of literature on urban climate since the 19th century. Pioneering effort, according to Chandler (1970a), was made by Luke Howard (1818) who tabulated temperature differences between London and the surrounding country-side in 1909. Reports of Chandler (1970b), Oke (1974, 1979) and WMO (1970) put together, reveal the increasing attention of scientists to the characteristics of city climates over the years. Contributions within the past two decades are particularly phenomenal.

Although investigations have focussed generally on comparing the climatic parameters of cities with those of the surrounding rural environments, majority of the works done to date are on urban-rural temperature disparity, that is, the urban 'heat island' intensity. In fact, the study of urban 'heat island' has become synonymous with urban climatology (Terjung and Louie, 1973). Other branches like the studies of cloud cover, precipitation, sunshine, evaporation, atmospheric vapour content and pollution, radiation and energy balances and airflow are also receiving attention. To enhance a meaningful understanding of the past contributions as related to this research, the review will be in three stages. Firstly, it will look at various approaches to investigations, secondly, some important contributions, will be examined and finally we shall discuss areas that need urgent attention.

2.2.a <u>Approaches to Investigation</u>

Over the years, there have been changes and improvements in the approaches to problem-solution in urban climatology. There has been a progressive shift from the erstwhile descriptive approach deficient of quantification to the contemporary highly quantitative technique which makes use of very sophisticated equipment to amass and analyse data. The reasons for the changes are not far-fetched: firstly, improvement in technology which has led to the manufacture of more sophisticated equipment; secondly, the development in numerical models and statistical techniques in physical sciences, and thirdly what Terjung, et al (1970) regard as modern viewpoints "which indicate that climates owe their individuality to the nature of the flux of energy, matter (e.g. moisture, CO_2) and momentum between the interface of the ground canopy, or epidermis, and the atmosphere". For the purpose of this review, two approaches can be identified, viz: traditional and modern.

The traditional approach, which dates back to the days of Luke Howard and persists to date, basically involves the acquisition and description of data on climatic elements collected either from a network of climatological stations or from automobile traverses. The modern approach on the other hand, in addition to the meteorological observations, pays more attention to the surface emissivity and aerodynamic roughness, amongst others, with a view to estimating properly the net radiation and energy balance components which are seen as the basis for microclimates. This approach therefore provides satisfactory explanation about the variability of climates over urban areas.

Comparison of urban and rural data on temperature, relative humidity, rainfall and windspeed and direction occupies the realm of the traditional approach. Owing to insufficiency of weather stations, urban and rural airports records are, in most cases, analysed for the description. Ocassionally, a network of temporary stations is set up over the urban metropolis to enhance arrival at more concrete conclusions. For diurnal analysis, researchers often employ assistants, positioned at strategic locations in the city and the rural areas, for full day recording of temperature and humidity. This mode of data collection may be repeated at intervals of weeks or months for effective comparison. Perhaps the most interesting aspects of the traditional method are cases where automobile traverses are carried out to supplement data from either temporary and/or permanent stations. Depending on the available financial and manpower resources, the strategies enumerated above could be employed jointly or severally.

Equipment used in the traditional approach are generally the ones installed in the climate observatory stations. They include the simple wet and dry bulbs, maximum and minimum thermometers, thermohygrograph, rainguage, wind vane, cup counter anemometer, sunshine recorder, Gun Bellani net radiation integrator and evapotranspirometer, amongst others.

Unlike the pioneering automobile traverses which basically involved the mounting of temperature and humidity equipment, contemporary ones add other equipment like the net radiometer, solarimeter and albedometer for the recording of net and global radiations and albedo respectively. The group involved in an automobile traverse stops at strategic, specific locations for rapid recording of climatic parameters in cases where the vehicle is not equipped with an automatic recorder. To and fro journeys along the same route across the settlement from one rural to another are also vital to make the information collected very meaningful. The journeys are planned in such a way that they do not last more than about ninety minutes in order to forestall the introduction of error from glaring temporal changes in the regional weather.

Introduction of radiation and energy budgets analysis to the urban surfaces was the beginning of modern approach which dates back to the nineteen fifties. Information on the components of equations 2.1 and 2.2 (excluding ΔP in 2.2) are collected from the urban and rural environments mainly via automobile traverses and remote sensing techniques (for example see Bornstein (1975) and Rao (1983)). These are interpreted in relation to the urban surface characteristics. In some cases mathematical models are evolved, using information collected on surface parameters and atmospheric conditions as inputs. Generally speaking, the modern approach is more diverse as more people see the same problem through varying spectacles of methodology.

Works done by Duckworth and Sandberg (1954); Landsberg (1956a); Chandler (1962a, 1965); Oguntoyinbo (1973, 1982); Unwin (1980) and Nkendirim (1976) exemplify the traditional approach. Their various researches involved gathering and describing climatic data.

Working on the effect of cities upon horizontal and vertical temperatures in San Francisco, Duckworth and Sandberg (1954) carried out observations at 2-meter level with automobile-mounted thermistor, and vertical temperature gradients in the lowest 300 metres with radiosondes. These were measured simultaneously at the urban centre and the rural periphery. The results revealed th temperature increased from open field to the city centre.

Landsberg (1956a) gathered various climatic data from various American cities. From his result, he concluded that cities affect important meteorological variables like temperature, radiation and rainfall. He emphasized the impact of pollution on these parameters.

The work Chandler (1965) did on the city of London is another very popular example of the traditional approach. In an attempt to describe its (London's) climate, he gathered archival data from several weather-recording stations in addition to various day and night automobile traverses carried out. Simple statistical analyses were performed on the data to bring them into meaningful arrays for descriptive purpose. He was able to group London into different climatic regions after describing conditions of wind, state of atmospheric pollution, variations in radiation and sunshine, temperature, evaporation and humidity, visibility, cloud amount and precipitation.

Hage (1975) worked on the urban-rural humidity differences in Edmonton by analysing archival airport data gathered over thirteen years. His own method mainly involved an analysis of the existing climatic data at suitable, comparable locations.

Nieuwolt (1966) worked on the climate of Singapore, a tropical city. The investigation was conducted at weekends with the assistance of students. In this case, they were equipped with the simple whirling hygrometers, positioned at strategic locations in the city. The results were also combined with those from airport stations. Impact of urbanization on temperature and humidity in Singapore was established through the description of the average data.

Oguntoyinbo (1973) worked on the impact of urbanization on the climate of Ibadan, another tropical city. School teachers on Workshop, students and laboratory assistants helped in collecting climatic data for this exercise. They used simple thermohygrographs and whirling hygrometers. The method involved gathering of data on temperature and relative humidity in transect forms across the city during the daytime. Thermohygrographs were also installed in traditional and modern houses to know their (houses') different effects on climate. All the results were complemented by data from the airports and other agrometeorological stations.

Nkendirim (1976) also worked on the climate of a Canadian city through the consideration of relative humidity and temperature characteristics. The approach is similar to the afore-explained ones which involve simple measurement, averaging and description of climatic data.

On contemporary approach, a well-known method of microclimatic investigation sprang up from the work of Halstead, et al (1957) who designed a computer programme for the investigation. The approach, which was improved by Myrup (1969) and latter fully developed and tagged Climatic Simulator Model (CLISIM) by Goddard (1971) describes the various microclimates in an urban region by using the energy balance approach. This is done by combining the information gathered about the microclimate of the city as a single entity with those collected on surface reflective, absorptive and emissive characteristics. In the end, the microclimates are simulated.

Morgan, et al (1977) employed CLISIM to investigate the various microclimates of Sacramento, California. The study revolved around the estimation of the various components of equation 2.2. To solve the equation, meteorological conditions such as cloudiness, atmospheric turbidity, sun angle, air temperature, humidity and windspeed at reference height as well as temperature at the bottom of thermally active substrate layer were specified. Values of the interface parameters such as albedo, emissivity, moisture property and roughness length plus the thermal conductivity of the surface were known. It was with the aid of these characteristics that various microclimates were delineated. The calculations of energy balance were done by land-use category.

A more simplified demonstration of the energy balance analysis abounds in the works of Fuggle and Oke (1968), Yab and Oke (1974), Terjung (1969, 1970), Nunez and Oke (1977) and Terjung, et al (1970). Their method involves a compilation of data on amounts of global and net radiation, ground heat flux, actual surface temperature, terrain radiant temperature and dry and wet bulb temperatures, with the aid of relevant equipment. With this approach different climatic data were amassed from which microclimatic conditions were described.

Compared with the traditional approach, the modern approach employs highly sophisticated, costly equipment which are too expensive for most research organizations to afford. In addition, the fieldwork is expensive.

The fieldwork of the traditional approach is always more time-consuming and energy-sapping. Generally speaking, although the modern approach seems to be more sophisticated because it produces the desired results by tackling the fundamental causes of urban microclimates, it is however often employed together with the traditional approach for the attainment of better information about the atmospheric environment. In fact, the tools used by local climatologists have been basically limited to standard climatological records from stations established primarily for synoptic purposes and, in some cases, to mobile surveys of temperature and humidity (Jauregui, 1984). This means that most contemproary urban climatology studies employ the traditional approach to investigation.

2.2.b <u>Results of Some Investigations</u>

From the numerous researches conducted so far, a lot has been said and known about the urban atmosphere, particularly in the middle latitudes. As earlier noted, areas in which investigation have focussed mostly are on urban-rural temperature disparity, that is, the 'urban heat island' intensity, relative humidity, clouds and precipitation, atmospheric pollution, radiation, energy and moisture balances and windspeed and direction. The earlier detailed surveys of urban climatology carried out by Chandler (1970b), Peterson (1971), Oke (1974, 1971 and 1979) and Bornstein and Oke (1974) form the essential bases for this brief account of some aspects of the city's atmospheric conditions.

There is no doubt about the fact that a lot has been written and known about 'heat island' effect of cities which is clearly the most documented aspect of urban climatology. Information about this is mostly obtained from temperature data of urban minus rural values (i.e., Tu-r) in relation to windspeed and direction. Several information of this type have revealed a lot about the dynamics of the 'heat island' intensity.

The time 'heat island' attains its maximum intensity and its values vary from place to place. For instance, Oke and Maxwell (1975) put this time as 3-5 hrs. after sunset in Montreal Vancouver. Hage (1972a, 1972b) puts this at 3-4 hours after sunset in all seasons in Alberta. The value of the highest intensity is more variable. While the findings of Duckworth and Sandberg (1954) in Sacramento reveal a magnitude of about 4.40°C, those of Helmut Landsberg (1979) show a maximum intensity of 8.0°C in the densely built-up town centre of Columbia, Maryland.

Heat island has been found to decrease with cloud cover, and high windspeed. It has also been proved that it varies with city size and population. Oke (1973) related the value of maximum surface heat island intensity to population figure for ten settlements whose population ranged from 1,000 to 2 million in St. Lawrence lowland in Canada, obtaining the equation:

$$\Delta T_{u-r} = 0.25 \frac{P^{1/4}}{U^{1/2}} \quad \text{---------} \quad (2.4)$$

Where ΔT_{u-r} is the 'heat island' intensity, P is the population and U, the windspeed. He also shows that the absolute maximum value of ΔT_{u-r} for any city is related to the log of P and has a value of about 2.5°C for cities with population of 1,000 and 10.2°C for cities with one million persons in North America.

Relative humidity is believed to be lowered by urbanization because it decreases with increase in temperature. Analysing data collected with the aid of wet and dry bulbs thermometer or the psychrometer, Chandler (1965, 1967), Nieuwolt (1966), Ackerman (1971), Oguntoyinbo (1973) Nkendirim (1976, 1977) and Hage (1973) worked on relative humidity of urban areas.

According to Hage (1975) perhaps the most comprehensive survey of city's effect on atmospheric moisture has been given by Ackerman (1971) who assessed a 20-year hourly dewpoint in Chicago. He found the city to be moist at night and dry by day relative to the surrounding country-side.

Comparing a 13-year record for Edmonton, Hage (1973) finds the city to be dry in summer and moist by mid-winter relative to the country, urban absolute humidities were lower by day but higher at night than those in the country in the warm season. In winter, both relative and absolute humidities were higher in the city because of mixing and combustion sources.

Chandler (1962b, 1967), working in Leicester also finds the night time absolute humidities to be frequently higher in cities than in the near-by country. Nieuwolt (1966), Oguntoyinbo (1973), Jaurequi (1982) and Maejima, et al (1983) worked in tropical areas. The results of Nieuwolt show the rural airport relative humidity to be higher than that of the town by about 20% in Singapore, summaries of Oguntoyinbo's findings for Ibadan show a 7% day time lower city humidity. Maejima, et al (1983) worked on recent climatic changes in Tokyo and environs over 100 years (1880-1980). They focused on description of temperatures, rainfall and water vapour. Their results show an increase in January and August maximum temperatures and number of drizzle days. It was discovered that there was on the whole a temporal change in temperature characteristics over Tokyo owing to urbanization. Like cities in other climatic areas of the world, tropical cities are regarded as having slightly lower absolute and relative humidities than the surrounding rural areas.

It is rather difficult to isolate the impact of towns on cloudiness and rainfall. Results of various findings have however shown a considerable effect of urbanization on these two parameters. After compiling series of reports, Landsberg (1956a) arrived at the conclusion that cities have 5-10% more cloudy days than their rural environments.

Changnon (1969, 1971) shows from his report on the findings in the United States that there is an apparent increase in annual rain days and precipitation to the extent of about 5-16% and an increase in thunderstoms to the extent of 7-12%. Huff and Changnon (1972) working in St. Louis, United States also found out that there was an increase in average summer rain by up to 6-15%.

Components of radiation and energy budgets have not attracted much literature compared with other areas. According to Oke (1979) global radiation is about 2-10% less in the city because of the effect of pollutants. Observations of both direct and diffuse solar radiation over St. Louis by Dabberdt and Davis (1974) yield a 19% urban decrease. There are also increases in values of outgoing long wave radiation and incoming atmospheric counterradiation. Net radiation is greater in cities.

City's influence on airflow is enormous. Urbanization has an impact on the boundary layer turbulence (Bowen and Ball, 1970). Landsberg (1962) gives the annual mean decrease in windspeed as 20-30%, extreme gust 10-30% and an increase in calms by 5-20% compared with rural environments. Chandler (1965) also noted that the velocity of wind is increased within the city if the regional wind is about 5m sec^{-1} or less. Extreme gusts are lower in the city by 10 to 20% while calms are more by 5-20%.

2.2.3. Progress in Urban Climatology

From the above review, it is clear that so many things are known about the states of various urban environments. Emphases have been placed on urban-rural differences in climatic parameters to the detriment of urban-land-cover-climate relationship. Lack of enough weather stations in most urban areas, the inadequacy of highly sensitive equipment, lack of research fund, and shortage of personnel constitute formidable barriers besetting research progress in area of urban climatology, thus retarding a speedy understanding of the dynamics of city climates.

The problems are more serious in the tropical and polar regions where according to Oke (1977b), special attention need be focussed so that their fast-growing urban centres will not repeat the mistakes of those in the temperate latitudes. Indeed, majority of the important studies have been carried out in the temperate countries when compared with the tropical, and African countries in particular, where the identified problems above are more serious.

It is also clear from the survey that despite the various efforts geared towards understanding the city microclimates, the application of the energy balance studies although just featuring in the literature is a more effective methodology for urban microclimatic studies because an energy balance approximation shows the ways in which the available net radiation is being utilized over the various surfaces.

In short, the dearth of knowledge in urban climatology, which is evident from the review could be summarized as follows:

1. little emphasis has been placed on the impact of surface texture on climatic parameters. Instead of concentrating on an analysis of urban climate, using the land-use components that generate climatic variability as the bases, most investigations are carried out without detailed analysis of the city surface texture, therefore making arrival at meaningful conclusion difficult. In the earlier studies the general practice had been to compare data from urban and rural airports;

2. necessary information on the prevailing climatic conditions of most tropical cities is still relatively scarce. Because of the lack of fundamental knowledge about the atmospheric condition of these cities, it has not been possible to take into consideration

the important microclimatic inputs in planning of some cities and,

3. sesonal variations in 'heat island' intensity, atmospheric humidity and components of radiation and energy balance equations are not well documented for most tropical cities.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Choice of Parameters

In order to consider the issue of urban-rural dichotomy in microclimates, the city was viewed from the "holistic" point of view; an entity within which complex heat-exchange activities take place. Solar energy received in the 'holistic' city is subjected to various uses by the highly heterogeneous surface. On the other hand, the climates of the surrounding rural areas depend on the rather heterogeneous surface. Because of these reasons, two categories of parameters are taken into consideration. These are, the city surface textural components and those related to climatic conditions.

Having an insight into the general characteristics of different land-uses in the city is very important because, as earlier emphasized, the urban surface texture essentially determines the behavioural patterns of its microclimatic conditions: as for climatic conditions, data are collected on radiation and energy budgets, temperature, relative humidity and rainfall. An analysis of radiation of radiation and energy budgets is very important because it forms the basis of any microclimate and it is therefore vital to the understanding of the variability of an urban climate. Temperature and relative humidity are considered because they are important parameters used in determining the state of human physiological comfort.

3.2 Sampling Procedure

The problem of data collection over the considerable areal and time extents was solved through the selection of samples. Sampling techniques were employed in the collection of two categories of data: city surface texture and climatic parameters. City surface texture in this project refers to the different land surface characteristics like building, roads, water, trees, lawn, bare ground and paved surfaces.

3.2.a Land-use Samples

Land-use maps of Ibadan were consulted (Oyelese, 1970 and Ayeni 1982) in order to delimit the different categories of land-uses within the city-surface. Using the maps as the main source, the land-use categories were later ascertained and further modified from mosaics of aerial photographs flown between 1975 and 1977 by the Federal Surveys, Lagos. Building densities of different land-uses were estimated. Results of these analyses were complemented by fieldwork. Based on the estimated building densities and the areal extent of each land-use (Table 3.1), the number of samples for the analyses of city surface texture was determined. Approximately one-third of the total area of each land-use type was marked for the city-surface texture analysis.

In order to select sample sites for the determination of roughness length, sampling areas were subsequently sub-divided into 1 km^2 grid cells. Considering the enormous size of each cell and the extent of detailed analysis needed to be accomplished, building samples were chosen, using table of random numbers, from the grid cells. This was done by uniformly taking into consideration 10% of the building density in each zone except for the land-use with building densities less than 100 buildings per km^2. In such cases, total values of building densities are considered (Table 3.1).

3.2.b <u>Sample Site Selection</u>

It became pertinent to resort to sampling because it was impossible to collect data over many spots in the city; and also incorporate all the available

Table 3.1

Land-uses of Ibadan Metropolitan Area

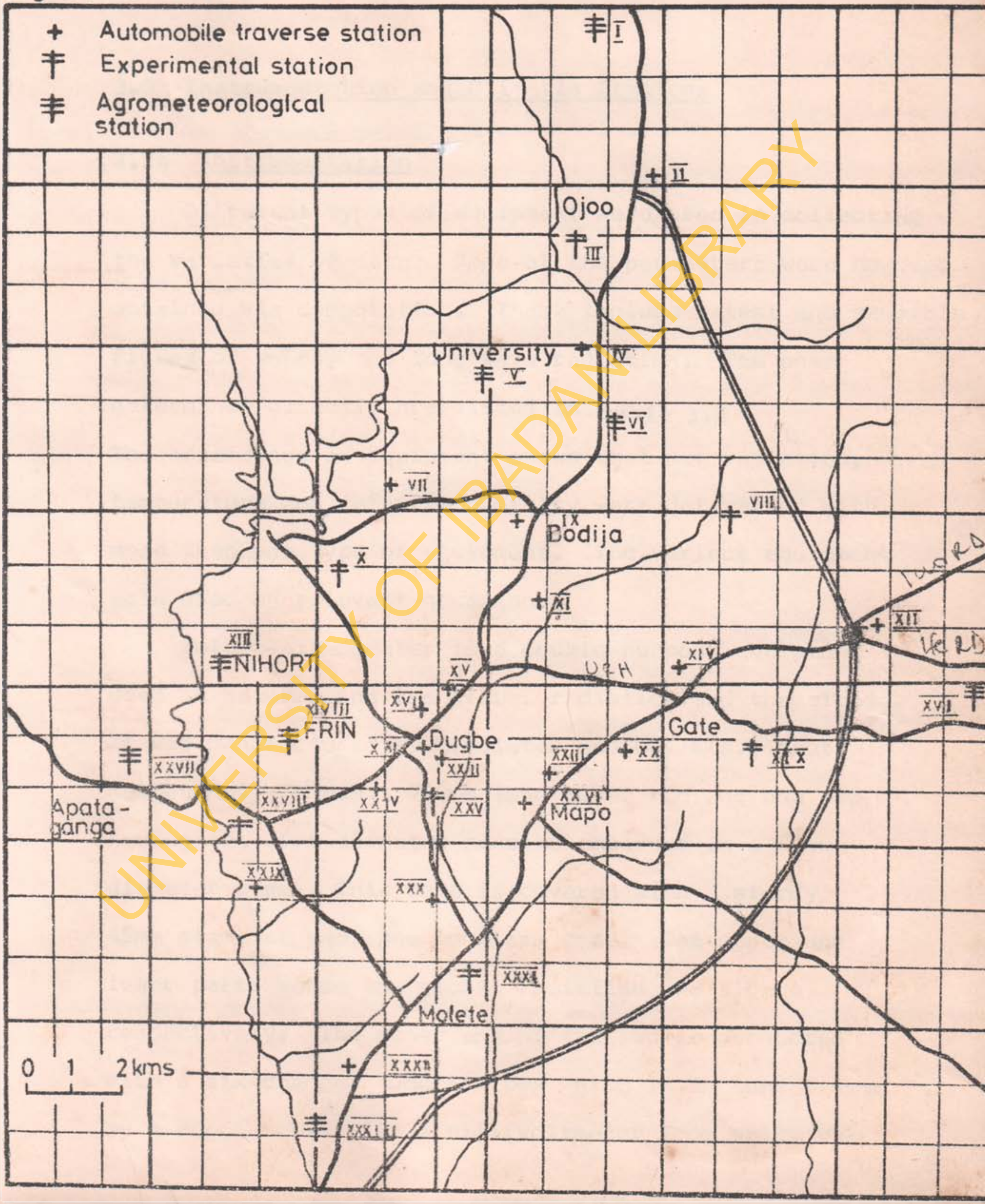
Land-use	Area in hectares	% of total City	No of Building Samples
1. High density Residential	12,968.75	29.5	800
2. Medium Density Residential	2,812.50	6.4	450
3. Low-density Residential	6,406.25	14.6	160
4. Educational	1,562.50	3.6	120
5. Medical	159.00	0.4	30
6. Rural	4,343.75	11.0	74
7. Agricultural	1,250.00	2.8	43
8. Industrial	7,500.00	17.1	380
9. Commercial	150.25	0.4	180
10. Acquisition	5,625.00	12.8	80
11. Open space	625.00	1.4	0
12. Total City	43,903.00	100.0	

Sources: Area modified after Ayeni (1982). Building Density Estimated after Oyelese (1970) and from Fieldwork (1983).

temporal data in the project. With respect to space, samples of data were collected with two aims in mind:
(i) to ensure adequate spatial representation, and
(ii) to monitor characteristics of the climatic conditions over each of the land-use zones. Data were collected by ensuring adequate representation of stations on different land-uses because of the theory-base of this research: that components of different land-uses combine to give rise to different microclimates. In addition to monitoring data from the climatic stations (Fig. 3.1) automobile traverses and diurnal recordings were carried out at different seasons.

The need for the collection of data over reasonable length of time led to taking the following categories of temporal data into consideration: (1) record over a period of twenty years were collected not only to monitor the effect of city growth, on its climate, but also for the purpose of being able to describe the climate of Ibadan with higher degree of certainty; (2) the day-time recording of some climatic parameters over a period of one year was done to enable proper description of the diurnal and seasonal variations in climatic parameters over different land-uses.

Fig. 3·1 Climate Stations



3.3 Instrumentation and Climatic Stations

3.3a Instrumentation

Different types of equipment were used in collecting the varieties of data. Some of the parameters were however obtained via computation. These include latent and sensible fluxes of energy and long wave radiation. The ones determined directly are listed in table 3.2
The assemblage of equipment shows that net radiation, temperature and relative humidity were determined with more than one type of equipment. The various equipment were used on relevant occasions.

Solari-albedometer is a double-purpose equipment used in determining the global radiation and the albedo. It was manufactured by Middleton and Co. Ltd., South Melbourne. It has a 700mm long pivot rod and one end having the 15mm diameter sensors embedded in a 65mm diameter base. This case is covered with a sturdy 45mm diameter hemispheric glass case. The upper and lower parts sense the global radiation and albedo respectively. The other end of the rod is connected with a six-channel junction box which is in turn linked by a short cable with a millivoltmeter from which the

Table 3.2

Climatic Parameters and Recording Equipment

Parameters	Equipment
1. Global Radiation	Solari-albedometer
2. Net Radiation	(a) Type S-1 Net Radiometer (b) Thornthwaite's Model 603 Net Radiometer
3. Albedo	Solari-albedometer
4. Temperature	(a) Thermohygrograph (b) Type T618 Thermistor (c) Whirling Hygrometer (d) Assman Aspirated Psychrometer
5. Relative Humidity	(a) Thermohygrograph (b) Whirling Hygrometer (c) Assman Aspirated Psychrometer
6. Rainfall	Rain guage

recording is carried out. This recording is converted from millivolts to the conventional unit of cal. Cm^{-2} min^{-1} or ly min^{-1}.

Type S-1 Net radiometer was manufactured by Swisstego Ltd. Melbourne. This instrument, which is highly sensitive, has a factory-manufactured collapsible stand which could be adjusted to a height of about one meter or attached with an improvised stand if a higher level of measurement is desired. It has a sensing element covered with a replaceable polythene dome 37mm in diameter. A rod, 600mm long is attached to the sensing end. Like the solari-albedometer, a variable length thermocouple links the other end of the rod and the junction box. The recordings are of the same procedure.

The model 603 portable net radiometer was manufactured by C.W. Thornthwaite Associates. This miniature instrument is an efficient, economical compact equipment which has a direct sensing element, which lies horizontally at the centre of a supporting split brass 6mm in diameter. It is shielded from wind and precipitation by two clear plastic windows, 50mm in diameter, sealed to the upper and lower halves of the ring to provide a means for monitoring on the field when necessary. The recording is done directly in cal. cm^{2} min^{-1} or ly min^{-1}.

Thermohygrograph is a self-operated portable instrument. Temperature recording is obtained from the alternation in the curvature of a strip of bimetal with its two portions having different linear coefficients of expansion. While one end is anchored to the main case, the other is fixed to an adjustable link attached to a spindle which also carries a pen. The two metals expand or contract according to changes in temperature which cause up or down movement of the attached pen for the linear recording on the chart to a span of 50°C. Alteration in length of specially treated human hair which is sensitive to changes in relative humidity by shortening when it decreases and lengthening as it increases gives the amount of relative humidity between the range of 0-100%. The pen has longer limb and goes above the temperature pen. Two different coloured inks or fibre tipped pens are used to distinguish the two records. The spring-driven clock of the thermohygrograph around which is a rectangular chart on which the temperature and relative humidity values are recorded could be set to record for 25 or 168 hours.

The T618 battery operated thermistor thermometer is designed for obtaining rapid measurements of temperature. This general purpose instrument is encased in a sturdy black plastic box with a carrying handle. It has the caliberating switch for accurate adjustment.

A popular equipment for measuring the relative humidity is the whirling hygrometer. It has both wet and dry bulb thermometers held in slotted frame, one end of which revolves on a handle, the other end having a polythene water reservoir into which dips the wick for the wet bulb. The thermometers are button topped, mercury filled with lens frames to magnify mercury column. These bulbs give quick response. For operations, the hygrometer is whirled rapidly for fifteen seconds, stopped and the two thermometers are read quickly, the wet bulb first. This is repeated until two consecutive pairs of readings are the same. During whirling, the hygrometer is shielded from solar radiation and held as far from the body as possible with the hygrometer up the prevailing wind. Depression of the wet bulb gives the relative humidity from slide rule or hygrometric table.

Assman aspirated Psychrometer was also used with the whirling hygrometer. It was manufactured by Casella, London. For operations, air is drawn by a fan past two thermometer bulbs, one of which is kept moist by a close fitting wick of water absorbent material, the other is uncovered and dry. The thermometer bulbs are supported on either side and flagged at the top by a central tube, and an inverted u-nylon moulding at the bottom. The thermometer bulbs extend through this nylon moulding and are protected from radiation effects by two detachable cylindrical open-ended chromium plated brass tubes, insulated from each other as well as from the main frame. The thermometer stems are protected from possible damage by stainless steel guards.

All equipment used are factory calibrated.

3.3.b <u>Climatic Stations</u>

With the exception of the records collected during automobile traverses, other measurements were taken at twenty spots located throughout the city (Fig. 3.1). These stations are in two groups (Table 3.3). First, there are those that are already in existence, being monitored by the Federal Department of Meteorology and some institutions/establishments. Second, are the additional twelve stations established to increase the network of stations over the city; for proper representation of the major land-use types. This second group of stations are two categories: "experimental" and "occasional".

Table 3.3

Designations and the Locational Characteristics of the Recording Stations†

	Altitude (m)	Designation	Land-use
FIRST CATEGORY - EXISTING STATIONS			
1. U.I	213.4	Synoptic	Low Density
2. IITA	228.4	-do-	Rural
3. Old Airport	227.1	Agrometeo-rology	Medium Density
4. New Airport	224.0	Synoptic	Rural
5. FRIN	205.7	Agrometeo-rology	Low Density
6. NIHORT	193.1	-do-	Rural
7. NCRI	132.9	-do-	Low Density
8. CRIN	121.9	-do-	Rural
SECOND CATEGORY - ESTABLISHED STATIONS			
9. Ajibode	220.9	Experimental	-do-
10. Eleyele	190.5	-do-	High Density
11. Odo-Ona	152.4	-do-	-do-
12. Oke-Bola	137.2	-do-	-do-
13 Molete	190.5	-do	-do-
14. Lagelu	213.4	-do-	-do-
15. Bashorun	236.2	Occasional	Low Density
16. UCH	205.9	-do-	-do-
17. Dugbe	190.0	-do-	Commercial
18. Ife Road	201.3	-do-	Medium Density
19. Orita Challenge	167.6	-do-	-do-
20. Agodi Zoo	199.3	-do-	Open Space

† Automobile traverse stations not included.

Installed at the 'experimental' stations were the self-recording thermohygrographs and the rainguages. The remaining stations were designated 'occasional' because they were used for occasional, diurnal recordings by field assistants. The need for greater coverage made their establishment desirable and worthwhile.

3.4 Data Collection

The project started in March 1983 through a series of pilot surveys aimed at a few important things: (1) to get more familiar with different locations of the city; (2) to select suitable sites as climatic stations; (3) to get appropriate routes for automobile traverse recordings that were to complement point recordings, and (4) to have some practice in the handling of the various equipment through test recordings.

Following the pilot survey, suitable sites were identified. The number of equipment available determined the maximum possible number of stations. The issue of security also played a vital role in the location of the individual stations. Seven 'experimental' stations were established after series of negotiations with school

Principals, Geography Teachers and Nightwatchmen. The remaining five stations were designated 'occasional' because the security factor coupled with shortage of automatic recorders compelled the carrying out of occasional, full-day recordings there.

The first major recording was between 19th and 26th of March. It involved the measurement of the components of radiation budget over different land-use zones. These measurements were taken close to the established stations from 0600 to 1800 hours of GMT. The equipment in the established stations also went into full operation by the beginning of April. The stations were monitored on weekly basis. It was not possible to take rainfall recordings more frequently than at seven day-intervals because of the problem of areal coverage. The sides of the rainguages at the 'experimental' and occasional stations were not directly exposed to minimize evaporative loss. It was therefore assumed that some amount of water was lost through evaporation. If any at all, the little loss would not have jeopardised the success of the research-goal which aimed at obtaining an idea about the spatial variation and not the point total amount of rainfall.

It is unfortunate to note that the inability to get suitable data from rainfall recording was the major failure of this project. This happened because on several occasions, geography students in the schools tampered with the rainguages by throwing away the water before the weekly recordings were carried out. The situation at stations X and XIV was worse as the nightwatchmen ignorantly covered the rainguages at the beginning of any rainfall because they wanted to protect them from being damaged by rainfall! The one at Odo-Ona was stolen for a while before it was later recovered. At Oke-Ado, it was the problem of over flooding on several occasions as the rainguages were over filled before the major routine recording. In view of these problems, results were so disjointed that it was impossible to make any meaningful deductions from the data. This led to the rejection of the rainfall data collected at the newly established stations. The data from the established stations were the only ones analysed in this exercise.

Detailed analysis of the city-surface texture also started with the identification of the composition of different land-uses from aerial photographs of scales 1:25,000 and 1:12,600 flown in 1975 and 1977 respectively.

The analysis, which was assisted by the Federal Department of Forestry, Ibadan, was mainly aimed at the estimation of the proportions of different land-use zones covered by buildings, water, tarred and untarred roads, paved surfaces, bare ground, lawns and trees. Because of the difficulty in identifying some of these components from the photographs, the analysis was complemented with detailed cross-checking on the field. Building density was calculated directly from the photographs.

Estimation of building geometry, that is height and area, and of roughness lengths, was carried out mainly on the field by the selection of some building samples. Survey chains, prismatic compasses and Abney Levels were used to determine the lengths, orientations and heights of buildings respectively. Roughness length Zo was calculated from Lettau's formula:

$$Zo = 0.5 \frac{h^* S_1}{S_2} \quad \text{----------} (3.1)$$

Where h* is the average height of obstacles, 0.5 the mean drag coefficient, S_1 average obstacle silhoutte area and S_2 specific area A/N; where A is the lot area and N is the number of roughness elements on the lot.

Archival records of the monthly mean temperature, relative humidity and rainfall were collected from some of the existing stations. Occasional, diurnal recordings of temperature and relative humidity for one year took place at seven stations. With respect to the components of radiation and energy budgets, data were collected from both the automobile traverses and full-day, occasional recordings. On the whole, there were six automobile traverses carried out, three during the wet season and three during the harmattan season.

Microclimatological recordings were not carried out on predetermined days; because of the lack of appropriate weather forecasting facilities. Each diurnal recording lasted from 0600 to 1800 hours GMT. These recordings were at every quarter of an hour. Traverse journeys were from the rural area through the urban centre and back to the rural area. Rapid recordings were made at pre-determined, fixed points during a round trip which lasted for not more than two hours.

The separation of LE and H in equation 2.2 has always been a problem in microclimatic investigation. In 1926 however, Bowen introduced the Bowen Ratio βB to solve this problem. This has also been employed by Kalanda, <u>et al</u> (1980)

and Ojo (1980), amongst others.

$$B = H/LE \quad \text{------------} \quad (3.2)$$

If similarity in eddy diffusivity for heat and water vapour is assumed, then this becomes

$$B = Y \frac{\Delta T}{\Delta e} \quad \text{------------} \quad (3.3)$$

Where Y is psychrometric constant, which is 4.2 mm/Hg^{oC}, ΔT is the mean air temperature difference at two measurement heights (T_2, 1,000 mm and T_1, surface) and Δe is the mean vapour pressure difference in mm Hg ($e_2 - e_1$) at the same heights. Substituting equation 3.2 in 2.2 where ΔP is assumed negligible, and re-arranging, then the energy balance equation then becomes

$$LE = \frac{Rn-G}{1 + B} \quad \text{------------} \quad (3.4)$$

$$H = \frac{Rn-G}{1 + 1/B} \quad \text{------------} \quad (3.5)$$

The similarity in eddy diffusivity, according to Kalanda, et al (1980), has been validated for unstable and near-neutral conditions for different surfaces. In this study, G is taken as being negligible because during the measurement period cloudy condition existed. In addition, heat fluxes in and out of the ground were assumed equal.

Bowen ratio has the advantage of being applicable at all times. Kalanda, et al (1980) pointed out some of Bowen ratio's advantages as: durability of the measurement system, its ability to run for extended period (days) without maintenance, and the measurement of turbulent energy partitioning even if the available energy (Rn-G) is in error or not available.

Since the Bowen ratio was not applied during the harmattan (dry) season, the calculation LE and H was therefore limited to the wet season.

The analysis of the impact of urbanization on some climatic parameters was based solely on the data collected for the thirteen months, March 1983 to March 1984, as enumerated above. The one-year data was employed in the assessment of the spatial pattern of microclimatic conditions.

3.5 Mode of Analysis

A large volume of data emerged from the various observations, areal demarcations and measurements. Data related to the city surface texture were the first to be analysed. In fact, it was after obtaining the clear picture of the urban surface characteristics that firm decisions were taken about the location of the climatic stations.

In order to obtain a clear picture of the surface texture of the city, averages of the different components of the land-uses were taken. For good visual assessment, line and bar graphs are used in the presentation of surface components across the city. Simple correlation analysis and tests of difference are employed in comparing the parameters of different land-uses.

A large amount of climatic data emerged from various sources. At the beginning of the analysis the data were organised on diurnal and seasonal bases. In other words, related components of radiation and energy balances, temperature and relative humidity were averaged for morning (0600 - 1200 hours of GMT) and afternoon (1200 - 1800 hours of GMT) periods over both wet and dry (harmattan) seasons. In essence, for all the climatic parameters under consideration, except H and LE, four categories of figures emerged as viz: 0600 -1200 hr GMT wet season; 1200 - 1800 hr GMT wet season; 0600 - 1200 hr GMT harmattan season and 1200 - 1800 hrs GMT harmattan season. Because of the use of Bowen ratio, the last two sets are not available for H and LE. In order to present the spatial pattern of these parameters on the map of Ibadan metropolis, the weighted average technique was employed. In doing this, two categories of rectangular grids were imposed on the land-use map of Ibadan (Fig. 4.1). The first was a larger grid numbering forty-two. The second was a smaller grid in which each of the forty-two grids was established nine smaller ones. The idea is that, since each land-use category has its characteristic microclimatic condition, then the microclimate of each of the forty two grid cells could be calculated by estimating the fractions of the different land-use types identifiable in the larger grid cell. This was done with the aid of the smaller grids. Having done this the value of any climatic parameter attached to larger grid cell could be known by multiplying the value of the climatic parameter attached to each land-use type with the fraction they represent within the grid. For example if for an hypothetical grid G there are land-uses A, B and C representing ½, ¼ and ¼ parts of the larger grid respectively. These proportions were estimated with the aid of the smaller grid. If the mean temperatures are 20.0°C, 20.4°C and 20.8°C respectively for land-uses A, B and C. Then the mean temperature for the whole grid will be $\frac{20.0}{2} + \frac{20.4}{4} + \frac{20.8}{4} = 20.3°C.$

CHAPTER 4

4.0 THE CITY-SURFACE TEXTURE

Land-use types in the city of Ibadan and their different associated characteristics are examined in this chapter. The primary aim is to give an account of the extent of man's impact on the 'natural' environment. In order to achieve this objective, two important things were done. Firstly, the extent of man's impact on the environment are shown by giving detailed account of the different components of the city. Secondly the different land-use zones of the city are deciphered through the grouping together of the surface components. The essence of this chapter is to establish a basis for examining the microclimatic patterns of the urban canopy of Ibadan. Quantified land-use associated characteristics are later, in subsequent chapters, related to some microclimatic parameters. Relevant data are obtained from sources like published maps, literature, air photographs, field-work, archival records from the census office and the Ministry of Works and Transport.

4.1 City-Country Dichotomy in Surface Cover

The differences between urban and rural surfaces are introduced by the erection of various cultural features in the former to replace the otherwise predominant soil, vegetation and water in the latter. Features that dominate the city of Ibadan include a mixture of buildings, corrugated iron roof with various degrees of rustiness, concretes, tarmacs, bare ground, refuse, scanty vegetation and water. All these have varying thermal and albedo characteristics. Oguntoyinbo (1970) worked on the variations in surface reflection coefficient (Table 4.1).

Table 4.1

Mean Reflection Coefficient of Urban Surfaces*

Surface	Description of Surface	Reflection Coefficient
1. Corrugated Iron roof	Very rusty	0.10
2. Concrete	Fairly new	0.14
	Surface in Petrol Station	0.15
3. Tarmac	Car Park in Supermarket	0.08
"	Road	0.14
Mean	All	0.12

* After Oguntoyinbo (1970).

With the city having a mean reflection coefficient of 0.12, it could be said that Ibadan has a lower reflection coefficient than the surrounding derived savanna kind of vegetation which has a mean of 0.15.

Crops like cocoa, kolanut, yam and cassava are grown around the city. Measurements over similar cultivated surfaces in the same tropical environment reveal that they have reflection coefficients of 0.19, 0.18, 0.17 and 0.17 respectively. This is an average of about 0.17, which is higher than that of the city.

Generally speaking, plant species like Samanea saman, Delonix regia, Elaeis guineensis, Theobroma cacao, Citrus sp, and Cola sp. were identified as dominant in and around Ibadan. Others include Albizia zygia, Chlorophora excelsa, Sterculia sp., Vitex grandifolia, Celtis sp. and Bamboo sp. (after Akande, personal communication). The rural environment is particularly dominated by arable farmlands. These are exposed grounds at the quarries commonly found around the city. Very few of the rivers and streams around are exposed to direct evaporation because of the protective shade provided by grass and trees. The vegetation cover is subjected to annual destruction through the characteristic bush burning caused by hunters and peasant farmers during the dry season.

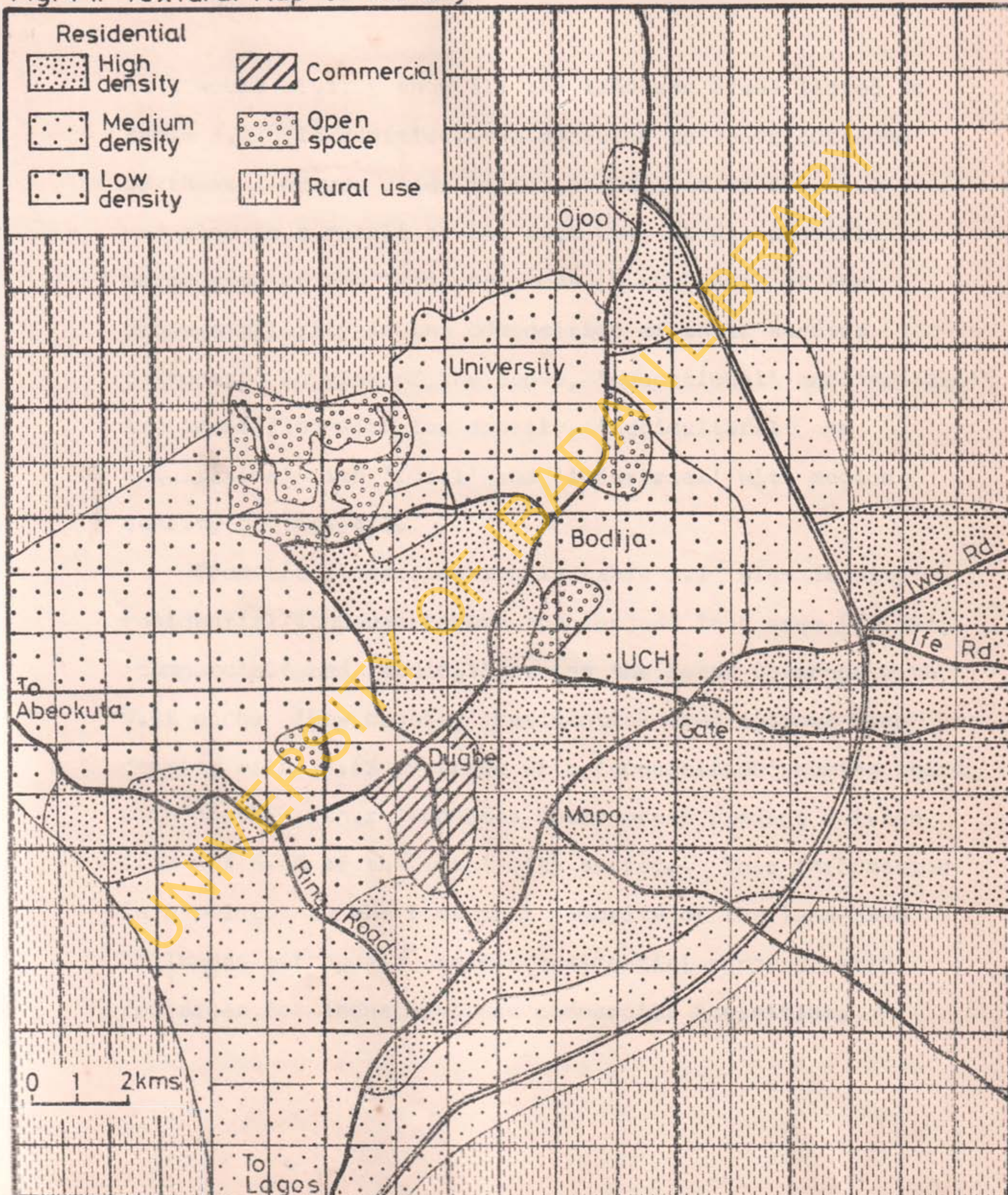
4.2 Land-Use Components Analysis

4.2.a Classification into Land-use Series

The spatial patterns of the conventionally recognized land-uses in Ibadan are difficult to demarcate. This is so because, by its intrinsic nature, the traditional city of Ibadan has a mixture of traditional and modern characteristics. The problem of areal demarcation is further compounded by the seemingly indiscriminate location of amenities all over the city. All these give rise to a pattern characterized by unplanned and planned areas in the core and peripheral regions of the city respectively. The traditional area in the city centre mainly constitutes the high density, heavily built-up commercial region (Fig. 4.1) while the low and medium densities located at the periphery are planned to a greater extent.

Because of the planlessness that characterises most parts of the city, it was difficult to produce a map

Fig. 4·1. Textural Map of the City.



Source: Modified after Ayeni 1982

that would clearly show all the land-use areas listed in table 3.1. In addition, the decision to leave out some of these land-use zones in the production of fig. 4.1 was also as a result of the fact that it was possible to merge some of the land-use areas on the basis of the close similarity in the composition of their surface textures. In view of the above, 'educational' and 'medical' are identified with low density, 'agricultural' and 'acquisition' with 'rural' and 'industrial' with medium density on fig. 4.1.

From the classification in table 3.1 'high density' residential land-use covers the largest land area (29.5%); 'commercial' and 'medical' having the least coverage with 0.4% each. 'Low density' residential area follows high density with 14.6% coverage with 'acquisition' coming third with 12.8%. Other land-uses cover areas ranging between 1.4% and 6.4% of the total city surface. This information is a pointer to the fact that majority of the land-uses in Ibadan metropolis are for residential purposes with few areas for industrial and commercial activities.

4.2.b Components of Different Land-uses

The components identified are as follows: building, water, roads (tarred and untarred), bare ground, paved surface, lawn and trees. These are regarded as vital urban micro-climatic determining factors.

It is clear from figs. 4.2, a-l, that in most of the land-use areas, the areas of proper urban uses are mostly covered with buildings, particularly the residential areas. In this context, areas of 'rural', 'agricultural', 'acquisition' and 'open space' are not regarded as areas of proper urban uses. The spaces occupied by buildings vary from 37.0% in 'educational' area through 43.0% in 'low density' to 50.0%, 54.8% and 60.5% in 'commercial' medium density' and high density' areas respectively. 'Low density' areas have the highest tree cover (34.2%), followed by 'educational' (31.3%), 'medical' (24.0), 'medium density' (18.5%) and 'high density' (13.0%). Areas of non-urban use have immense tree cover. 'Open space' records 96.0%, 'rural' 73.7% and 'acquisition' 58.0%. Lawns also cover appreciable land area of some land-uses, particularly 'agricultural' (51.0%), 'educational' (17.0%) and 'medical' (11.0%). Residential areas have poor lawn coverage while the major commercial area records zero per cent.

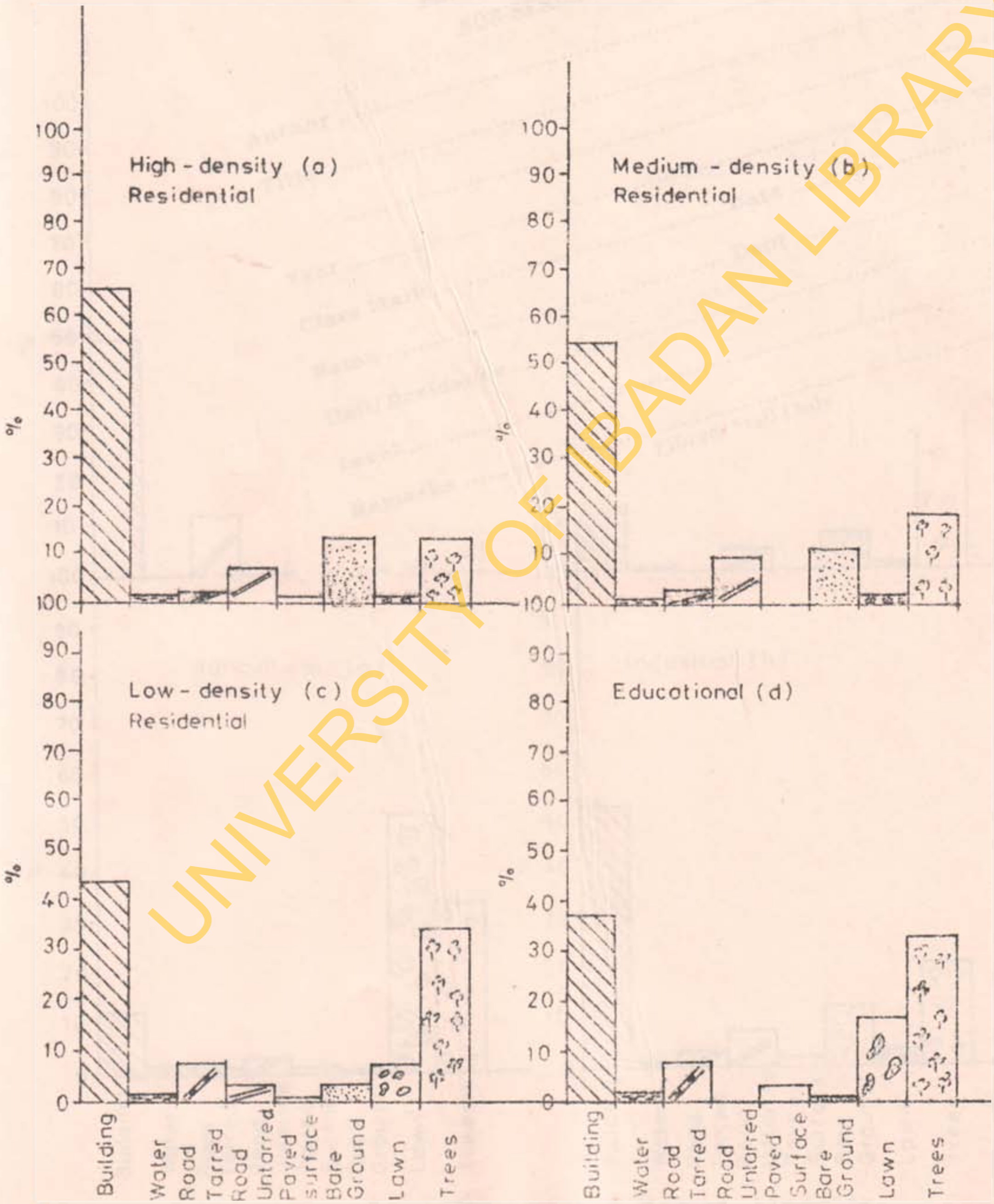


Fig. 4.2: Characteristic textures of different landuses
[Sources :- Aerial photographs and fieldwork (1983)]

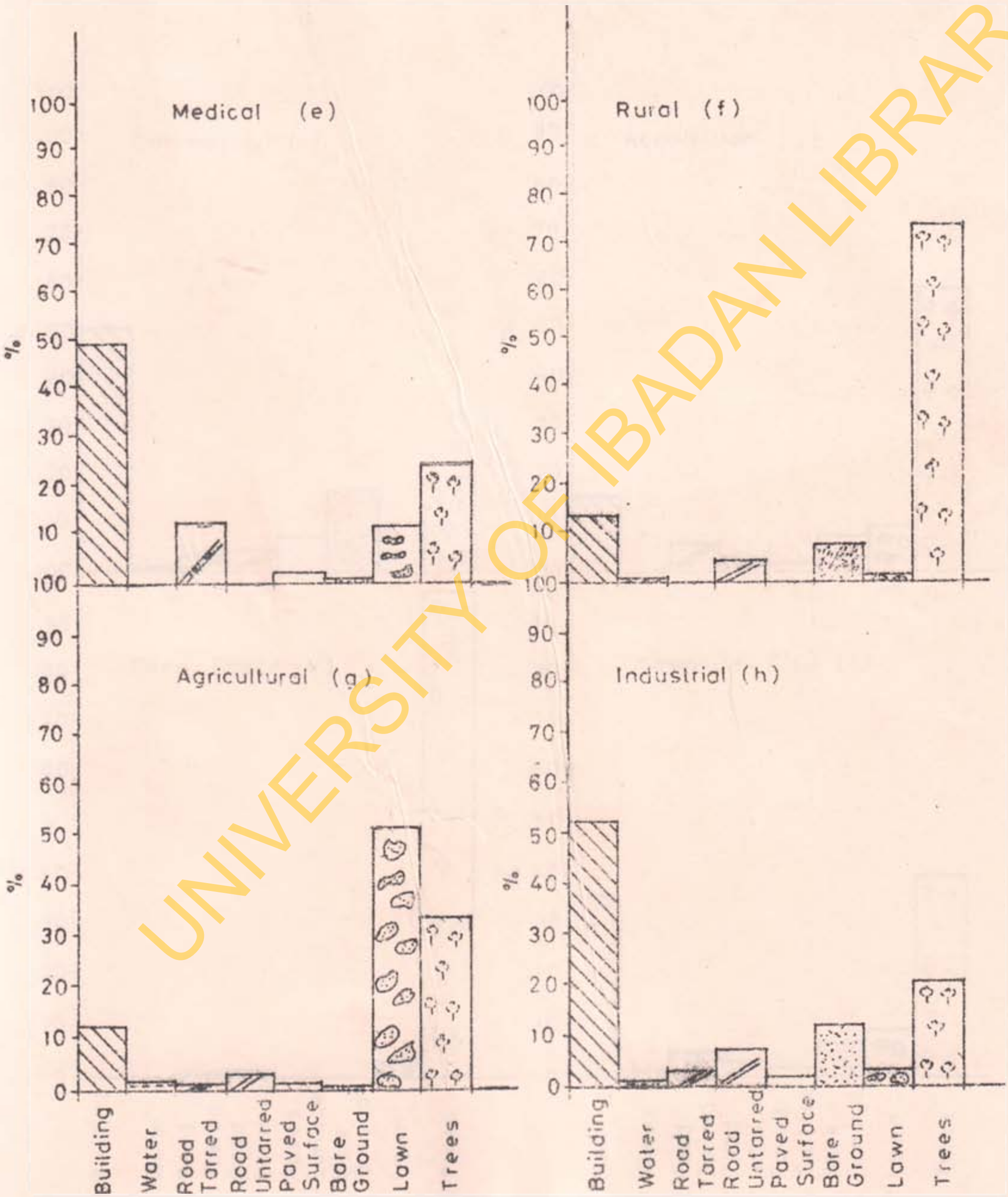


Fig. 4.2: Characteristic textures of different landuses
[Source :- Aerial photographs and fieldwork (1983)]

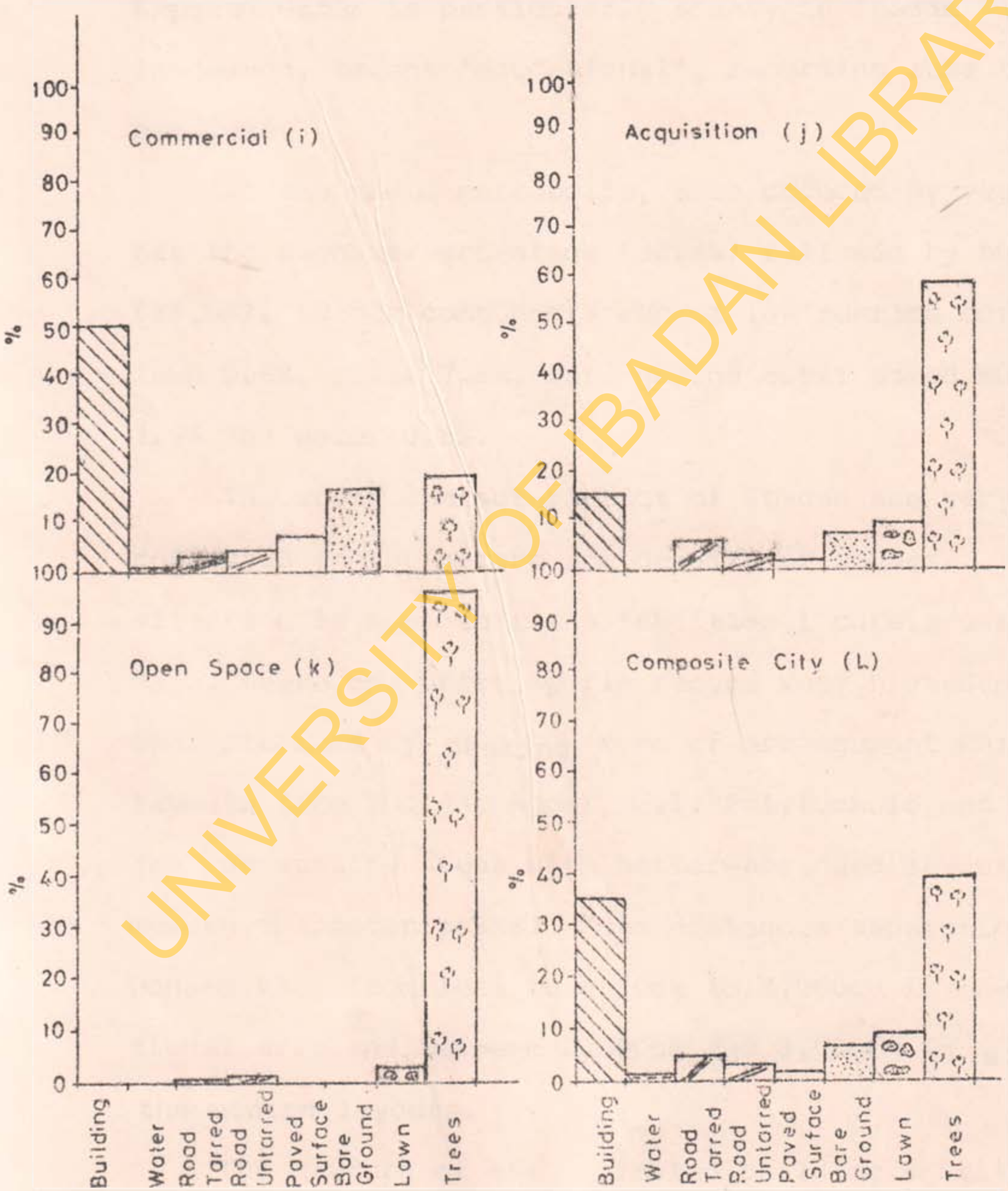


Fig. 4.2: Characteristic textures of different landuses
[Sources:- Aerial photographs and fieldwork (1983)]

Other components: water, roads, paved surface and bare grounds record low percentages of surface coverage. Exposed water is particularly scanty in Ibadan with all land-uses, except 'educational', recording less than two per cent.

In the whole metropolis, area covered by vegetation has the highest percentage (38.4%) followed by buildings (35.0%). Other components record low surface coverage; lawn 9.6%, roads 7.8%, bare ground 6.5%; paved surface 1.9% and water 0.8%.

The urban characteristics of Ibadan are very well reflected in the nature and density of houses. The situation is such that the traditional core areas of Mapo, Beere and Orita Aperin record very high density, characterized by choking form of arrangement while new layouts like Bodija, Agodi, U.I. Polytechnic and Jericho are low density areas with better-arranged layouts and modern characteristics. Mean distances separating the houses vary from less than 50cm to 1,000cm in the traditional area and between 2,000cm and 3,000cm in some of the modern layouts.

The pattern of the estimated building density of Ibadan metropolis, as shown on table 4.2, is such that 'high density' area records average of 8,000 buildings per km^2 which is about twice that of the nearest value, that is the 'medium density' area with 4,500 buildings per km^2.

Table 4.2

Mean Building Densities of Different Land-uses

	Land-use	Building Density (km^{-2})
1.	High Density Residential	8,000
2.	Medium Density Residential	4,500
3.	Low Density Residential	1,600
4.	Educational	1,200
5.	Medical	300
6.	Rural	74
7.	Agricultural	43
8.	Industrial	3,800
9.	Commercial	1,800
10.	Acquisition	800
11.	Open Space	0

Sources: Estimated after Oyelese (1970), and air photograph and fieldwork (1983).

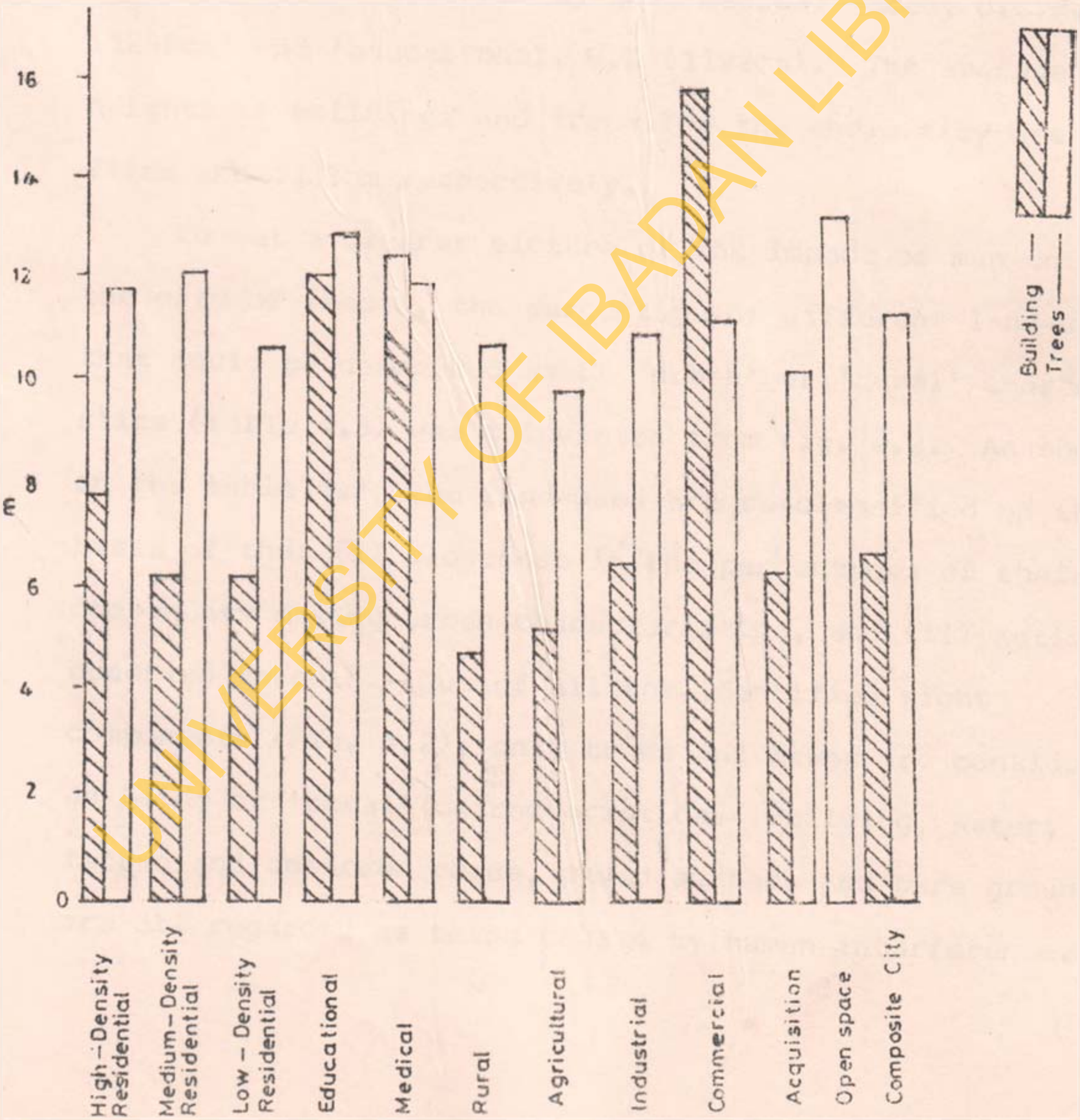


Fig. 4.3: Mean heights buildings and trees (source: Fieldwork 1983)

Heights of buildings, unlike of trees, vary considerably with land-uses (Fig. 4.3). Dugbe, the heartland of the city's commercial activities has the highest mean building height (1581cm) followed by the 'medical' area, U.C.H. (1230cm) and 'educational, U.I (1192cm). The average heights of buildings and trees for the whole city are 743cm and 1133cm respectively.

To get a clearer picture of the impact of man on the city of Ibadan, the percentage of different land-uses that could be described as of 'urban' or 'rural' characteristics (table 4.3) was calculated from fig. 4.2. As shown on the table 4.3, the land-uses are re-classified on the bases of the: (i) closeness in the percentages of their components making urban characteristics, and (ii) activities observed therein. Out of all the identified eight components (Fig. 4.2), only trees and lawns are considered as being of 'rural' characteristics. Building, water, tarred and untarred roads, paved surface and bare ground are all regarded as being caused by human interference.

Table 4.3

Percentage Urban Characteristics of Different Land-Uses

Land-use Classification	% Urban	Rank	Re-classification
1. High Density Residential	84.7	1st	High Density
2. Medium Density Residential	80.0	3rd	Medium Density
3. Low Density Residential	58.6	6th	Low Density
4. Educational	49.9	7th	Low Density
5. Medical	68.0	5th	Low Density
6. Rural	24.1	9th	Rural
7. Agricultural	16.0	10th	Rural
8. Industrial	76.5	4th	Medium Density
9. Commercial	80.5	2nd	Commercial
10. Acquisition	33.0	8th	Rural
11. Open Space	0.8	11th	Open Space
12. Composite City	51.7	-	Urban

'Commercial' and 'high density' residential areas have not been grouped together because: (i) there are taller buildings, less trees and more impervious surface in the former, and (ii) there are intensive daytime activities with higher human population concentration and traffic counts in the commercial area. Areas regarded as 'open spaces' in Ibadan have only trees with few untarred, narrow winding roads passing through therefore they cannot be re-calssified as 'rural'. But 'acquisition' and 'agricultural' areas are re-classified as 'rural' because they are located at the periphery where there are little urban-oriented activities. In addition they have very scanty surface infrastructures and low concentration of human population which could be likened to what obtain in typical rural settlement set-ups. Low population, less surface infrastructures and higher concentration of residential houses, differentiate, both 'low density' and 'medium density' residential areas from the 'high density' residential areas.

An array of the percentage cover of the land-use parameters for each of the land-uses is compared with the aid of correlation coefficient test. The level of significance, at which the test is carried out is 5%, the sample size is eight, and the degree of freedom six. Results of the correlation tests, table 4.4, show that there are significant relationships between components of 'high density', medium density', 'low density', 'industrial' and 'commercial' areas. The relationship between all of the above land-uses and 'rural', 'agricultural', 'acquisition' and 'open space' are not significant. With these results, the extent of the relationships between land-use components in Ibadan could be described as one whereby significant relationships exist between highly urbanized land-uses but insignificant relationships exist between the urbanized and the poorly urbanized land-uses. This test clearly brings out the extent of the differences between urban and rural land-used because of the sharp differences between their surface components.

Table 4.4

Correlation Coefficient Test Results for the Relationship between Land-use Components

High Density Residential	(1)	1.0										
Medium Density Residential	(2)	0.99*	1.00									
Low Density Residential	(3)	0.82*	0.88*	1.00								
Educational	(4)	0.71	0.77	0.96*	1.00							
Medical	(5)	0.88*	0.90*	0.95*	0.99*	1.00						
Rural	(6)	0.18	0.30	0.65	0.61	0.39	1.00					
Agricultural	(7)	-0.02	0.04	0.33	0.55	0.29	0.42	1.00				
Industrial	(8)	0.98*	0.99*	0.91*	0.80*	0.92*	0.36	0.0[illegible]	1.00			
Commercial	(9)	0.97*	0.98*	0.86*	0.74	0.88*	0.32	-0.02	0.98*	1.00		
Acquisition	(10)	0.21	0.33	0.69	0.67	0.42	0.99*	0.52	0.39	0.34	1.00	
Open Space	(11)	0.00	0.13	0.53	0.53	0.74	0.98*	0.46	0.19	0.15	0.92*	1.00
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

* Significant at 5% level

4.3 Surface Roughness Lengths

The impact of urban landscape on airflow is one of the factors to be given priority in a study of urban microclimate. Roughness length is some fraction of the thickness of the surface boundary layer (Nicholas and Lewis, 1970). A knowledge of the roughness lengths of the city throws more light on how its morphology affects winds from different directions. This is to say that all other things being equal, areas with high aerodynamic lengths constitute wind break to the regional winds more than areas with lower roughness lengths. Under the same condition, it could be said that, since this parameter is a function of height and silhuoette area, lower frequency of turbulence would also be recorded in areas with lower roughness lengths.

Roughness length of buildings is computed for winds coming from four different directions. This is so because unlike a tree which has uniform response to winds from different directions, at least the four faces of a building affect winds differently.

In Ibadan, by the nature of the city surface components, particularly the appearance of buildings and trees, there is not much disparity in the pattern of roughness length all over the city. This however varies with land-use zones. Fig. 4.4 shows clearly that 'medical', 'educational' and commercial areas surpass other parts of the city in their building's roughness lengths. In fact, apart from the three areas, roughness length values in other land-use zones are close. Roughness length values for trees are almost uniform throughout the metropolis with the exception of 'agricultural', 'low density' and 'industrial' areas with relatively lower values. Roughness lengths in 'medical', 'educational' and 'open space' areas show higher values than for other areas of the city.

Correlation coefficient tests are carried out between building densities and roughness lengths for the purpose of knowing whether or not the latter is dependent on the former. Data analysed consist of arrays of eleven roughness lengths for all of the original land-uses, versus corresponding building densities. This is done for the roughness lengths of winds from the four directions (table 4.5). The level of significance is 5%, the sample size eleven and the degree of freedom nine.

Results of the analyses on table 4.5 show insignificant relationships all through. This means that surface

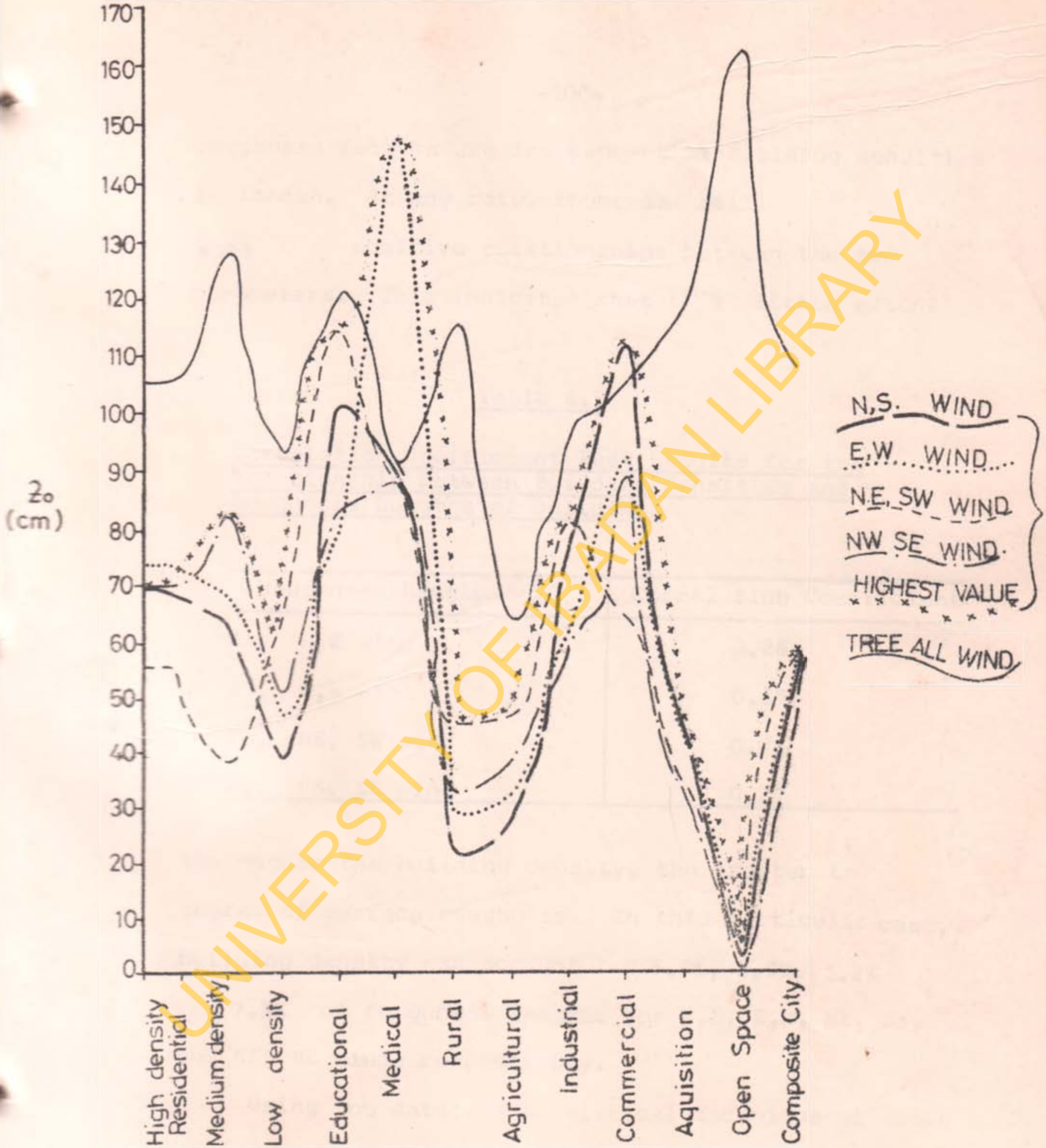


Fig.4·4: Mean Roughness of Buildings and Trees for major Wind Directions

Source: Computed after Lettau's formula (1969). Inputs from Fieldwork (1983).

roughness lengths are independent of building densities in Ibadan. At any rate, there is still some positive relationships between the two parameters. This indicates that to a little extent

Table 4.5

Correlation Coefficient Test Results for the Relationship Between Building Densities and Roughness Lengths of Buildings

Roughness Length	Correlation Coefficient
Zo, N,S wind	0.26
Zo, E,W wind	0.17
Zo, NE, SW wind	0.11
Zo, NE, SE wind	0.27

the higher the building density, the greater the degree of surface roughness. In this particular case, building density can account for 6.8%, 2.9%, 1.2% and 7.3% of roughness lengths for N,S, E,W, NE, SW, and NE, SE winds respectively.

Using the data and statistical technique as above other tests are carried out between roughness lengths and building heights. Results, as shown in table 4.6, indicate that there is a highly positive relationship between roughness lengths for all winds and building heights. This means that areas with tall buildings exhibit high degree of surface roughness in Ibadan.

Table 4.6

Correlation Coefficient Test Results for the Relationship Between Building Heights and Building Roughness Lengths

Roughness Length	Correlation Coefficient
Zo, N,S wind	0.70
Zo, E,W wind	0.84
Zo, NE, SW wind	0.85
Zo, NW, SE wind	0.60

In other words, the higher the building the more the surface roughness. Building height can be said to account for 49.0%, 70.2%, 72.3% and 36.0% of roughness lengths for NE, E.W, NE, SW, and NE, SE winds respectively.

4.4 Atmospheric Pollution in Ibadan

Considerable amounts of gaseous pollutants are suspended in the lower atmosphere in Ibadan. From the work of Oluwande (1977, 1979), it is clear that there are urban-rural differences in the concentration of sulphur dioxide and carbon monoxide in the atmosphere, with the highest concentration in the urban areas being more than three hundred times the highest in rural areas. Table 4.7 shows a typical variation in sulphur dioxide and carbon monoxide at the rural and urban centres.

Table 4.7

Typical Daily Variations of Sulphur dioxide and Carbon monoxide Concentration at two Sampling Stations in Ibadan (Unit = ppm)*

Time	Sulphur dioxide		Carbon monoxide	
	Urban	Rural	Urban	Rural
1200 - 1500	0.64	0.002	57	1.6
1500 - 1800	0.34	0.001	10	1.2
1800 - 2100	0.23	0.001	12	1.2
2100 - 1000	0.06	0.000	3	1.0
1000 - 0300	0.01	0.000	1.5	0
0300 - 0600	0.05	0.000	5	0
0600 - 0900	0.10	0.001	5	1.2
0900 - 1200	0.31	0.001	19	1.5

* After Oluwande (1977)

It is clear from the table that higher amounts of pollutants exist between 1200 - 1500 hrs of GMT in the afternoon than other times of the day. There is a general increase in pollutants from morning to afternoon, and a decrease towards evening. The least concentration is at night. There are urban-rural differences and the temporal variations in traffic concentrations. There are more automobiles in the city than the rural area. There is a higher concentration of vehicles in the roads during the afternoon hours than at other times of the day.

Onianwan and Egunyomi (1983) also used the occurrence of trace metal levels in some mosses in Nigeria to study the level of atmospheric pollution in Ibadan. The study revealed that lead (pb) values in mosses collected in rural areas were significantly lower than those of mosses in the city centre which has a high traffic density (Oguntoyinbo, 1984). Mean values are as high as 157.2 $mg.g^{-1}$ in the city while values in the rural areas (Botanical Garden, University of Ibadan) varied between 13 and 30 $mg.g^{-1}$.

4.5 The Microgeography of Ibadan

The impact of man is more felt at the city centre of Ibadan than the suburb. The traditional core area of the city centre is characterised by narrow, winding roads and close concentration of buildings. The 'low density' residential area is limited to the new layout in the suburb while other land-use categories occur in patches all over the city.

Land-use attributes like water, roads, paved surface and bare grounds do not vary much from one land-use to the other. Using building cover, tarred and untarred roads, paved surface and bare ground as the bases, it has been possible to partition the land-uses into the two categories of "non-urban" and "urban" uses with 'rural', 'agricultural', 'acquisition' and 'open space' areas constituting the former and the remaining land-use types making up the latter. Areas of 'non-urban' uses are generally noted for higher concentration of trees and lawns and lower concentration of buildings and roads.

North-south and east-west traverse views of the city further throw more light on the condition of surface characteristics. Figs. 4.5 and 4.6 show that there is

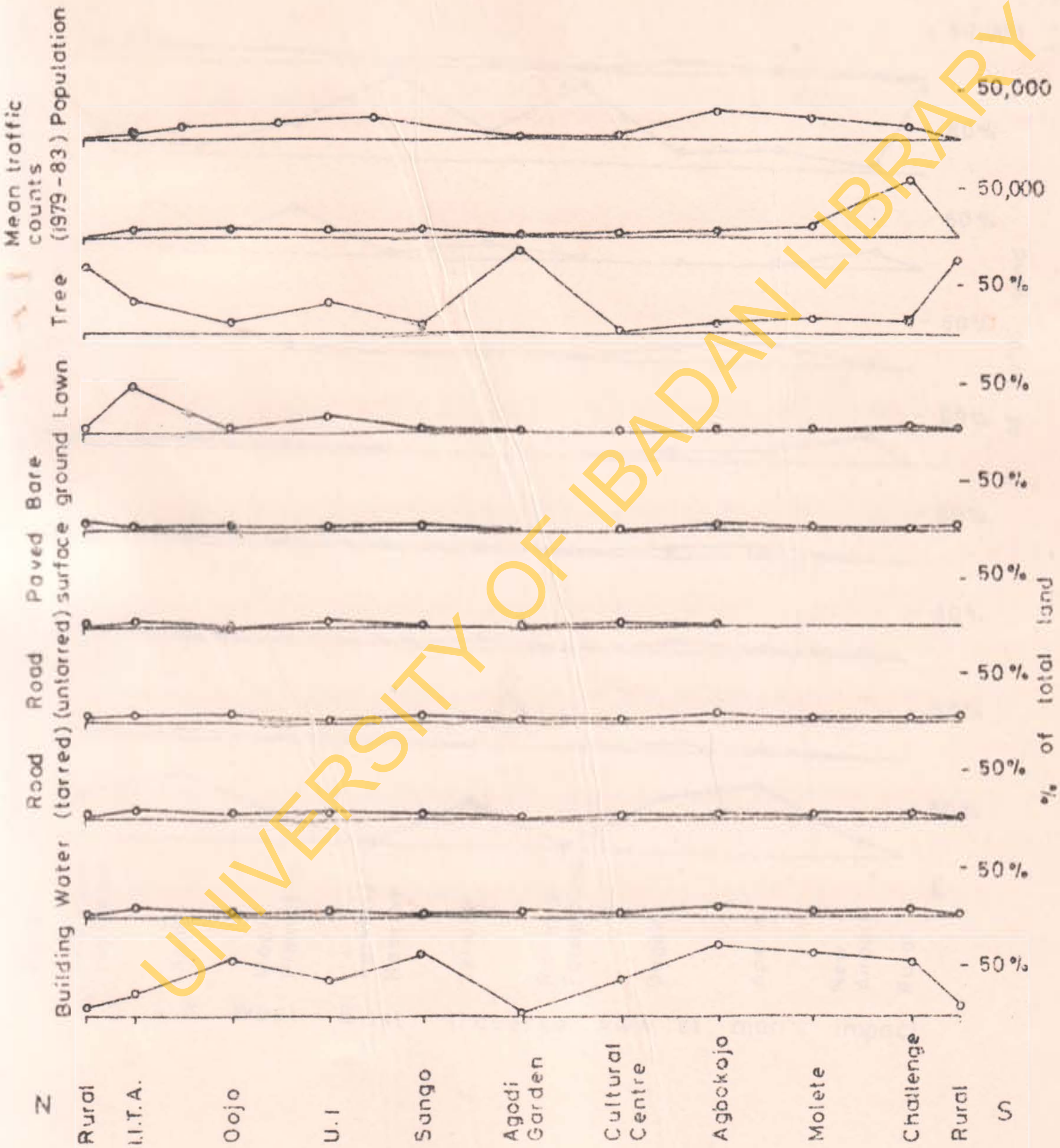


Fig. 4.5: North - South traverse view of man's impact

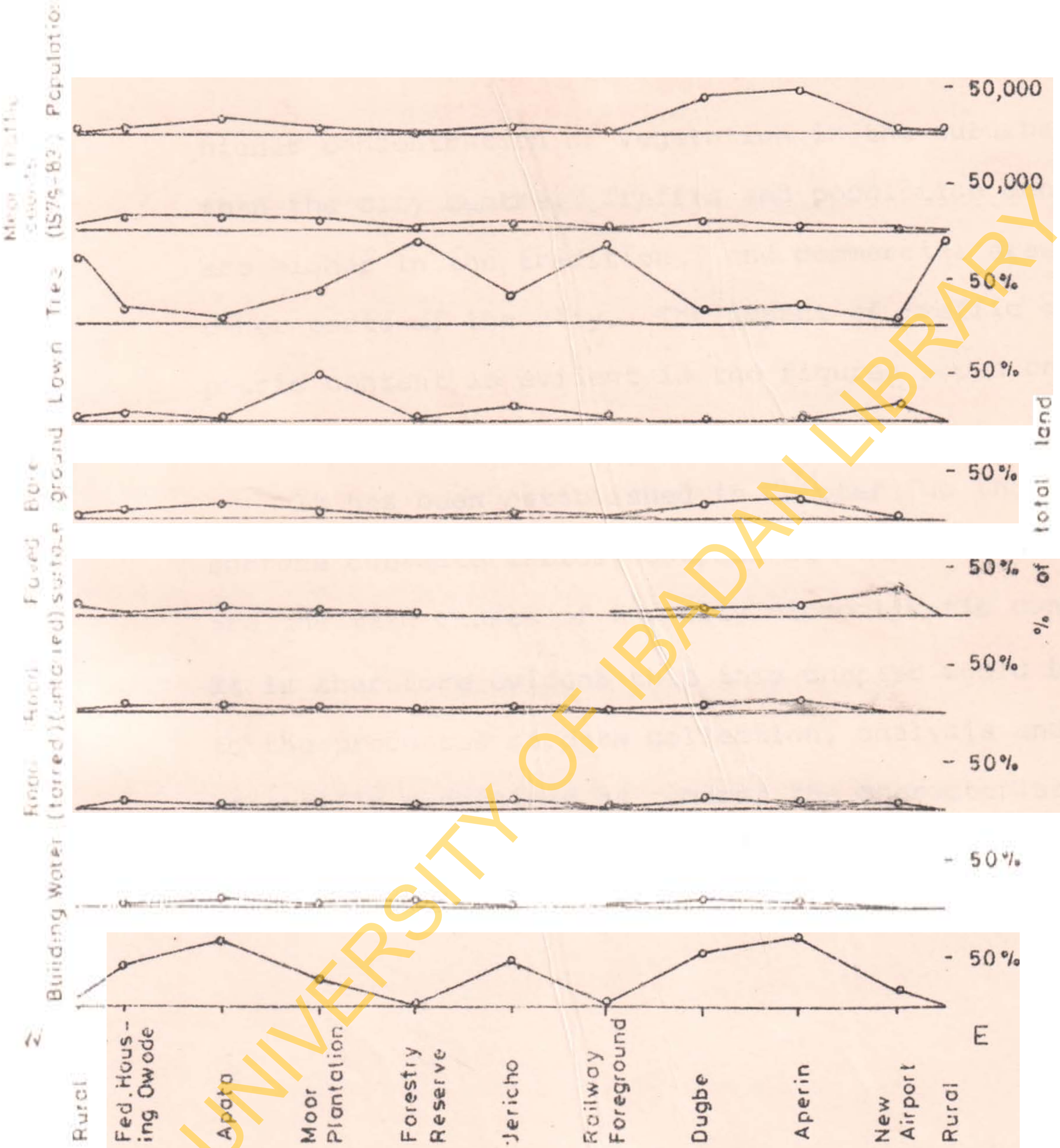


Fig. 4.6 : West - East traverse view of man's impact

higher concentration of vegetation in the suburban area than the city centre. Traffic and population densities are higher in the traditional and commercial areas than other parts of the city. The impact of traffic on atmospheric content is evident in the figures shown on table 4.6.

It has been established in Chapter Two that urban surface characteristics, coupled with human activities, are the main causes of the city microclimatic conditions. It is therefore evident that this chapter would be vital to the processes of data collection, analysis and scientific deductions as regards the characteristics of the microclimates within the complex urban canopy of Ibadan.

CHAPTER 5

5.0 CHARACTERISTICS OF ENERGY DISTRIBUTION WITHIN THE URBAN CANOPY

It was established in Chapter Two that the energy coming from the sun is distributed and utilized in various ways at the earth-atmosphere interfaces because of the heterogeneous nature of the earth's surface and the atmospheric contents. It has also been made clear, in the same chapter, that it is the diverse utility of solar energy that forms the basis of microclimates. The analysis of surface texture of Ibadan, in the preceding chapter, shows both the intra-city variation and the city-country differences in surface components, population concentration and various human activities. All of these contribute to cause appreciable spatial and temporal variations in the microclimatic characteristics within the urban canopy of Ibadan. It is the condition of surface disposition of energy and the pattern of its subsequent utilization that this chapter is set to establish.

In order to understand the fundamental cause of any microclimatic pattern, it is essential to analyse the characteristics of interface disposition and utilization of the solar energy. This would mean an analysis of both the radiation and energy budgets components in relation to the physical surface textural characteristics. It is in the light of these that the spatial, diurnal and seasonal patterns of the radiation and energy budgets equations are examined in this chapter.

Data analysed here have come from two sources. (1) the six automobile transects carried out during the wet and the dry seasons, and (2) , the full-day (0600 - 1800 hrs GMT) monthly recordings of these various components at twenty spots, to cover the recognized land-uses, all over the city (Fig. 3.1). Twelve days in each month were spent collecting the second category of data. Information from these recordings is used in producing the maps showing the spatial patterns of components under consideration, on diurnal and seasonal bases. To produce the maps, the weighted average method, described in Chapter Three, was employed. Analyses begin in this chapter with a look at the patterns of global radiation (Q + q) because it is the initial source of energy from the sun. This is followed by the description of albedo (a) patterns and then net radiation (Rn). The net long wave radiation which was not directly measured is then described. Next, a look is taken into how net radiation is utilized, in other words, the latent (LE) and sensible (H) fluxes of heat, for the wet season only since the Bowen ratio employed in calculating it is only applicable on wet days. The chapter ends with a general look at the characteristics of radiation and energy budgets within the urban canopy in Ibadan.

The data analysed for the radiation and energy budget components are those collected on clear days, so that the urban-rural dichotomy could easily emerge.

5.1 Radiation Budget Characteristics

The impact of various components of an urban surface and its atmospheric contents on the components of radiation budget (eqn 2.1) leads to the resultant alteration of the net radiation. This impact begins from the time the incoming global radiation enters the urban boundary layer. This short wave global radiation undergoes a great deal of reflection, absorption and scattered within the urban atmosphere. Its remaining part reaches the surface to be partly reflected, absorbed and re-emitted in the form of terrestrial long wave. The remaining portion is now the net radiation.

5

5.1.a Global Radiation

Global radiation could be aptly described as the energy coming from the sun (Brunt, 1932). The analyses of the spatial, seasonal and temporal patterns of global radiation reveal a general decrease towards the urban centre from the rural area throughout the period under consideration (Figs. 5.1 - 5.6). A number of reasons are responsible for this.

Firstly, the urban atmosphere contains more pollutants, particularly oxides of sulphur, carbon and nitrogen than the rural atmosphere (see table 4.6). In fact these pollutants constitute the urban plume within the boundary layer (Fig. 2.2), which is absent in the rural environment. These pollutants scatter, diffuse and even absorb some portions of the incoming solar radiation.

Secondly, the urban canopy atmospheric view factor is reduced by the tall buildings (Fig. 2.5) therefore reducing the energy received within the urban canopy. All these factors, put together, lead to considerable spatial diurnal and seasonal variations in global radiation.

Fig. 5·1 Global Radiation during the Wet Season (Ly.min-1)

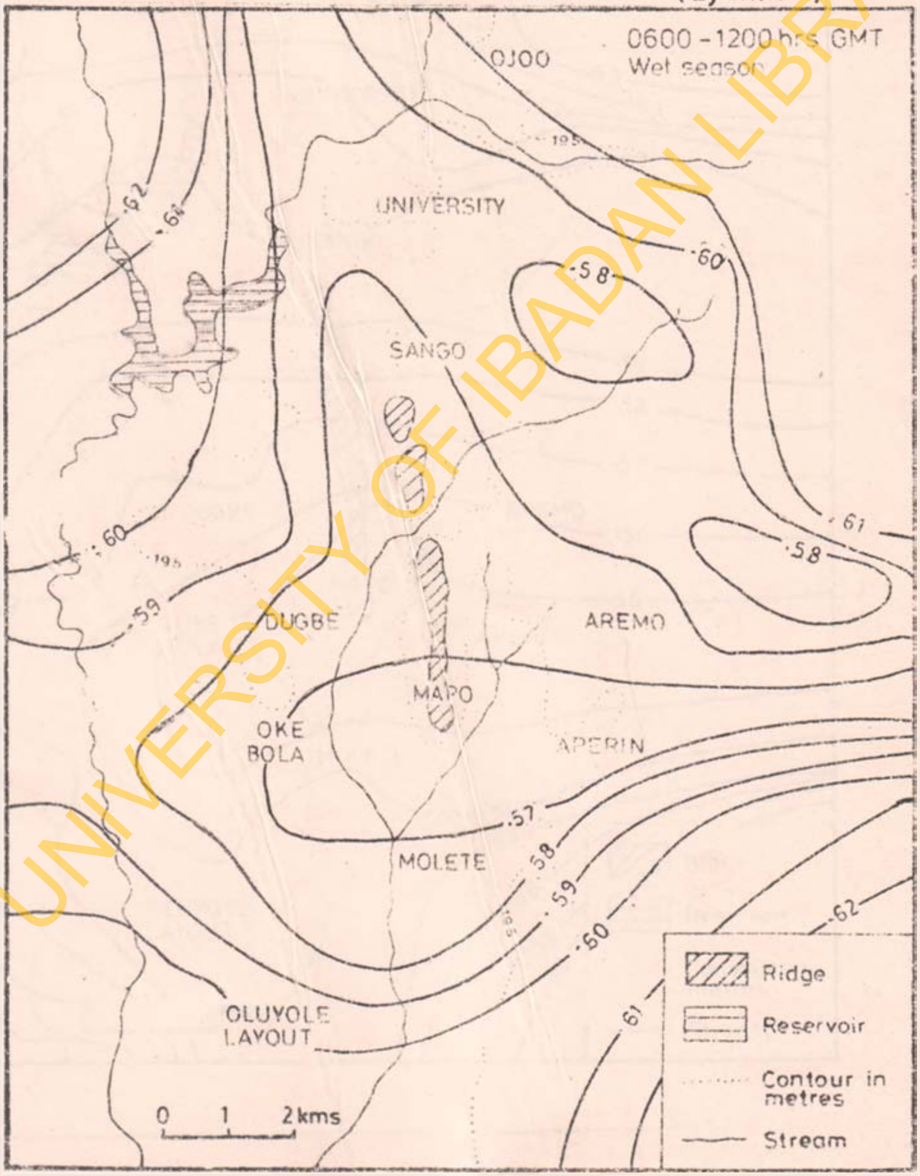


Fig. 5· 2 Global Radiation during the Wet Season (Ly. min -I)

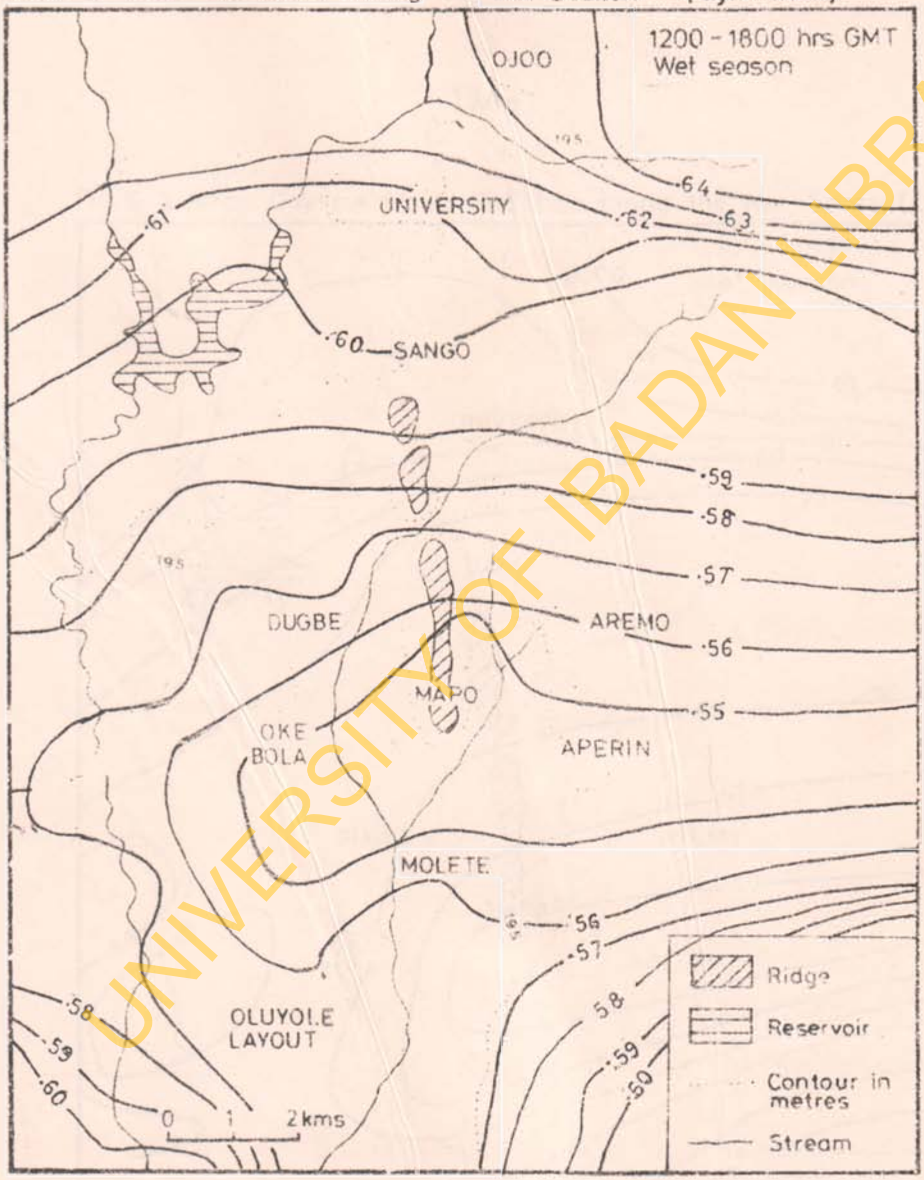


Fig. 5. 3 Mean Daytime Global Radiation during the Wet Season (Ly.min-!)

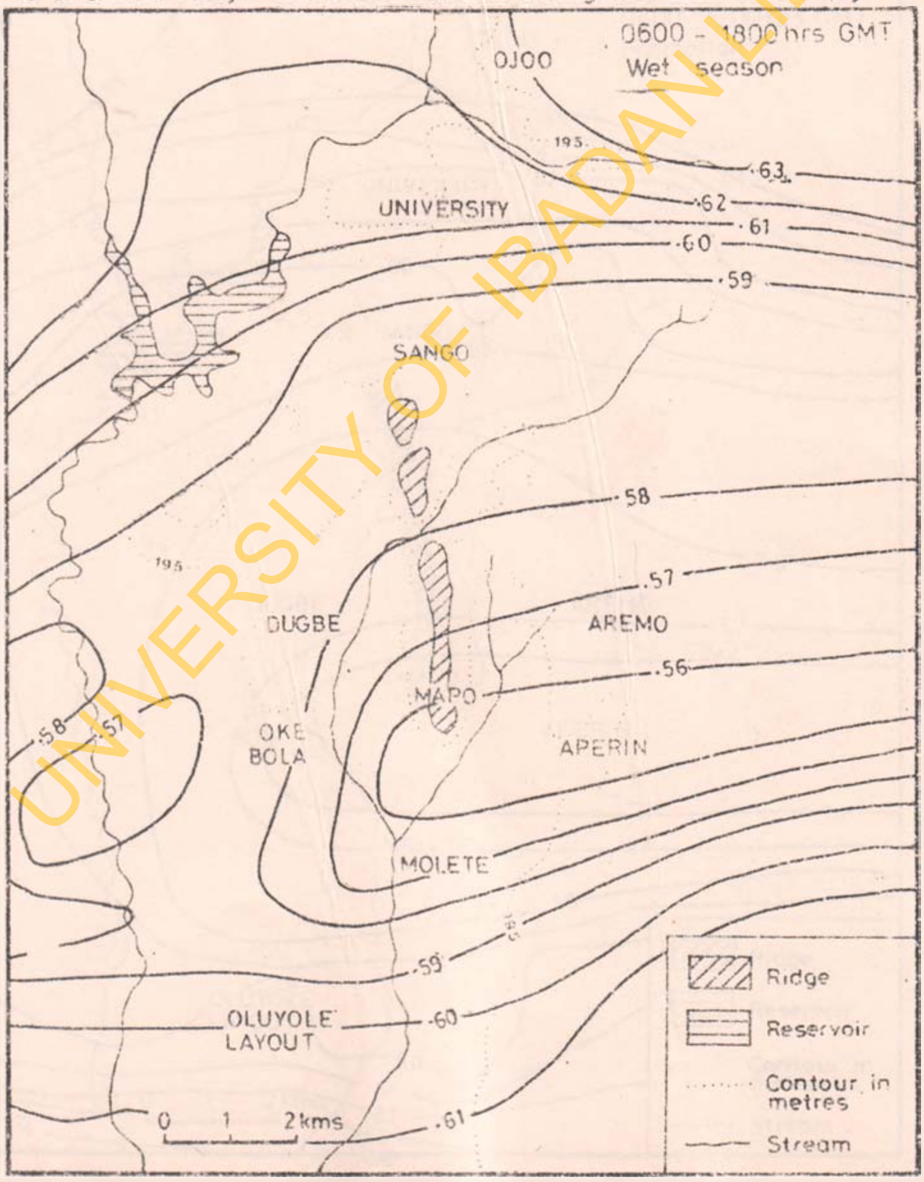


Fig. 5· 4 Global Radiation during the Harmattan (Ly.min-1)

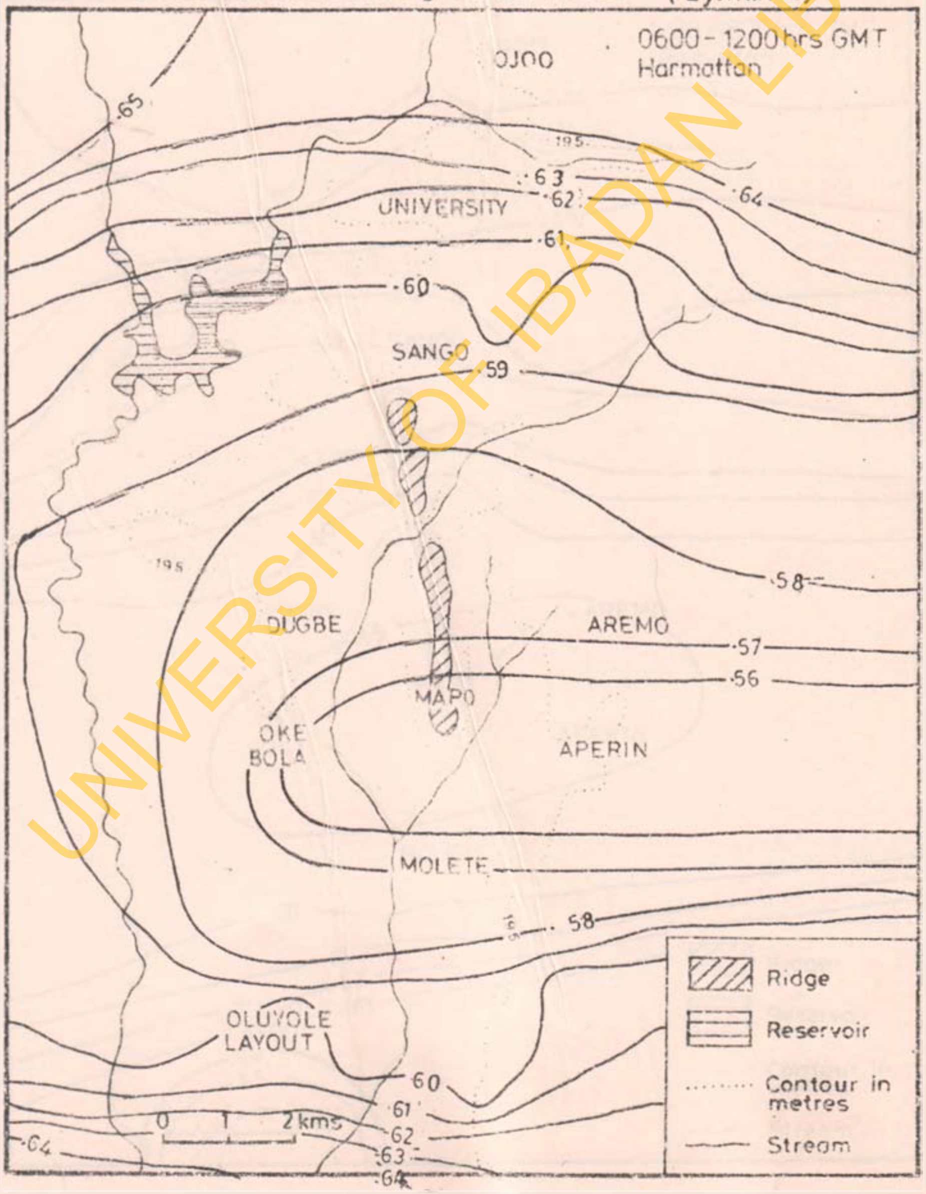


Fig. 5· 5 Global Radiation during the Harmattan (Ly. min-1)

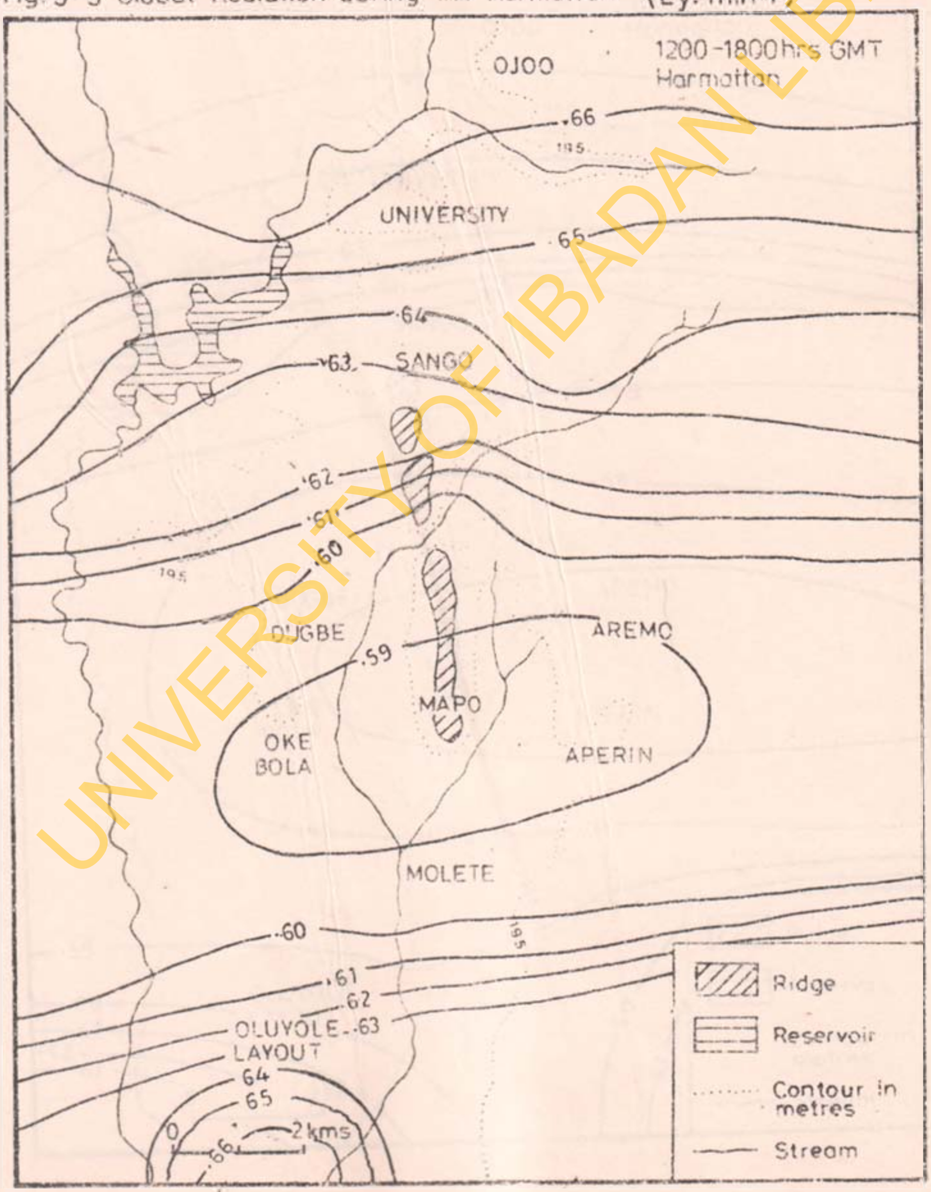
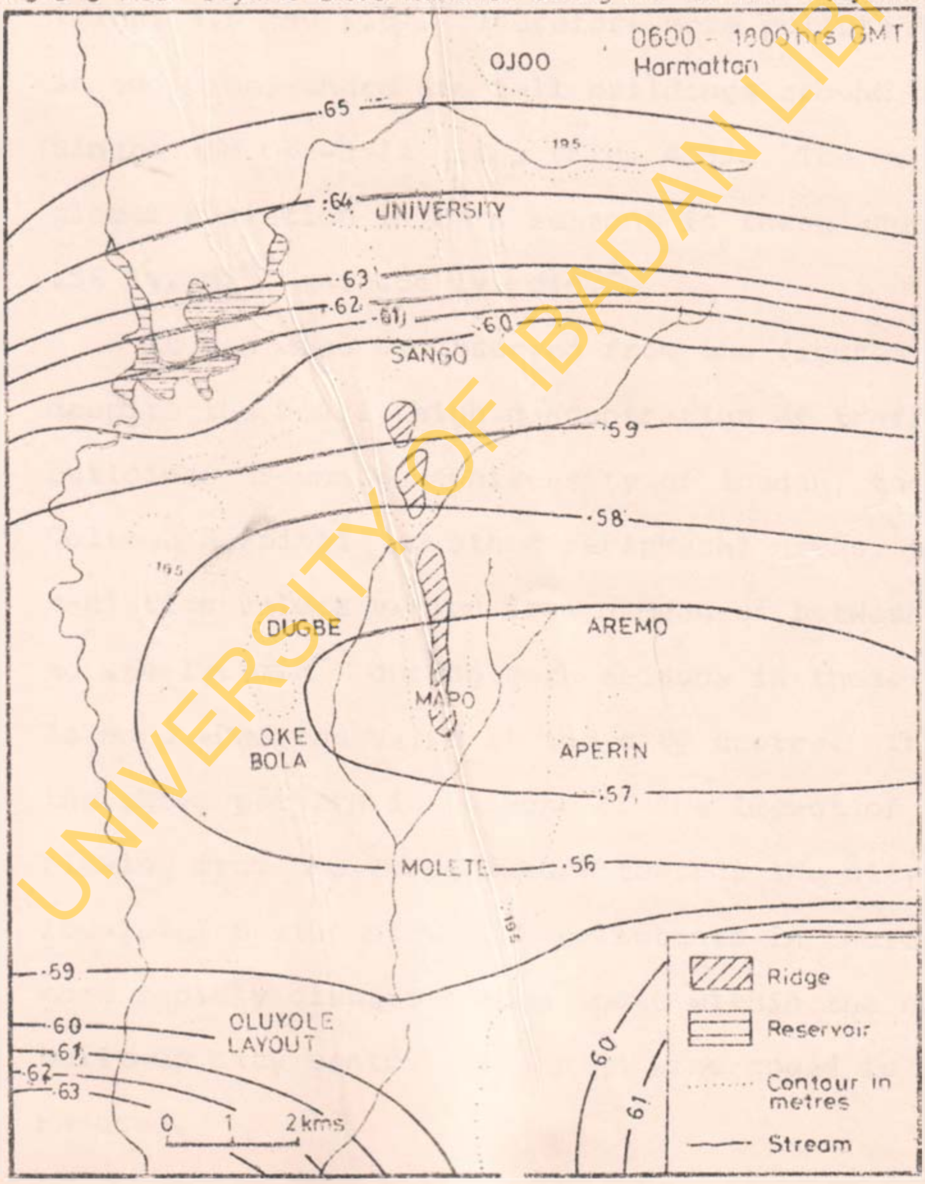


Fig. 5·6 Mean Daytime Global Radiation during the Harmattan (Ly.min-1)



It can be generally observed, from Figs. 5.1 - 5.6, that the least amount of global radiation is received around Dugbe, Oke-Bola, Adamasingba, Mapo and Orita Aperin. These are areas with the highest concentration of traffic (Figs. 4.5 and 4.6). Therefore more pollutants are expected. In addition, there are tall buildings around Dugbe, Adamasingba and Oke-Bola areas (Fig. 4.3). The mean amount of global radiation in both seasons in these areas was between .56 ly. mi^{-1} and .64 ly. min^{-1}.

It can also be observed from the figures that, despite the fairly high concentration of traffic and tall buildings around the University of Ibadan, the University College Hospital and other peripheral areas, the global radiation values varied from a mean of between .61 ly. min^{-1} to .64 ly. min^{-1} during both seasons in these areas, which is more than the value at the city centre. The reason for the above pattern is because of the impact of the wind blowing from the rural suburb towards the city on the low-level pollutants. The pollutants in these areas are more rapidly dispersed than those within the heavily built-up city centre where high wind speed is generally reduced.

Average amount of global radiation in the rural environs during the period under consideration ranges between .62 ly. min^{-1} and .64 ly. min^{-1}. This is about 14% more than the values at the city centre.

There is not much change in the spatial pattern of global radiation between morning and afternoon hours. There is a general increase in the amount of global radiation over the city in the afternoon hours. The relatively lower value of global radiation at the urban centre, compared with the rural area, increased in the afternoon. Three reasons are suggested for these spatial and temporal variations.

Firstly, there is the general increase in atmospheric pollutants over the city (see table 4.6) because the increases in pollutants from automobiles and industrial activities would cause the warding off of global radiation. Secondly, general decrease in windspeed, results in the day time divergence of more pollutants from the periphery to the urban centre. Thirdly, by afternoon hours, buildings and concretes are still being heated up, compared with the rural soils and vegetation that are in most cases fully heated up because of their low absorptive and storage capacities. This would mean a continued absorption of the in-coming global radiation in the city by tall buildings which also prevents some of the radiation from reaching the surface (see Fig. 2.5), therefore leading to a greater decrease in the amount of global radiation received within the urban canopy by afternoon hours.

The diurnal pattern during the harmattan season is different from that during the wet season. The pattern is such that the urban decrease in global radiation reduces from 16.7% in the morning to 11.8% in the afternoon hours. This is because according to Ayoade (1980) there is a decrease in the regional wind velocity during the harmattan periods, which causes a reduction in the movement of pollutants to the city by the rural winds, leading to less concentration of artificial pollutants and therefore less impact on the global radiation during afternoon hours. This factor is important because there are more pollutants in the afternoon hours (see table 4.7).

Seasonal changes in the regional climate influence urban-rural differences in global radiation condition. The situation is one whereby the decrease at the urban centre compared with the rural surrounding is about 12.5%

during the wet season and about 14.0% during the harmattan season. Three reasons are responsible for this.

Firstly, the turbulent condition observed during the wet season allows for more mixing of both the urban and the rural environments therefore making urban-rural differences in atmospheric conditions during the wet season not glaring enough. Secondly, the more cloudy condition during the wet season prevents the uniform heating of both surfaces because of the non-uniformity in the receipt of global radiation. Thirdly, the reduction in the low-level pollutants during the wet season by the precipitating effect of rainfall indirectly causes a reduction in the impact of pollutants on global radiation during this season.

5.1.b <u>Albedo</u>

Albedo is the surface reflectivity of energy. According to WMO (1963), it is the ratio of the global radiation from the sun and sky reflected by the surface to that incident upon it. Knowing the albedo characteristics of the urban environment is important because albedo forms part of the components of the radiation budget equation, which is used in describing the surface disposition of energy. It therefore helps in the detailed description of how surface net radiation is obtained.

It could be observed from Figs. 5.7 to 5.12 that there are spatial, diurnal and seasonal variations in albedo characteristics over Ibadan and its environs. The spatial pattern is in such a way that the albedo within the canopy increases from the city centre to the rural suburbs. It increases from a mean of between 8% and 10% around Dugbe, Adamasingba, Oke-Ado, Mapo and Orita Aperin areas to between 14% and 15% in the surrounding rural environments during the wet season. The albedo values increase during the harmattan season. The means show a variation from around 12% at the city centre to 18% at the surrounding rural area.

There is a decrease in albedo towards the city centre because of the following reasons:

(1) There are more of the dark, dull and irregular surfaces which reduce the albedo towards the city centre. This, as established in Chapter Four, is as a result of the replacement of rural vegetation that has higher reflection coefficients,

Fig. 5·7 Albedo during the Wet Season(%)

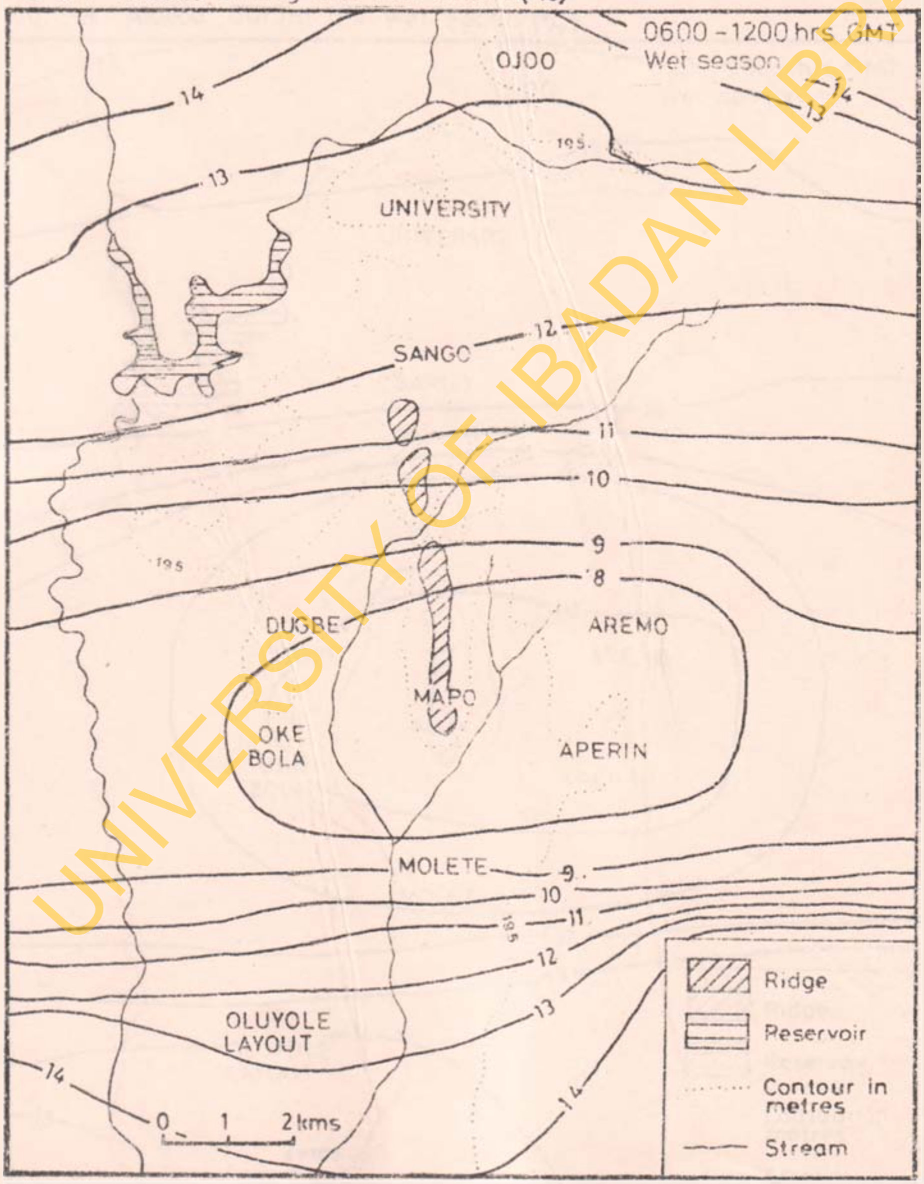


Fig. 5·8 **Albedo** during the Wet Season(%)

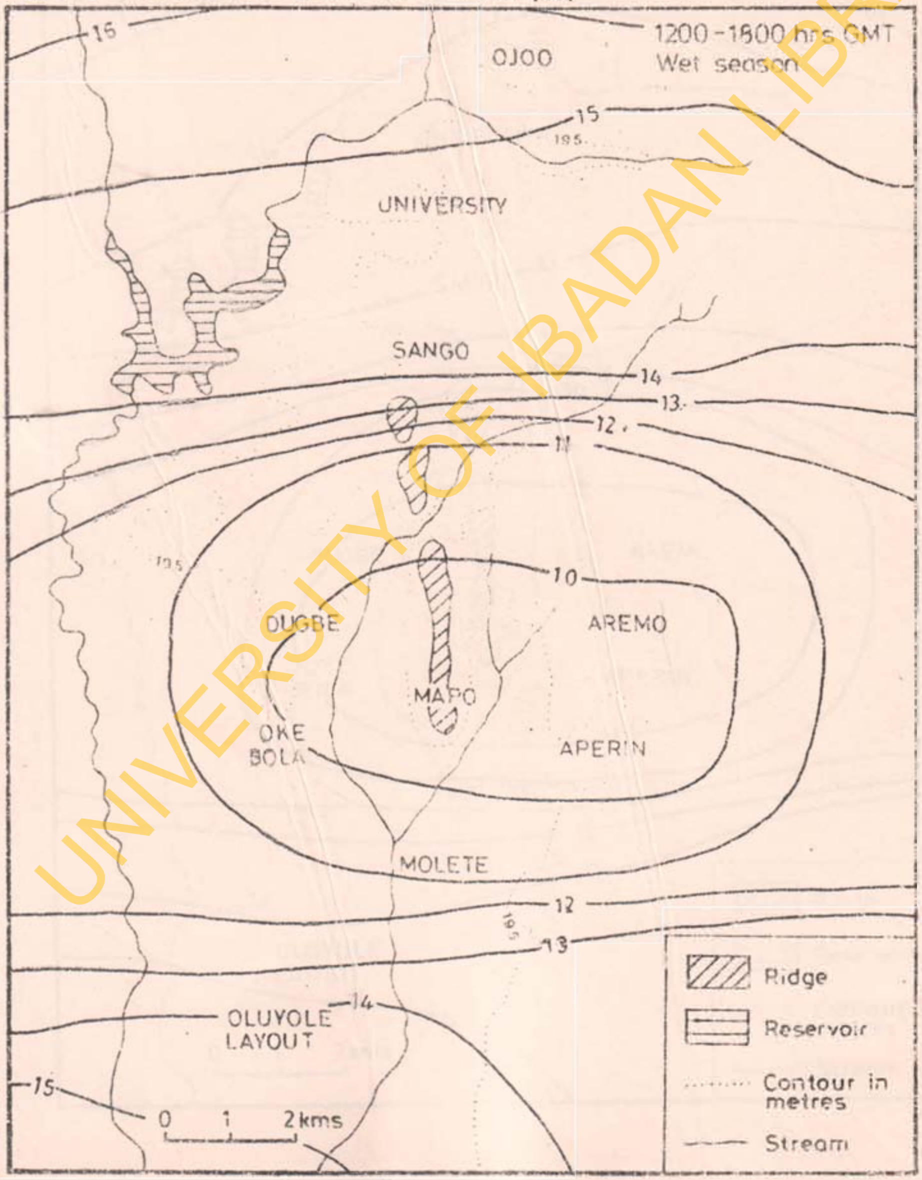
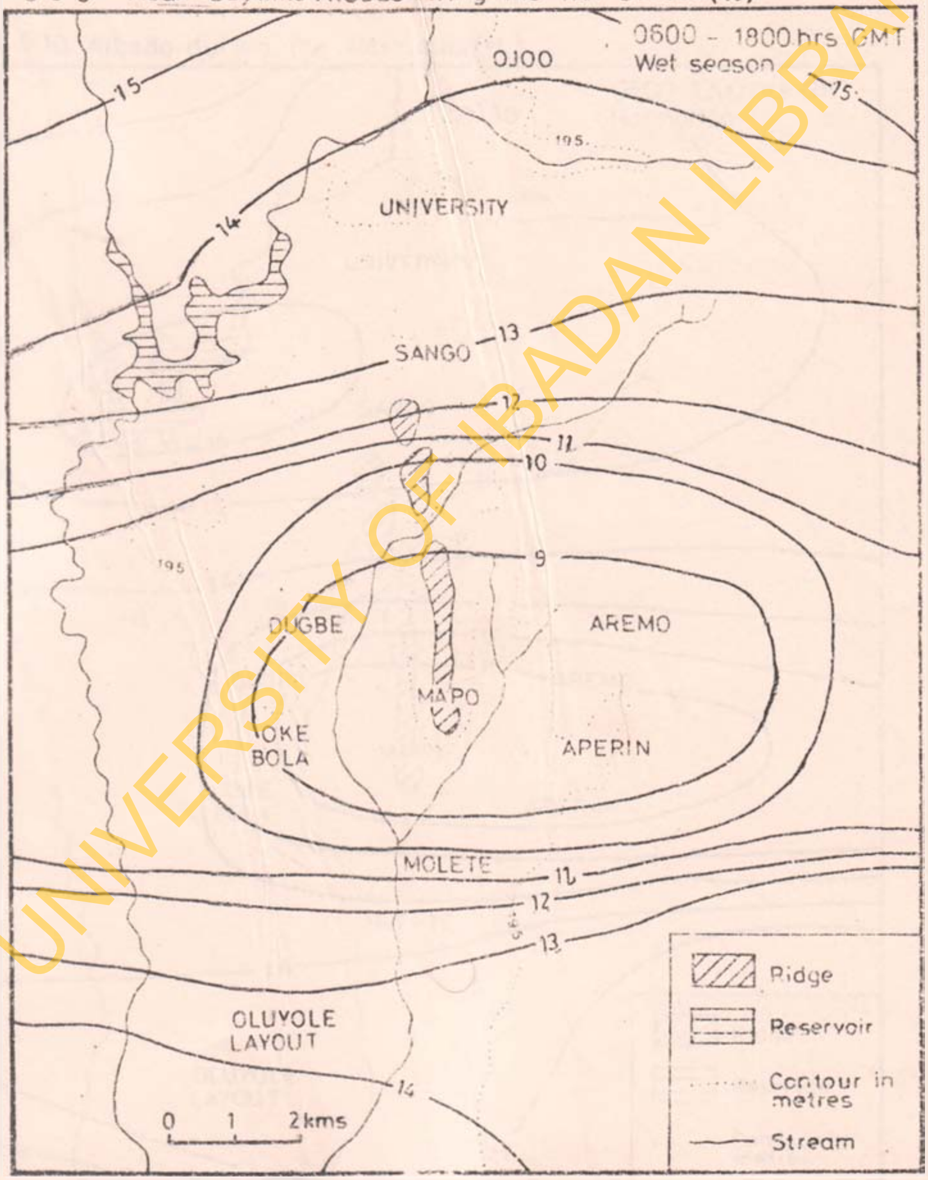


Fig. 5·9 Mean Daytime Albedo during the Wet Season (%)



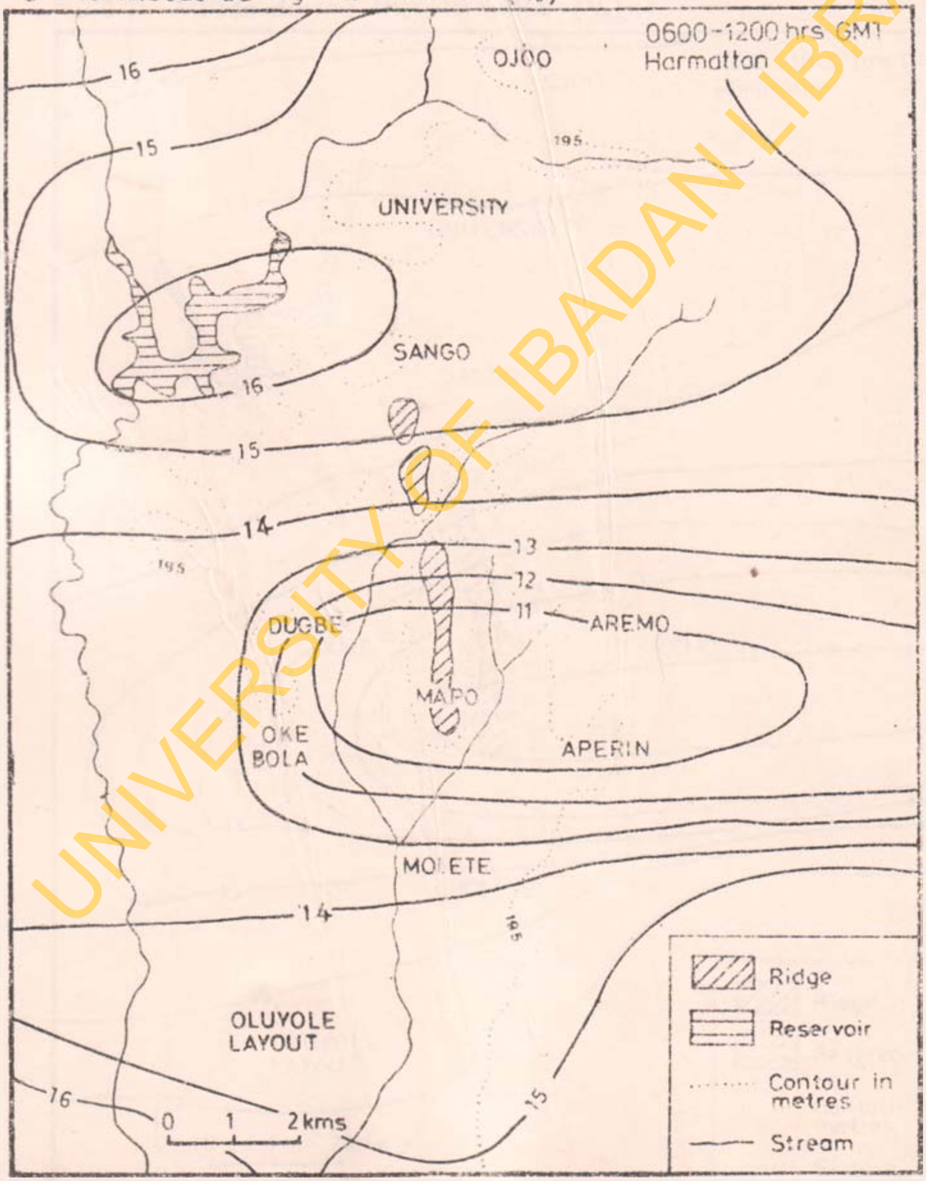


Fig. 5·10 **Albedo during the Harmattan(%)**

Fig. 5·11 Albedo during the Harmattan (%)

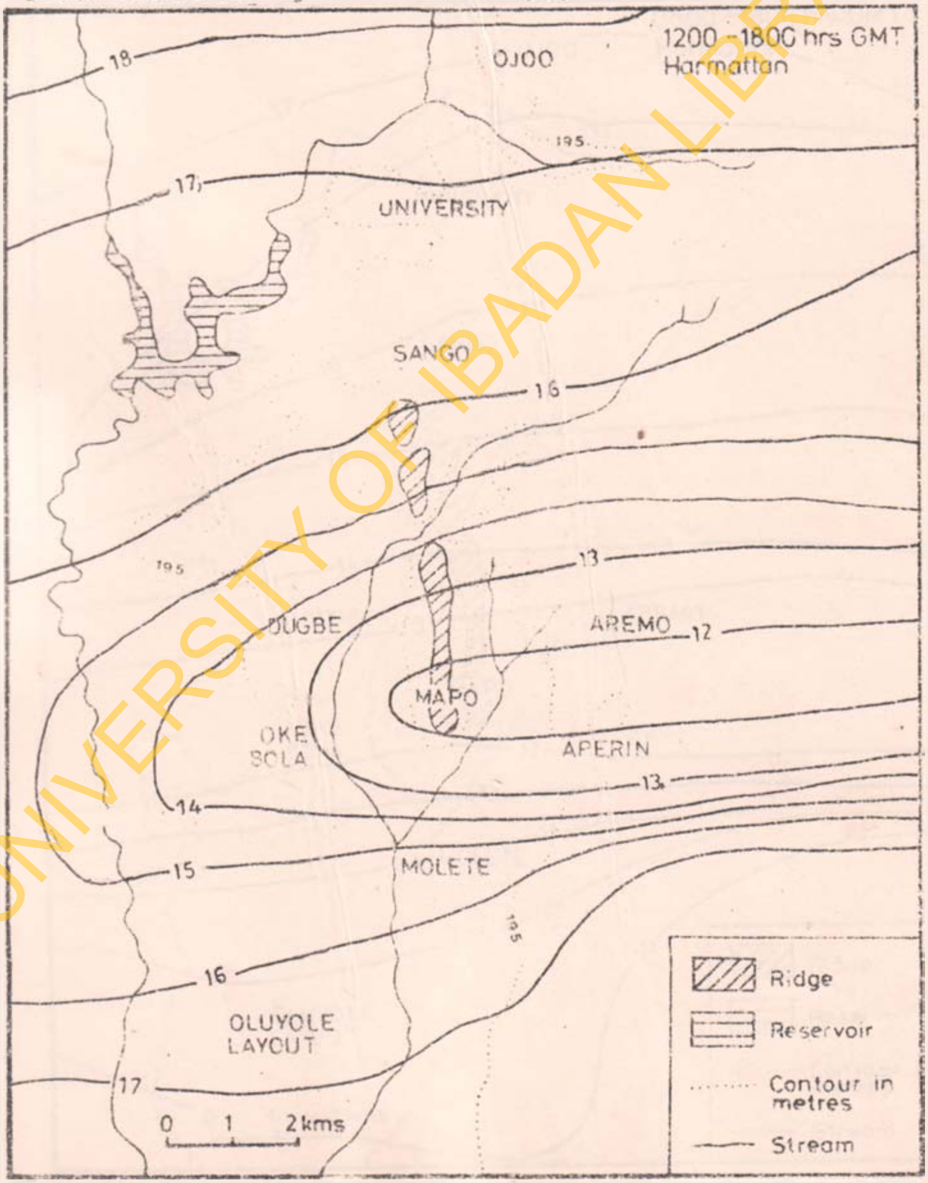
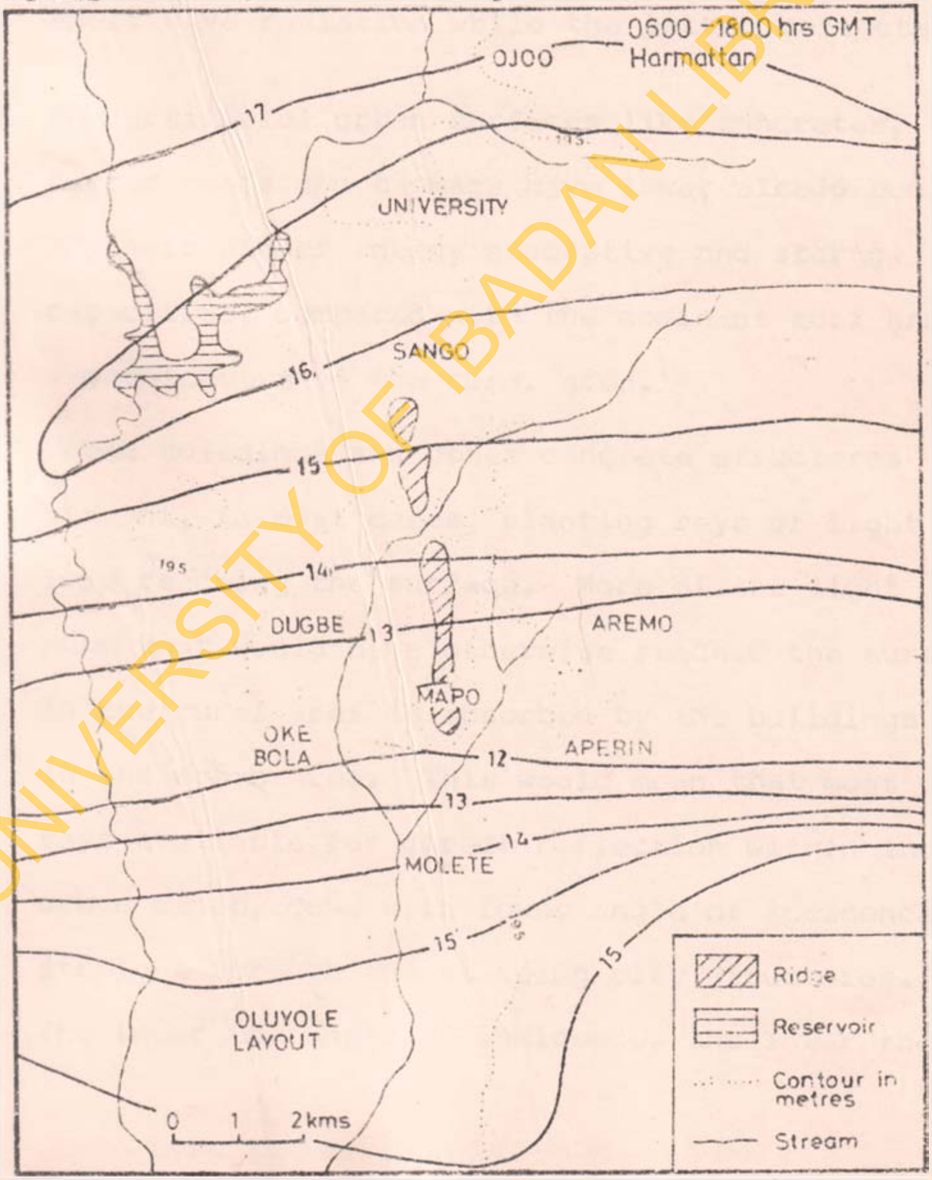


Fig. 5·12 Mean Daytime Albedo during the Harmattan (%)



with various man-made concretes, tarmacs, untarred and tarred roads, buildings, amongst others, at the urban centre. Dark, dull and irregular surfaces have lower albedo than white, bright and smooth surfaces because the former can absorb more of the short wave radiation while the latter reflects

(2) The artificial urban surfaces like concretes, tarred roads and tarmacs have lower albedo because of their higher energy absorptive and storage capacities, compared with the dominant soil and vegetalcovers of the rural area.

(3) Urban buildings and other concrete structures prevent, in most cases, slanting rays of light from reaching the surface. More of the light beam that would have otherwise reached the surface in the rural area is absorbed by the buildings in the urban area. This would mean that most of the rays available for direct reflection within the urban canopy come with lower angle of incidence straight through the standing city structures. The lower the angle of incidence, the lower the

reflection because the more the direct penetration of the solar rays into the various surfaces.

The afternoon hours mean albedo values are greater than those for the morning hours as could be seen on Figs. 5.7, 5.8, 5.10 and 5.11. These differences do not, however, affect the spatial pattern. The increase in afternoon albedo is as a result of the fact that by afternoon hours, the absorptive and storage capacities of most surfaces must have dwindled. Thus the surfaces tend to reflect more of the sun's rays. This particular reason accounts for why there are reductions in the differences between the rural and urban centres' albedo values during afternoon hours.

Albedo values during the harmattan period are higher than during the wet periods. The differences between the urban and rural areas are however reduced during the harmattan season. For instance, Fig. 5.9 and 5.12 show that the rural albedo values are higher than the urban ones during the wet and the dry seasons respectively.

Two reasons are responsible for the higher harmattan albedo. They are as follows:

(1) Reduction in sewage water and soil moisture

because of the generally dry condition which increases the albedo as dry surfaces reflect more than wet surfaces.

(2) The deposition of greyish harmattan dust on the surface making surfaces more greyish and therefore increasing the albedo.

A reduction in the differences between the rural and urban areas during the harmattan is as a result of the relatively more homogeneous surface conditions during the harmattan season, which is caused by the generally dry condition and mass deposition of harmattan dusts.

5.1.c Net Radiation

Net radiation, according to Chang (1970), is the balance that is left on the earth's surface after the reflection, absorption and the re-radiation in the form of long-wave of the incoming global radiation at the surface (see eqn. 2.1 and Fig. 2.1). The amount of net radiation depends directly on the amount of in-coming global radiation, surface reflectivity, absorptivity and emissivity. Factors like cloud cover, wind speed and direction and atmospheric pollution play indirect roles in determining the conditions of net radiation. Net radiation and the net long wave radiation are also very related (Monteith, 1962). The former could therefore be affected very significantly by the latter.

More detailed description of the net radiation characteristics are carried out in this section, in addition to the spatial, diurnal and seasonal variations as done for the components of radiation budgets earlier described. This is because of:

(1) the availability of more portable equipment which allowed for more automobile transects to be carried out, results of which are presented in this work, and

(2) net radiation characteristics are perhaps more important to climatologists than other components because net radiation represents a summary of the surface disposition of solar radiation, a knowledge of its pattern would therefore be of immense use in various spheres of planning. It is also because of this reason that a hypothesis is being tested in this section for the purpose of knowing whether or not there is significant difference between the human and rural net radiation characteristics.

As expected, the spatial pattern of net radiation in Ibadan follows the pattern of other components of the radiation budget (Figs. 5.13 to 5.18). The highest net radiation is received around the heavily built-up city centre. The amount varies from a mean of between .220 and .230 ly. min^{-1} around Dugbe, Adamasingba, Oke-Bola, Mapo, Aperin and Aremo areas to .190 and .200 ly. min^{-1} in the rural suburbs during the wet season. This is about 15.8% increase towards the city centre. It also varies from a mean of between .210 and .220 ly. min^{-1} in the rural suburb during the harmattan to between .240 and .250 ly. min^{-1} at the city centre, having an increase of about 14.0% towards the centre.

Decrease in surface albedo and therefore increases in the amount of energy absorbed at the surface and long wave radiation by the atmospheric pollutants, are factors that are responsible for the increase in net radiation towards the city centre.

The morning and afternoon hours spatial patterns of net radiation are not quite different except that there is a slight reduction in the afternoon net radiation during the wet season (Figs. 5.13 and 5.14) because most of the data used in computing the maps were obtained on days when

Fig. 5·13 Net Radiation during the Wet Season (Ly-min -1)

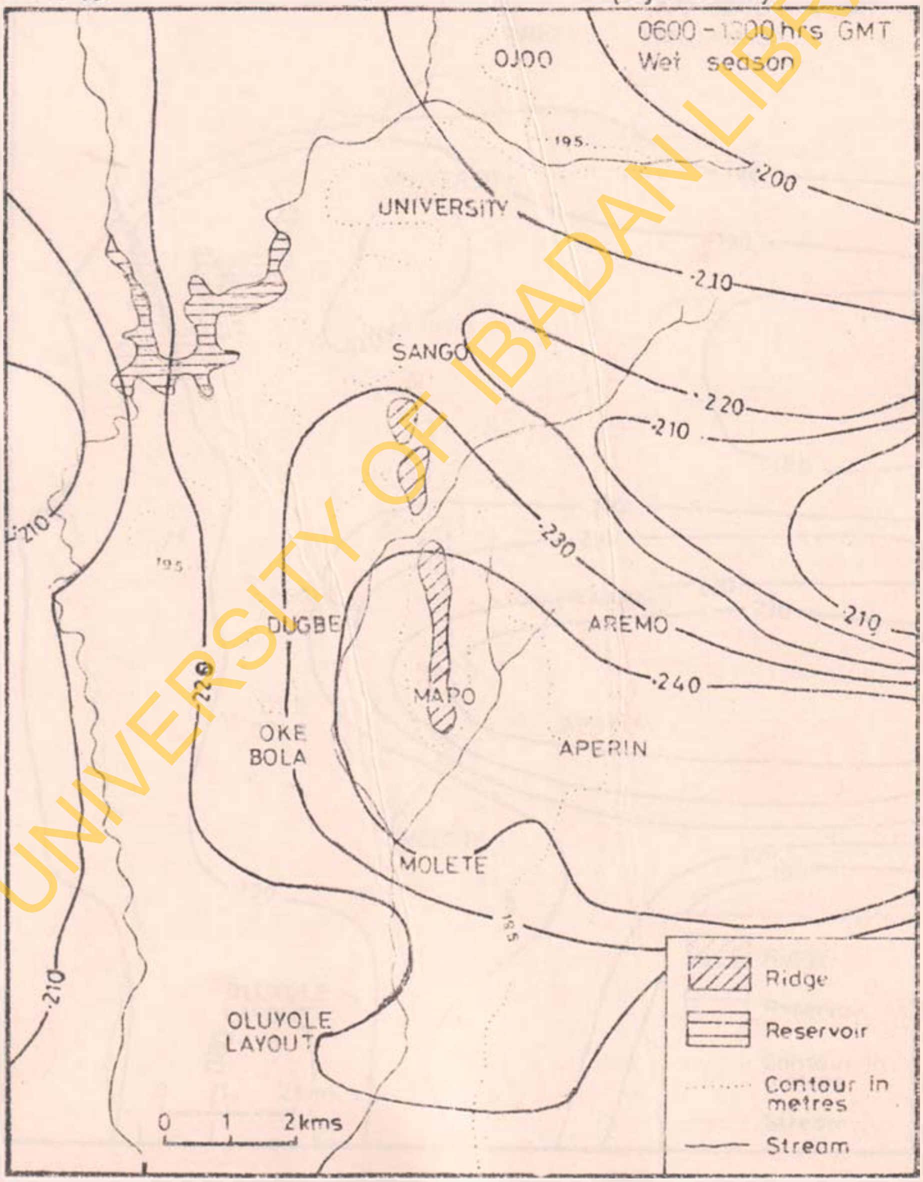


Fig. 5-14 Net Radiation during the Wet Season (Ly. min -1)

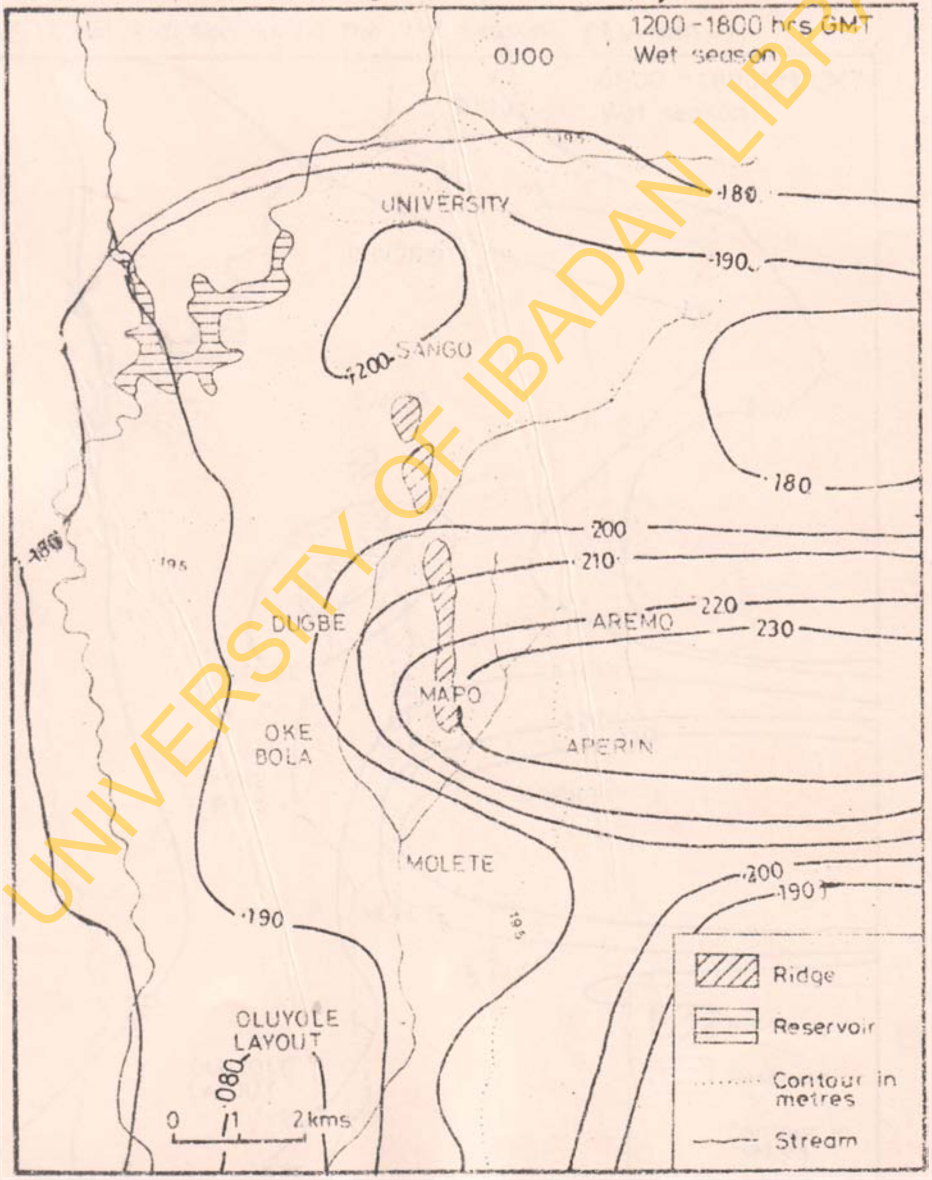


Fig. 5·15 Net Radiation during the Wet Season (Ly·min – I)

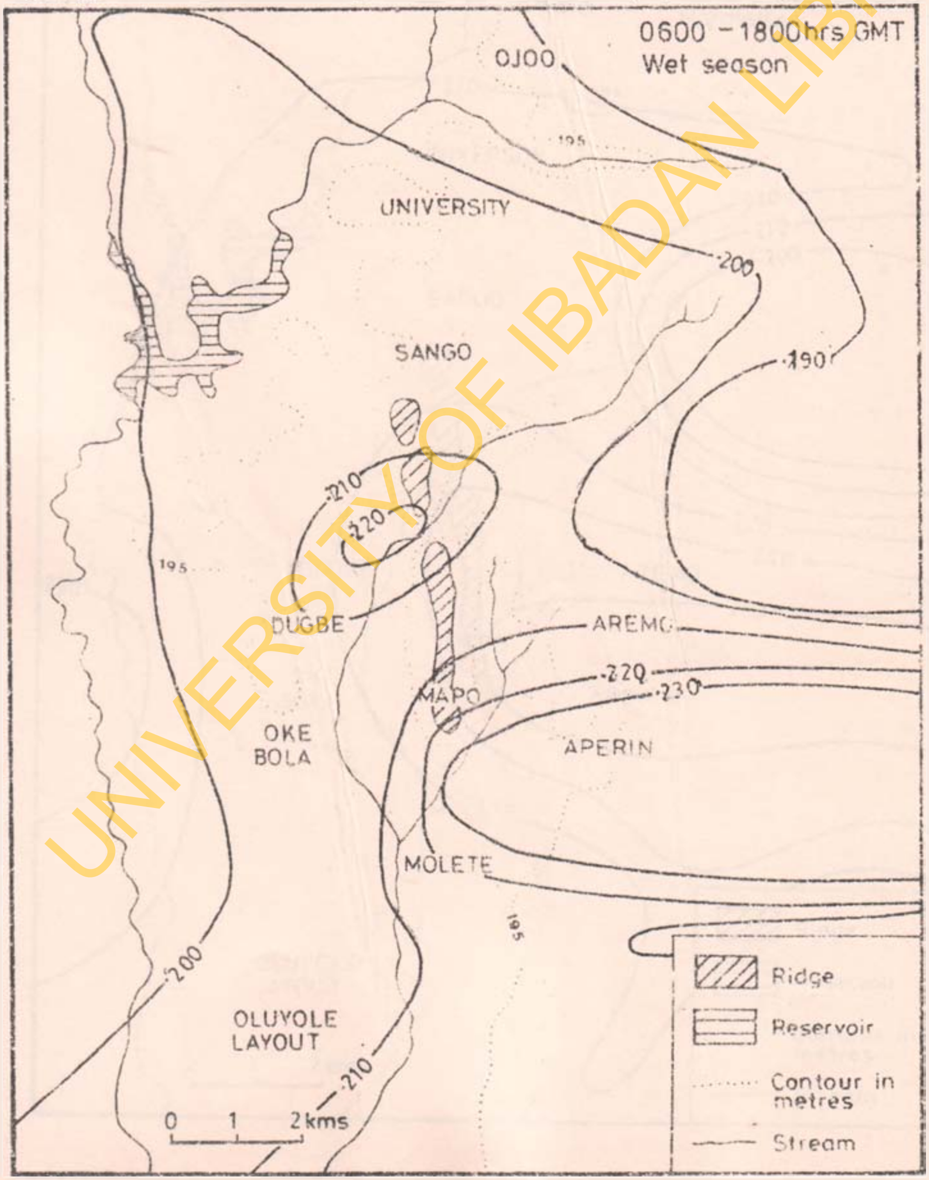


Fig. 5·16 Net Radiation during the Harmattan (Ly.min -1)

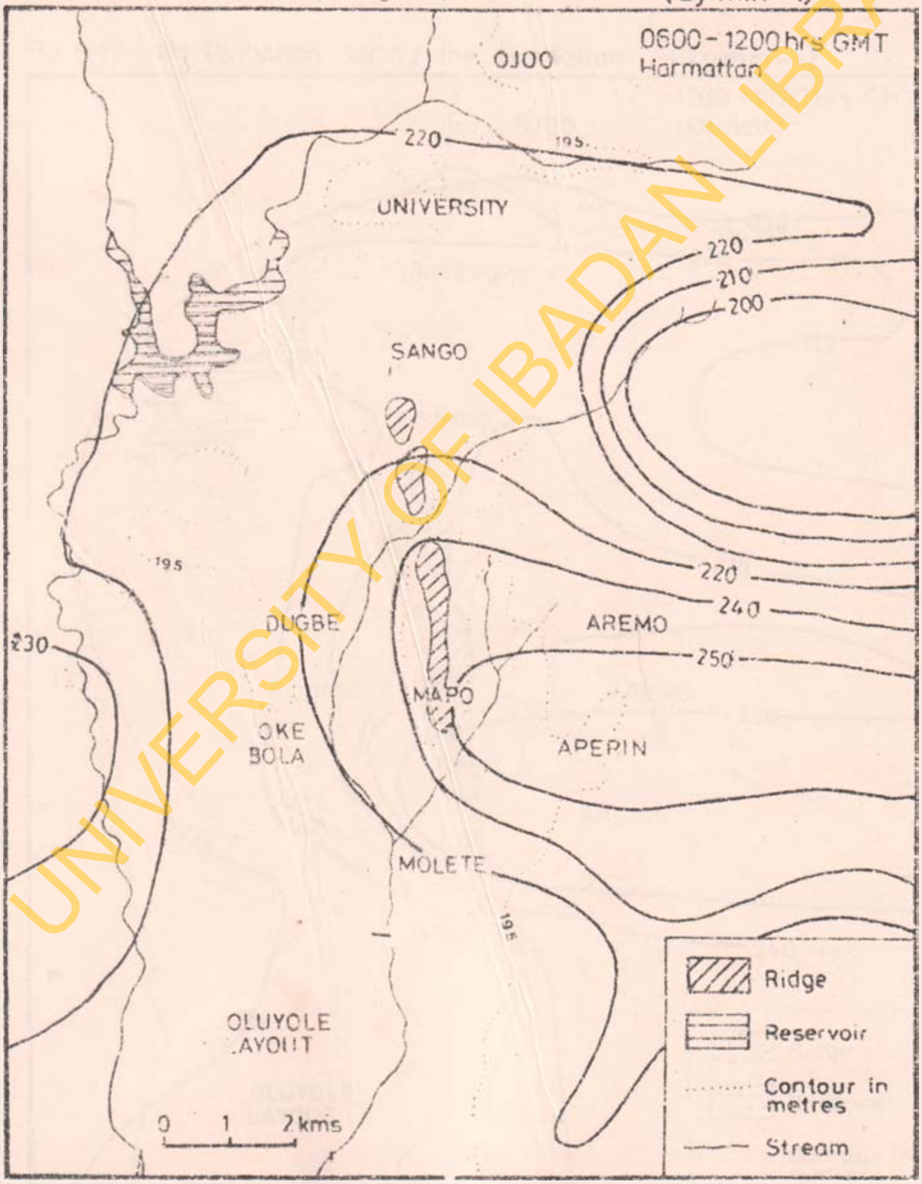


Fig. 5-17 Net Radiation during the Harmattan (Ly.min -1)

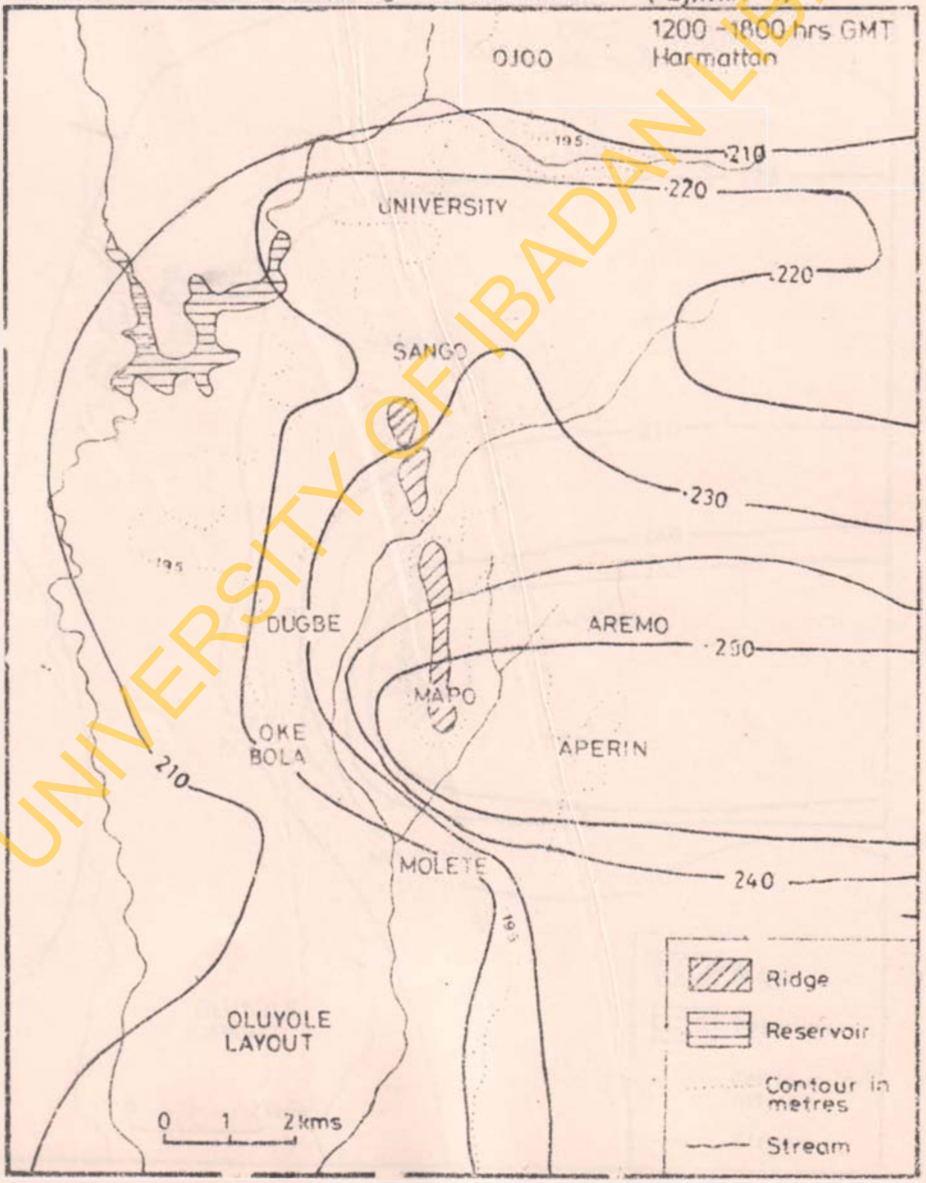
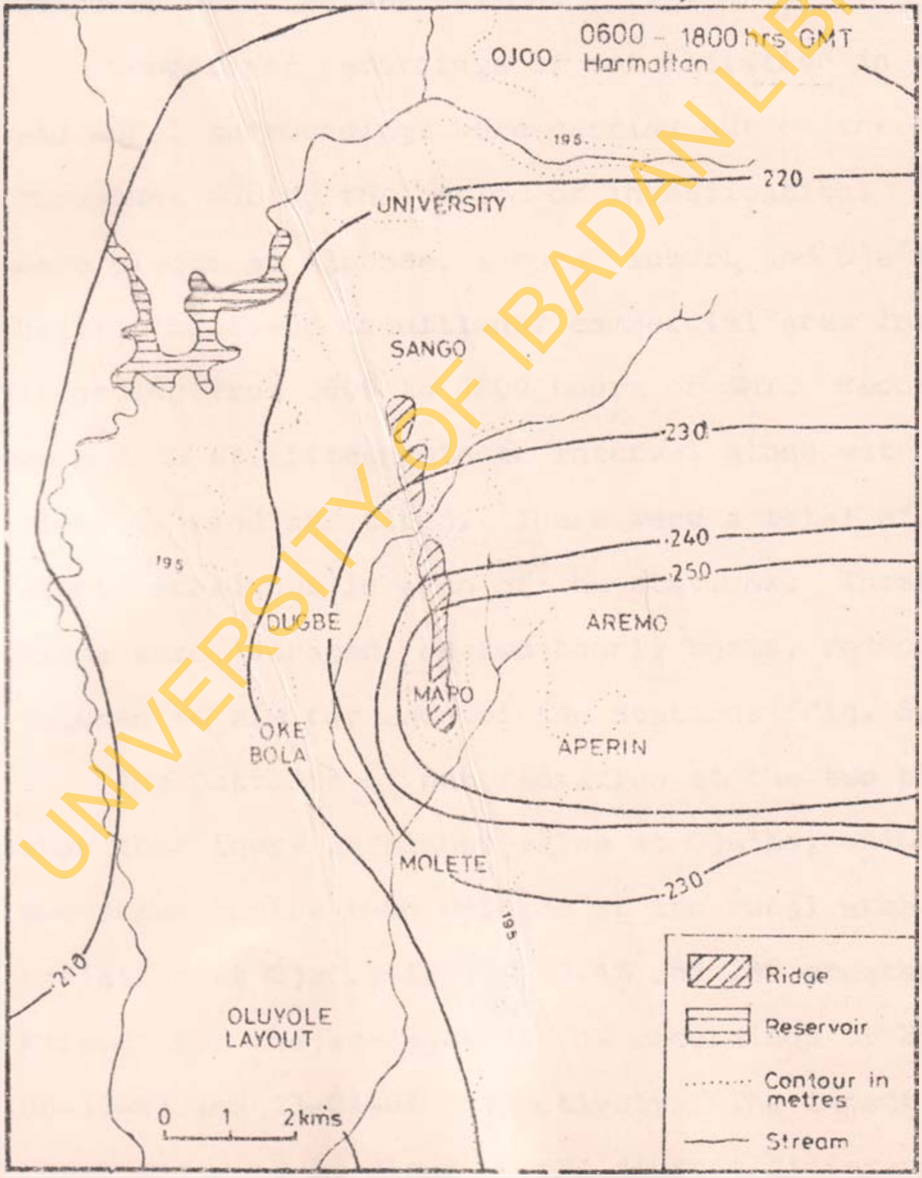


Fig. 5·18 Net Radiation during the Harmattan (Ly· min -l)



there was rain during the afternoon. Cloudlessness of the skies, general reduction in wind and increases in pollutants from harmattan dusts dusts are responsible for the higher net radiation during the harmattan season compared with the wet season.

Concurrent recordings of net radiation in the urban and rural surroundings were carried out on three different occasions during the period of investigation. Equipment were placed at Ajibode, a rural suburb and Oja'ba a heavily built-up traditional commercial area for the recording from 0600 to 1800 hours of GMT. Recordings were done at fifteen minute interval along with conditions of wind and cloud. There were a total of forty eight recordings in each of the stations. These observations were averaged, on two hourly basis, reducing the figures to six for each of the stations (Fig. 5.19).

The patterns of net radiation at the two places show that there is higher value at Oja'ba, which is at the urban centre than Ajibode at the rural area. The net radiation at Oja'ba is 20%, 9.1% and 25% greater than that at Ajibode for the averages of the recordings of 28-03-83, 06-10-83 and 13-01-84 respectively. The impact of cloud cover and wind is clear on the diurnal differences in net radiation between the urban and the rural areas.

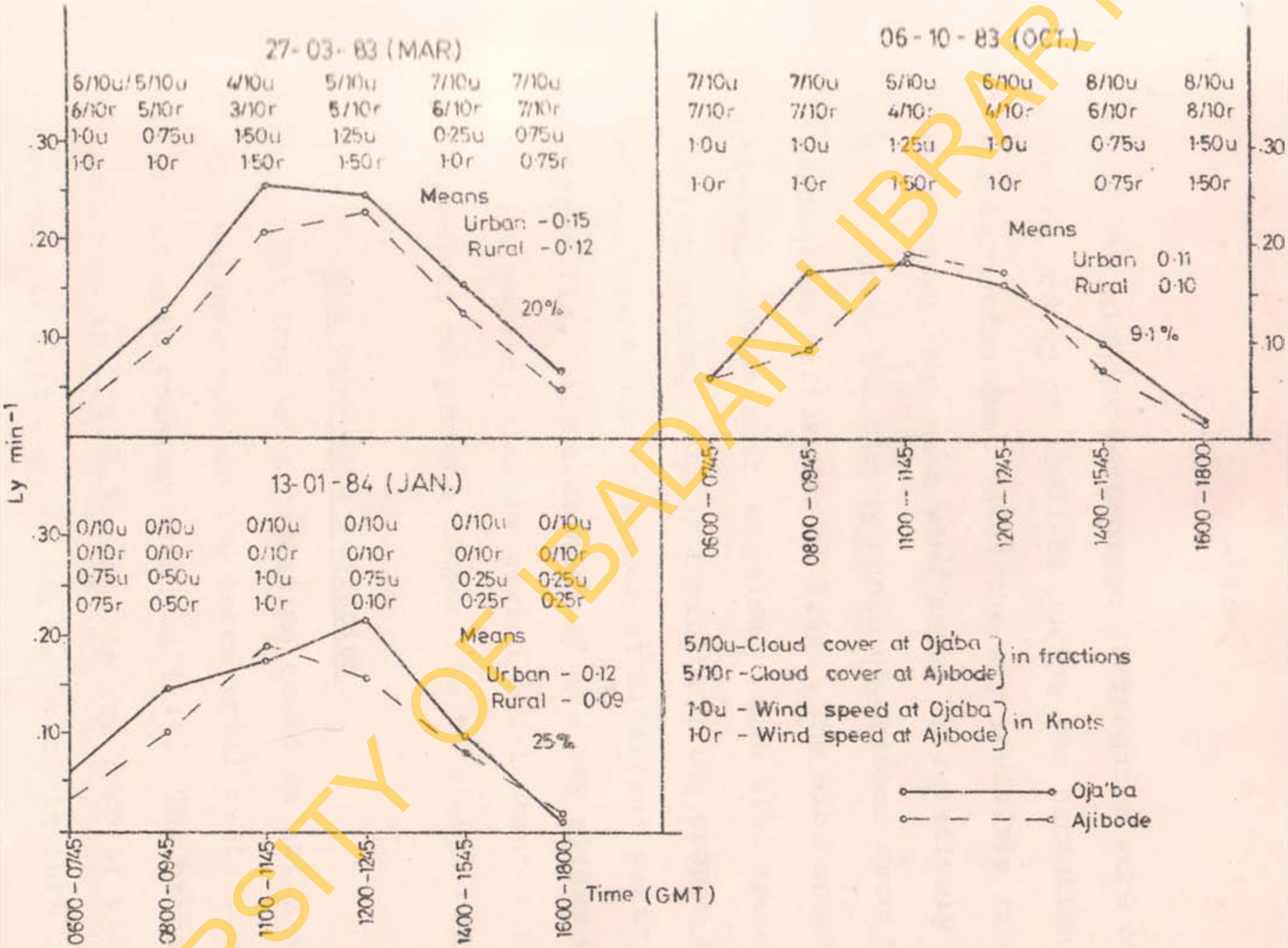


Fig.5·19 Urban / Rural Net Radiation (Rn) Comparison

The highest percentage differences were observed during the recording of 13-01-84 during the harmattan period when the harmattan dust makes the sky invisible from the surface and the mean wind speed is relatively low. On the other hand, the cloudy month of October records the least percentage difference of 9.1%. The wind speed was relatively high on that occasion. High wind speeds encourage surface mixing thereby inhibiting the proper development of different microclimates at different parts of the metropolis. Cloudlessness of the sky allows uniform heating of the surface thereby giving equal chances to the responses of surface components to global radiation.

5.1.d Net Long Wave Radiation

Net long wave radiation could be aptly described as the balance between the terrestrial radiation (L↑) and the atmospheric counterradiation (L↓). The global radiation, as shown in Fig. 2.3, comes in the form of visible short wave. It heats up the earth, which in turn becomes a source of long wave radiation. Most of the radiation is emitted in the infrared spectral range from 4 to 50 microns with a peak near 10 microns (Sellers, 1965). Because this radiation is emitted by the earth's surface, it is called terrestrial radiation. The atmosphere, which is nearly transparent to short wave radiation readily absorbs terrestrial radiation. The absorbers therein are water vapour, ozone, carbon dioxide and clouds. According to Sellers (1965) only 9% of the terrestrial radiation escapes directly to space through the "atmospheric window", while the rest is absorbed by the atmosphere. The atmosphere, in turn, re-radiates these partly to space and partly back to surface in form of counter-radiation. Because of this, the net or the effective outgoing radiation from the surface is reduced considerably.

The net long wave values in this work are calculated from equation 2.1, after measuring other components of the equation directly with relevant equipment. The equation then becomes

$$- L^{*} = Rn - (Q + q)(1 - \alpha) \text{ ------ } 5.1$$

With this, values of long wave radiation are presented in minus forms.

From Figs. 5.20 to 5.25, it could be observed that net long wave radiation decreases from the centre of the city to the rural environment. This varies from a mean of about $- .18$ to $- .19$ ly min^{-1} around Dugbe, Aremo,

Fig.5.20 Net Long Wave Radiation during the Wet season (Ly.min -1)

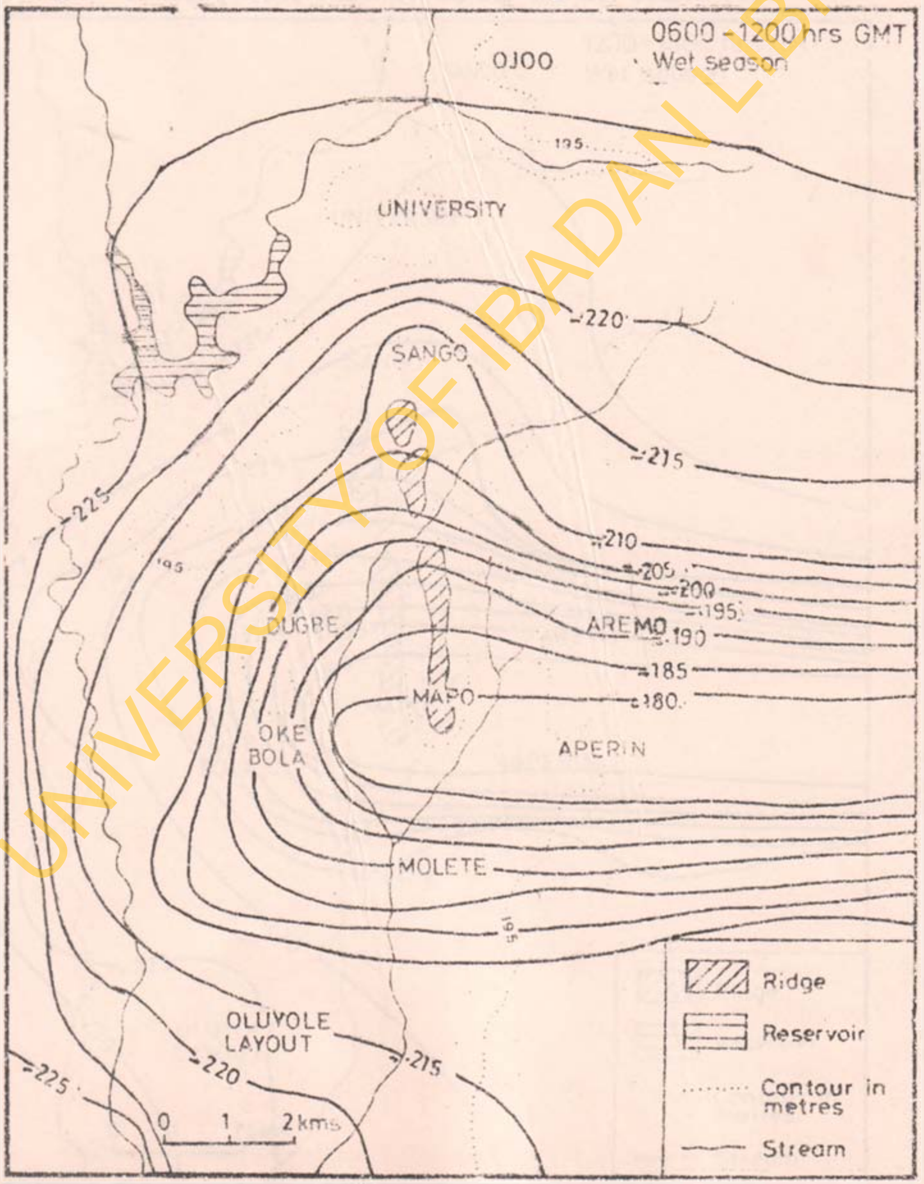


Fig.5.21 Net Long Wave Radiation during the Wet season (Ly.min -1)

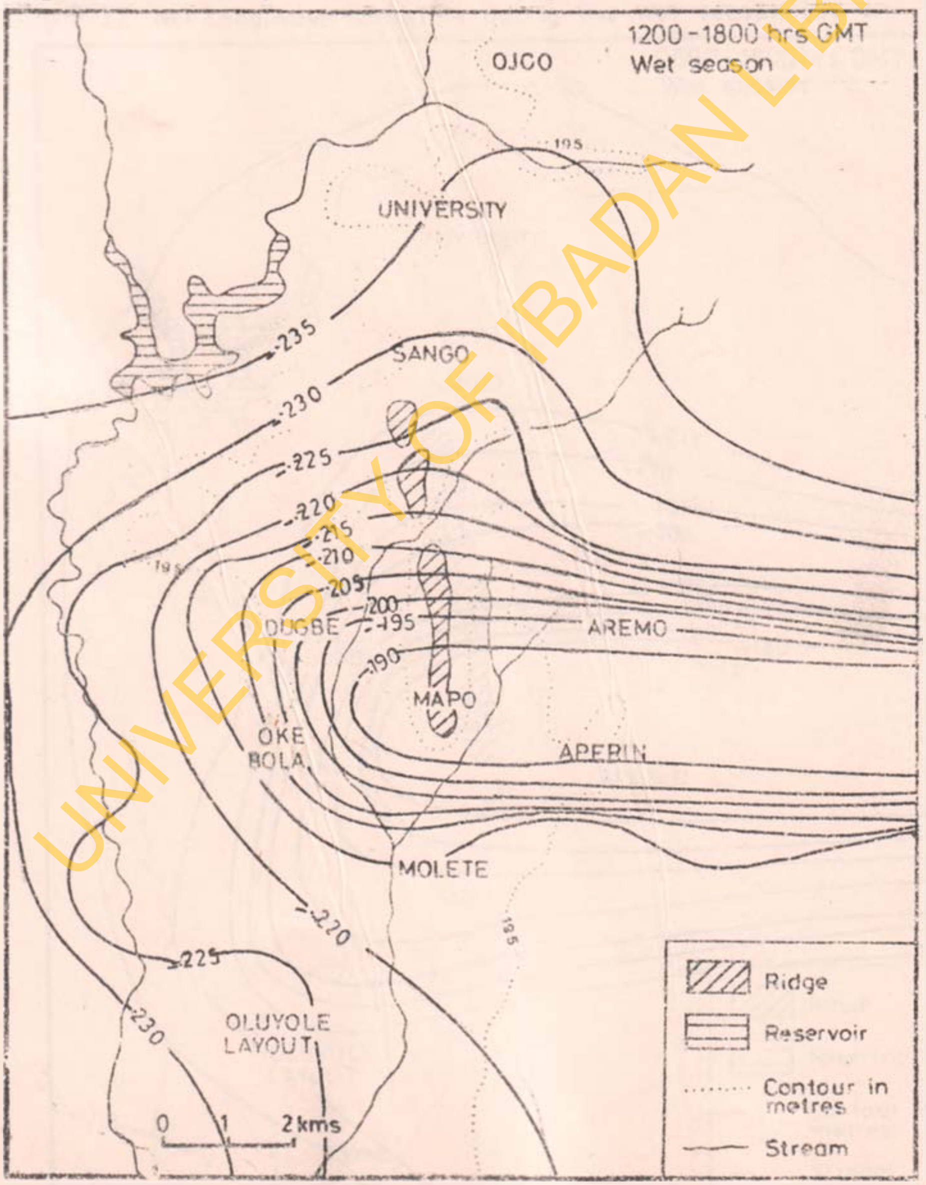


Fig.5.22 Net Long Wave Radiation during the Wet season (Ly. min -1)

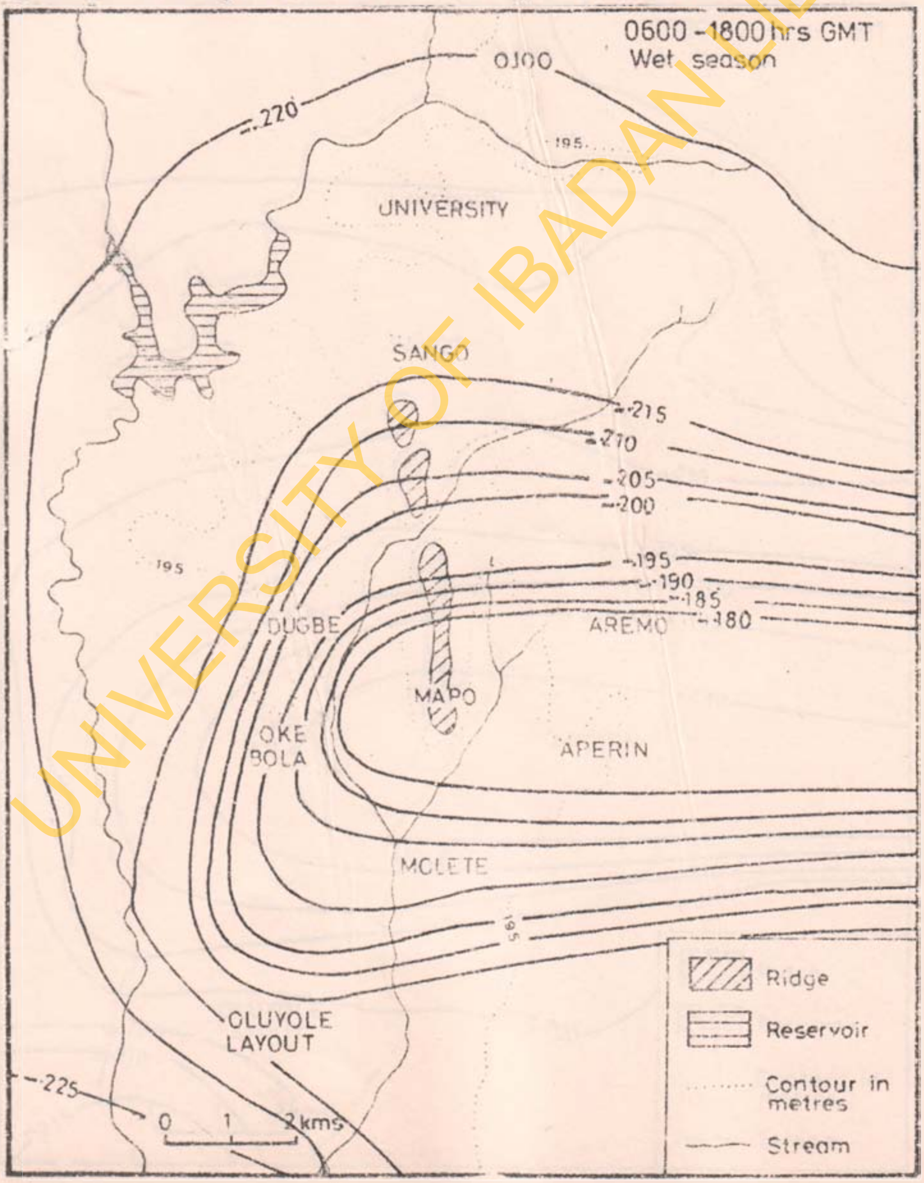


Fig.5.23 Net Long Wave Radiation during the Harmattan (Ly. min −1)

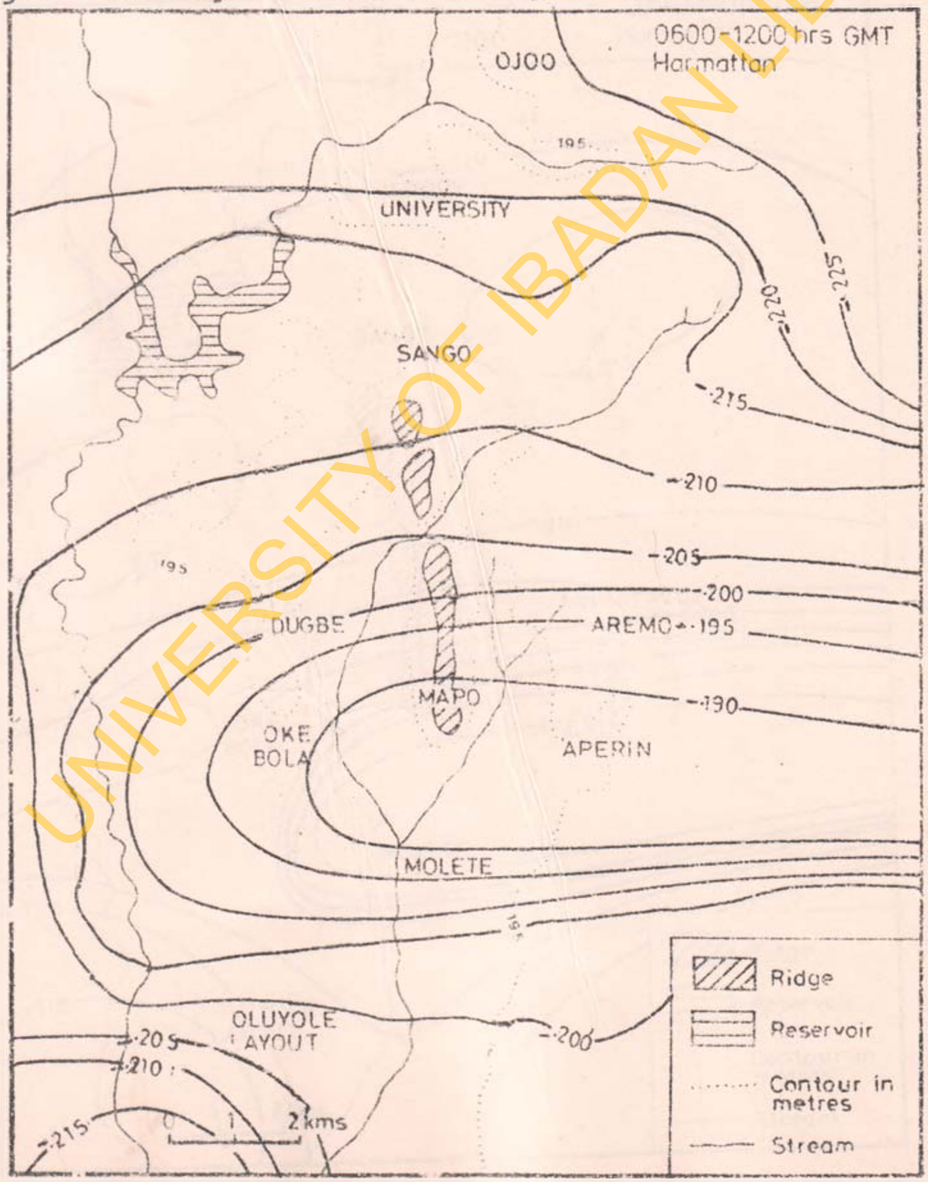


Fig.5.24 Net Long Wave Radiation during the Harmattan (Ly.min⁻¹)

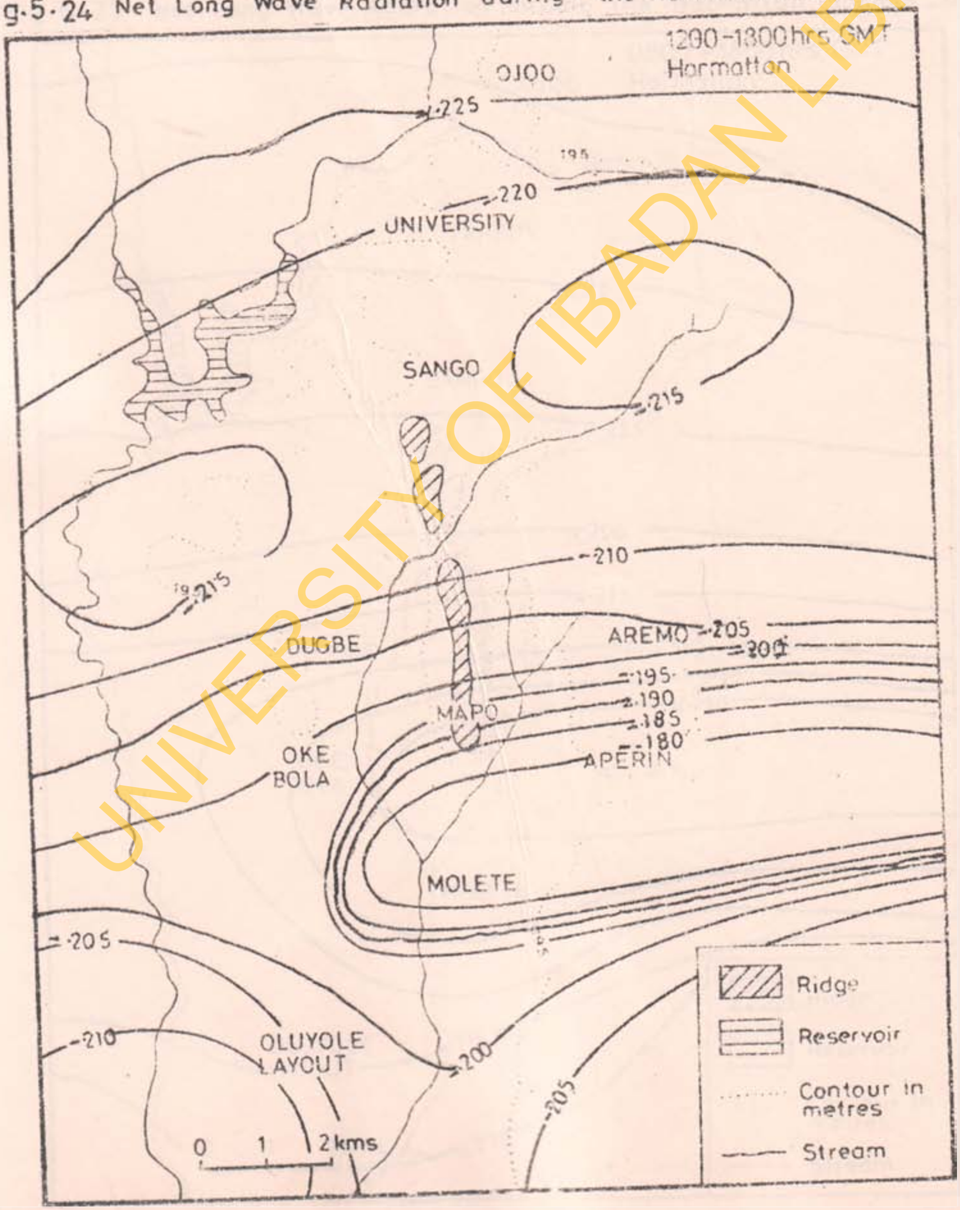
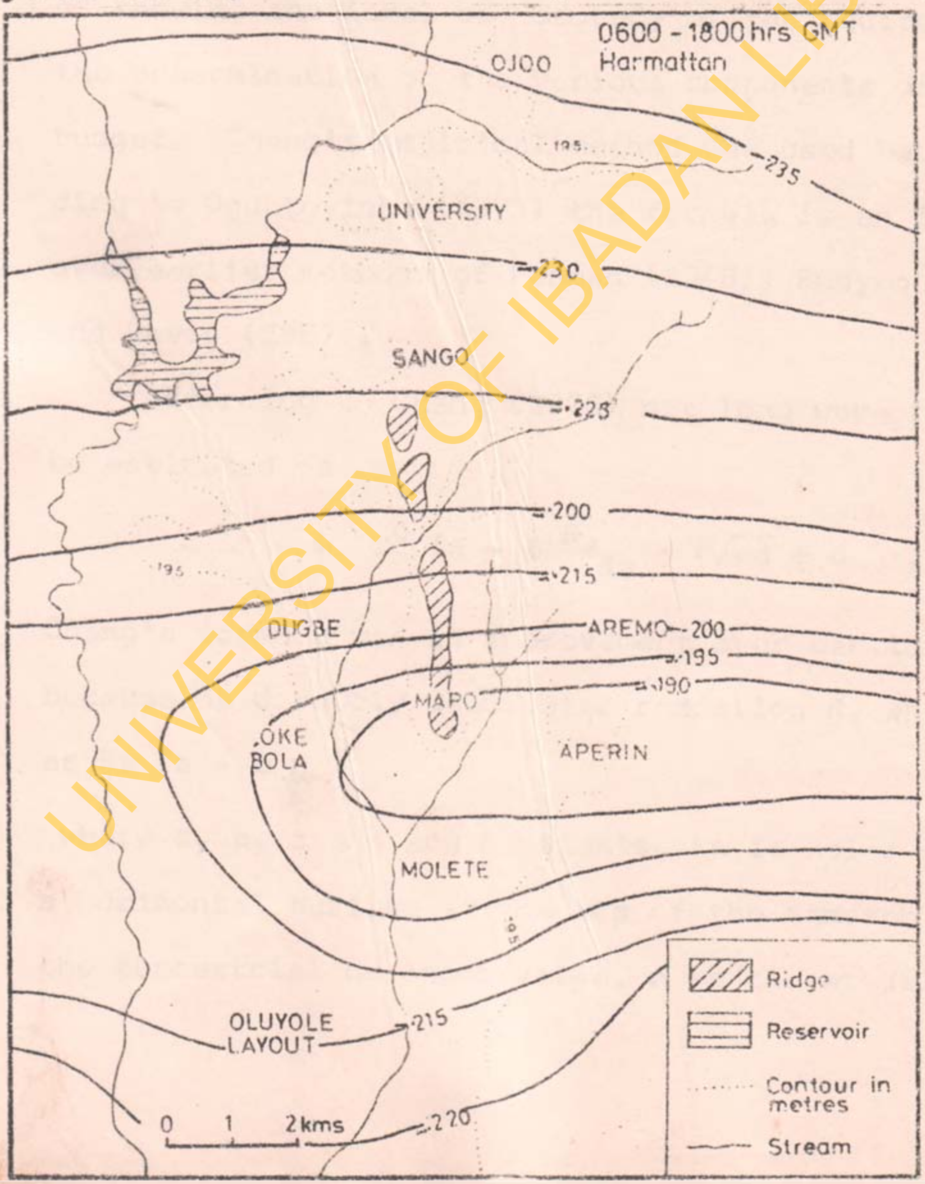


Fig.5.25 Net Long Wave Radiation during the Harmattan (Ly.min -1)



Oke-Bola, Adamasingba, Mapo and Orita Apori areas to about $-.210$ to $-.222$ ly min^{-1} in the rural area. This is a decrease by about 16.7% at the rural area.

Net long wave radiation was also estimated through the use of an empirical method. This was for the purpose of knowing the level of accuracy of the equipment used in the determination of the various components of radiation budget. Chang's empirical method was used because according to Oguntoyinbo (1972) the formula is an improvement over earlier methods of Penman (1948), Budyko (1956, 1963) and Davis (1967).

According to Chang (1970) net long wave radiation could be estimated as

$$- L^* = - T^4 \left(a + b \, {}^{R}/_{Ra} + c\sqrt{ed} + d \, {}^{R}/_{Ra} \sqrt{ed}\right) \quad \ldots (5.2)$$

Chang's formula was an improvement over earlier approaches because he directly used solar radiation R, which is given as Ra $(a + b \frac{n}{N})$

where a, b, c and are constants, Ra is solar radiation on a horizontal surface at the top of the atmosphere i.e. the terrestrial or Angot value, n is the actual number of sunshine hours, N is maximum possible hours of sunshine, is the Stefan Boltzman's constant (8.17×10^{-11} ly. min^{-1} T^{-4}), T the air temperature and ed the saturated vapour pressure.

Given all the constants in equation (5.2), Chang's formula could be written as

$$- T^4 (286.18 + 202.60. {}^{R}/_{Ra} - 45.24 \sqrt{ed} - 10.92 {}^{R}/_{Ra} \sqrt{ed}) \quad .... (5.3)$$

This equation was applied to measurements taken within the urban canopy over a period of one year.

Table 5.1: Comparison of Measured and Estimated -L* ($ly\ min^{-1}$) Using Chang's Formula

	M	J	J	A	S	O	N	D	J	F	M	A
Mea-sured	-.159	-.166	-.104	-.083	-.070	-.056	-.035	-.071	-.090	-.011	-.112	-.138
Esti-mated	-.162	-.151	-.095	-.079	-.081	-.061	-.030	-.080	-.075	-.103	-.095	-.129

The above results show that Chang's formula has over-estimated L* by 4.5%. This compares with Oguntoyinbo's result which shows that Chang's formula over-estimated L* by 3.9%.

Factors like increase in low-level pollutants, higher concentration of concretes and tarmac and reduction in albedo at the city centre are responsible for the higher net long wave radiation in the city. Low-level pollutants increase the atmospheric counterradiation and reduce the escape of terrestrial radiation. High emissive capacity of concretes and tarmac in the city increases the amount of long wave radiation while reduction in albedo increases the amount of energy to be absorbed therefore increasing the re-radiated terrestrial radiation. All these combine to increase the long wave radiation towards the city centre.

There is a general increase in the afternoon hours net long wave radiation particularly at the city centre. This further brings to light the importance of the surface infrastructures in radiating more energy. This is because higher terrestrial radiation lost from the surface is expected in the afternoon when the storage capacities of surface components are at their peak. In addition, the global radiation is high (Fig. 5.26). More low-level pollutants are also expected in the afternoon (table 4.6) when traffic density and industrial and domestic activities are at their peaks. This would mean the formation of thicker pollution veil to prevent the rapid escape of terrestrial

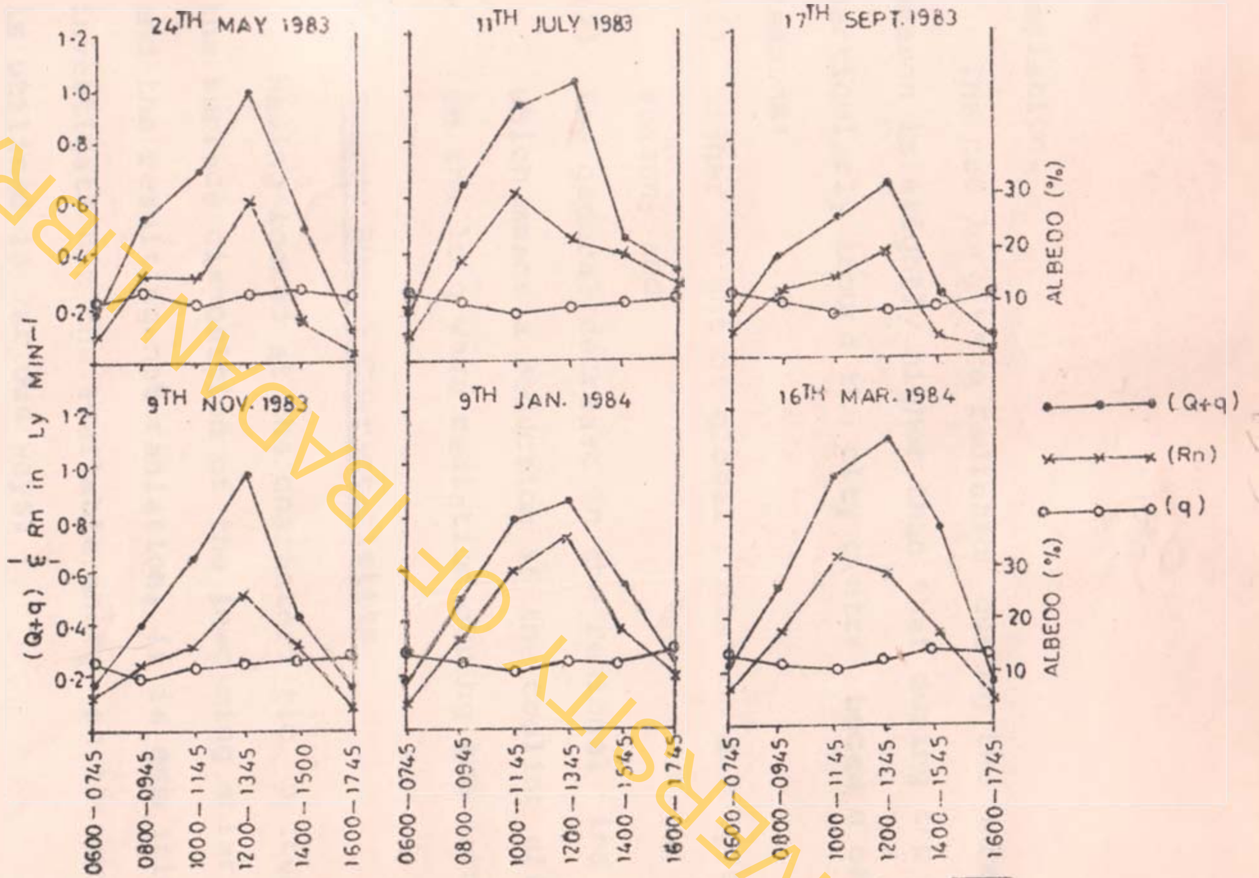


Fig. 5·26 VARIATIONS IN (Q+q), Rn AND q OVER URBAN SITE XXVI radiation.

The net long wave radiation during the harmattan season is slightly higher than that during the wet season, particularly around the city centre because of the following reasons:

(1) higher amount of global radiation during the harmattan season, and

(2) the general decrease in the regional wind speed which means a reduction in the cooling effect of winds on the long wave radiation during the harmattan season.

5.2 Energy Budget Characteristics

Having looked at the characteristic patterns of the surface disposition of the in-coming solar radiation and the resulting net radiation, it is essential to investigate how the available energy on the surface is utilized in various ways.

Net radiation is essentially used in four important ways at the surface. These are as:

(1) latent heat, to vaporise water from different surfaces;

(2) sensible heat, to warm the air;

(3) ground heat, to heat the ground surface, and

(4) photosynthetic heat utilized during the process of plant's photosynthesis, which is however negligible.

At the global level, the advection of heat into the ocean, which is also negligible, is also considered as the fifth way. The first two ways will be considered in this section because of the following reasons:

(1) it was assumed that the fluxes of heat into and out of the ground were equal for the measurement period which covered the whole day;

(2) it was also assumed that the ground heat flux exists in very small proportion, therefore very negligible, and

(3) the partitioning of latent and sensible fluxes of heat in the urban surfaces is of very vital interest to microclimatologists because both parameters mainly account for the surface pattern of energy utilization.

Bowen ratio (see eqns. 3.2 to 3.5) was employed in the calculation of latent and sensible heat fluxes. The analysis was limited to the wet season because relevant data were available for that period.

The patterns of latent and sensible fluxes of energy as presented in Figs. 5.27 to 5.32, calculated only for periods just after rainfall, show higher utilization of latent heat around the city centre with decreasing trend to the periphery. More energy is utilized as latent heat around the city centre because the impervious city surface has more standing pools of water just after rainfall compared to the relatively porous rural soils.

Figs. 5.33 to 5.35 show the patterns of net radiation, latent and sensible fluxes of heat on different automobile transect days across the city. From the figures, it is clear that net radiation, latent and sensible fluxes are generally high around the urbanized areas than the suburbs.

5.3 Conditions of Radiation and Energy Budgets within the Urban Canopy of Ibadan

Spatial, diurnal and seasonal variations in components of radiation and energy budgets have been discussed in this chapter. Various maps representing the variations in these climatic parameters were compiled by using the land-use approach. The clear spatial views of these parameters emerged on the maps.

Fig. 5·27 Latent Heat Flux during the Wet Season (Ly. min-1)

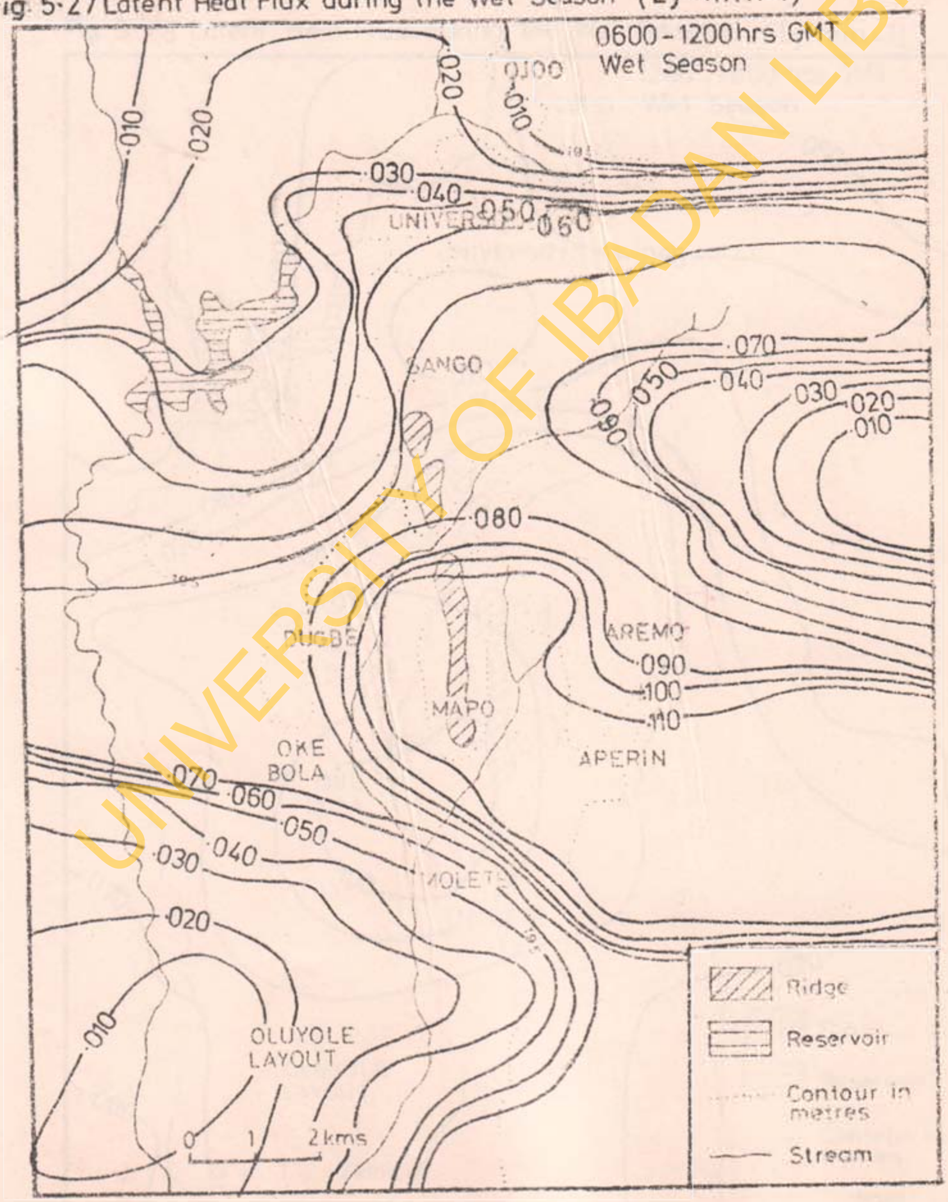


Fig. 5·28 Latent Heat Flux during the Wet Season (Ly.min-1)

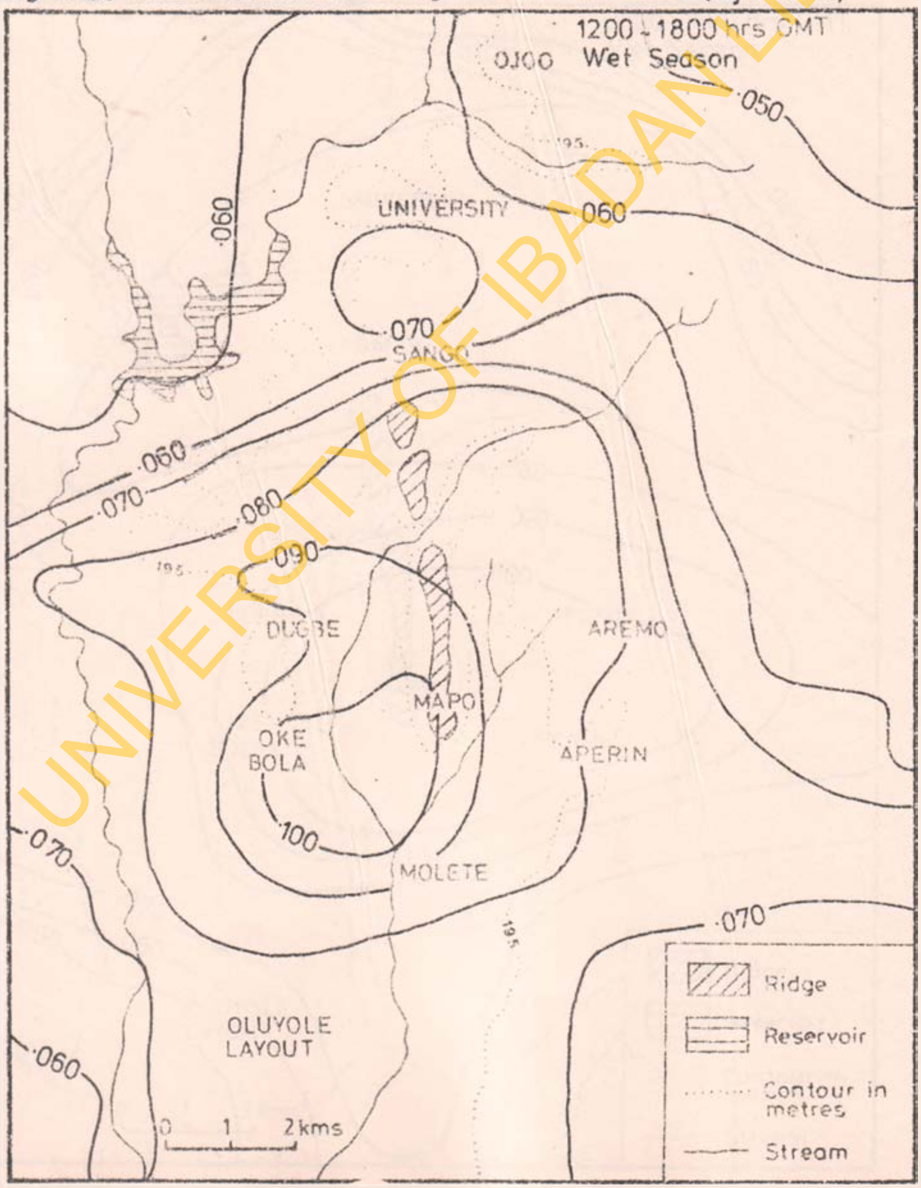
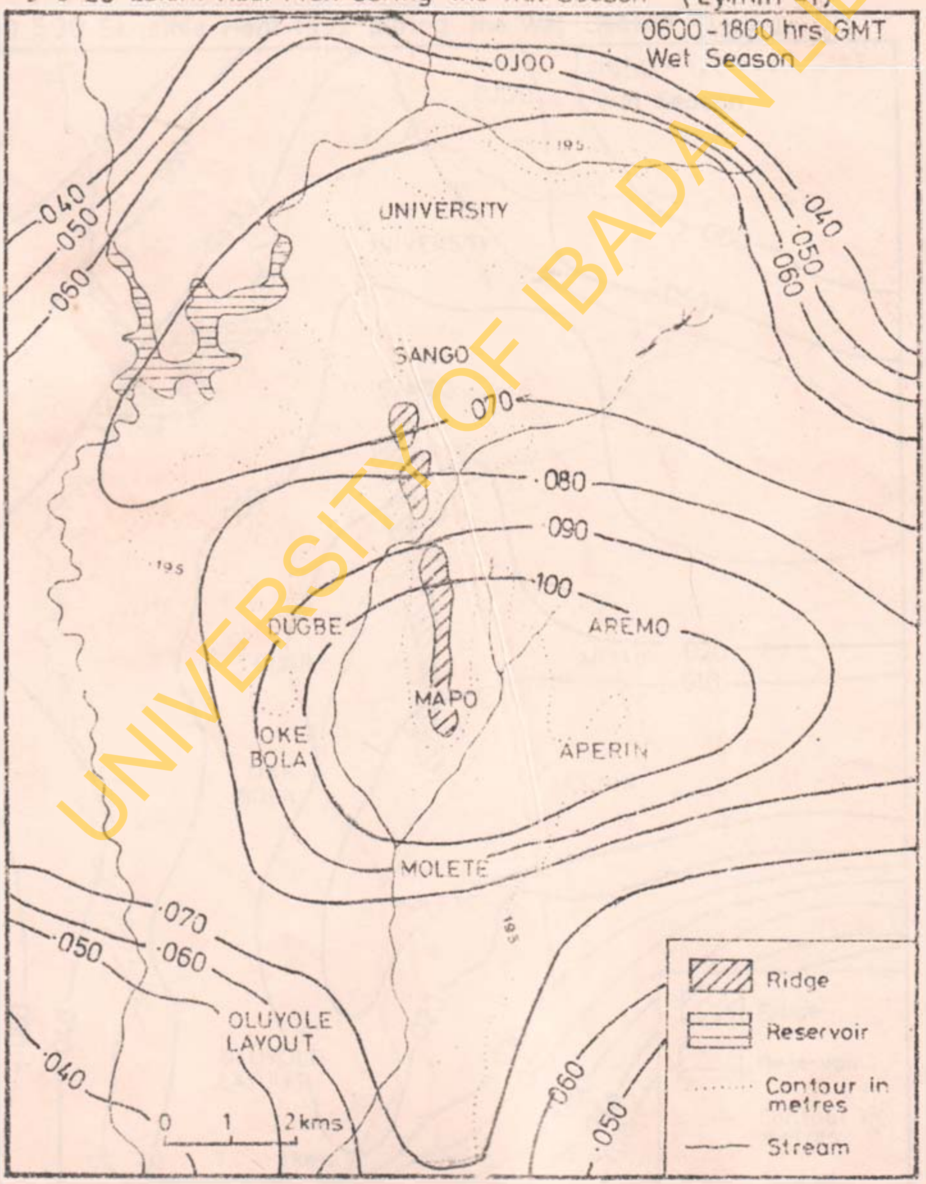


Fig. 5.29 Latent Heat Flux during the Wet Season (Ly.min -1)



160

Fig. 5·30 Sensible Heat Flux during the Wet Season (Ly. min -1)

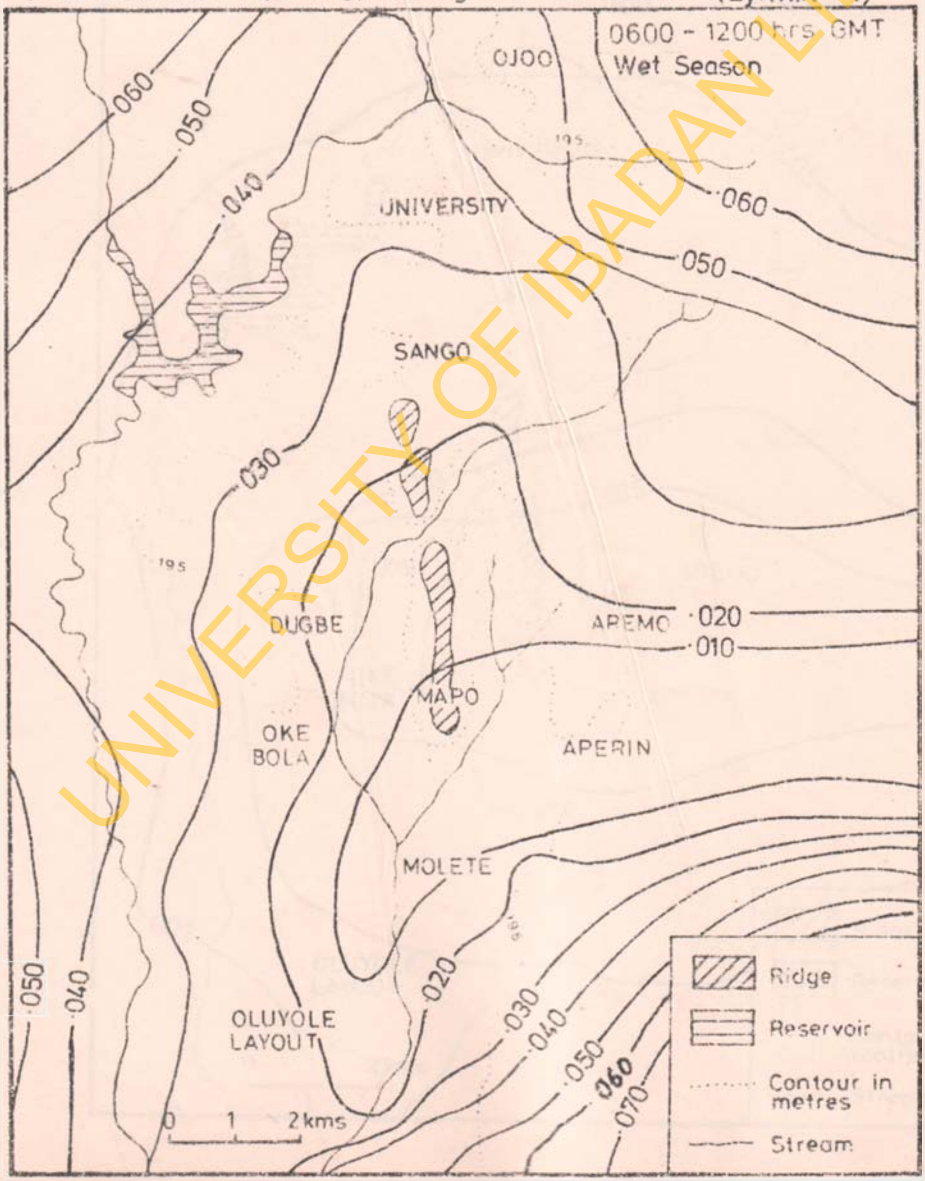


Fig. 5.31 Sensible Heat Flux during the Wet Season (Ly.min-1)

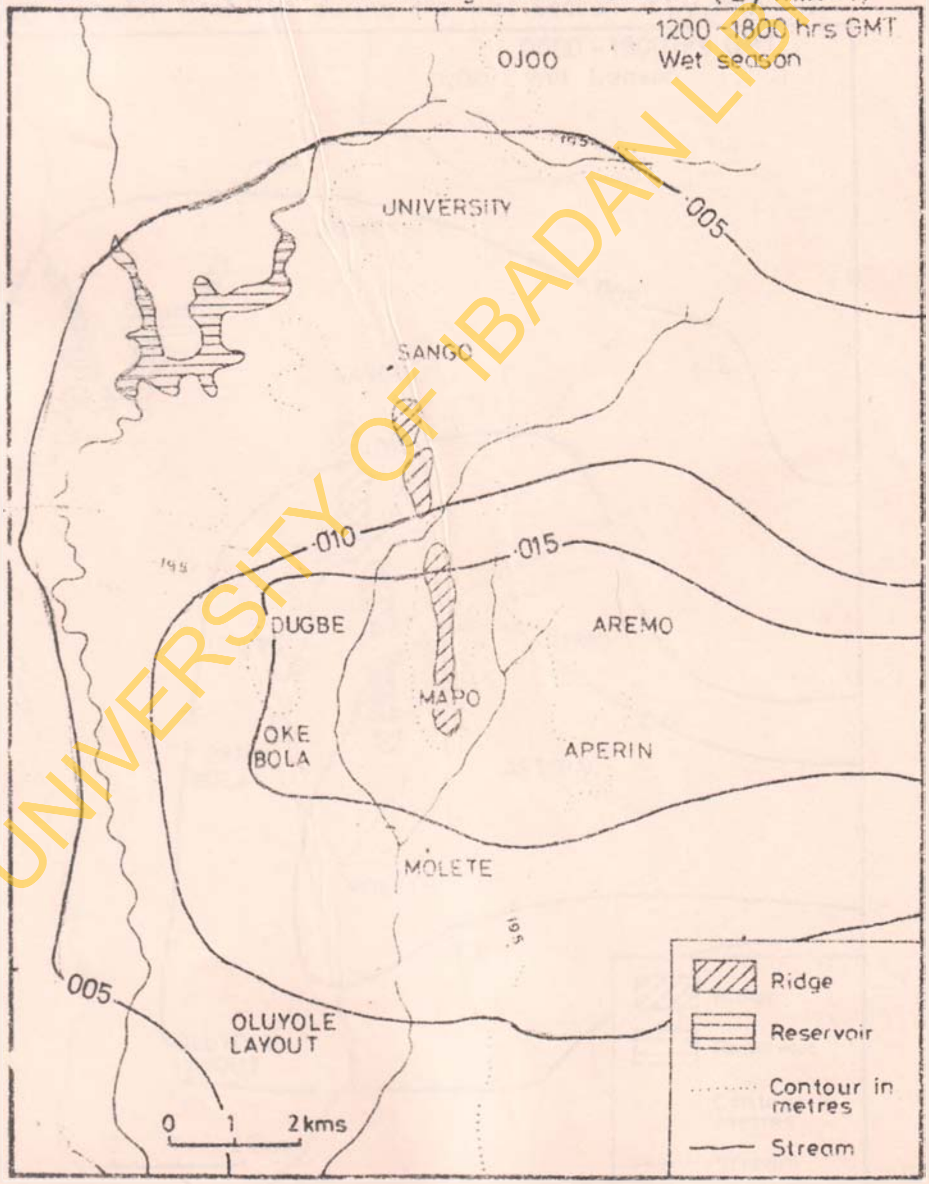
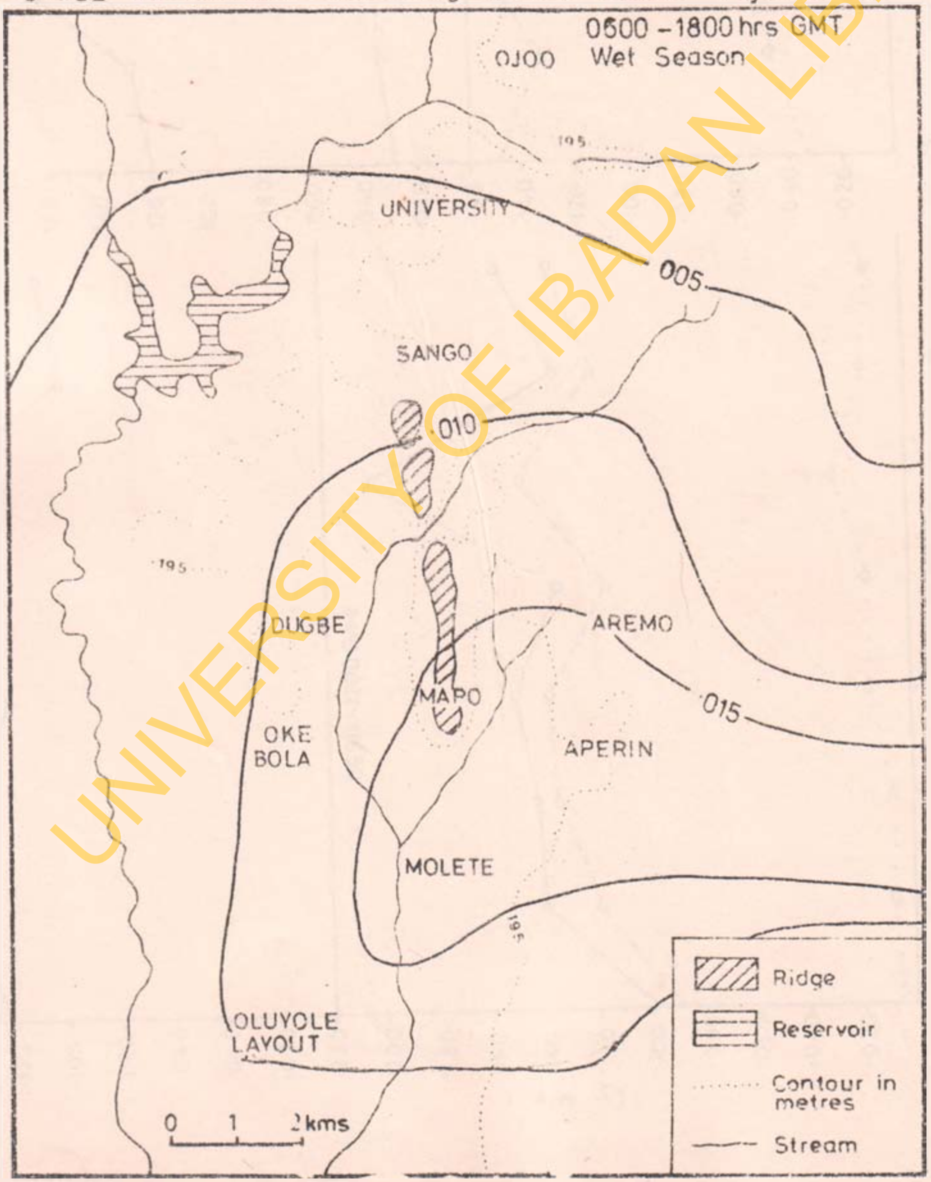


Fig. 5·32 Sensible Heat Flux during the Wet Season (Ly.min -1)



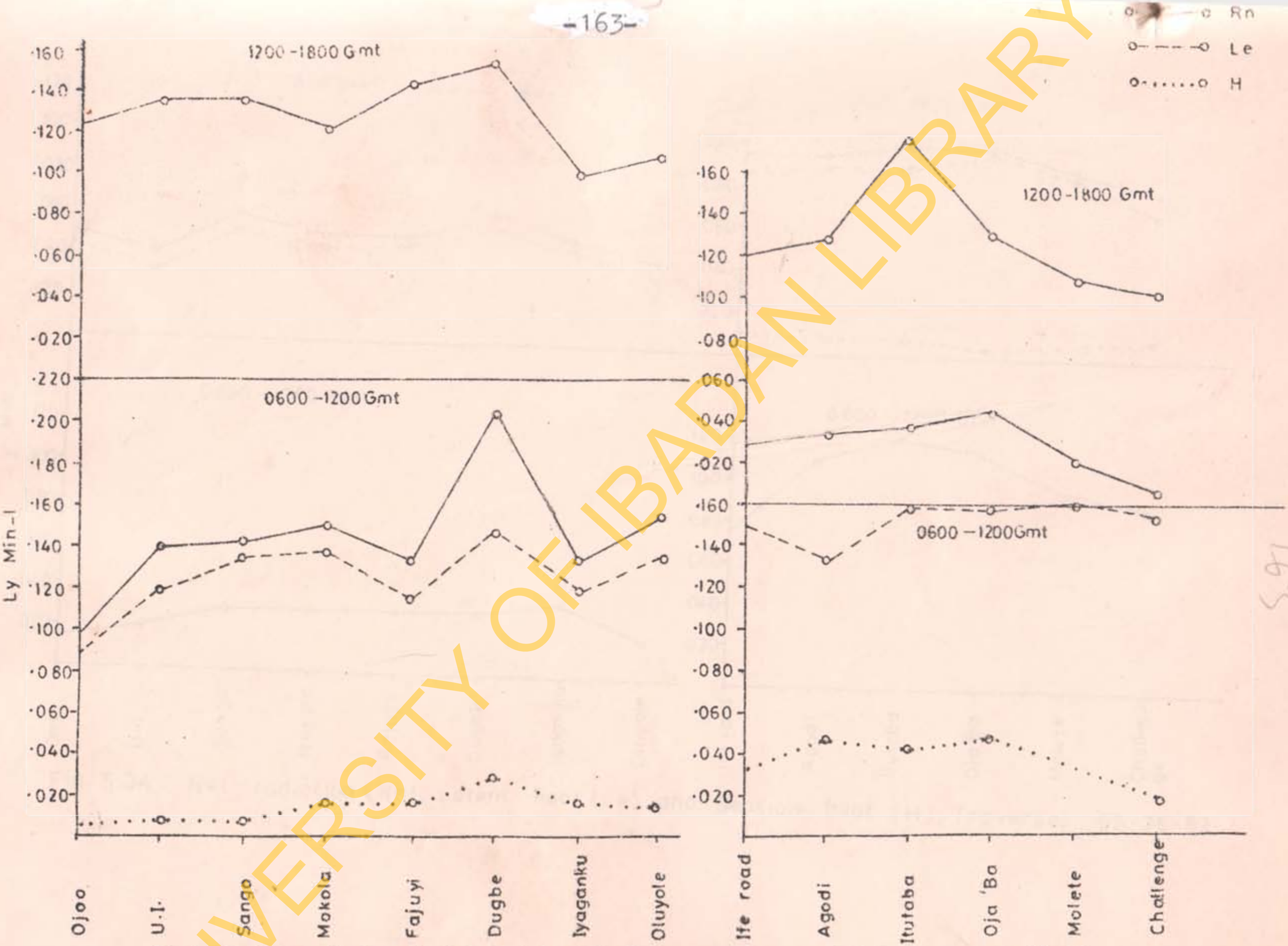


Fig.5.33 Net radiation (Rn), Latent heat (Le) and sensible heat (H) Traverses 11-08-83

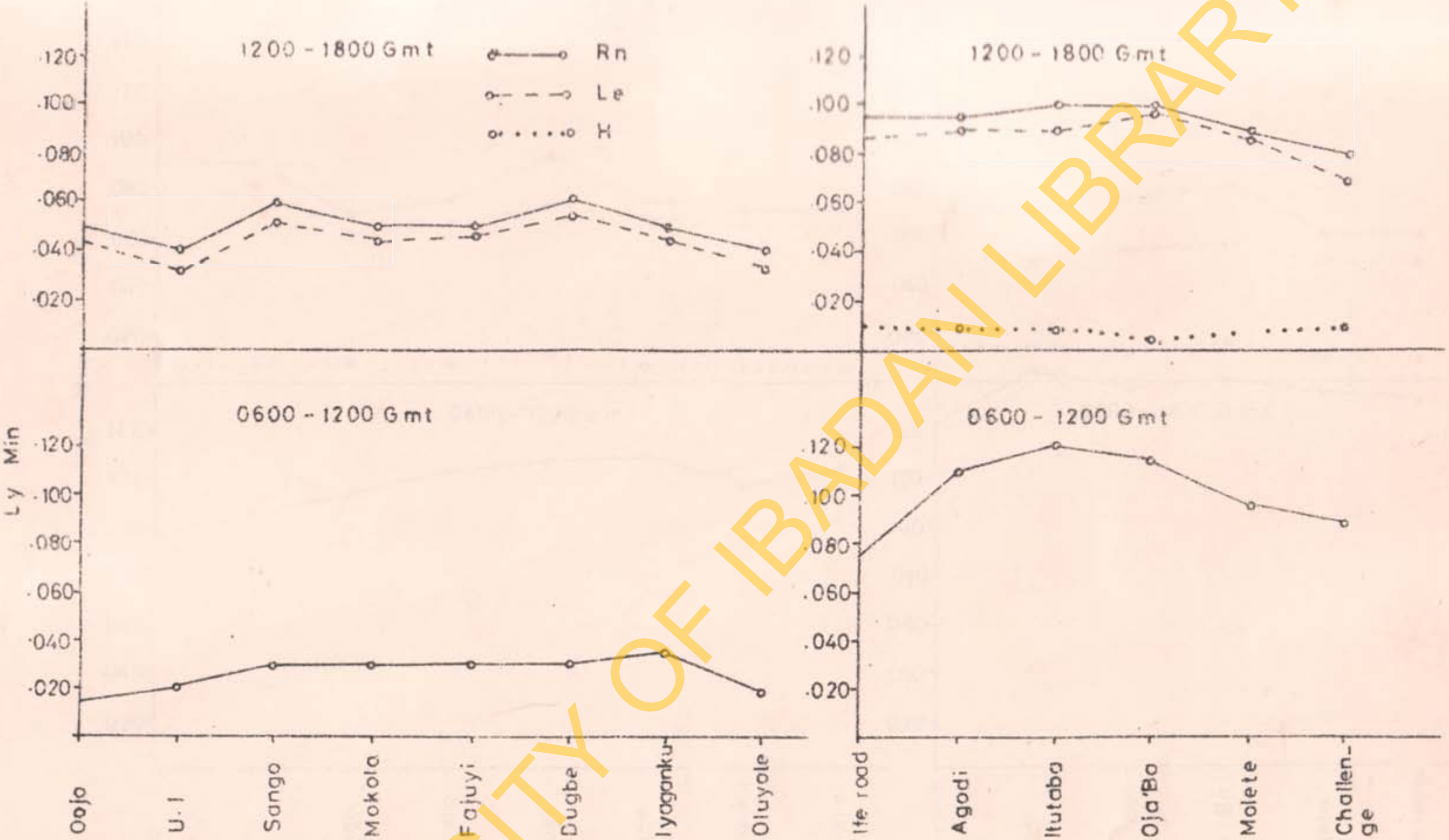


Fig. 5.34 : Net radiation (Rn), Latent heat (Le) and Sensible heat (H) Traverses 08-06-83

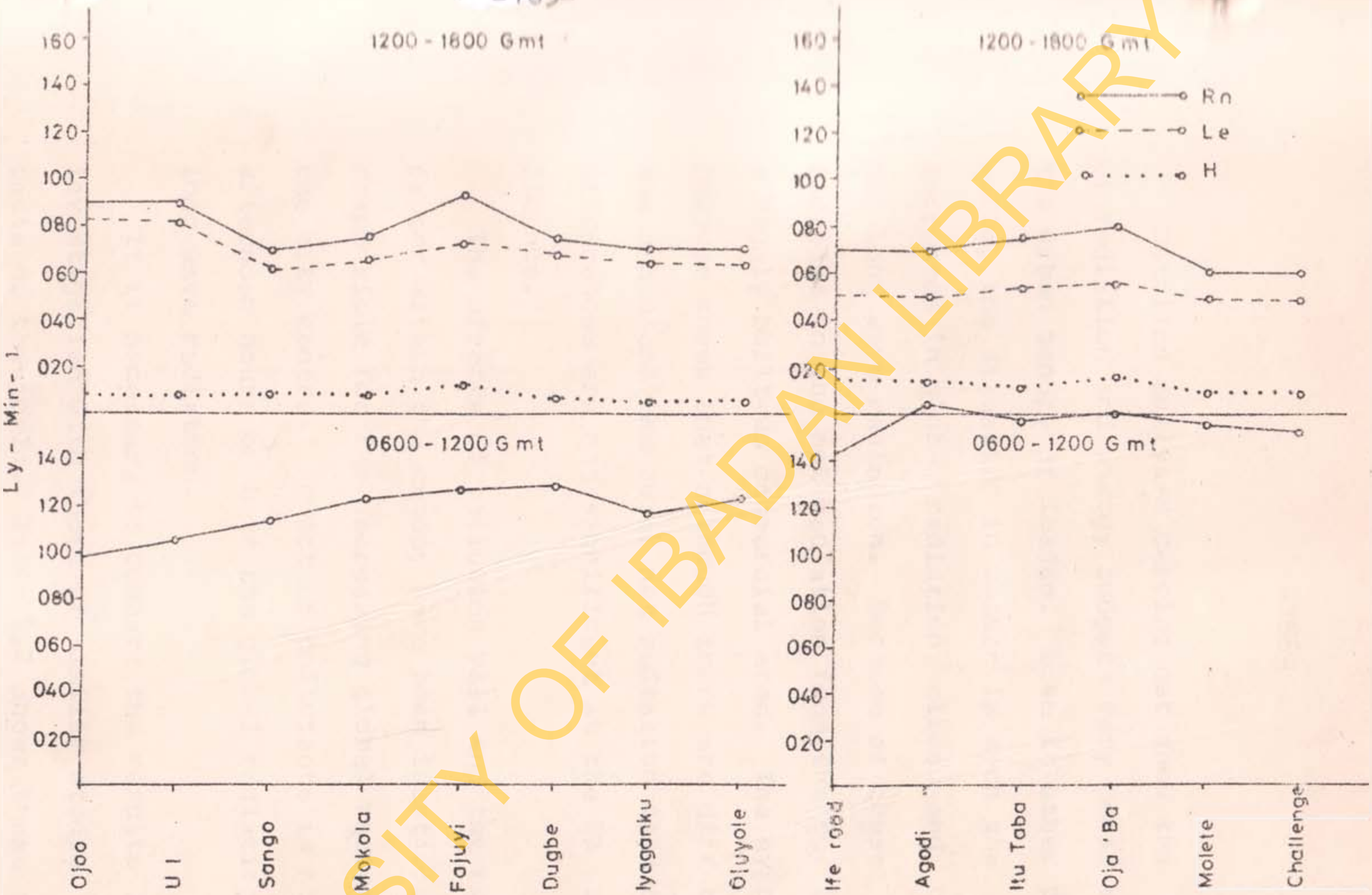


Fig. 5.35 : Net radiation (Rn) Latent heat (Le) and Sensible heat (H) Traverses (03-08-83)

Detailed analyses carried out show tha components of radiation and energy budgets vary consi erably over the urban canopy of Ibadan. Like in other parts of the world, the situation in Ibadan is such tha there are decreases in global radiation, albedo and ncrease in net long wave radiation. Because of these there is an increase in the net radiation from the rur l areas towards a highly built-up commercial area. The hypothesis tested however shows that although there are differences between the urban and the rural net radiation conditions, the differences are not significant at the 5% level of significance.

The effects of pollution veil and the reduced sky view factor within the canopy have been identified as being responsible for the decreasing global radiation towards the city centre. Impact of pollutants is more felt during afternoon hours on both the global radiation and the net long wave radiation.

It is necessary to compare the results of this investigation with those of similar studies in other parts of the world. Table 5.2 shows these results, with the exception of results for net long wave radition which was not directly measured.

Table 2

Comparison of Urban Effect on Some Components of Radiation Budget

Parameter	Observation Area	Observer	Urban Decrease/Increase
Global Radiation (Q + q)	Houston	Randerson (1970)	23% decrease
	Los Angeles	Stair (1966) Nader (1967)	38 - 50% decrease
	St. Louis	Dabberdt and Davis (1974)	19% decrease
	Ibadan	Present study	**14% decrease**
Albedo (a)	Lagos	Ojo (1981)	11% decrease
	Sacramento, California	Morgan, *et al* (1977)	30% increase
	Columbia, Maryland	Landsberg (1979)	10 - 20% decrease
	Ibadan	Oguntoyinbo (1970)	20% decrease
	Ibadan	Present study	**25% decrease**
Net Radiation (Rn)	Sacramento, California	Morgan, et al (1977)	6% decrease
	Columbia, Maryland	Landsberg (1977)	20% decrease
	Ibadan	Present study	**15% increase**

It is clear from the table that there is general decrease in global radiation over most cities. This shows the role generally played by pollutant, which is the major cause of decrease in short wave global radiation over the urban areas. Pollution is common to urban atmospheres. There is also a general decrease in albedo except for Sacramento, California where there are likely to be more reflecting surfaces within the city than the seasonal green rural surroundings. Net radiation increases towards the city centre in California and Maryland. This could be because of the time the recordings were carried out, in the morning and late afternoon hours, when the impact of the city on net radiation is not likely to be glaring. The net radiation is generally higher in the afternoon hours.

CHAPTER 6

6.0 CHARACTERISTICS OF TEMPERATURE AND RELATIVE HUMIDITY WITHIN THE URBAN CANOPY

In the preceding chapter, the surface disposition and utilization of the energy coming from the sun was considered. This was done through the detailed analyses of the spatial, diurnal and seasonal patterns of some of the components of the radiation and energy budgets equations (see eqns 2.1 and 2.2). Results of these analyses show that there are spatial variations in these climatic parameters because of the variations in urban surface textural characteristics and its atmospheric contents. The spatial disparities in the city surface texture and the atmospheric characteristics had earlier been established in Chapter Four and was found to be as a result of the process of urbanization.

This chapter discusses the conditions of temperature and relative humidity within the urban canopy of Ibadan because these climatic parameters are regarded as being dependent on the radiation and energy budgets conditions studied in the previous chapter.

An analysis of temperature and relative humidity characteristics within the urban canopy is also important because human physiologic comfort is determined primarily by them.

The first to be considered are temperature characteristics, whose variabilities are considered on spatial, diurnal and seasonal bases. Further look is taken into the diurnal characteristics by considering the conditions at 0700 and 1500 hours of GMT. The pattern of urban heat island intensities is presented in both tabular and map forms for both the wet and dry seasons. Following are the analyses of relative humidity conditions which focus on the spatial, diurnal and seasonal variabilities. A hypothesis is tested on the urban-rural differences in both climatic parameters before a conclusion is drawn on the general conditions of temperature and relative humidity within the urban canopy of Ibadan.

6.1 Temperature Characteristics

Temperature is regarded as the degree of hotness and/or coldness of a surface or a body. According to Critchfield (1979), it is a relative term implying a degree of molecular activity, or heat, of a substance.

If the heat of one body flows to another we say that the former has the higher temperature. We can talk of the temperature of a body or of the air atmosphere). In this investigation, we are referring to the latter. Urban temperature is very important because it affects human physiologic comfort, commerce, day to day activities and even other climatic parameters. The spatial, diurnal and seasonal patterns are dealt with under this section.

There is a general increase in temperature towards the city centre (Figs. 6.1 – 6.6). In the wet season, the temperature varies from 23.0°C in the rural area to 24.5°C at the city centre of Dugbe, Adamasingba, Oke-Ado, Mapo, Orita Aperin and Aremo areas during morning hours. It increases to 26.0°C in the rural area and 27.5°C in the urban area during afternoon hours of the wet season. These represent about 1.0°C to 1.5°C increase in temperature towards the city centre during the wet season. The temperature of the city centre, is thus, between 5.5% and 6.1% higher than that of the suburb during this period.

The spatial pattern during the harmattan season is not quite different (Figs. 6.4 to 6.6) except the increase in gap in the temperature amount between the

172

Fig. 6· 1 Temperature during the Wet Season (°C)

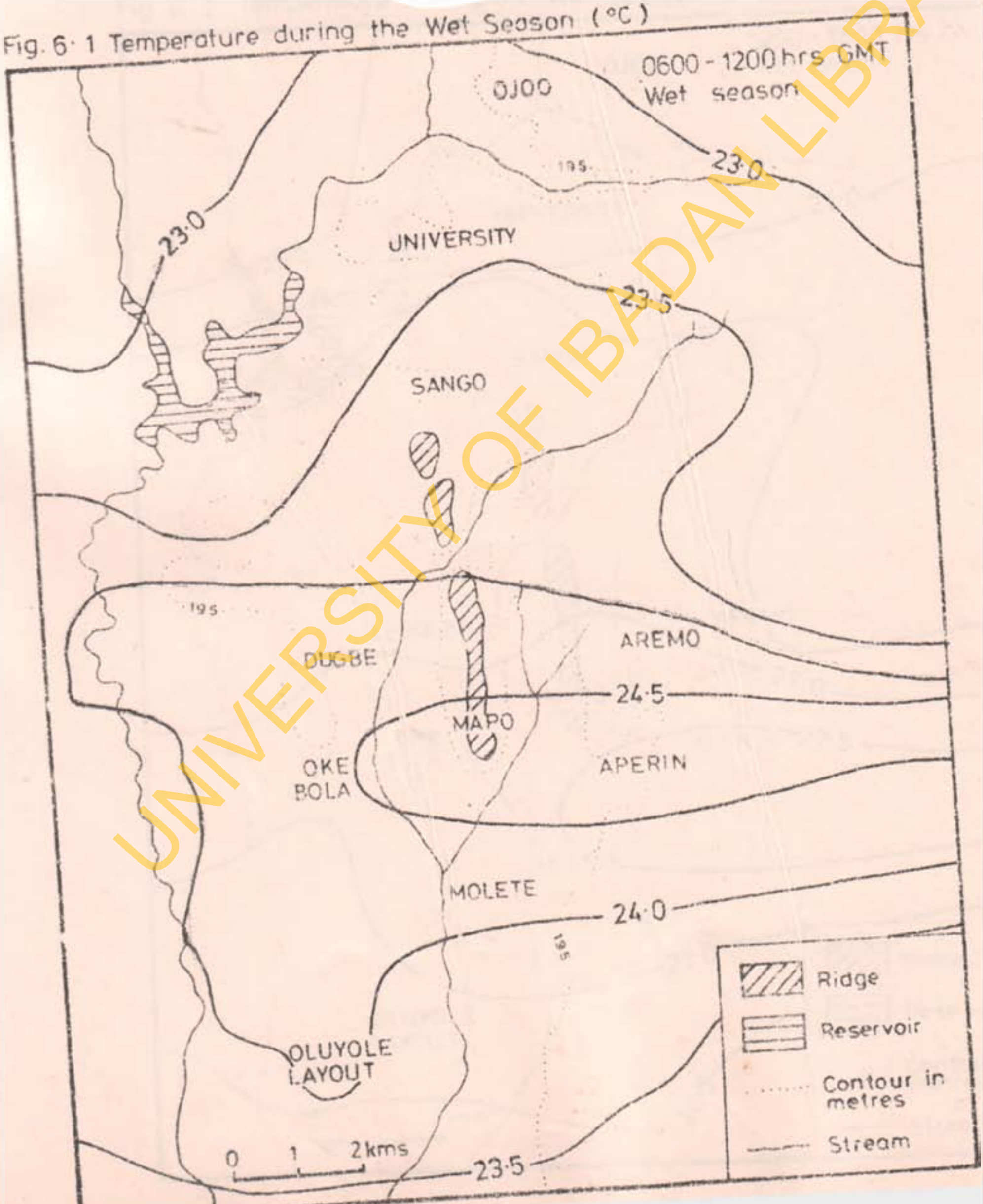


Fig. 6·2 Temperature during the Wet Season (°C)

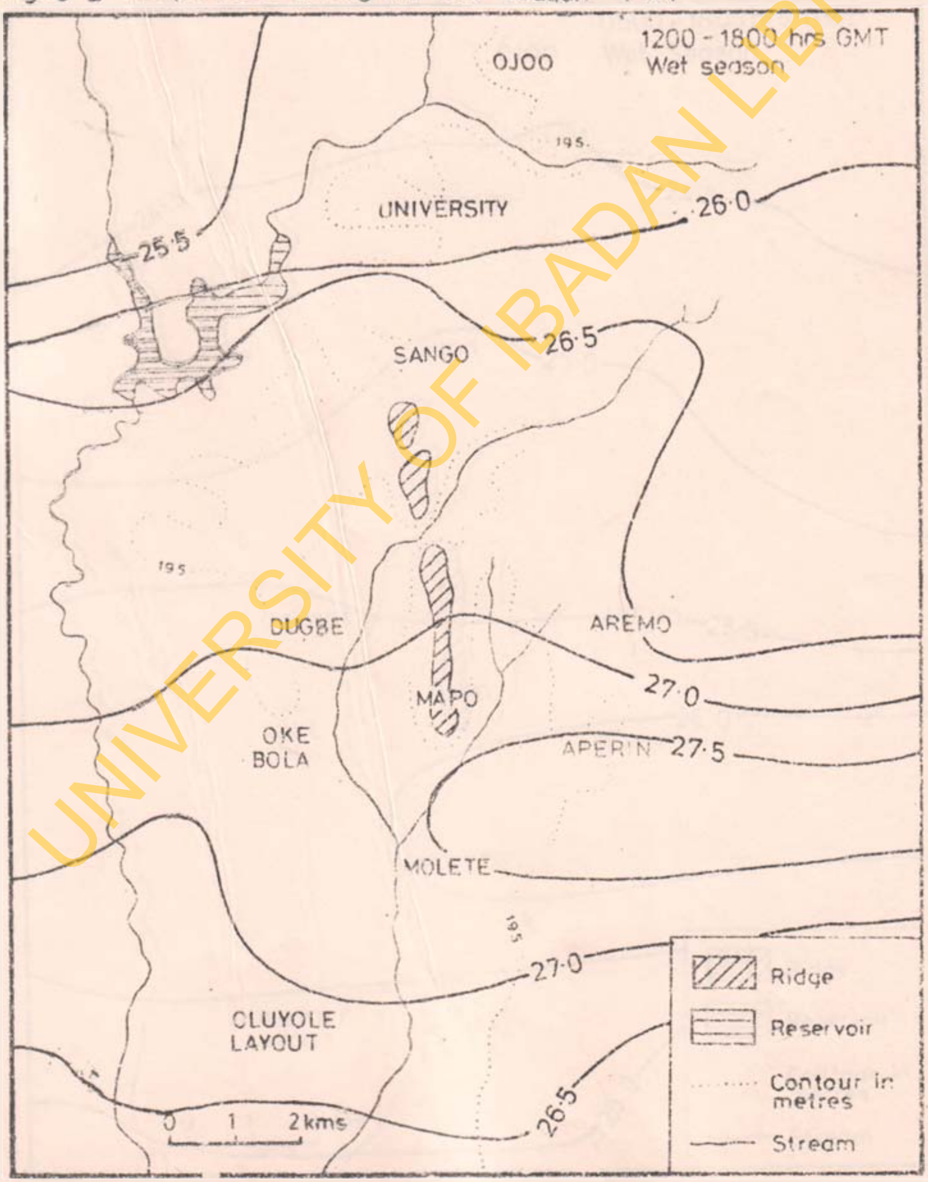


Fig. 6·3 Temperature during the Wet Season (°C)

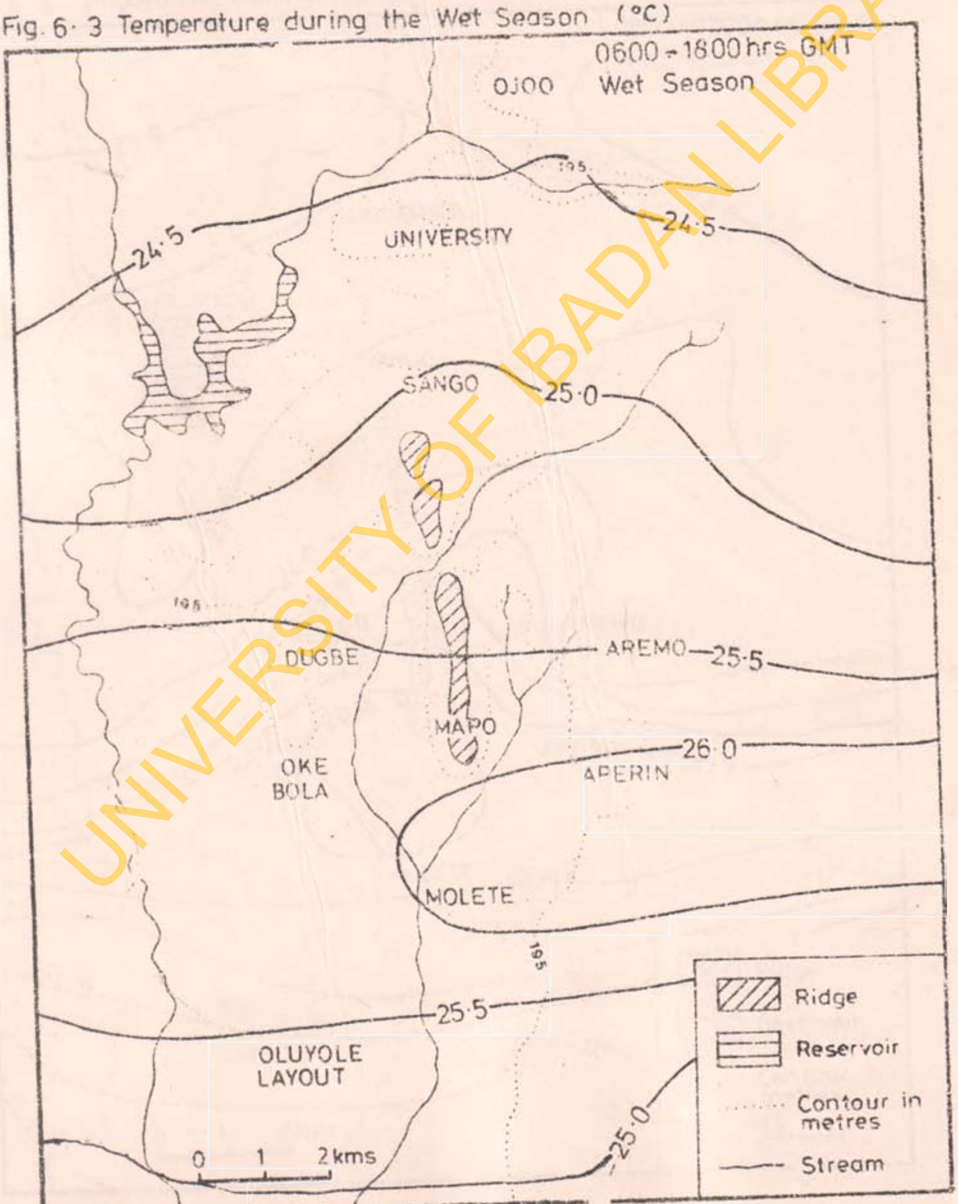


Fig. 6·4 Temperature during the Harmattan (°C)

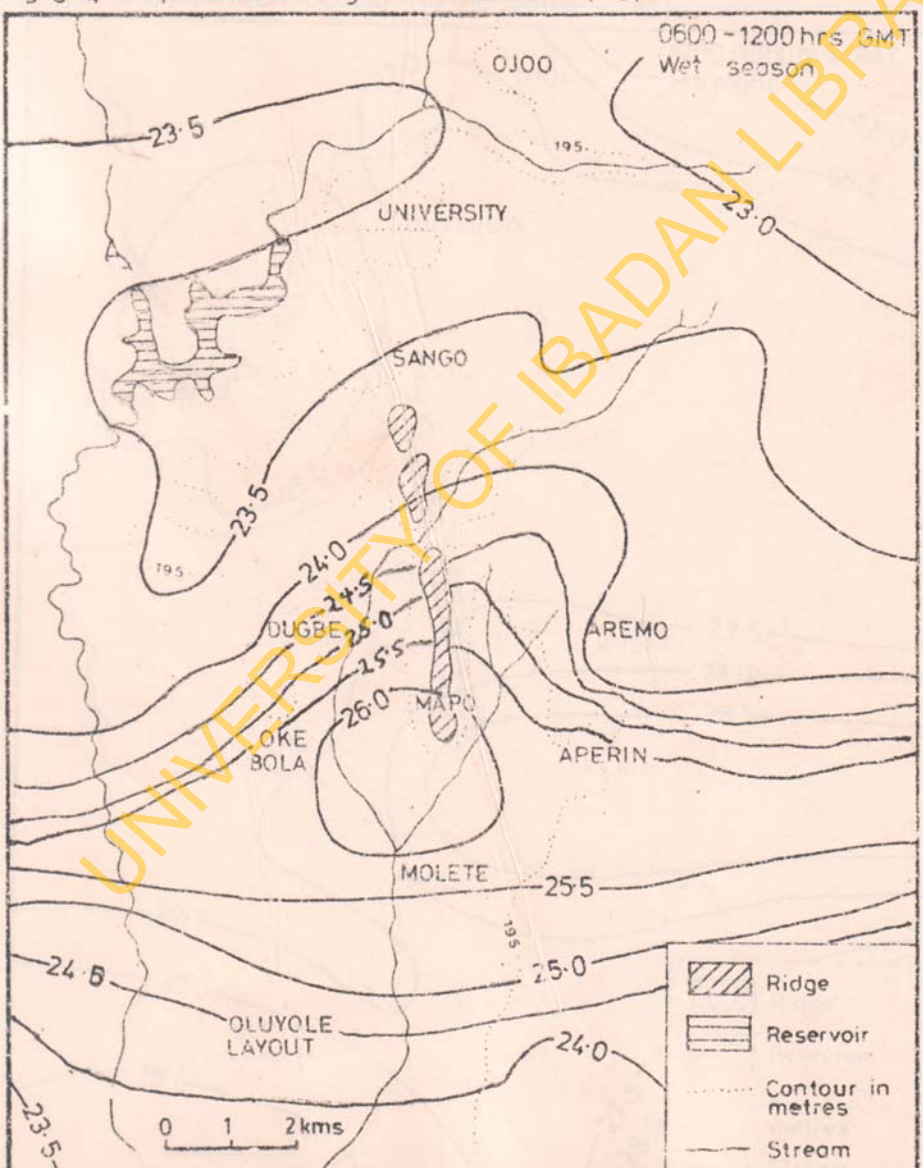


Fig. 6·5 Temperature during the Harmattan (°C)

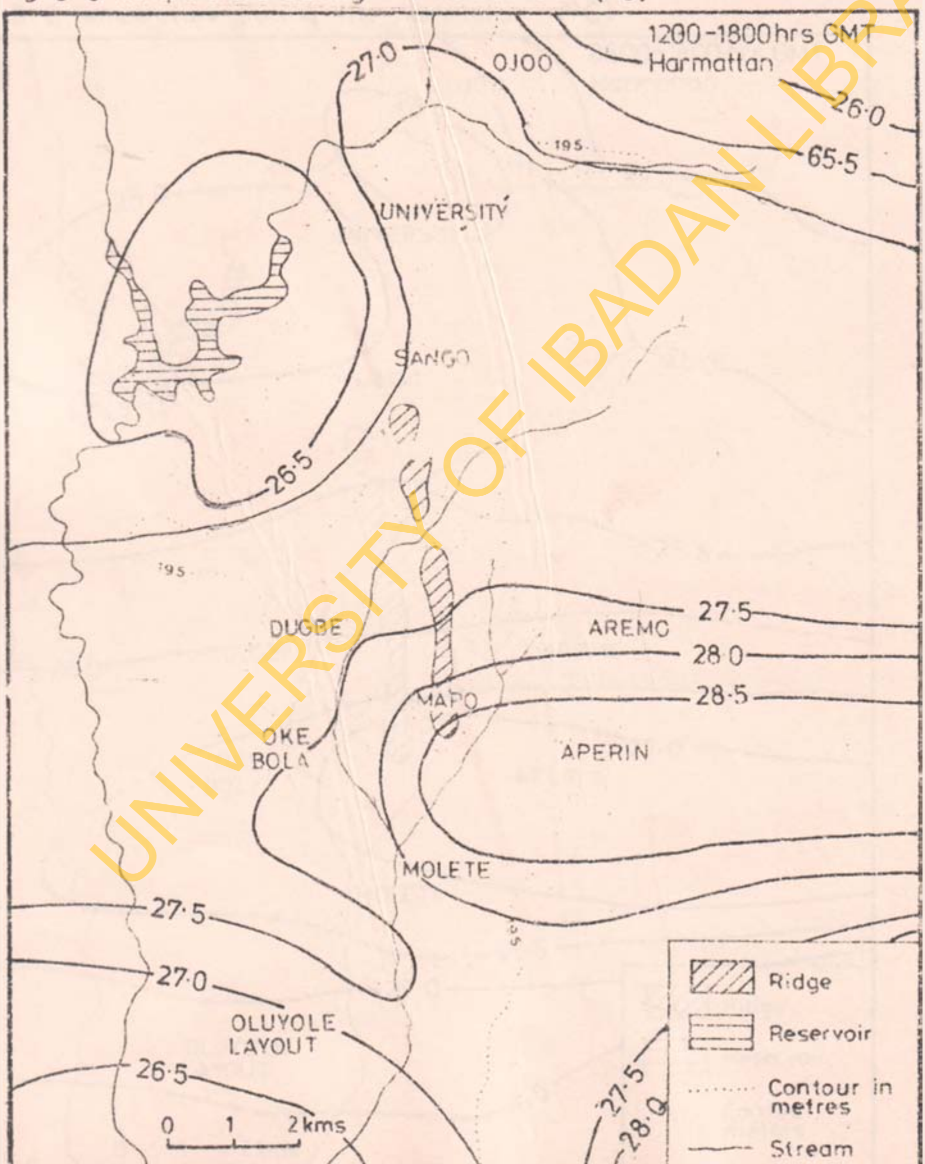
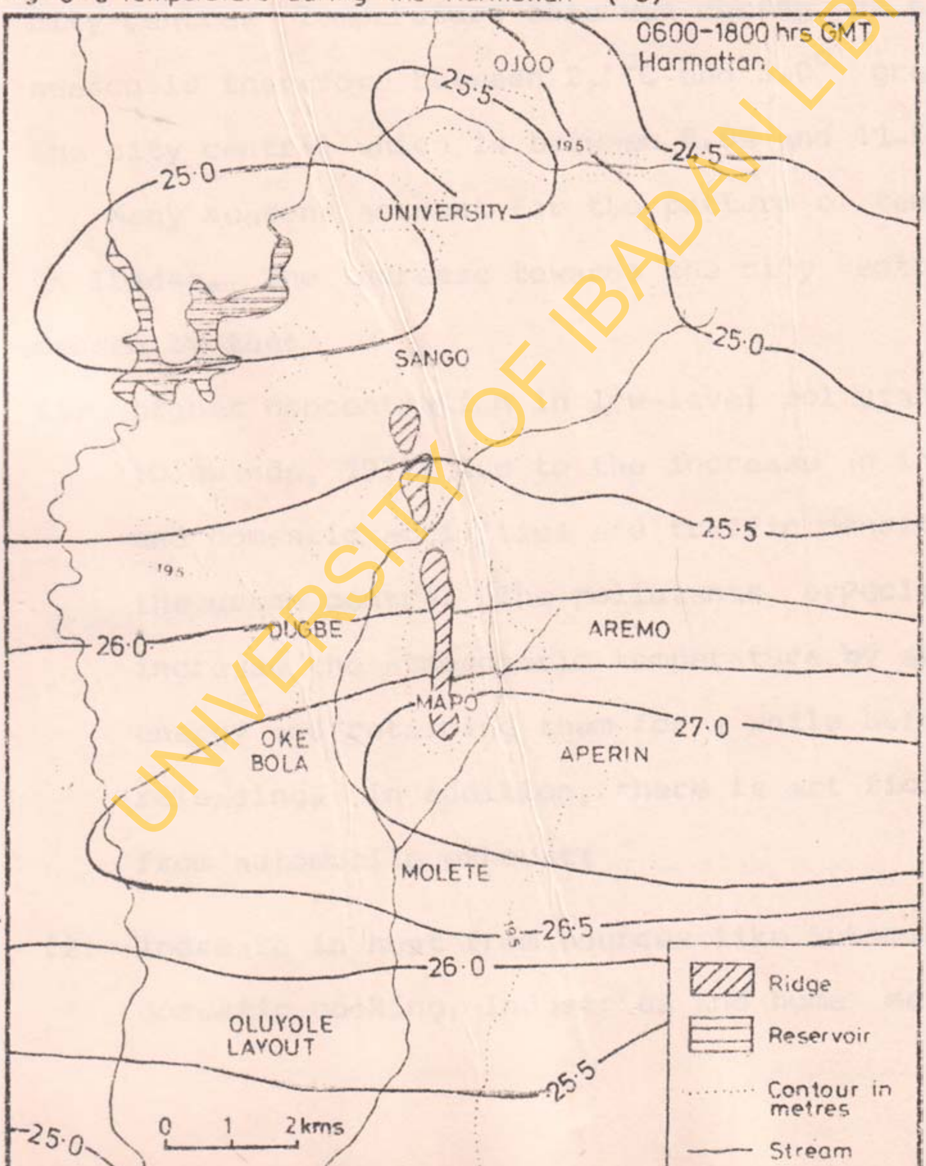


Fig. 6· 6 Temperature during the Harmattan (°C)



urban and rural environments. The tempera ure increases from 23.0°C in the rural area to 26.0°C in the urban area in the morning hours, and from 26.0°C to 28.5°C in the afternoon hours. With these there is mean increase from between 24.5°C in the rural area to 27.0°C at the city centre. Temperature observed during he harmattan season is therefore between 2.5°C and 3.0° greater at the city centre, which is between 8.8% and 11.5% increase.

Many reasons account for the pattern o temperature in Ibadan. The increase towards the city entre is caused by the:

(1) higher concentration in low-level pollutants (Oluwande, 1977) due to the increase in industrial and domestic activities and traffic density towards the urban centre. The pollutants, especially CO_2, increase the atmospheric temperature by absorbing energy and retaining them for a while before releasing. In addition, there is art ficial heat from automobile exhaust;

(2) increase in heat from sources like automobiles exhaust domestic cooking, industries and huma metabolism.

(3) emission of heat absorbed by buildings, tarmac and concrete surfaces whose concentration increases towards the heavily built-up area, and

(4) increase in net radiation towards the city centre because of the reduction in the effective out-going long wave radiation. Increase in the intensity of the pollution veil towards the city centre leads to a reduction in the amount of energy lost to space.

There is a clear diurnal variation in temperature condition in the figures 6.1 to 6.6 earlier described. The figures show that there is almost an equal degree of difference in the mean amount of temperatures for both morning and afternoon hours. To have more insight into this, temperature conditions at 0700 hours of GMT, when the atmosphere is just heating up in the morning, and 1500 hours of GMT when the highest amount of temperature was observed in the afternoon, are plotted (Figs. 6.7 to 6.10). Figs. 6.7 and 6.8 show that variation in temperature begins right from the morning hours when as much as between 1.0°C and 3.0° differences exist between the urban centre and the rural environments. The differences increase to between 3.0°C and 8.0°C at 1500 hours of GMT.

Fig. 6· 7 Temperature during the Wet Season (°C)

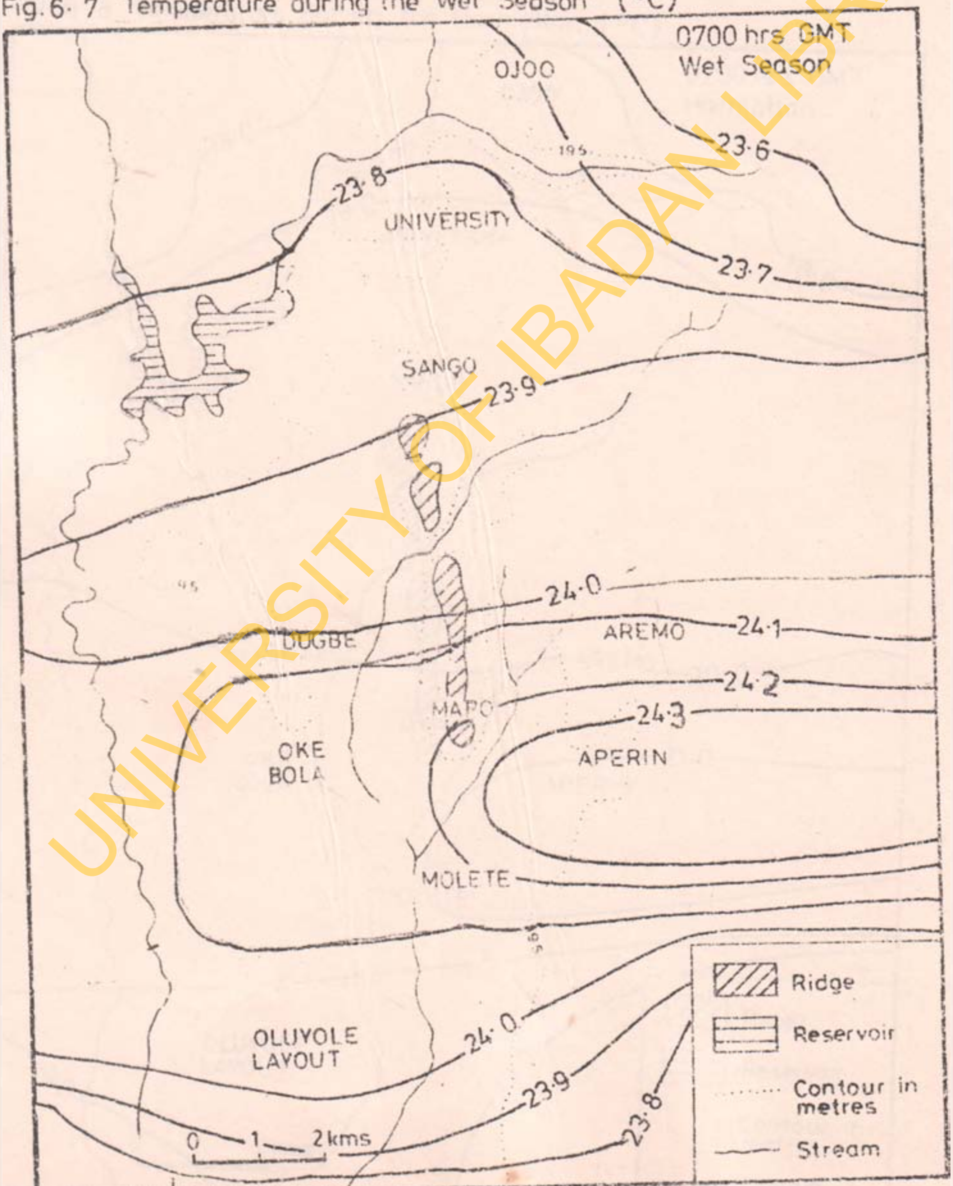


Fig. 6· 8 Temperature during the Harmattan (°C)

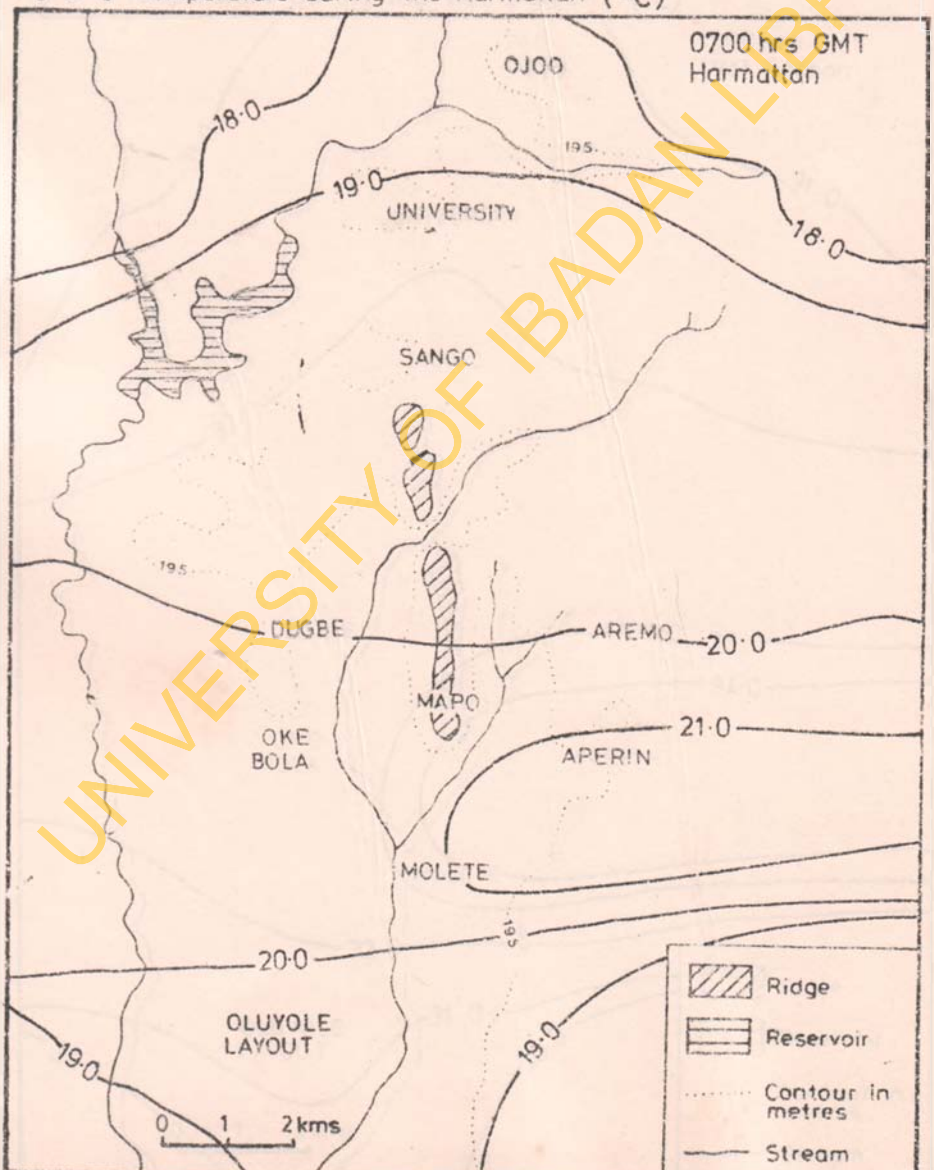


Fig. 6· 9 Temperature during the Wet Season (°C)

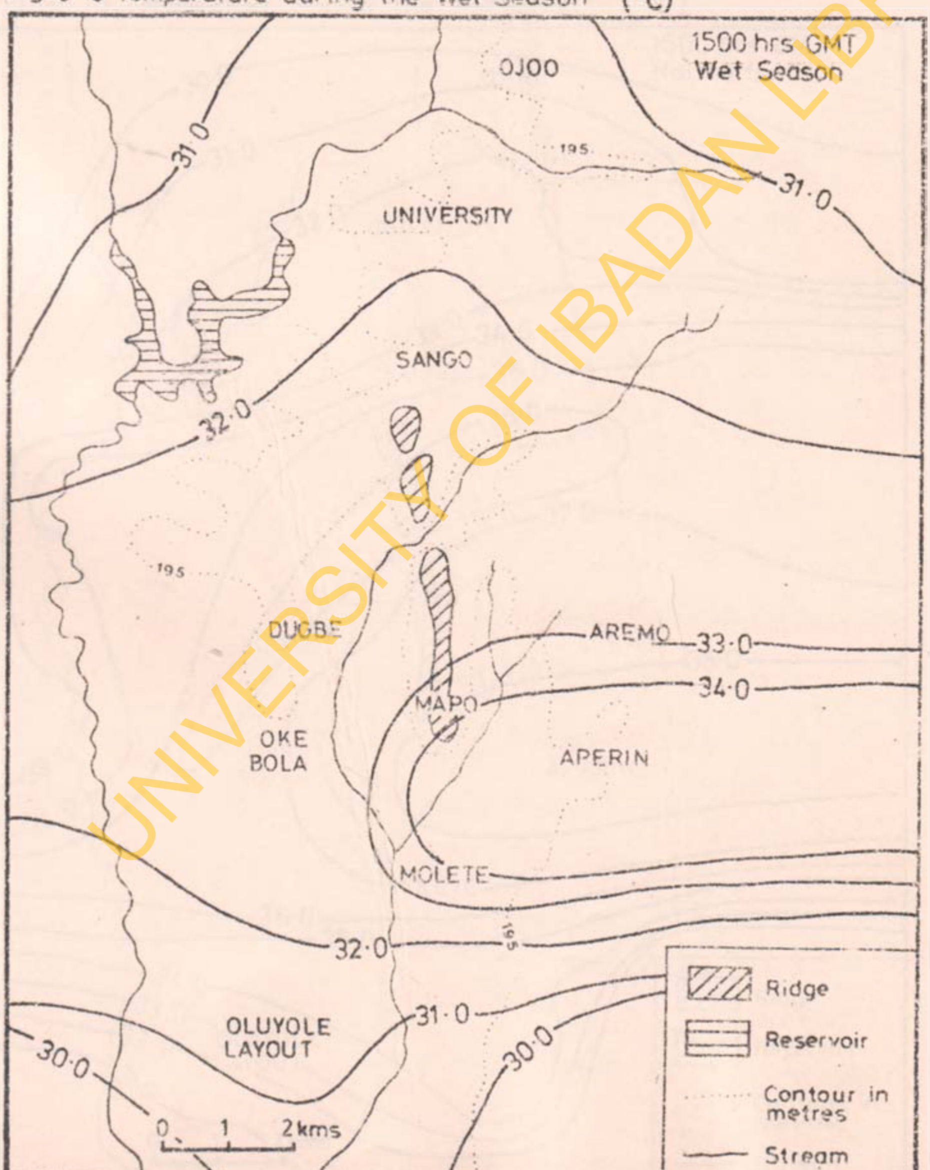
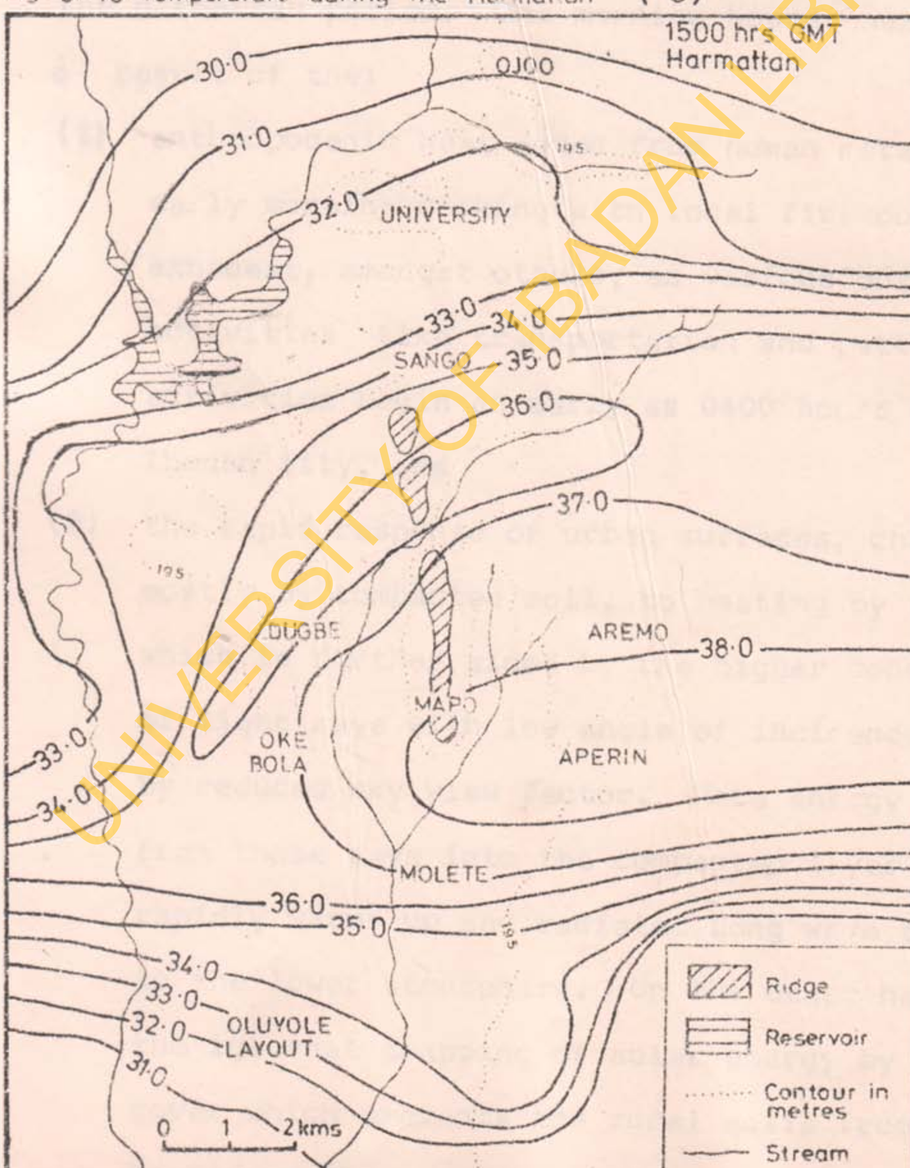


Fig. 6·10 Temperature during the Harmattan (°C)



From the diurnal pattern analysed, it is clear that the temperature within the city centre is higher than that of the rural surroundings by as much as 3.0°C during the wet season. This difference increases to about 8.0°C during the harmattan period. The morning hours 'heat island' is as a result of the:

(1) anthropogenic heat added from human metabolism, early morning cooking with local fire wood, automobile exhauast, amongst others, as various outdoor activities like transportation and petty commercial activities begin as early as 0400 hours of GMT in Ibadan city, and

(2) the rapid response of urban surfaces, characterized mostly by compacted soil, to heating by the sun which is further aided by the higher concentration of light rays with low angle of incidence caused by reduced sky view factor. More energy is absorbed from those rays into the compacted layer of soil which rapidly warms up and radiates long wave to return heat to the lower atmosphere. On the other hand, there is the internal trapping of solar energy by the vegetal cover which prevents the rural soils from being directly heated up (Oguntoyinbo, 1972).

The urban 'heat island' maps, Fig. 6.11 and 6.12 are produced for the 1800 hours GMT. The 'heat island' increases from the rural area to the urban centre because of the reasons given earlier. There is also an increase in the harmattan season's 'heat island' compared with the wet season. The heat island varies from a mean of 0.5°C to 3.0°C and a mean of 1.5°C to 7.0°C during the wet and the harmattan seasons respectively. Fig. 6.10 shows that a temperature difference of 8.0°C exists between the urban and the rural environment at 1500 hours GMT. It can thus be concluded that the urban 'heat island' effect is higher at 1500 than at 1800 hours. Observations of 'heat island' on traverse days show considerable variation over time. There is higher amount during the harmattan season (see table 6.1).

Fig. 6·11 Urban Heat Island Intensity during the Wet Season (°C)

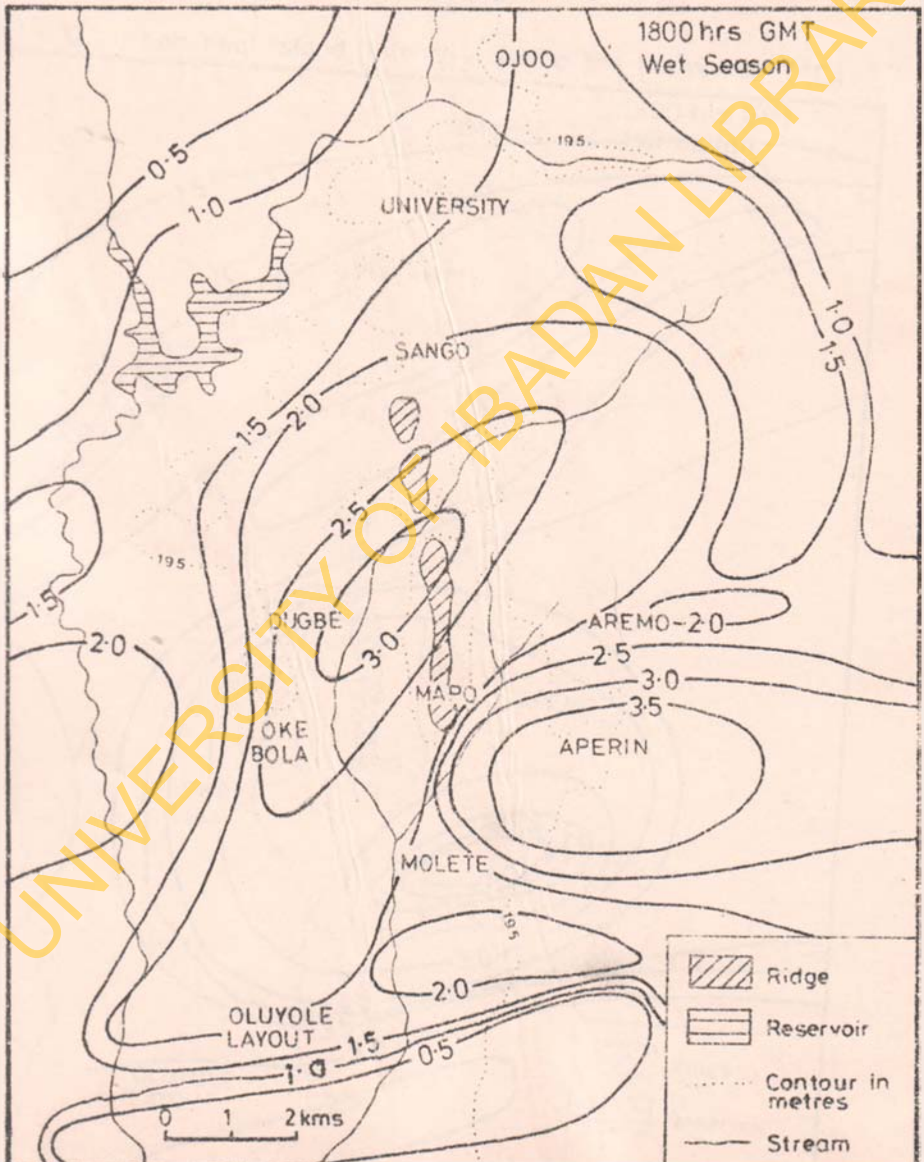
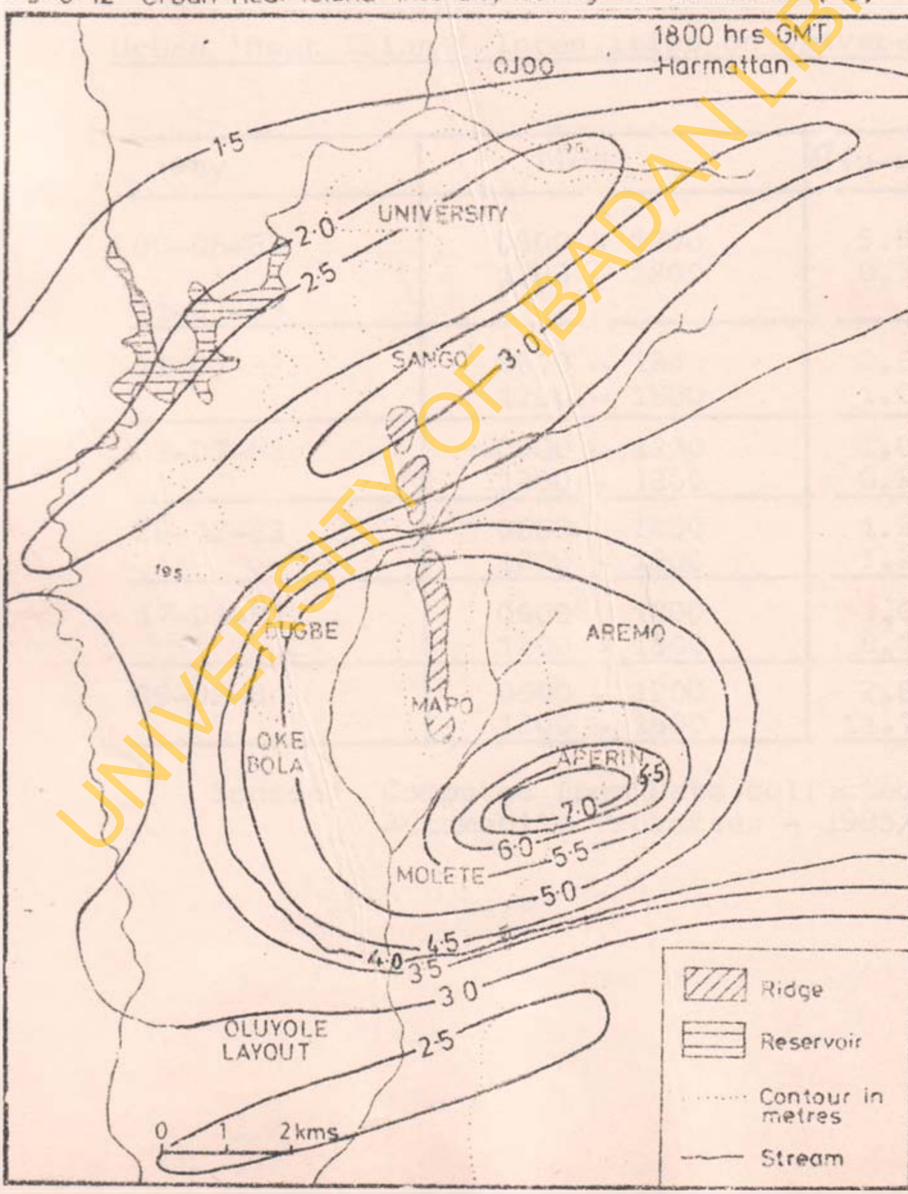


Fig. 6·12 Urban Heat Island Intensity during the Harmattan (°C)



There is higher amount duri.g the harma'tan season (see table 6.1).

Table 6.1

Urban 'Heat Island' Inten:ities on Traverse Days

Day	Time	ΔT (u-r) °C	Period
08-06-83 11-07-83	0600 - 1200 1200 - 1800	5.9 0.7	Wet Season
11-07-83	0600 - 1200 1200 - 1800	0.6 1.0	Wet Season
03-07-83	0600 - 1200 1200 - 1800	1.0 0.2	Wet Season
28-12-83	0600 - 1200 1200 - 1800	1.2 1.2	Harmattan Season
17-01-84	0600 - 1200 1200 - 1800	3.0 6.1	Harmattan Season
09-02-84	0600 - 1200 1200 - 1800	2.8 11.7	Harmattan Season

Source: Computed from Data collected during Automobile Traverses - 1983/84.

6.2 Relative Humidity Characteristics

Humidity is a general term connoting the amount of water vapour in the air. There are three different common measures of humidity: specific, absolute, and relative. Critchfield (1979) defined them as follows: specific humidity is the ratio of the mass of water vapour actually in the air to a unit mass of air; absolute humidity is the mass of water vapour contained in a unit volume of air, and relative humidity is the ratio of the amount of water vapour actually in the air to the amount the air can hold at a given temperature and pressure.

The analysis of urban impact on relative humidity is important because it (relative humidity) is one of the very important factors which influence the energy budgets, and human physiological comfort.

Different factors account for the variations in relative humidity. These include the:

(1) availability of water for the process of evapotranspiration;

(2) availability of energy in the atmosphere, to vaporize water, with more evaporation, the water in the air increases;

(3) the velocity of the prevailing wind which regulates the process of evapotranspiration, higher wind speed aids the process of evapotranspiration, and

(4) air temperature which controls the expansion and contraction of air parcels, therefore indirectly determining the capacity of the air to hold moisture.

The factors listed above do not act differently. It is the interplay of all the forces that determines the amount of water vapour in the air. The above factors vary considerably over the heterogeneous city surface. It is therefore desirable to study the pattern of the variation in humidity, as affected by these factors over the highly complex urban metropolis of Ibadan.

Spatial characteristics of the relative humidity over different periods are presented in Figs. 6.13 to 6.18. The results of the observations show there is a decrease in relative humidity towards the city centre. This varies from a mean of 80% in the rural area to 75% in the urban centre during the wet season, which shows a 6.3% decrease. During the harmattan season, the relative

Fig. 6·13 Relative Humidity during the Wet Season (%)

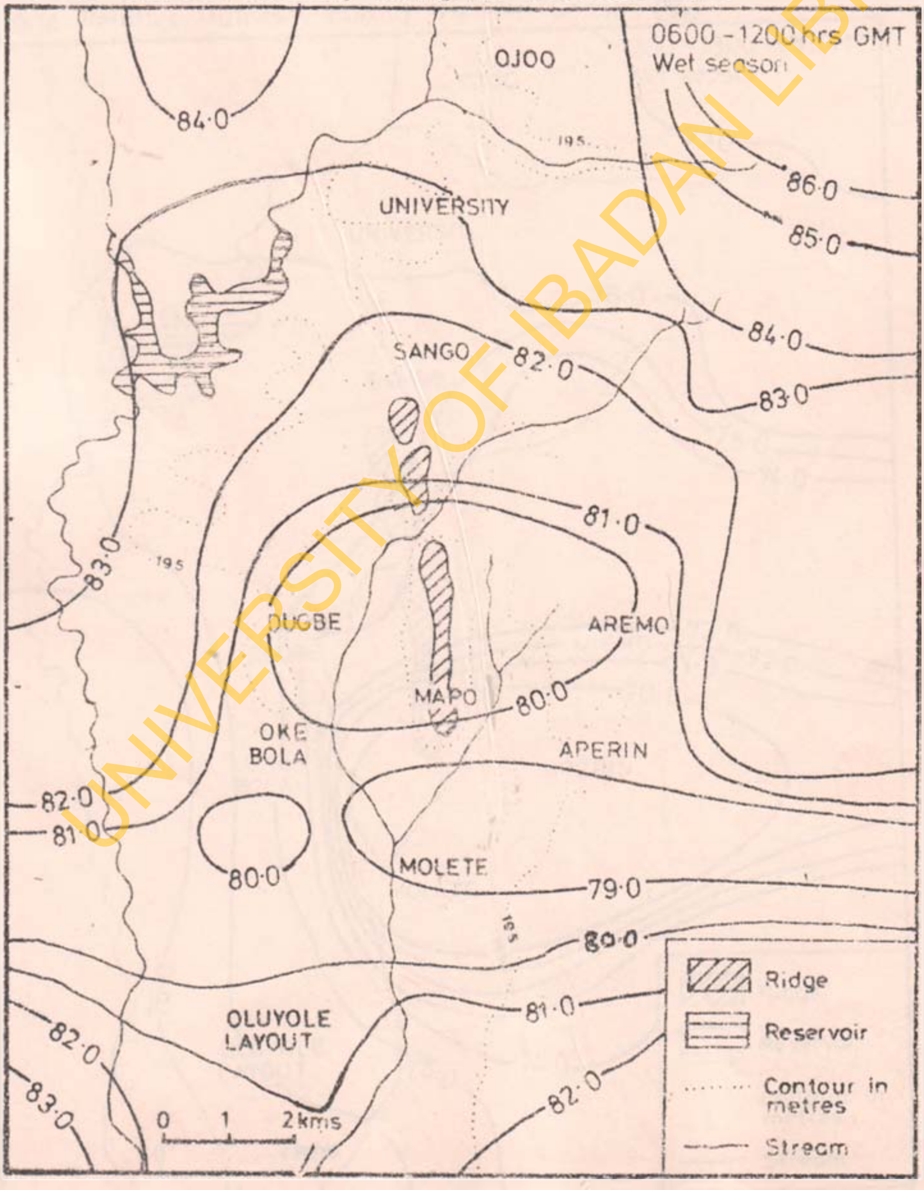


Fig. 6-14 Relative Humidity during the Wet Season (%)

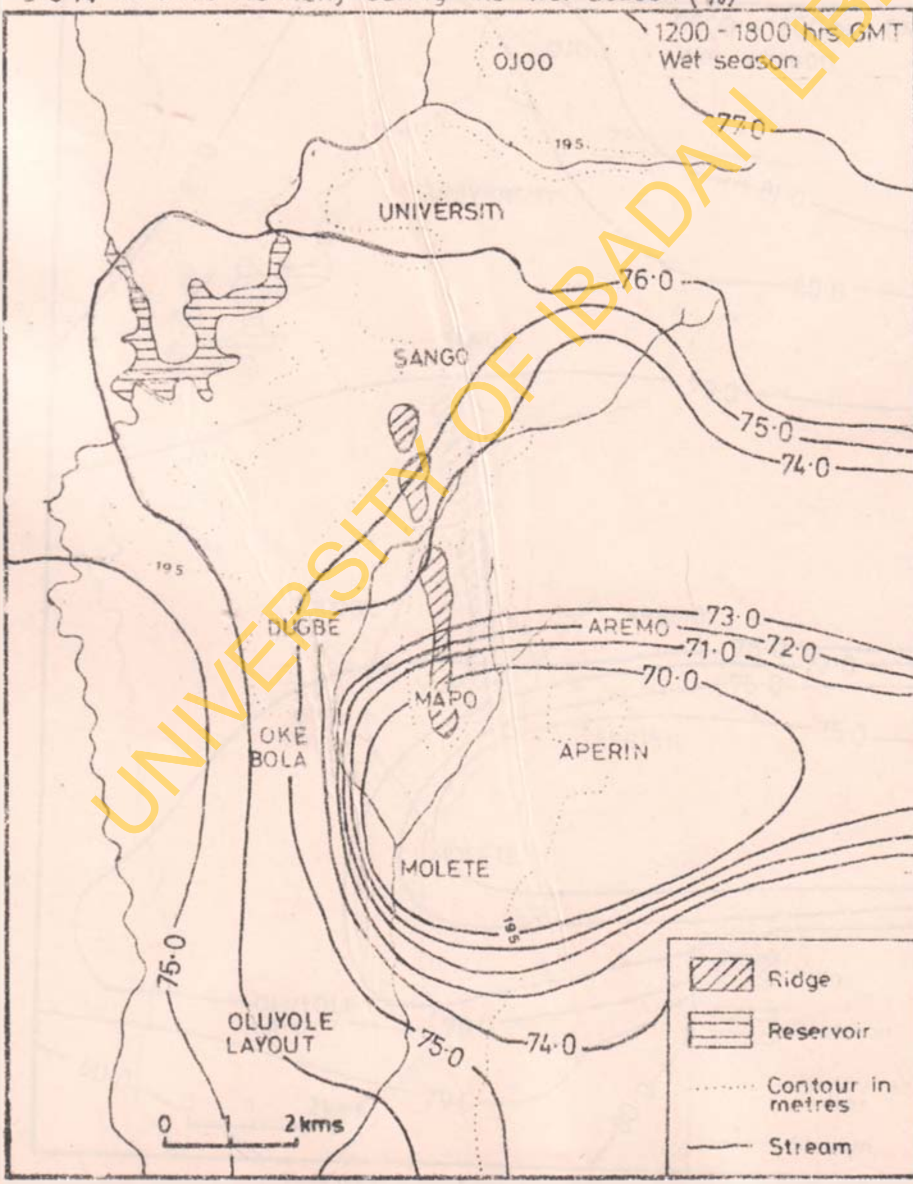


Fig. 6·15 Relative Humidity during the Wet Season (%)

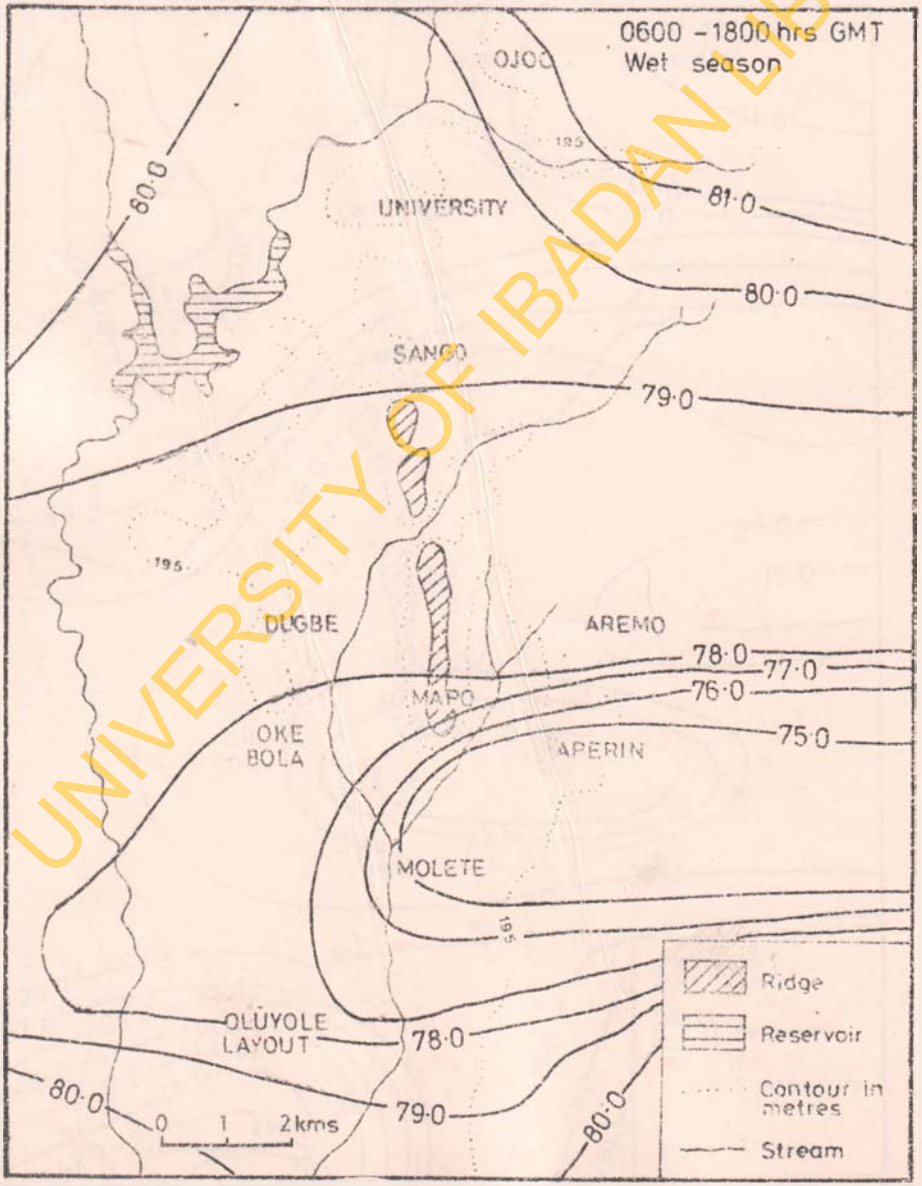
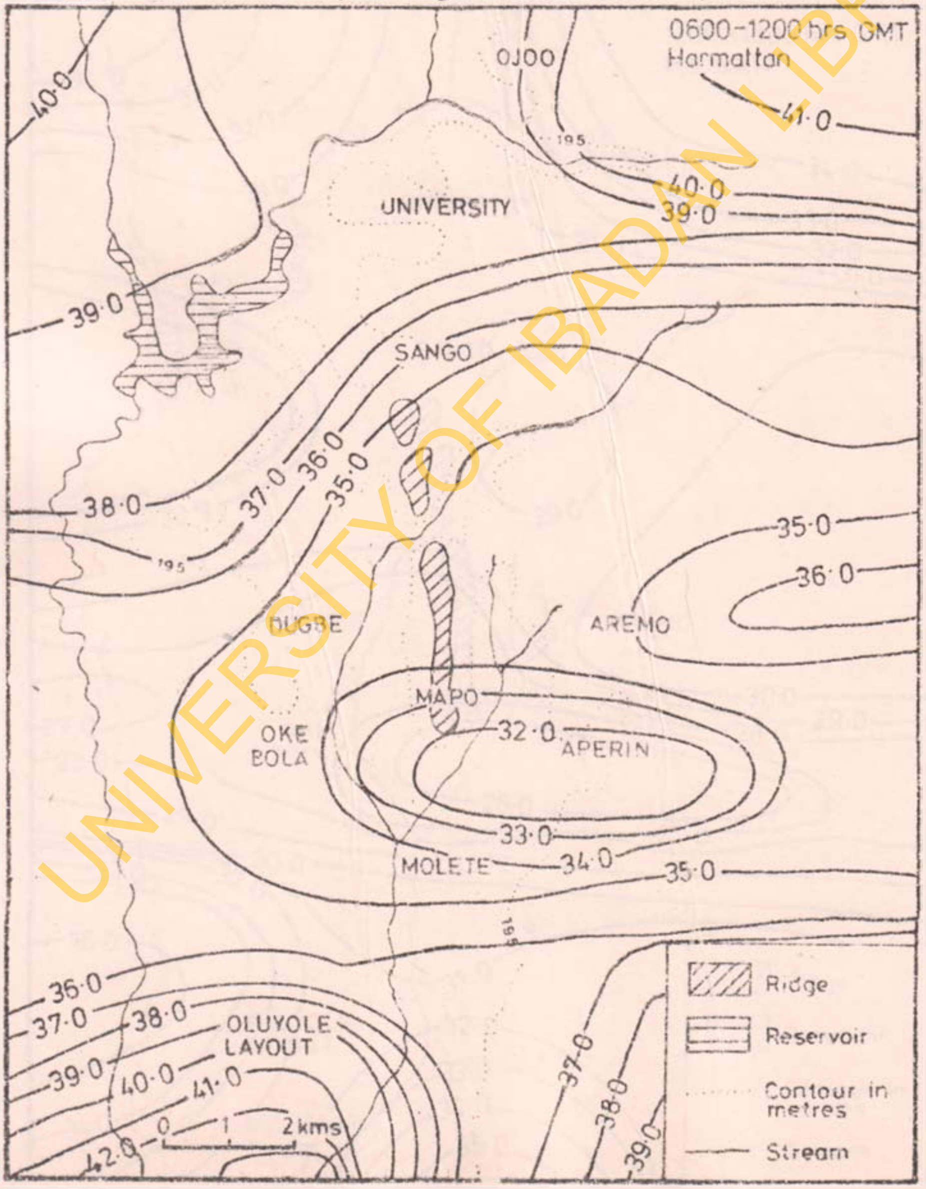


Fig. 6·16 Relative Humidity during the Harmattan (%)



195

Fig. 6·17 Relative Humidity during the Harmattan (%)

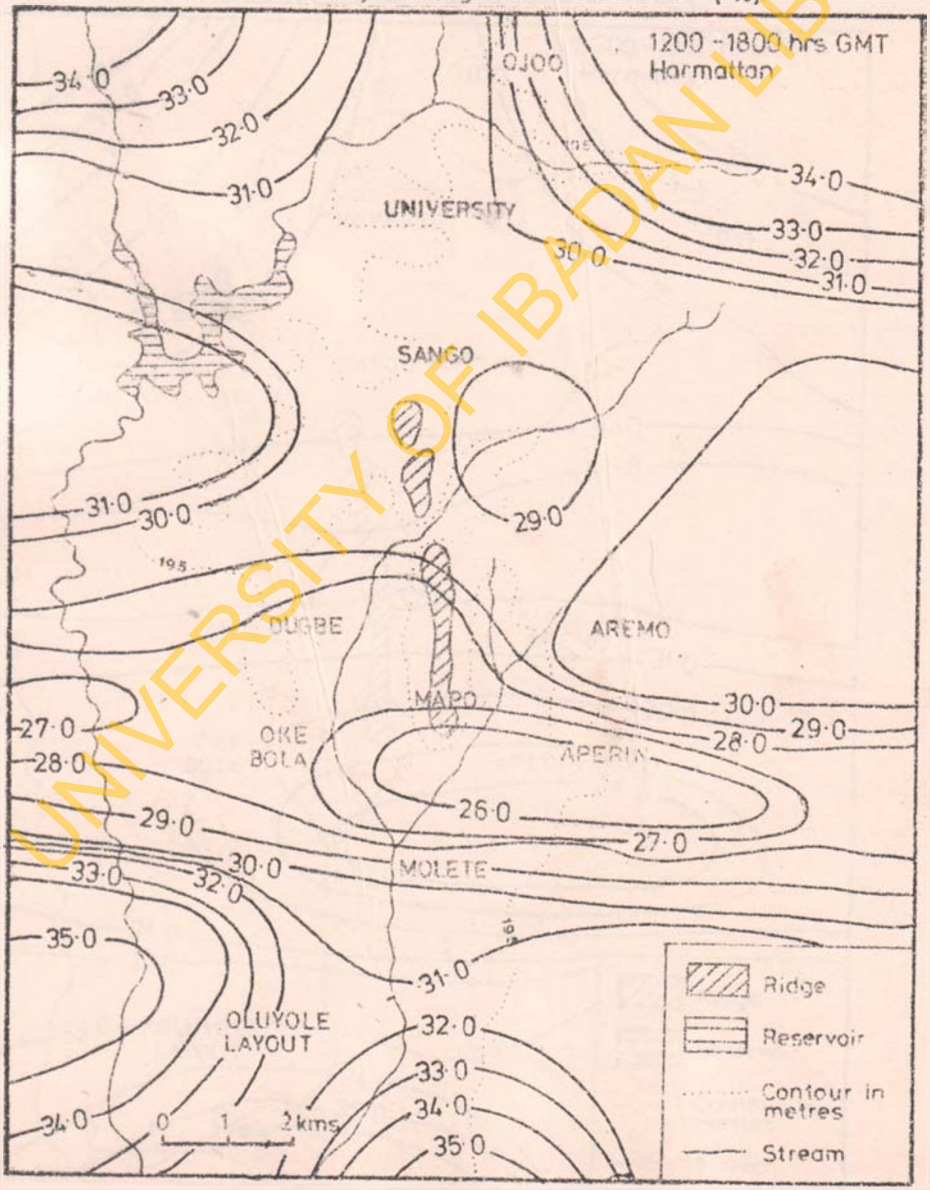
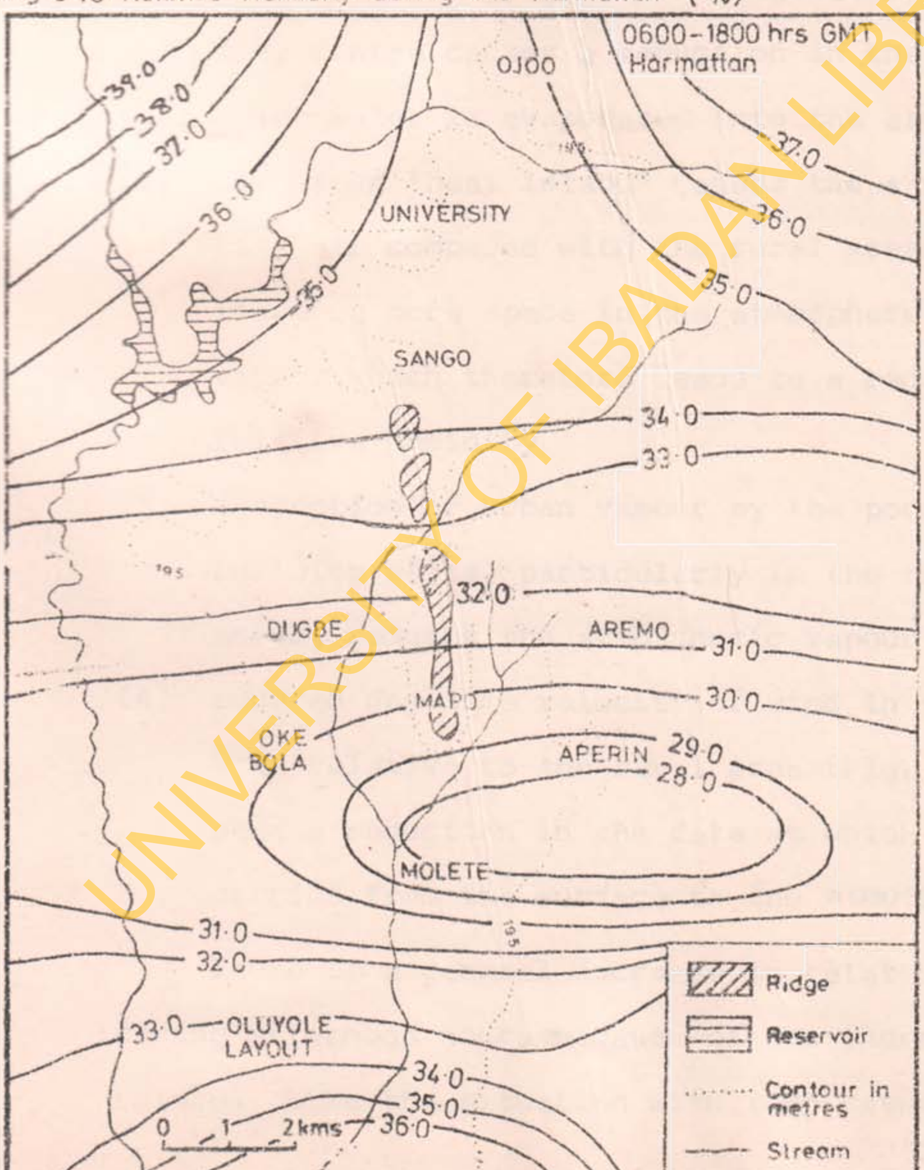


Fig. 6·18 Relative Humidity during the Harmattan (%)



humidity reduces from a mean of 37% in the rural area to 29% in the urban centre, representing a 24.3% fall.

The decrease in relative humidity to the urban centre is caused by a number of factors:

(1) reduction in the amount of vegetation towards the city centre causes a reduction in the source from which water is evaporated into the atmosphere;

(2) the urban 'heat island' causes the expansion of city air compared with the rural areas. Therefore there is more space in the atmosphere for water vapour which therefore leads to a reduction in the relative humidity.

(3) absorption of urban vapour by the porous urban building walls, particularly in the tr_aditional areas, reduces the atmospheric vapour content, and

(4) reduced day-time velocity of wind in the urban area relative to the rural area (Fig. 5.19) would mean a reduction in the rate at which water vapour is carried from the surface to the atmosphere.

There is a general decrease in relative humidity during afternoon hours because of the increase in temperature. Like the situation with temperature, the fall in urban relative humidity is higher during the harmattan period than during the wet season. While the falls are 8.1% and 11.4% respectively during morning and afternoon hours for wet season, they are 21.9% and 28.6% for morning and afternoon hours respectively during the harmattan season. This is because of the increase in urban 'heat island' effect during the harmattan season.

6.3 Temperature and Humidity Characteristics Within the Urban Canopy

The distribution of temperature and humidity within the urban canopy has been considered in this chapter. The analyses have shown that there are spatial, diurnal and seasonal variations in both climatic parameters. While the temperature increases towards the city centre, particularly in the afternoon, the relative humidity decreases.

Figs. 6.19 to 6.24 show the distribution of both temperature and relative humidity across two major transect routes in Ibadan. The return journey for each traverse took about 90 minutes and there were three traverses between 0600 and 1200 hr. GMT. It is also clear

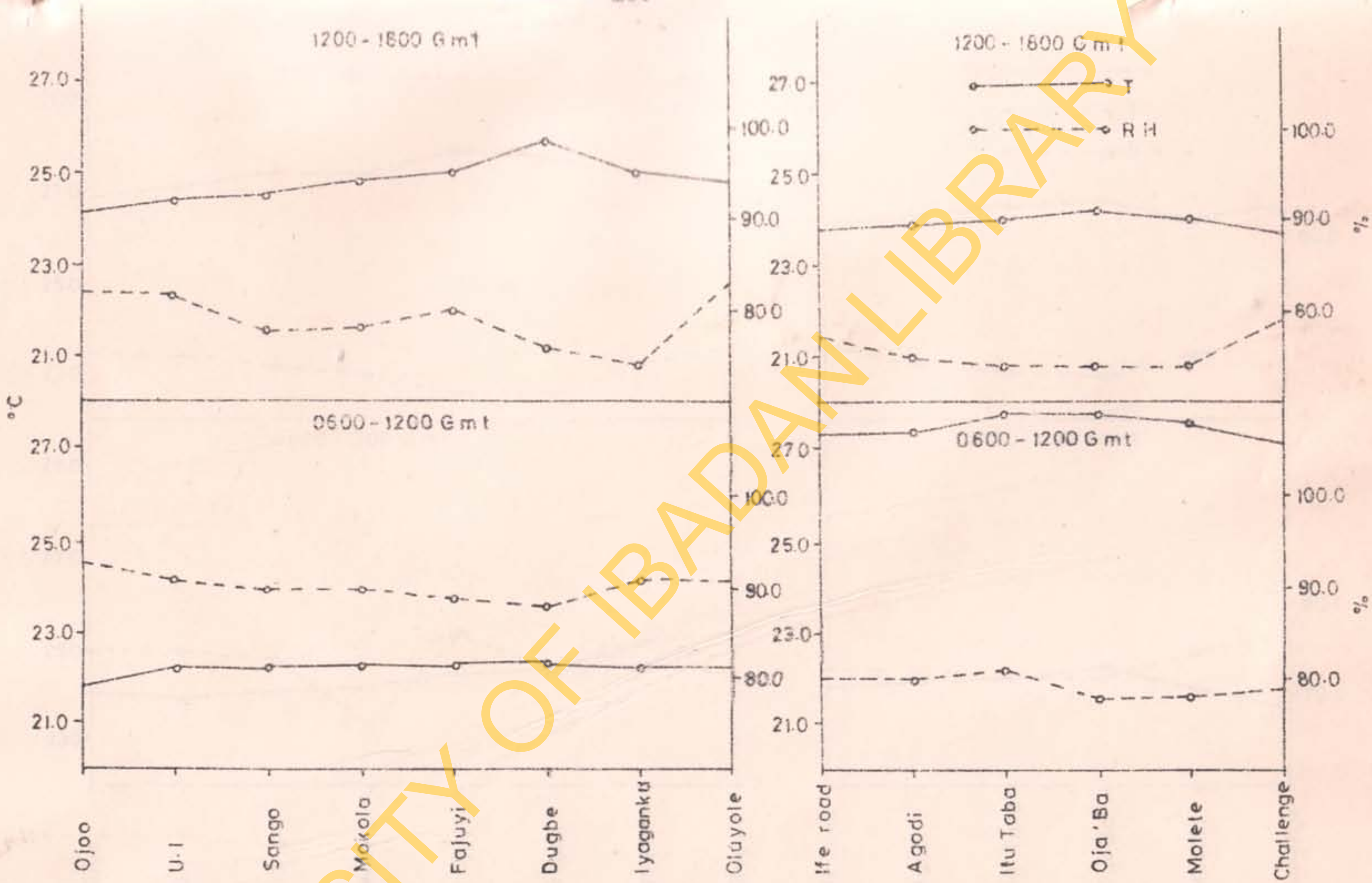


Fig. 6·19 : Temperature (T) and Humidity (RH) Traverses 10-06-83

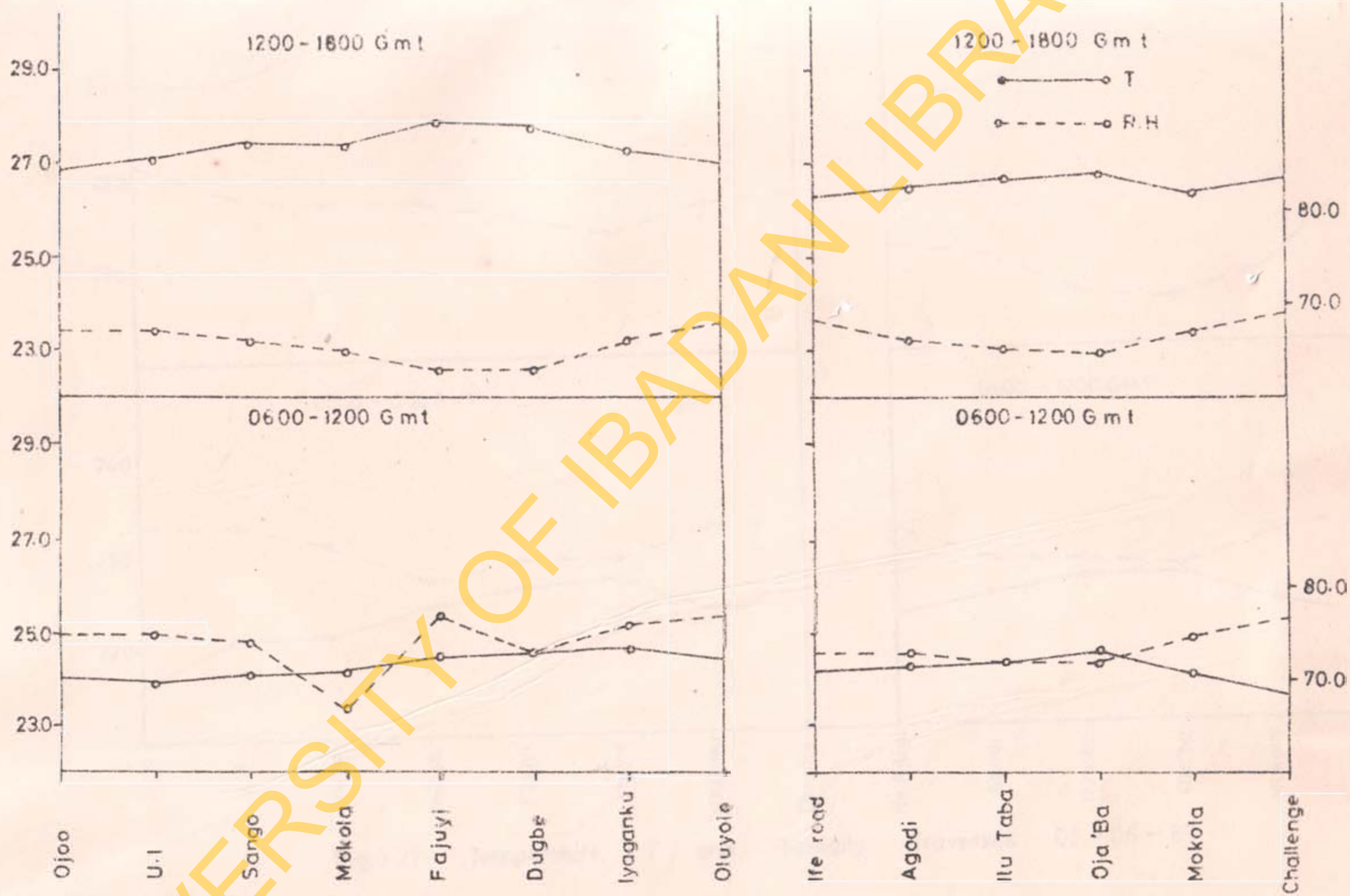


Fig. 6.20: Temperature (T) and Humidity (RH) Traverses 11-08-83

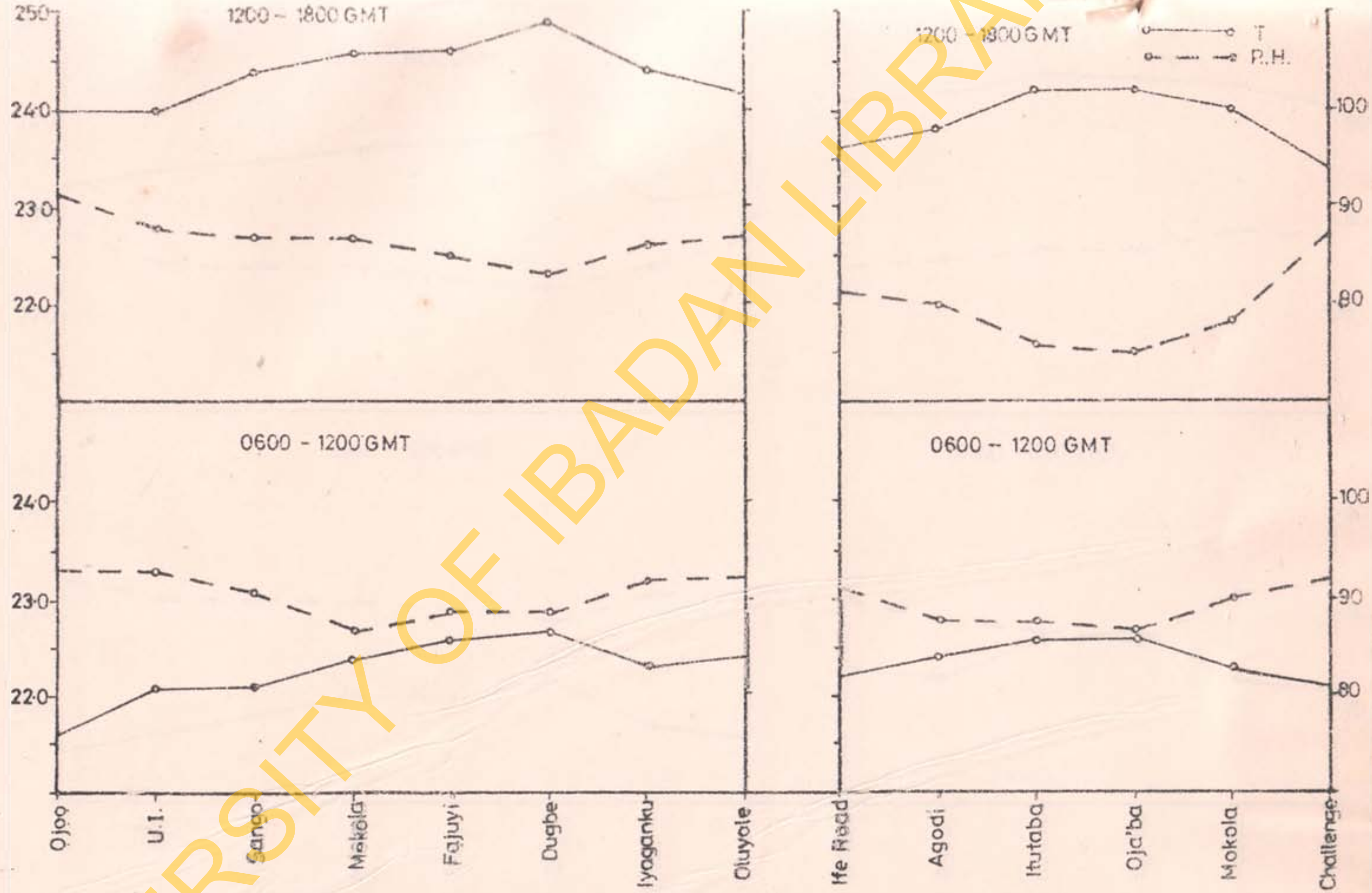


Fig.6·21: Temperature (T) and Humidity Traverses 03 – 08 – 83

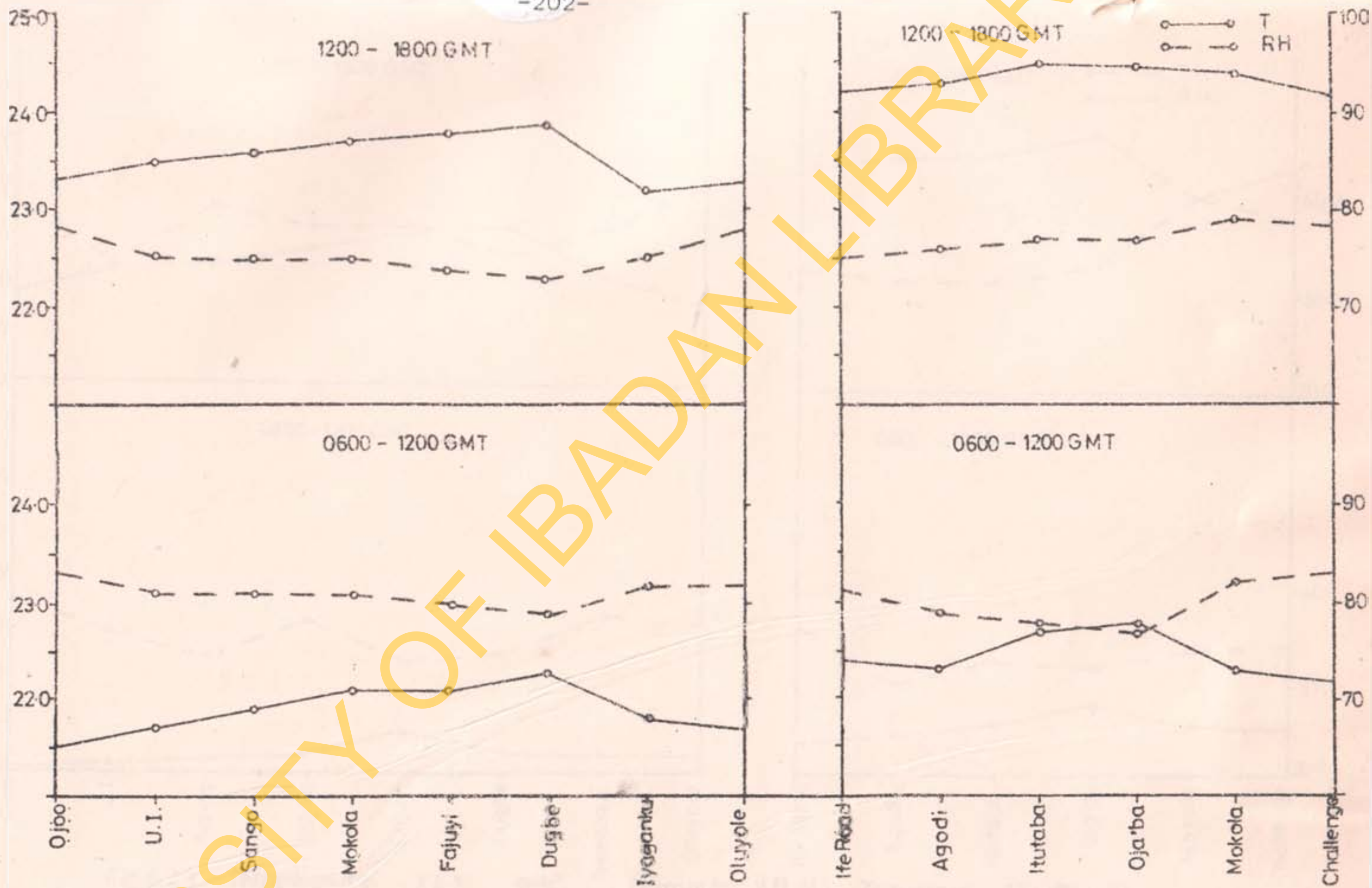


Fig.6·22: Temperature (T) and Humidity (RH) Traverses 28-12-83

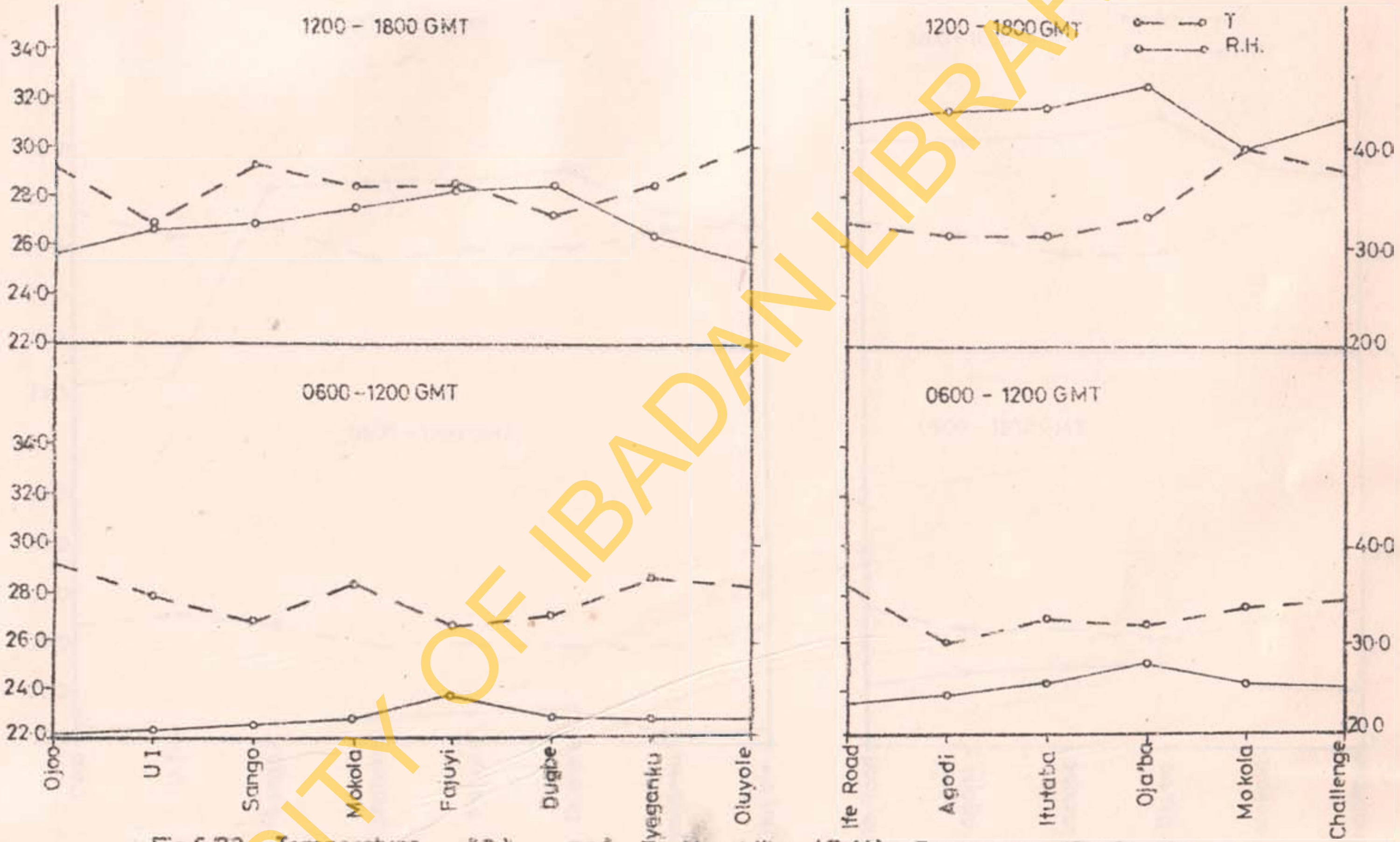


Fig.6·23 Temperature (T) and Humidity (R H) Traverses 17 - 01 - 84

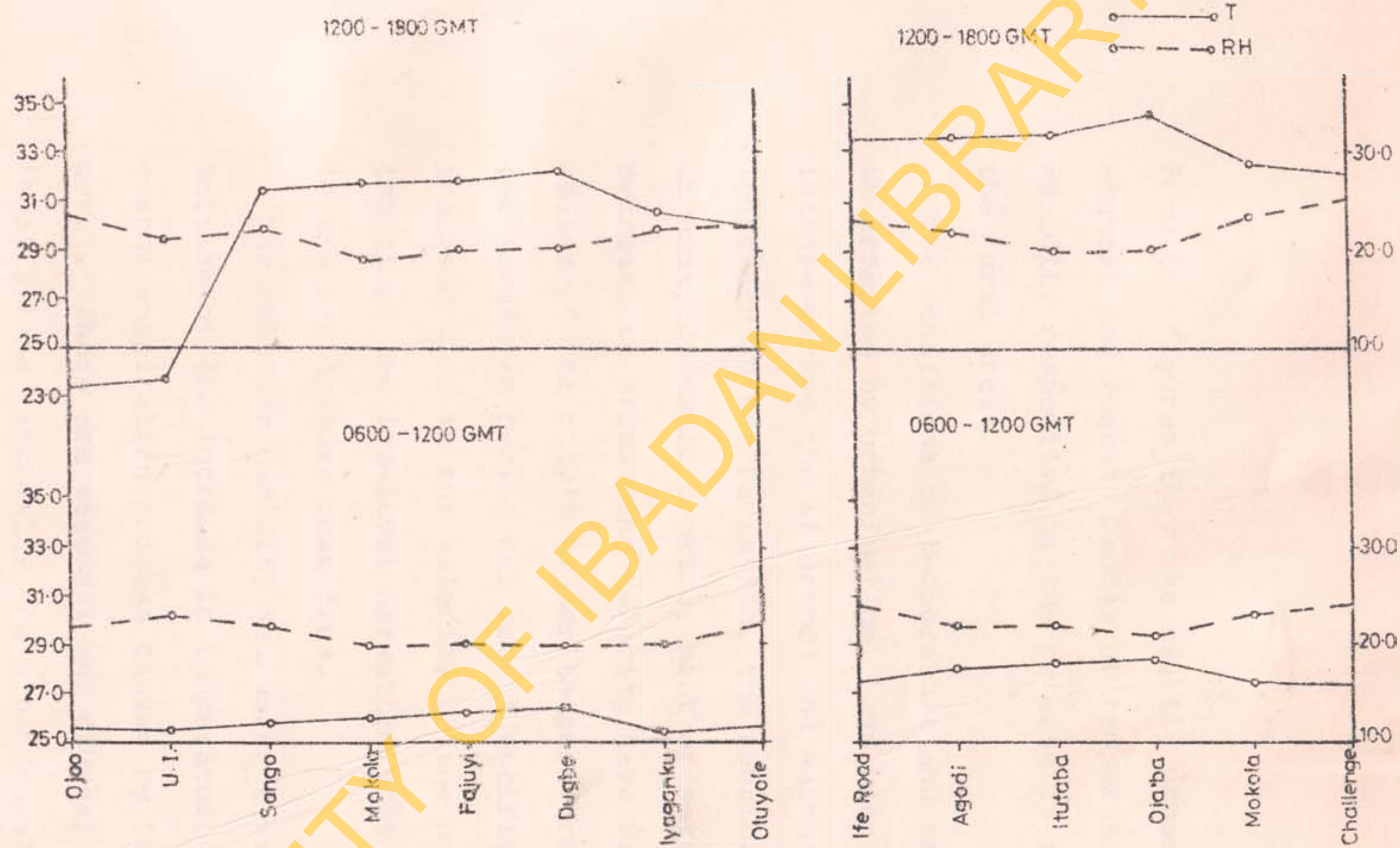


Fig.6.24 Temperature (T) Humidity (RH) Traverses 09 - 02 - 84

from the figures that the heavily urbanized areas have the highest and lowest amounts of temperature and relative humidity respectively; the reverse is the situation with the rural areas.

The conditions of temperature and relative humidity, as affected by urbanization, have been found to be more intense during the afternoon and harmattan periods. Increases in net radiation, the sensible heat, automobile exhaust, domestic cooking, heat of metabolism and the decrease in urban wind velocity have been identified as causes of the city's higher temperature. The case of the harmattan period has been identified as being caused by the reduction in the velocity of the prevailing wind, impact of the low-level harmattan dust and the reduction in the evaporative heat flux.

The relative humidity decreases towards the city centre because of the increase in temperature and reduction in evapotranspiration process caused by the reduced vegetal cover. There are seasonal and diurnal variations in urban 'heat island' intensity and urban/rural differences in relative humidity as shown in Figs. 6.25 and 6.26.

The data collected for temperature and relative humidity for a period of eight weeks covering both seasons have been

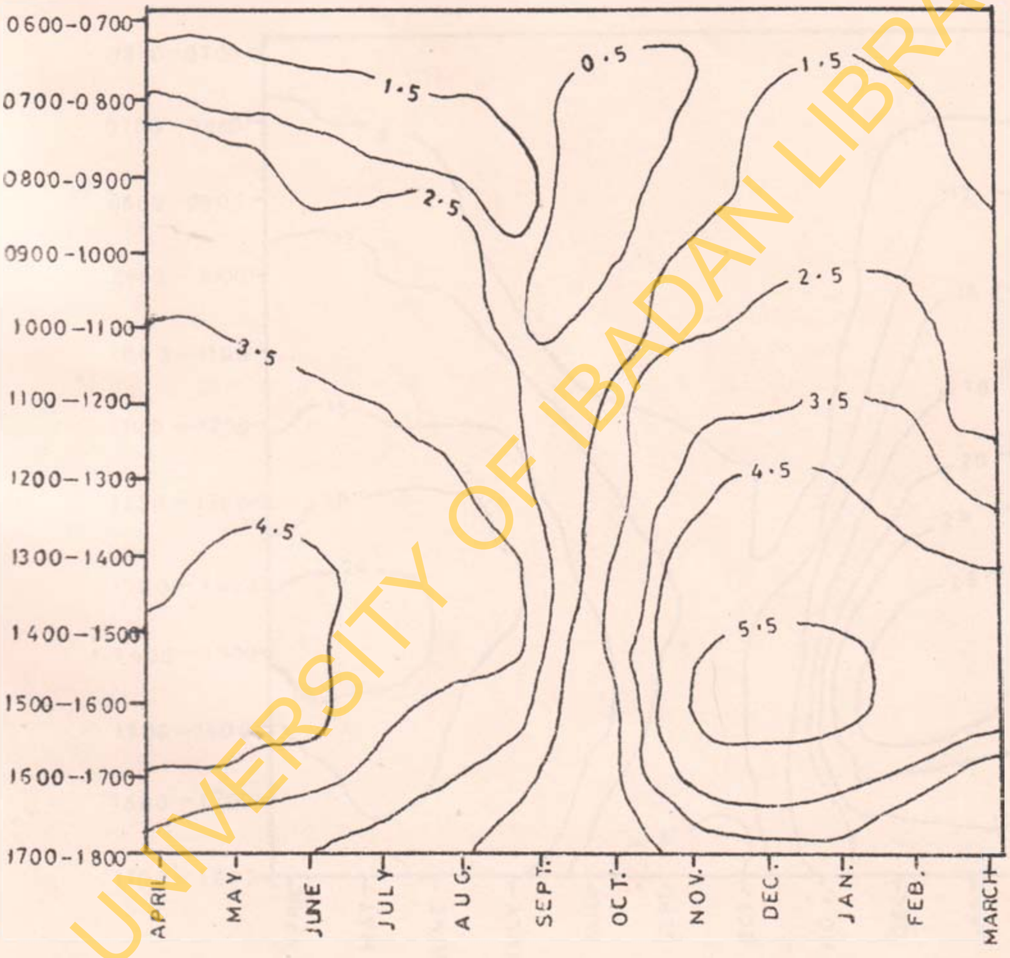


Fig 6·25 Urban Heat Island [ΔT(u-r)] Isoline Map(°C)

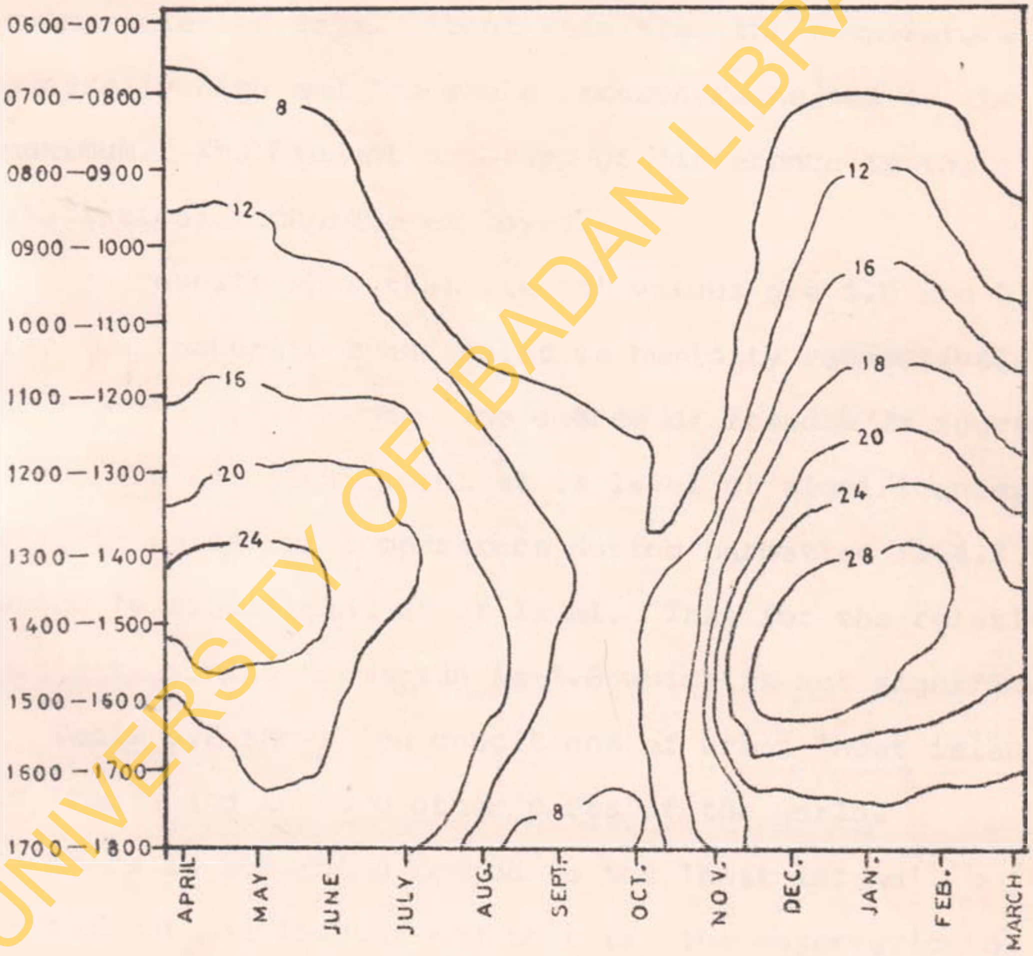


Fig 6·26 Rural-Urban Percentage Differences in Relative Humidity [ΔR·H(r u)] Isoline Map (%)

subjected to the Student's t-test. This would mean a pair of eight samples. The months are June and July for wet period and January and February for the harmattan period. The figures are for 1500 hours of GMT; of cloudless, calm, selected days. About this time the temperature is generally high and the whole atmosphere heated to the maximum. The Student's t-test of difference is the statistical technique employed.

The results show that the 't' values are 1.6 and 0.8 for the temperature and relative humidity respectively during the wet season. The degree of freedom is fourteen. These are not significant at 5% level of significance. The 't' value for temperature during harmattan is 4.3 which is significant at 5% level. That for the relative humidity during harmattan is 1.8 which is not significant.

Table 6.2 shows the conditions of urban 'heat island' in Ibadan and in some other parts of the world.

There is something common to the 'heat island' in Nairobi and Ibadan, and that is, the observation of the phenomenon by morning hours in both places. The strength of their 'heat island' increases to 1500 hrs. As much as 11.5°C 'heat island' extreme was observed in Ibadan. The 'heat island' in Montreal, observed by

Table 6.2

Comparison of Urban Effect on Temperature and Relative Humidity

Parameter	Observation Area	Observer	Urban decrease increase
Temperature T(u-r)°C	Nairobi (0900 hr.)	Nakamura (1967)	2.0 increase
	Nairobi (1500 hr.)	Nakamura (1967)	4.5 increase
	Nairobi (1700 hr.)	Nakamura (1967)	1.0 increase
	Nairobi (2100 hr.)	Nakamura (1967)	1.5 increase
	Montreal (mean)	Oke (1973)	7.5 increase
	Singapore (mean)	Nieuwolt (1966)	3.5 increase
	London (mean)	Chandler (1963;66)	1.3 increase
	Ibadan (0700 hr.)	Present study	3.0 increase
	Ibadan (1500 hr.)	Present study	8.0°C increase
	Ibadan (extreme)	Present study)	11.7°C increase
Relative Humidity (%)	Singapore (mean)	Nieuwolt (1966)	20% decrease
	Ibadan (mean)	Oguntoyinbo (1973)	7% decrease
	Ibadan (mean)	Present study	6-24% decrease

Oke(1973) was about 7.5°C. This compares a little bit with Ibadan in the sense that they both have their population within the range of 2 million.

Relative humidity decreases to the city centre. As much as 20% decrease was observed in Singapore while a range of between 6% and 24% was observed in Ibadan.

CHAPTER 7

7.0 TEMPORAL VARIATIONS IN SOME CLIMATIC PARAMETERS

The earlier chapters focused on the spatial variations in surface characteristics of the city and the microclimates. These have been done by employing results of the city-surface texture analyses as the guides for collecting, analysing and explaining data on climatic parameters. Results of the analyses show that the urban surface and atmospheric characteristics are playing considerable roles in the alteration of the 'natural' microclimates. This is evident in the urban-rural differences and the spatial variability in microclimatic characteristics.

The fact that the spatial variations in the microclimates within the canopy of Ibadan metropolis are as a result of urbanization has been established in the preceeding chapaters. It is clear that, with the contemporary rapid growth in human population, the high rural-urban migration and the terrific, human, social and technological sophistications, the process of urbanization has become a permanent global phenomenon. In view of these, temporal variations in urban climates are expected. Having established, in the earlier chapters therefore, that urban microclimates in Ibadan vary spatially with the extent of surface coverage, it is worthwhile to discuss the impact of the city-growth on the climates of the city.

In this chapter, temporal variations in three important climatic parameters are examined. Theyare temperatures, relative humidities and rainfall. These three parameters are chosen because they:

(1) more readily show the climatic condition of a place than most other climatic parameter;

(2) are the few parameters with the most consistent records for the period under consideration, and

(3) are sufficient measures for knowing the temporal change in climate of the city.

The data analysed cover the period of twenty years, 1961 to 1980, because documented evidences like aerial photographs, maps and practical field surveys that could show the pattern of city growth for the periods earlier than 1960 are not readily available. Furthermore, compared with earlier periods, the rate of urbanization in Nigeria was high in the post-independence years of the sixties and seventies because of the general increase in the availability of jobs, and the better conditions of living in towns and cities. Finally, consistent, comparable records for periods earlier than 1960 are not available in meteorological stations within the city.

In order to isolate the problem of differentiating between natural climatic change and the impact of urbanization, data from three standard meteorological stations are taken into consideration. They are the University of Ibadan climatological station (U.I.), Old Airport agrometeorological station (airport) and the Forestry Research Institute of Nigeria agrometeorological station (FRIN). See Fig. 7.11.

7.1 Recent Growth of the City

There has been a tremendous growth in the population and size of the city of Ibadan over the past few decades. The 1963 census figure showed that the population of Ibadan was 625,000. Based on a 2.8% annual growth rate, Ayeni (1982) estimated the population to be 1,119,280 in 1983. This shows that the population of Ibadan had almost doubled within a period of ten years.

Alongside the population growth has been the increase in city size. From aerial photographs of 1963 Oyelese (1970) estimated the total area of Ibadan as 103.8 sq km with 36.2 sq km devoted to urban land-uses (Fig. 7.1). According to Areola (1982), the area of the urban landscape had spread over about 101.9 sq km by 1973 with non-urban uses confined to the urban fringes (Fig. 7.2). This had also increased by 1981 (Fig. 7.3)

Many industries were established during the period under consideration. Table 7.1 shows that there was appreciable increase in the number of industries.

Table 7.1

Growth of Modern Large Scale Industries in Ibadan 1961-72*

Year	Establishment	% increase
1961	25	-
1964	30	16.7
1970	54	44.4
1972	61	11.5

* Computed after Onyemelukwe (1982).

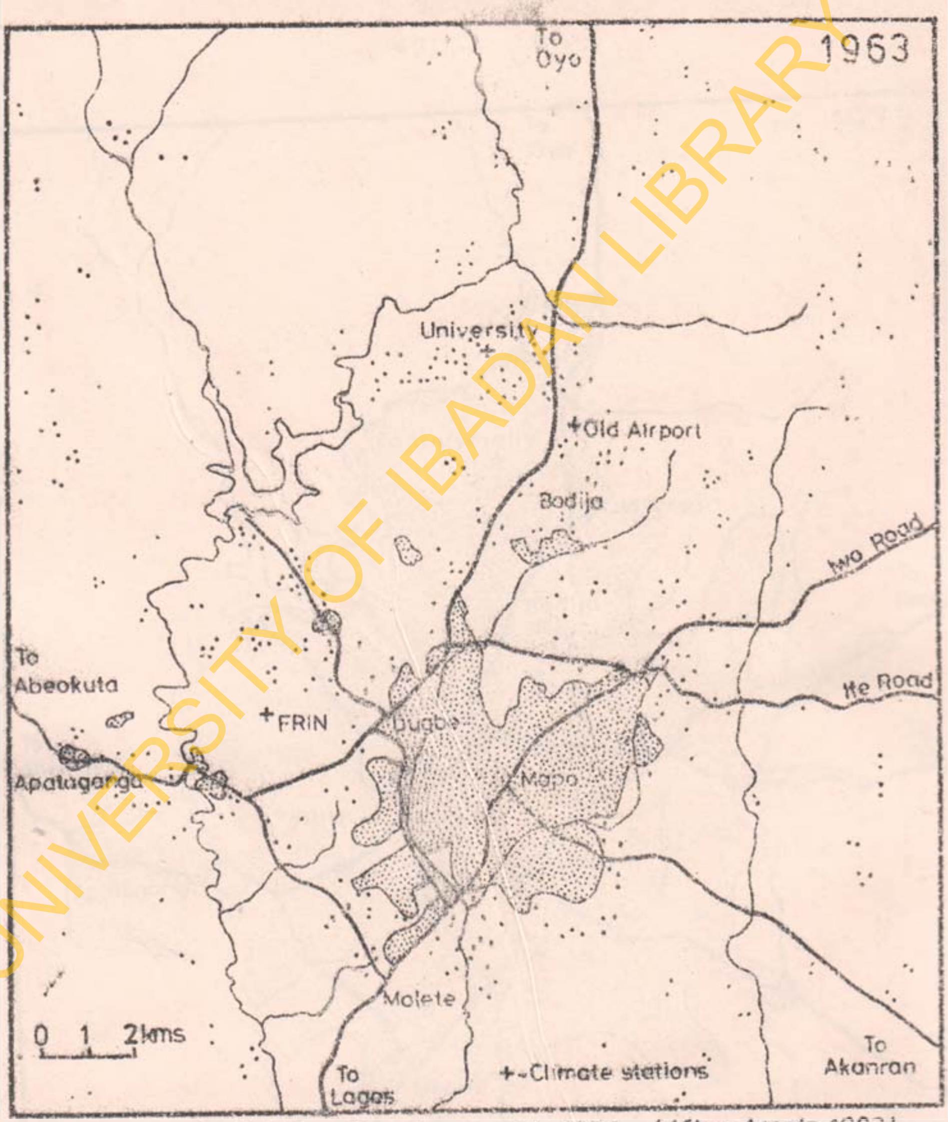


Fig. 7.1: The Spatial Growth of Ibadan City 1963 *(After Areola 1982)*

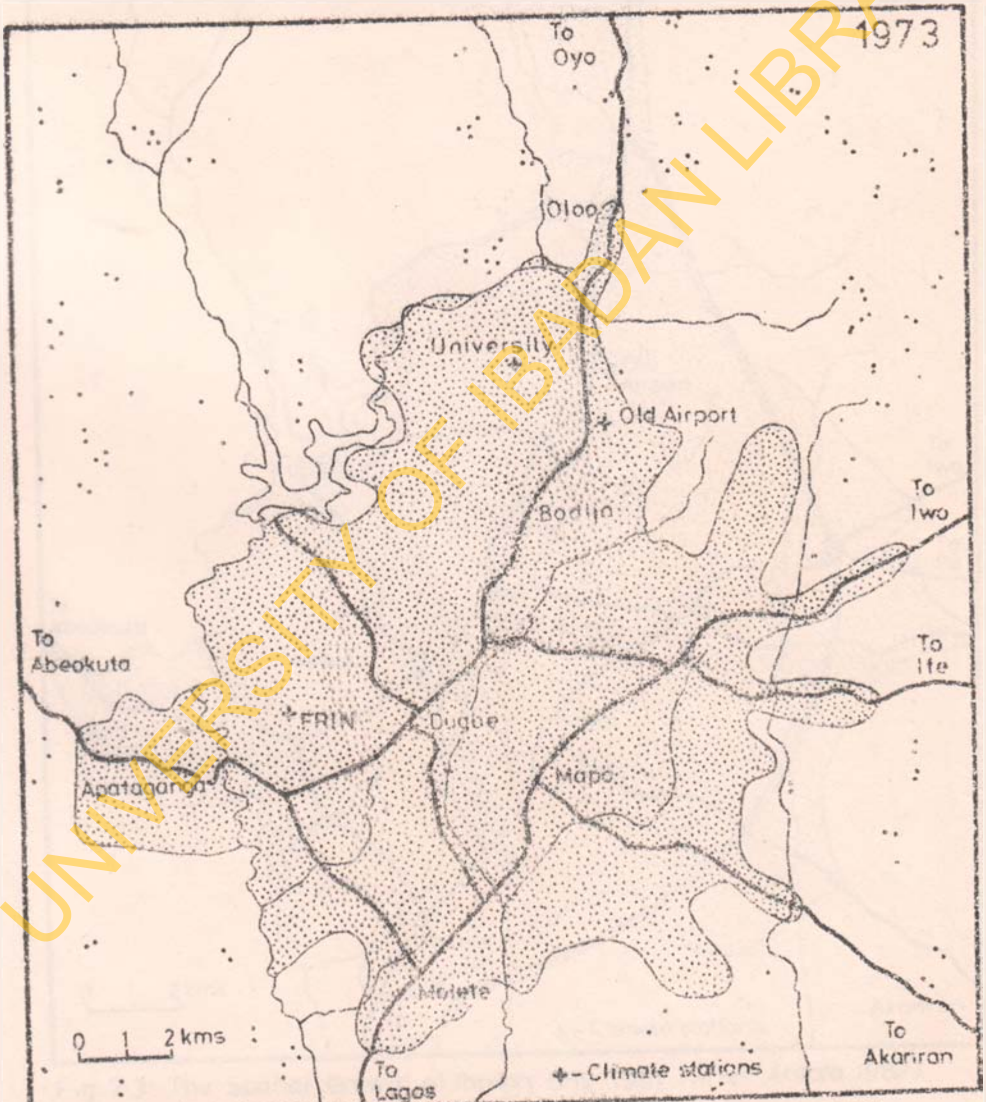


Fig 7·2: The Spatial Growth of Ibadan City 1973 (After Areola 1982)

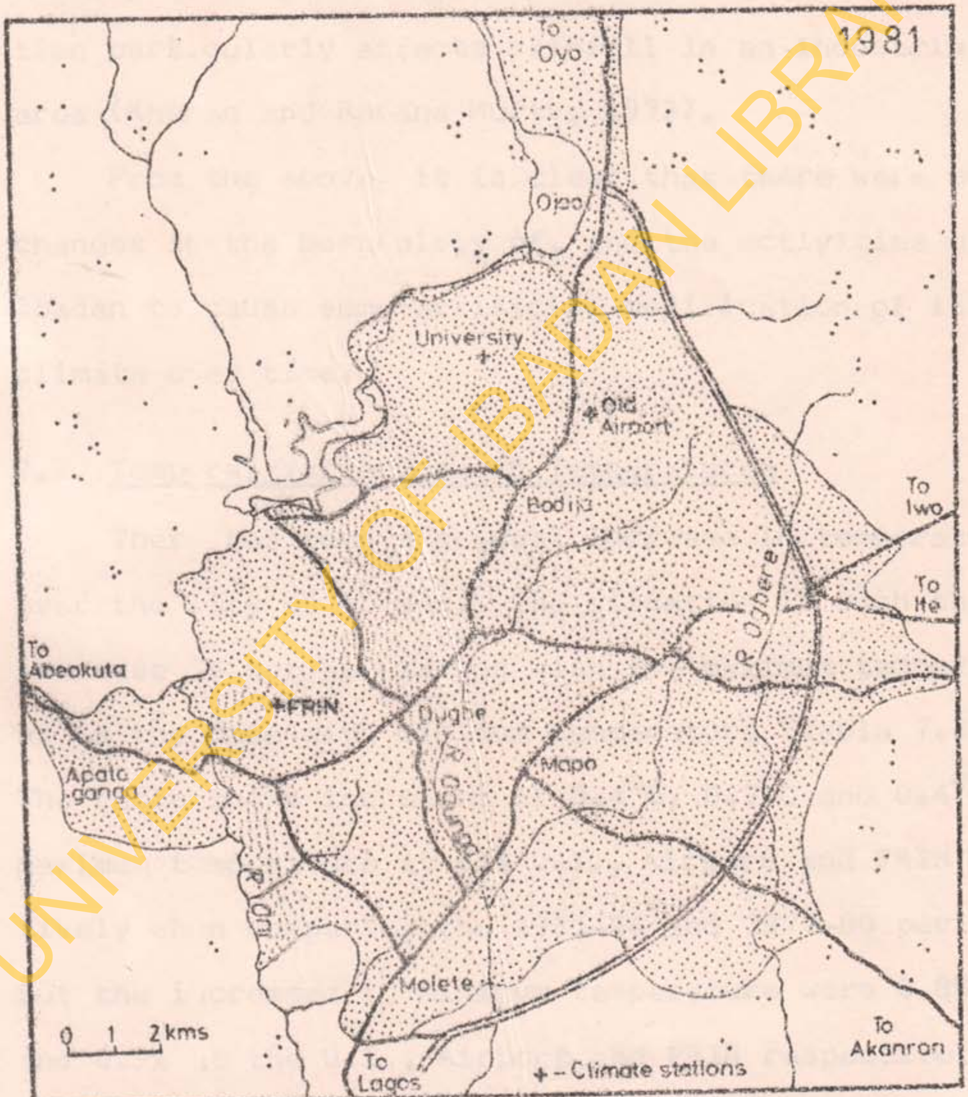


Fig. 7·3: The Spatial Growth of Ibadan City 1981. *(After Areola 1982)*

The increase in industries would certainly have increased the impact of pollutants on the climate. Industrial pollution particularly affects rainfall in an industrialised area (Kheman and Ramana Murty, 1973).

From the above, it is clear that there were enough changes in the morphology of, and the activities within, Ibadan to cause some artificial modification of its climate over time.

7.2 Temporal Variations in Temperatures

There has been a gradual increase in temperatures all over the city of Ibadan. The situation is such that the increase is not as glaring with the maximum temperature as is the case with minimum temperature (Table 7.2). The table shows increases of 0.4°C, 0.7°C and 0.4°C in maximum temperature at the U.I., Airport and FRIN respectively when comparing the 1961-64 and 1977-80 periods. But the increases in minimum temperature were 0.8%, 0.7% and 0.9% at the U.I., Airport and FRIN respectively for the same period.

Fig. 7.4 also shows the patterns of the 5-year moving averages computed for the temperature characteristics. Although increases are apparent in both maximum

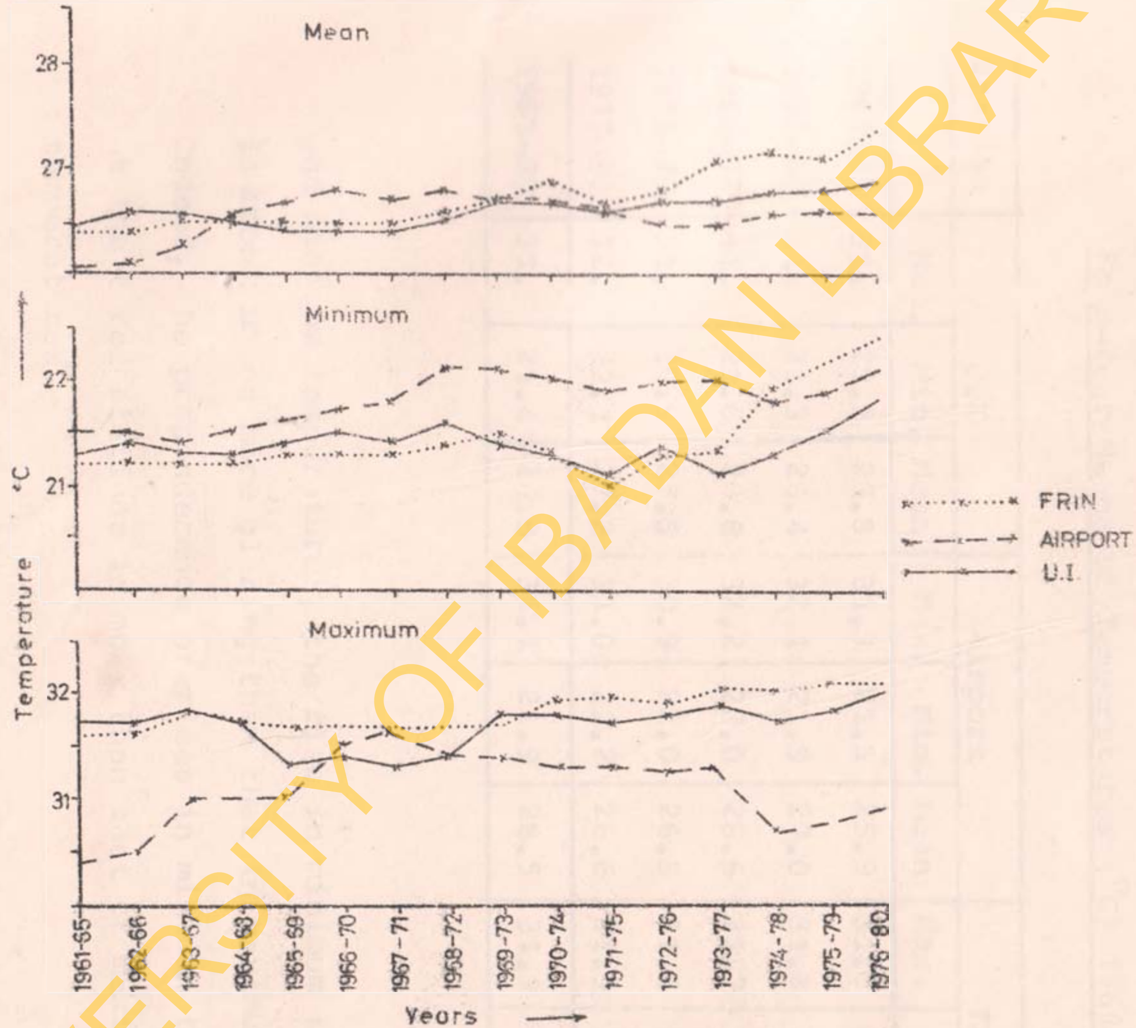


Fig.7.4: Five Year moving average for Temperature in Ibadan 1961-80

Table 7.2

Four-Year Means of Temperatures (°C) 1961–80

Station	U.I			Airport			FRIN		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1961–64	31.	21.2	26.5	31.3	21.5	25.9	31.5	21.3	26.5
1965–68	31.	21.3	26.4	32.1	21.9	27.0	31.3	21.3	26.6
1969–72	31.	21.6	26.6	32.2	22.0	26.6	31.7	21.4	26.6
1973–76	31.	20.9	27.5	30.9	22.0	26.5	31.4	21.1	26.8
1977–80	32.	22.1	27.2	31.0	22.2	26.6	31.9	23.2	27.5
1961–80	31.	21.4	26.8	31.1	21.9	26.5	31.9	21.7	26.8

and minimum temperatures, the rise in minimum temperature is steadier and more glaring than that in maximum temperature. Indeed, the preponderance of rises in minimum temperature at the three stations is more than that of maximum temperatures.

Correlation coefficient tests carried out between time and temperatures show positive relationship. The level of significance is 5%. The correlation coefficients are 0. 0, 0.10 and 0.13 for the U.I., airport and FRIN maximum temperatures respectively; 0.36, 0.60 and 0.48 in the three stations respectively for minimum temperature. Results for minimum temperature show that there are more positive relationships between time and minimum temperature, therefore greater increase in minimum temperature with time, compared with maximum temperature. Airport and FRIN minimum temperatures are significant at 5%.

The greater rise in minimum temperature is as a result of the gradual warming up of the city as a whole which increases the level to which the minimum temperature attains when the city cools down. This result shows the role of atmospheric pollutants in the modification of urban climates. More of the pollutants, from the work of Oluwande (1977), are in the urban lower atmosphere because of increases in combustion activities like smoke from automobiles, domestic cooking and industrial activities. CO_2 absorbs and retains heat, therefore contributing to the rise in minimum temperature.

Maximum temperature occurs mostly at about 1500 hours of GMT in the afternoon. Increase in maximum temperature over time is not as much as that of minimum temperature, as revealed by the correlation test and Fig. 7.4. The lower rise compared with minimum temperature, could be attributed to the fact that there is the cooling effect of winds, which is more during afternoon hours when maximum temperature occurs. This causes a moderation or reduction in the increases in maximum temperature compared with minimum temperature. There are less calm periods during afternoon hours (Adebayo, 1980).

The greater correlation coefficients between the minimum temperatures and time at the airport (0.60) compared with U.I. (0.36) and FRI (0.48) shows the greater increase in the minimum temperature at that station. This is because, over the years the rate of expansion in the city has been more towards the northern end of the city Fig 7.1, 7 2 and 7.3). The 20-year mean minimum temperature at the airport is 21.9°C compared with 21.5°C at FRIN and 21.4°C at U.I. A look at the 20-year mean maximum temperature however shows that the airport has the the lowest maximum temperature of 31.3°C with FRIN and U.I. having the means o 31.9°C and 31.7° respectively. This could be as a result of the fact that the airport is situated on a higher altitude of 227.1m and more exposed surroundings, compared with FRIN (205.7m) and U.I. (213.4m). Higher radiative cooling on high altitude because of higher wind velocity causes a reduced maximum temperature. This factor, coupled with the closer distance of FRIN to the CBD of Dugbe are responsible for its highest values of maximum temperature.

7.3 Temporal Variations in Relative Humidity

As established in the previous chapter, relative humidity is affected by urbanization because it decreases towards the city centre with increase in temperature. In most cases however, the effect of urbanization is pronounced, in fact, it is more obvious during the afternoon hours when the urban 'heat island' is high.

An analysis of relative humidity conditions over twenty years shows a gradual fall in the parameter during afternoon hours (Fig. 7.5). The correlation coefficient tests carried out show negative relationship between relative humidity at 1500 hours and years. The values are 0.00 and -0.05 for the U.I. and Airports respectively. None of these is significant at 5%. This shows that although there has been a gradual decrease over time, the decrease is not as marked as the increases in temperature characteristics over time.

The 20-year mean annual relative humidity is 70.2%, 70.4% and 74.0% at U.I., Airport and FRIN respectively. The highest value at FRIN could be attributed to the surrounding vegetation in the area which increases the evapotranspiration and subsequently, atmospheric water vapour.

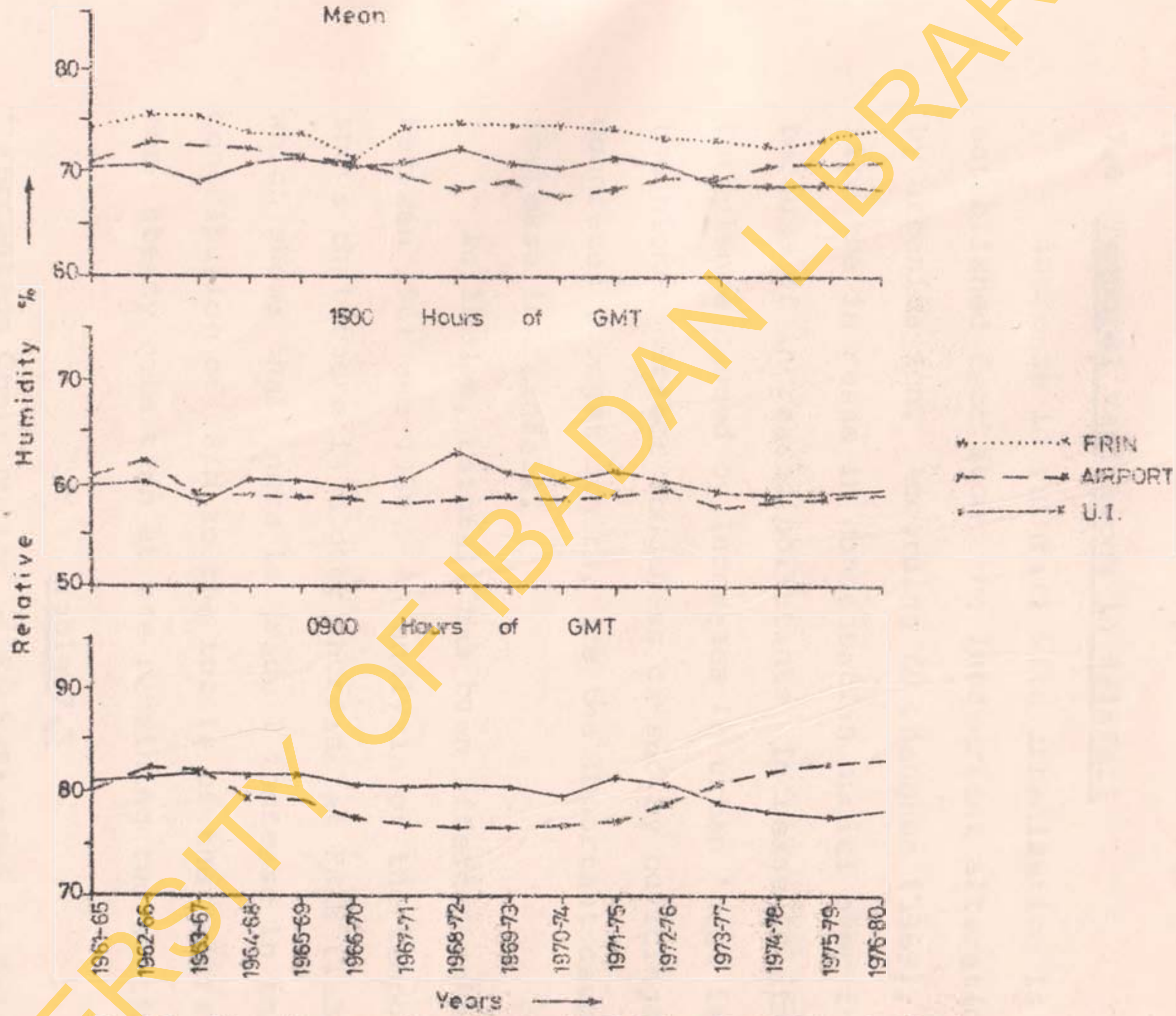


Fig.7·5: Five Year moving average for Relative Humidities in Ibadan 1961 - 80

7.4 Temporal Variations in Rainfall

Increase in rainfall with urbanization is an established fact about the inadvertent alteration of climate by urbanization. According to Changnon (1969), factors like the increase in condensation nuclei over the city because of increased pollutants increase in atmospheric turbulence caused by increases in urban 'heat island' and the higher surface roughness caused by buildings and erected concretes amongst others, are the important causes of the increase in rainfall.

In Ibadan, rainfall has been affected considerably between 1961 and 1980. An analysis of the temporal variation shows that there is higher increase at FRIN (Table 7.3) which shows that there is gradual increase in the relative contribution of FRIN to the totals of the rainfall, at a more steady rate than at the remaining two stations.

Table 7.3

Percentage Contribution of Each Station to Rainfall Total

Year	U.I	Airport	FRIN	
1961-64	33.5	34.0	32.5	100.0
1965-68	33.5	33.8	32.7	100.0
1969-72	32.5	31.6	36.0	100.0
1973-76	30.6	30.2	39.2	100.0
1977-80	27.2	34.9	37.9	100.0
1961-80	31.4	32.9	35.7	100.0

Correlation coefficient tests between years and rainfall show that U.I, airport and FRIN have values of 0.00, 0.06 and 0.38 respectively. None of these is significant at 5%. The conditions at FRIN and the Airport show a steady rise. The negative correlation at U.I. means that there has not been much impact of urbanization on rainfall there, instead, the rainfall varies more with the regional pattern.

Fig. 7.6 shows 5-year moving averages of the mean annual rainfall for the three stations in Ibadan. It is clear that the rates of increase at the FRIN, and the airport are more than at the U.I. The figure also shows that although the general pattern at the three stations are the same, urbanization plays more important role in increasing the rainfall at FRIN and the Airport.

7.5 The Impact of Urbanization on the Climate of Ibadan

The process of urbanization is a global phenomenon. In recent years, the increasing rate of city-growth is alarming, particularly in African countries where the rural-urban migration is at an alarming rate. This is also evident in the growth of Ibadan within the past twenty five years, which, according to Areola (1982) has been considerable. Industrial growth, concentration of educational centres, increasing business and commercial activities are the major factors responsible for the growths in size and population of Ibadan. Because of these the population of Ibadan had almost doubled within a span of ten years (1963-1973) and the area of urban landscape increased from 35.2 sq. km in 1963 to 101.9 sq. km by 1973 and about 130.5 sq km in 1982.

Alongside the city growth there have been variations in climatic characteristics. The temperature conditions, particularly minimum temperature, are most affected while the relative humidities are least affected. The situation is one of gradual increases in temperature and rainfall over time but decrease in relative humidity.

The annual means of temperatures, relative humidities and rainfall are correlated with years over a period of twenty years, 1961-80, in order to know the impact of city growth on these climatic parameters over the period of twenty years. Results of the analyses show that the relationships are significant with some parameters but not with others (see Table 7.4).

Significantly positive relationship exists with minimum temperatures at the airport and FRIN and mean temperature at FRIN.

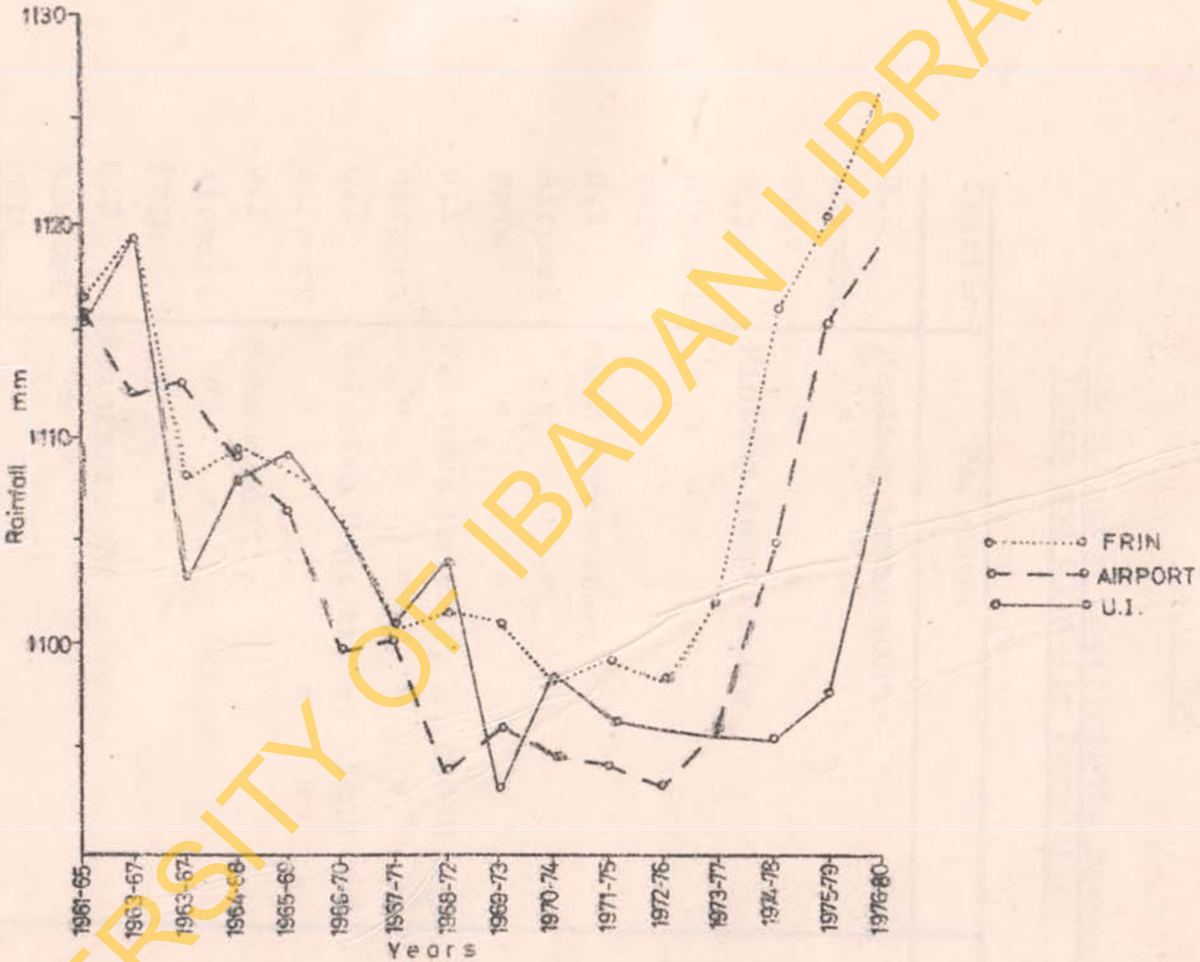


Fig.7·6: Five Year moving average for rainfall in Ibadan 1961-80

Table 7.4

Correlation Coefficients Between Years and Climatic Parameters

Station	Parameter	Correlation Coefficient
U.I	Maximum temperature	.20
Airport	" "	.10
FRIN	" "	.14
U.I	Minimum temperature	.36
Airport		.60*
FRIN	" "	.48*
U.I	Mean temperature	.38
Airport	" "	.31
FRIN	" "	.56*
U.I	Relative Humidity at 0900H GMT	-.24
Airport	" " " " "	.25
U.I	Relative Humidity at 1500H GMT	-.00
Airport	" " " " "	-.05
U.I	Mean Humidity	-.40
Airport	" "	.30
FRIN	" "	-.25
U.I	Rainfall	-.01
Airport	"	.06
FRIN	"	.38

* Significant at 5%

CHAPTER 8

8.0 THE GENERAL CHARACTERISTICS OF SURFACE TEXTURE AND MICROCLIMATES WITHIN THE URBAN CANOPY OF IBADAN

The microclimatic characteristics within the urban canopy vis-a-vis the city surface texture have been analysed. Although a lot of things have been discussed and found out about land-use - climate variations in Ibadan, there has not been any specific test to establish the relationships between surface texture and the microclimates. It is in this light that attempts are made in this chapter to know the extent of the relationship between them.

Following the above analysis are the comparison of the results for Ibadan with those in other parts of the world and an idealised pattern of surface disposition of the in-coming global radiation in Ibadan.

The last section in this chapter dwells on the major findings and recommendations emanating from this study. Such a summary, it is hoped, should be useful for the pursuance of further research in urban climatology.

8.1 Relationships Between Surface Texture and Microclimatic Parameters

The relationships between climatic parameters and surface texture are analysed under four different ways, viz: (1) by relating the percentages of different land-uses that are urban with climatic parameters; (2) by relating building densities of different land-uses and climatic parameters; (3) by analysing the relationship of the building roughness lengths and climatic parameters, and (4) by correlating both tree roughness lengths and climatic parameters. The last three analyses are carried out because buildings and vegetation are the most prominent urban surface characteristics that vary significantly from one land-use type to another and that could be more easily quantified and related to the measured climatic parameters.

Relevant data on different land-uses, as determined in Chapter Four, are correlated with corresponding mean values of the climatic parameters measured over two seasons. Spearman's rank correlation coefficient is used because the samples of the different land-use components under consideration are very small. In addition, ranking would serve the purpose of relating the variables on the basis of how they rank amongst the land-uses.

A look at the results on Table 8.1 shows that, with the exception of the cases of net radiation, relative humidity during both seasons and temperature during wet season, significant relationships exist between percentages of different land-uses that are urban and all other climatic parameters.

The results afford the opportunity of knowing the nature of the relationships between the surface components and climatic parameters. In cases of negative relationship, that means with higher percentages of land-uses that are urban or building densities of different land-uses or building roughness lengths or tree roughness lengths, there are decreases in the amounts of the climatic parameters. The reverse is the case if the relationships are positive.

8.2 Situations in Ibadan and other Parts of the World

It is unfortunate to note that it is very difficult to compare results of microclimatic investigations generally because most data are gathered under different prevailing regional climatic conditions. In addition, the variations in the period of time over which most of the investigations are carried out make reasonable comparison a difficult exercise. At any rate, attempts

Table 8.1: Correlation Coefficient Tests Between Percentages of Urban Land-Uses, Selected City Surface Components and Climatic Parameters

	Q + q RA	Q + q HA	a RA	a HA	L* RA	L* HA	LE RA	H RA	T RA	T HA	RH RA	RH HA	Rn RA	Rn HA
% Urban	-.80	-.90*	-.70	-.90*	-.90	.90*	.89*	.88*	.84	.89*	-.80	-.80	.86	.86
Building Density	-.70	-.80	-.90*	-.70	-.70	-.70	.75	.88*	.73	.75	-.70	-.70	.77	.77
Z_o Building	-.40	-.50	-.54	-.54	-.54	-.54	.55	.53	.14	.55	-.49	-.54	.54	.54
Z_o Tree	-.19	-.31	-.49	-.32	.22	.22	.20	.37	-.13	.18	-.30	-.23	.17	.17

- * Significant at 5%
- % Urban - Percentage Land-uses
- Z_o Building - Roughness Length of Building
- Z_o Tree - Roughness Length of Tree
- a - albedo
- H - Sensible Heat Flux
- T - Temperature
- RH - Relative Humidity
- RA - Rain
- HA - Harmattan

are made to compare the results of this investigation with those of other similar investigations carried out in other parts of the world.

To justify the comparability of these results, results of investigations carried out by using the same methodology, as used in this project, are specifically chosen, in addition, only urban-rural differences in these parameters are compared.

There are not much differences between results of this investigation and those from other parts of the world. The decreases in global radiation and albedo are also compared with those of other parts of the world. In Ibadan the mean reduction in global radiation in urban centre is by about 14%. Randerson (1970) found same to be 23% in Houston while Stair (1966) and Nader (1967) found it to be highly variable in Los Angeles, varying between 38% and 50% or even up to 90%.

The urban decrease in albedo is about 25% while the n long wave radiation is increased by about 16.7% in the urba centre in Ibadan. The net radiation increases by around 15%.

The urban 'heat island' is highly variable. But one interesting thing about it is that it has been observed in the morning at Ibadan. Nakamura 1967) also observed it in the morning in Nairobi to be about 1.5°C at 0900 hours GMT. This increases to 3.5°C at 1500 hours, decreasing to 2.0°C by 1700 hours and 1.5°C by 2100 hours.

'Heat island' was as much as between 1.0°C and 5.9°C on traverse days in Ibadan during wet season between 0600 and 1200 hours of GMT, and between 1.2°C and 3.0°C during harmattan within same period. As much as 11.7°C extreme 'heat island' was observed by afternoon hours on traverse harmattan days. Nieuwolt (1966) observed about 3.5°C 'heat island' in Singapore. Chandler (1963; 1966) observed it to have a mean of 1.3°C in London. Duckworth and Sandberg (1954) observed a mean temperature 'heat island' intensity of 4.4°C in Sacramento. As much as 8.0°C temperature 'heat island' was observed in the densely built-up area of Columbia Maryland by Landsberg (1979). The 'heat island' intensities at Delhi, Bombay, Pune, Calcutta and Visakhapatuan respectively are 6.0°C, 9.5°C, 10.0°C, 4.0°C and 0.6°C (Padmanabhmurty, 1984). These results are similar to those for various periods in Ibadan as revealed by this investigation.

In Ibadan, the relative humidity varies between 6.3% decrease towards the urban centre in the wet season to 24.3% during the harmattan season. In Singapore, Nieuwolt (1966) found it to be 20% less in the city than at the rural airport.

From the above brief comparison, it is clear that there is not much difference between the degree of the impact of urbanization on the urban climates of Ibadan and those in other cities of the world. One significant thing however is the morning 'heat island' effect observed in some tropical cities; which is not found in temperate cities. This has also been observed in Nairobi Kenya, a tropical country. The 'heat island' effect of about 5.9^{o}C was observed between 0600 and 1200 hrs of GMT in Ibadan, on a traverse day. On the whole, the 'heat island' intensities observed in tropical cities are not quite different from those observed in temperate cities. Seasonal variations in urban effects on climatic parameters had also been observed like in other parts of the world. This is simply because of the regional variations in climate and surface compositions over different seasons.

8.3 Idealised Pattern of Radiation Budget in Ibadan

A traverse view of the city was taken in such a way that all the recognized land-use types were represented.

Mean values of the results on the components of radiation budget are used in representing an idealised pattern of the radiation budget (eqn 2.1). This as shown by Fig. 8.1, gives a view of how incoming solar radiation is disposed of on different surfaces within the urban canopy of Ibadan city. The figure shows a considerable variation in the surface disposition of energy all over the city.

8.4 Conclusions and Recommendations

8.4.a Conclusions

The results of the present study reveal a number of features about urban climatology. Salient amongst these is that there exists appreciable gap in the knowledge of climatologists about the microclimates of cities. This lack of knowledge is in two broad ways. Firstly, not much is known about the impact of cities in different parts of the world on microclimatic parameters. Secondly, the need to determine viable yardsticks, from the available information about urban climates, in order to enable us predict and understand the variabilities in urban energy, mass and momentum as in relation to the global climate, the socio-economic conditions of the city dwellers.

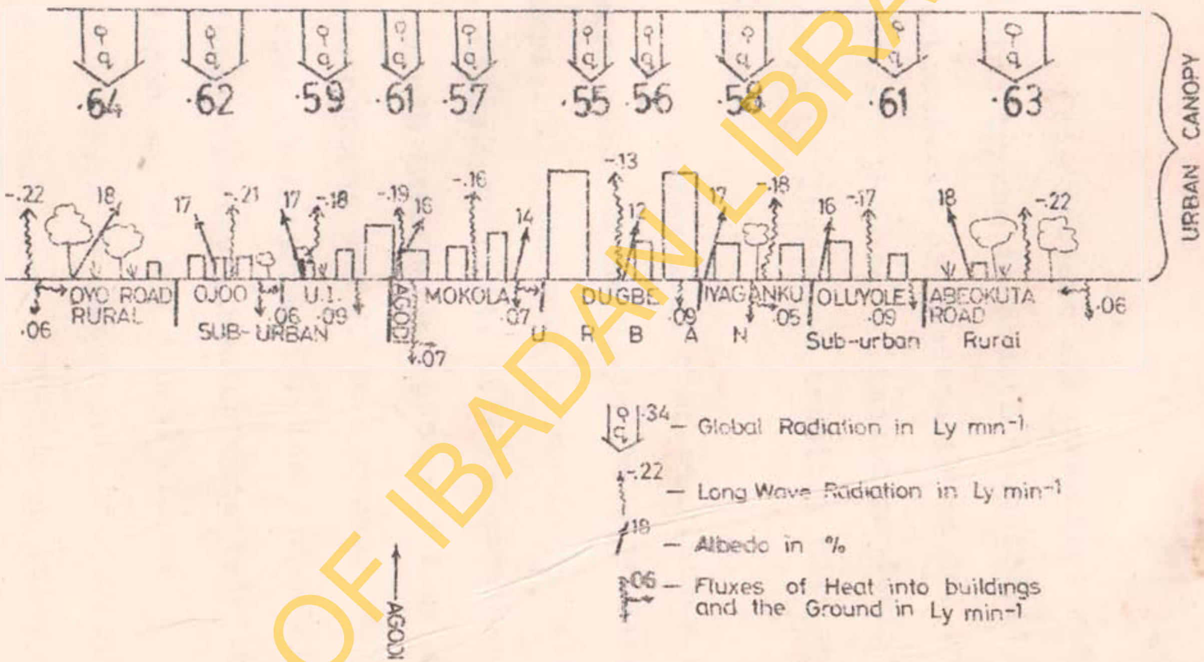


Fig 8·1: Idealised pattern of Surface Energy Distribution within the Urban Canopy in Ibadan.

This project was conceived with the aim of contributing to the information on tropical cities which is particularly as inadequate as the knowledge about polar cities. The microclimatic conditions within the urban canopy of Ibadan, a tropical city was therefore investigated.

The textural characteristics of the city surface were used as the basis for gathering, analysing and explaining the microclimatic patterns within the city surface. The city-surface components were analysed through information gathered from archival records, aerial photographs and field surveys. Six land-use types were later identified for the purpose of this project. They are 'high density', medium density' 'low density', 'commercial', 'open space' and 'rural' uses.

Data on components of radiation, energy budgets, temperature and relative humidity were collected over a period of twelve calendar months all over the city in a manner that did reflect the land-use types; through point, diurnal recordings and automobile traverses. Results of subsequent analyses of the data show decreases in global radiation and albedo, and increases in long wave radiation which culminated in the increase in net radiation. Increases in low-level atmospheric pollution, buildings and paved surfaces towards the city centre were identified as the principal causal factors. There is also considerable urban-rural variation in latent and sensible fluxes of energy.

Temperature increases towards the city centre. The urban 'heat island' effect was also observed in morning hours to be up to a value of 3.0°C. Causes of this are the high net radiation and heat from 'anthropogenic' sources. Relative humidity decreases towards the city centre by up to 24% because of the increase in the temperature and decrease in vegetal cover.

Harmattan has been found to be exercising some impact on the variability of urban climate because of its low-level dusts and the general reduction in the regional wind speed during the harmattan season as compared with wet season. Heat island is better developed under calm condition

There are also the temporal variations in temperature, relative humidity and rainfall over a period of twenty years. These have been caused by the effect of city growth as the microclimatic causal factors increase in their effects with increases in city size, population

8.4.b Recommendations

Based on the results of this investigation, it is possible to make a few recommendations that would touch on both the effective management of the atmospheric resources and areas that need closer attention in urban climatology.

The 'natural', less heterogeneous and more predictable rural tropical climates are generally preferred to the 'artificial' heterogeneous and less predictable city climates. This is because the inadvertent alterations in climate by man either directly or indirectly affects his socio-economic activities. In view of this, a plan for an utopian city climate should be geared towards attaining the closest condition to a rural, 'natural' climate. Nothing else is better than the nature's air conditioner (Landsberg, 1956b).

In order to attain something close to an 'ideal' city climate, a reduction in the number of people migrating to towns should be the first step. This should be done by improving the lots of the rural dwellers through the provision of adequate infrastructures.

The fact that the growth of towns and cities cannot be totally checked is unassailable. It is therefore necessary to take the subsequent impact of city growth on its climates into consideration while planning both new and old settlements. The following need be incorporated in urban planning and considered for future investigations.

(1) Reduction in the amount of pollutants released into the lower atmosphere from industrial and domestic chimney-stacks by concentrating their outlets in a way that the smoke could be released far from the urban canopy, into the urban boundary layer. Smoke outlets should therefore be taller.

(2) Planting of trees and flowers around buildings and roads in particular to filter smoke released from automobiles, industrial and domestic combustions.

(3) Discouraging the burning of refuse and waste in towns. Burying them in farmlands is a more reasonable alternative.

(4) Location of industrial areas in areas downwind, to reduce the impact of pollution.

(5) Construction of lawns and open fields in residential and commercial areas as better alternative to bare grounds and paved surfaces.

(6) Decentralisation of commercial areas through the building of many supermarkets and stores in residential areas.

(7) Exclusive ownership and allocation of the land by government planning authorities, to check the indiscriminate allocation of land by the feudal lords and petty-bourgeoises which causes the springing up of chaotic, choking, shanty layouts.

(8) The setting up of weather-monitoring stations and the installation of highly sensitive equipment for the monitoring of the changing levels of pollution at strategic locations in towns. In addition, wind-monitoring masts should be set up all over the city.

(9) This research focussed on the conditions of climate within the urban canopy only. It is hereby recommended that a further look should be taken into the situations at the urban boundary layer.

(10) The documentation of the absorptive, storage and emissive capacities of different surface components in Ibadan. This is for the purpose of knowing the thermal properties of different surfaces.

(11) A comparison of the impact of both traditional and modern houses on both the in-door and the out-door microclimates for the purpose of future design of buildings suitable for this climatic region.

REFERENCES

Ackerman, B. (1971). Moisture Content of City and Country Air. Preprints Conf. Air Pollution Meteorol. Amer. Met. Soc. pp. 154-158.

Adebayo, Y.R. (1980). Spatial and Seasonal Variations in Wind Speed and Direction Over Nigeria. Unpublished. B.Sc. Dissertation. Dept. of Geog., University of Ibadan.

Akande, T. (Personal Communication). Species of Trees in Ibadan. Dept. of Botany, University of Ibadan.

Akinola, R.A. (1966). Flood Problems in Ibadan, Western Nigeria. Nigerian Geog. Journ. Vol. 9, No. 2.

Akintola, F.O. (1974). The Parameters of Infiltration Equations of Ibadan Land-Use Surfaces. Unpublished Ph.D. Thesis, Dept. of Geog. University of Ibadan.

Areola, O. (1982). The Spatial Growth of Ibadan City and its Impact on the Rural Hinterlands. In Filani, M.O. (ed) Ibadan Region. Dept. of Geog. University of Ibadan.

Atwater, M.A. (1971a). Radiation Budget of Polluted Layer of Urban Environment. Journ. of Appl. Met. Vol. 10 pp 205-214.

__________ (1971b). Radiation Effect of Pollutants in Atmospheric Boundary Layer. Journ of Atm. Sci. Vol. 28, pp. 1367-1393.

__________ (1975). Thermal Changes Induced by Urbanization and Pollutants. Journ. of Appl. Met Vol. 14 pp. 1061-1071.

Ayeni, B. (1982). The Metropolitan Area of Ibadan: Its Growth and Structure. In Filani, M.O. (ed) Ibadan Region. Dept. of Geog. Univ. of Ibadan.

Ayoade, J.O. (1977). On Climatological Considerations in Urban Planning. Dept. of Geog. Staff/Post-graduate Seminar. University of Ibadan.

__________ (1980) A Note on Spatial and Seasonal Variations in Wind Speed Over Nigeria. Singapore Journal of Tropical Geography. Vol. 1, No. 2, pp. 11-15.

Bach, and Patterson, W. (1969). Heat Budget Studies in Greater Cincinnati. Proc. Ass. Amer. Geog. 1, pp. 7-11.

Black, J.M. et al (1954). Solar Radiation and Duration of Sunshine. Quart. Journ. of Roy. Met. Soc. Vol. 80 pp. 281-235.

Bornstein, R.D. (1968). Observations of the Urban Heat Island Effect in New York City. Journ. of Appl. Met. Vol. 7 pp. 575-82.

__________ (1975). The Two-Dimensional URBMET Urban Boundary Layer. Journ. of Appl. Met. Vol. 14. No. 8.

Bornstein, R.D. and Oke (1979). Influence of Pollution and Urbanization on Urban Climates. Prepared for Adv. in Env. Sci. and Engineering Vol. 2 Gorden.

__________ (1980). Influence of Pollution on Urban Climatology. In Adv. in Env. Sci. and Engineering Vol. 2.

Bowen, I.S. (1926). The Ratio of Heat Losses by Conduction and by Evaporation from any Water Surface. Phys. Rev. Vol. 29 pp. 779-787.

Bowen, N.E. and Ball, J.T. (1970). Observational Comparison of Rural and Urban Boundary Layer Turbulence. Journ. of App. Met. Vol. 9, pp. 362-873.

Brunt, D. (1932). Notes on Radiation in the Atmosphere. Quart. Journ. of Roy. Met. Soc. Vol. 58, pp. 389-420.

Budyko, M.I. (1956). The Heat Balance of the Earth's Surface. Translated from Russian by the U.S. Dept. of Comm., Weather Bureau, Washington, D.C. 259 pp.

Bud__________ (1963) Atlas of the Heat Balance of the Earth. Moscow Geof. 3 Obser. 69 pp.

Chandler, T.J. (1962a). London's Urban Climate. Geog. Journ. Vol. 128, pp. 270-98.

__________ (1962b) Temperature and Humidity Traverses Across London. Weather Vol. 17, pp. 235.

__________ (1964). City Growth and Urban Climates. Weather, Vol. 19 pp. 170.

__________ (1965). The Climate of London. Hutchinson and Co.

__________ (1967). Absolute and Relative Humidities in Towns. Bull. of Amer. Met. Soc. Vol. 8, No. 6.

__________ (1970a). Urban Climatology. Summary and Conclusions of the Symposium in Urban Climates, WMO Tech. Note. No. 108 Geneva pp. 375-379.

__________ (1970b). Selected Bibliography on Urban Climate WMO. No. 276, Geneva, 383 pp.

__________ (1976). Urban Climatology and its Relevance to Urban Design. W.M.O. Tech. Note. No. 149 61 pp. Geneva.

Chang, J. (1970). Global Distribution of Net and Solar Radiation According to a New Formula. Ann. Assoc. of Amer. Geog. Vol. 60 pp. 340-351.

Changnon, S.A.Jr. (1969). Recent Studies of Urban Effects on Precipitation in the United States. Bull. of Amer. Met. Soc. Vol. 50 No. 6.

__________ (1971). Comments on the Effects on Rainfall of a Large Steelworks. Journ. of Appl. Met. Vol. 10 pp. 165-168.

Changnon, S.A.Jr. et al (1971). METROMEX: Am Investigation of Inadvertent Weather Modification. Bull. Amer. Met. Soc. Vol. 52 pp. 958-967.

Clarke, J.F. & Paterson, J.T. (1972). The Effect of Regional Climate and Land-use on the Noctural Heal Island. Proc. Conf. on Urban Env. & Soc. Conf. on Biometeorology. Amer. Met. Soc. pp. 147-152.

Dabbardt, W.F. and Davis, P.A. (1974). Determination of Energetic Characteristics of Urban-Rural Surfaces in Greater St. Loui Area. Reprints Symposium on Atm. Diffusion and Air Pollution, Santa Barbara, Amer. Met. Soc., Boston.

Davis, J.A. (1967). A Note on the Relationship Between Net Radiation and Solar Radiation. Quart. Journ of Roy. Met. Soc. Vol. 93 pp. 109-115.

Douglas, L. (1981). The City as an Ecosystem. Progress in Physical Geography, Vol. 5 No. 3 pp. 315-367.

Duckworth, F.S. and Sandberg, J.S. (1954). The Effect of Cities Upon Horizontal and Vertical Temperatures. Bull. Amer. Met. Soc. Vol. 25 pp. 198-44.

Faniran, A. (1982). Relief and Draingage. In Filani, M.O. Ibadan Region. Department of Geog., University of Ibadan.

Filani, M.O. and Osayimwese, (1979). Intra-City Traffic Flow Problem in Nigeria. The Case of Ibadan Metropolitan Area. The Nig. Geog. Journ. Vol. 22 No. 1, pp. 21-31.

Fonda, R.W. et al (1971). Heat Islands and Frost Pockets in Bellingham, Wash, Bull. Amer. Met. Soc. Vol. 52 pp. 552-555.

Fowler, S.D. and Sandberg, J.S. (1954). Effects of Cities Upon Horizontal and Vertical Temperatures Gradients. Bull. Amer. Met. Soc. Vol. 55 pp. 198-207.

Fuggle, R.F. and Oke, T.R. (1968). Long Wave Relative Flux Divergence and Nocturnal Cooling of the Urban Atmosphere. Reidel Publishing Company. Holland.

Garnett, A. and Bach, W. (1965). An Estimation of the Ratio of Artificial Heat Generation to Natural Radiation Heat in Sheffield. Monthly Weather Review. Vol. 93 pp. 383-385.

Garnier, B.J. (1967). Weather Conditions in Nigeria. Climatological Research Series No. 2 Montreal. McGill University.

Geiger, R. (1966). The Climate Near the Ground. Harv. Univ. Press. Massachussetts.

Goddard, W.B. (1971). Heat, Mass and Momentum Transfer Process in the Biosphere. Unpublished Doctoral Dissertation, University of California, Davis.

Hage, K.D. and Langley, R.W. (1970). Ventilation and Mixing in Alberts Cities. In Man and His Environment. Pergerson Oxford. pp. 99-113.

Hage, K.D. (1972a). Nocturnal Temperatures on Edmonton Alberta. Journ of Appl. Met. Vol. 11 No. 1

___________ (1972b). Urban Growth Effects in Low-Temperature Fog in Edmonton. Boundary Layer Met. Vol. 2 pp. 335-347.

___________ (1973). Urban-Rural Humidity Difference. Journal of Appl. Met. Vol. 14 No. 7.

___________ (1977). Research in Urban Climatology at the University of Alberta. In McGill University. Dept. of Geog. Climatological Bulletin. No. 22.

Halstead, et al (1957). A Preliminary Report on the Design of a Computer for Micrometeorology Journ.of Appl. Met. pp. 308-325.

Harnack, R.P. and Landsberg, H.E. (1975). Selected Cases of Convective Precipitation Caused by the Metropolitan area of Washington D.C. Journ of Appl. Met. Vol. 14 No. 6 pp. 105-1060

Huff, F.A. and Changnon, S.A. Jr. (1972). Climatological Assessment of Urban Effects on Precipitation of St. Louis. Journ of Appl. Met. Vol. 11 No. 5.

Jaurequi, E. (1984). Tropical Urban Climates: Review and Assessment. W.M.O. Tech. Conf. on Urban Climatology and its Applications with Special Regards to Tropical Areas. Mexico Nov. 1984.

Jaurequi-C'stos (1982). Some Aspects of the Effects of Climate on Human Settlements in Low Latitudes. In Report of Experts on Urban and Building Climatology, W.M.O. Geneva.

Kalanda, B.D. et al (1980). Suburban Energy Balance Estimates for Vancouver B.C. Using Bowen Ratio-Energy Balance Approach. Journ of Appl. Met. Vol. 19 No. 7.

Khemani, L.G. and Ramana Murty Bh.V (1973). Rainfall Variations in Urban Industrial Region. Journ. of Appl. Met. Vol. 12 pp. 187-194.

Landsberg, H.E. (1956a). The Climate of Towns. In Thomas W.L. (ed) Man's Role in Changing the Face of the Earth. Univ. of Chicago Press.

__________ (1956b). Nature's Air Conditioner. American Forestry Assoc. Washington D.C.

__________ (1970a). Microclimatological Temperature Differentiation Through Urbanization. In Urban Climates W.M.O. Tech. Note. No. 108. Geneva.

__________ (1970b). Metropolitan Air Layer and Pollution. In Danscrean, P. (ed) Challenge for Survival Columbia Univ. Press, New York.

Landsberg, H.E. and Maisel, T.N. (1972). Micrometeorological Observations in an Area of Urban Growth. Boundary Layer Meteorology. Vol. 2, 365-370

Landsberg, H.E. (1973). The Meteorologically Utopian City Bull. of Amer. Met. Soc. Vol. 54 No. 2 pp. 86-89.

__________ (1974). Inadvertent Atmospheric Modification through Urbanization. In W.N. Hess (ed). Weather and Climate Modification, John Wiley and Sons, New York, pp. 726-768.

__________ (1975). The Atmosphere from Farm to Town. Paper Presented at 141st Meeting of the Amer. Assoc. for the Advance of Science Americana, Melmaison.

__________ (1979). Atmospheric Changes on a Growing Community: The Columbia Maryland Experience. Urban Ecology Vol. 4, pp. 53-81.

__________ (1981a). City Climate In Landsberg, H.E. (ed) World Survey of Climatology. Vol. 3, Elsevier Scientific Publishing Co. Amsterdam pp. 299-334.

__________ (1981b). Urban Climate International Geophysics Series, Vol. 23, Academic Press, New York, 275 pp.

Lemon, K.R. (1963). The Energy Balance of the Earth's Surface. Part 1. Quart. Journ of Roy. Met Soc. Vol. 85 pp. 386-392.

Lettau, N.H. (1969). Note on Aerodynamic Roughness Parameters Estimation on the Basis of Roughness-Element Description. Journ of Appl. Met. Vol. 8 No. 5, pp. 828-832.

Lewis, J.E. (1977). Surface Energy Exchange as a Function of Urban Terrain Characteristics. In McGill University Dept. of Geog. Climatological Bull. No. 22.

Lewis, J.E., et al (1976). Urban Surface Thermal Response Associated with Land-use. Extract from Clim. Bull. of the McGill University No. 19, 1976.

Mabogunje, A.L. (1962). The Growth of Residential Districts in Ibadan. Geog. Review Vol. 52

__________ (1968). Urbanization in Nigeria. London Univ. Press, London.

__________ (1981) Towards an Environmental Policy in Nigeria. Lecture Delivered at the 24th Annual Conference of the Nigerian Geog. Assoc., Kano, Nigeria.

Maejima, I, et al. (1983). Recent Climatic Change and Urban Growth in Tokyo and Environs. Japanese Progress in Climatology.

Malone, T.F. (ed) (1951) Compendium of Meteorology Waverley Press, Baltimore.

Monteith, J.L. (1962). Relationship Between Net and Short Wave Radiation. Quart. Journ. of Roy Met. Soc. Vol. 88 pp. 375.

Morgan, D.L. and Rogers, D.I. (1972). Texture of a City; the Foundation of Urban Meteorology Reprints Conf. on Urban Env. and Second Conf. on Biometeorology. Amer. Met Soc. Vol. pp. 295-302.

Morgan, D.L. et al (1977). Microclimate Within an Urban Area. Ann. of Ass. of Amer. Geog. Vol. 69 No. 1.

Munn, R.E. (1966). Descriptive Micrometeorology. Academic Press, New York.

Myrup, L.O. (1969). A Numerical Model of the Urban Heat Island. Journ of Appl. Met. Vol. 8 No. 6

Myrup, L.O. and Morgan, D.L. (1972). Numerical Model of Urban Atmosphere. Vol. 1. The City Surface Interface. Contributions in Atmospheric Science No. 4 University of California, Davis.

Nader, J.S. (1967). Pilot Study of U.V. Radiation in Los Angeles, Oct. 1965. Publ. No. 999-Ap 38, U.D. Public Health Service, Cincinnati. 91pp

Nakamura, K. (1967). City Temperature of Nairobi. Japanese Progress in Climatology pp. 61-65.

Nicholas, N.W and Lewis, J.E. (1970). Relationships Between Aerodynamic Roughness and Land-use and Land cover in Baltimore, Maryland. U.S. Geological Survey Professional Paper 1098C

Nieuwolt, S. (1966). The Urban Microclimate of Singapore. Journ of Tropical Geog. Vol. 22.

Nkendirim, L.C. (1976). Dynamics of an Urban Temperature Field: A Case Study. Journ of Appl. Met. Vol. 15 pp. 818-828.

___________ (1977). Research in Urban Climatology at the University of Galgary. McGill Univ. Dept. of Geog. Climatological Bulletin No. 22.

Nunez, M. and Oke, T.R. (1977). The Energy Balance of an Urban Canyon. Journ. of Appl. Met. Vol. 16 No. 1.

Oguntoyinbo, J.S. (1970). Reflection Coefficient of Natural Vegetation, Crop and Urban Surfaces in Nigeria. Quart. Journ. of Roy Met Soc. Vol. 96 No. 409.

___________ (1972). The Radiation Balance Over Natural and Agricultural Vegetation Surface in Nigeria. Unpublished Ph.D Thesis Dept. of Geog. Univ. of Ibadan.

Oguntoyinbo, J.S. (1973). Temperature and Humidity Traverses in Ibadan. Paper Presented at the 17th Annual Conference of the Nig. Geog. Ass. Univ. of Lagos.

__________ (1982a) Climate and Mankind. University of Ibadan Inaugural Lecture Series.

__________ (1982b). Climatic Characteristics. In Filani, M.O. (ed) Ibadan Region Dept. of Geog. Univ. of Ibadan.

__________ (1984). Urban Climatology in Tropical Africa. World Met. Organization Conference on Urban Climatology and its Application to Tropcial Areas. Mexico Nov. 1984.

Ojo, O. (1977). The Climates of West Africa. Heinemann, London.

__________ (1978). Applied Climatology and City Planning in the Tropics. In Symposium of the IGU Working Committee of Tropical Climate and Human Settlement IGU Regional Conference Proceeding Univ. of Ibadan, pp. 163-284.

__________ (1980) Radiation and Temperature Traverses Over Lagos Island. Nig. Geog. Journ. Vol. 23 pp. 38-44.

__________ (1981). Land-Use Energy Balance Relationship and the Planning Implications in Metropolitan Lagos. In Spatial Expansion and Concomitant Problems in Lagos Area. Univ. of Lagos Occasional Paper No. 1

Oke, T.R. (1973). City Size and the Urban Heat Island. Atmospheric Environment. Vol. 17 pp. 769-779.

__________ (1974). Review of Urban Climatology 1968-73. W.M.O. Tech. Note No. 134.

Oke, T.R. (1976). The Distinctions Between Canopy and Boundary Layer. Urban Heat Islands. Atmosphere. Vol. 14, pp. 268-278.

________ (1977a). Research in Urban Climatology at the University of British Columbia. In McGill University. Dept. of Geography. Climatological Bulletin No. 22.

________ (1977b). The Climate of Urban Areas. A Textbook of Science and Future Encyclopaedia Britannica, Chicago.

________ (1978). Boundary Layer Climates. Menthuen and Co. Ltd. London.

________ (1979). Review of Urban Climatology 1973-76 W.M.O. Tech. Note No. 169.

________ (Personal Communication, 1983). The Significance of the Atmosphere in Planning. Human Settlements. Research in Urban Climatology at the Dept. of Geog. British Columbia.

Oke, T.R. and Hannel (1970). The Forum of the Urban Heat Island in Hot Hamilton, Canada. In Urban Climates W.M.O. Tech. Note No. 108, Geneva pp. 113-126.

Oke, T.R. and East, C. (1971). The Urban Boundary Layer in Montreal. Boundary Layer Met. Vol. 1 pp. 411-437.

Oke, T.R. and Fuggle, R.F. (1972). Comparison of Urban/ Rural Counter and Net Radiation at Night. Boundary Layer Met. Vol. 2 pp. 290-308.

Oke, T.R. and Maxwell, G.B. (1975). Urban Heat Island dynamics in Montreal and Vancouver. Atm. Env. Vol. 9 pp. 191-200.

Oke, T.R. et al (1981). Parametrization of Heat Storage in Urban Areas. Urban Ecology. Vol. 5 pp. 45-54.

Oluwande, P.O. (1977). Automobile Traffic and Air Pollution in a Developing Country: An Example of Affluence-Caused Environmental Problems. Intern. Journ of Env. Studies. Vol. 11 pp. 191-203.

__________ (1979). Automobile Exhaust Problem in Nigeria. Ambio. Vol. 8 No. 1.

Onianwa, P.C. and Egunyomi, J.K. (1983). Trace Metal Levels in Some Nigerian Mosses used as Indicators of Atmospheric Pollution. Env. Pollution Ser. 13.5, pp. 71-81.

Onyemelukwe, J.O.C. (1982). Industries. In Filani, M.O. (ed). Ibadan Region. Dept. of Geog. University of Ibadan.

Outcalt, S.I. (1972a). The Development and Application of Simple Digital Surface Climate Simulation. Journ. of Appl. Met. Vol. 11 pp. 1369-73.

__________ (1972b). A Reconnaisance Experiment in Mapping and Modelling. The effect of Land-use on Urban Thermal Regions. Journ. of Appl. Met. Vol. 11 No. 8.

Oyelese, J.O. (1970). The Ortho-Photo Map Approach to Land-use Mapping. Nig. Geog. Journ. Vol. 13, No. 1

__________ (1971). The Growth of Ibadan City and its Impact on Land-use Patterns 1961-65. Journ of Tropical Geog. Vol. 32 pp. 49-55.

Page, J.K. (1976). Application of Building Climatology to the Problems of Housing and Building for Human Settlements. W.M.O. Tech. Note No. 150, 64 pp.

Padmanabhamurty, B (1984). Some Aspects of Urban Climates In India. W.M.O. Tech. Conf. on Urban Climatology and its Applications with Special Regard to Tropical Areas. Mexico, Nov. 1984

Paterson, J.T. (1971). Climate of the City. In Detwyler T.R. ed) Man's Impact on Environment McGraw-Hill U.S.A.

Pease, R.W. et al (1976). Urban Terrain Climatology of Remote Sensing. Ann. of Ass. of Amer. Geog. Vol. 66 No. 4.

__________ (1980) Influence of Land-Use and land cover cover on climate: An Analysis of the Washington-Baltimore Area that couples Remote Sensing with Numerical Simulation. U.S. Govt. Printing Office, Washington.

Rao, P.K. (1983). Remote Sensing of Urban Heat Island from an Environmental Satellite. Bull of Amer. Met. Soc. Vol. 53, pp. 647-648.

Reed, W.E. and Lewis, J. (1978). Land-use and Land Cover Information and Air Quality Planning. U.S. Govt. Printing Office.

Sanderson, M. et al. (1973). Three Aspects of the Urban Climate of Detroit - Windsor. Journ. of Appl. Met. Vol. 12, No. 4.

Sellers, W.D. (1965). Physical Climatology. The Univ. of Chicago Press. Chicago.

__________ (1969). A Global Climatic Model Based on the Energy Balance of the Earth-Atmosphere System. Journ. of Appl. Met Vol. 8 No. 3

Smith, K. (1975). Principles of Applied Climatology. McGraw-Hill Book Company (U.K) Ltd. London.

Stair, R. (1966). The Measurement of Solar Radiation with Principal Emphasis on U.V. Component. Int. Journ. of Air and Water Pollution. Vol. 10 pp. 665.

Stanhill, G. (1966). Radiation Balance of Natural and Agricultural Vegetation. Quart. Journ. of Roy Met Soc. Vol. 92 pp. 128

Sundborg, A. (1950). Local Climatological Studies of the Temperature Condition in an Urban Area. Tellus. Vol. 2 pp. 222-232.

Terjung, W.H. (1969). The City-Man System in Urban Energy Balance Climatology. Proc. Ass. Amer. Geog. pp. 145-14

____________ (1970). Urban Energy Balance Climatology: A Preliminary Investigation of the City Man Systems in Los Angeles. Geog. Review Vol. 60 No. 1

Terjung, et al (1970). The Energy Balance Climatology of a City-Man System. Ann. of Ass. of Amer. Geog. Vol. 60 pp. 446-492.

Terjung, W.H. and Louie, S.F. (1973). Solar Radiation and Urban Heat Islands. Ann Ass. of Amer. Geog. Vol. 63, No. 2.

____________ (1974). A Climatic Model of Urban Energy Budgets. Geog. Analysis 6, 391-367.

Terjung, W.H. and O'Rourke, P.H. (1980). Influences of Physical Structures on Urban Energy Budgets. Boundary Layer Meteor. Vol. 19 pp. 421-439.

Udo, R.K. (1982). Ibadan in its Regional Setting: In Filani, M.O. (ed) Ibadan Region. Dept. of Geog. Univ. of Ibadan.

Unwin, D.J. (1980). The synoptic Climatology of Birmingham's Urban Heat Island (1965-71). Weather Vol. 35, No. 2.

W.M.O. (1963). Guide to Met. Instr. and Practice No.8 Geneva.

W.M.O. (1970). Urban Climates.Tech. Note No. 108. Geneva

W.M.O. (1982). Report of Meeting of Experts on Urban and Building Climatology, Geneva.

____________ (1983) Pamphlet on Climate, Man and Urbanization, Geneva.

Yab, D. and Oke, T.R. (1974). Sensible Heat Flux over an Urban Area - Vancouver. B.C. Journal of Appl. Met. Vol. 13, No. 8.

APPENDIX I

MEAN TRAFFIC DENSITY (1979-83)*

Position of Enumeration Description	5 Year Average
1. Lagos-Ibadan (opposite Ekpo House)	86,120
2. Molete-Dugbe (at British-America Ins. C Company)	7,446
3. Molete-Dugbe (opposite S. Allen's Sameday cleaner)	6,569
4. Dugbe-Mokola (opposite NEPA office)	10,197
5. Dugbe-Mokola (at National Filling Station)	9,865
6. Orita Mefa-Bodija (U.I. Junction)	8,414
7. Orita Mefa-Bodija (opposite Awolowo Avenue)	9,191
8. Orita Mefa-Bodija (opposite First Bank)	9,243
9. Elizabeth-Parliament Road (at Mokola Junction)	111,036
10. Elizabeth Road (opposite N.T.A. Ibadan)	9,872
11. Orita Mefa-Bodija (opposite U.C.H Entrance)	7,305
12. Parliament Road (opposite Forest Reserve)	4,837
13. Iwo Road (opposite Way Side Juu Hotel)	7,587
14. Ife Road (old) (opposite Green Spring Hotel)	10,492
15. Taffy-Highway (Methodist Church)	8,994
16. Taffy-Highway (Yemetu Stream Bridge)	8,169
17. Mapo-Molete Road (opposite Mapo Hall)	7,735
18. King Road (Lagos Road and Challenge Junction)	8,076

APPENDIX I (Contd.)

Position of Enumeration Description	5-Year Average
19. Ring Road (Abeokuta Road End)	8,907
20. Lagos/Abeokuta Ibadan Road (Idi-Moli Iyaganku)	8,472
21. L gos/Abeokuta Ibadan Road (opposite Maryway College)	10,986
22. Lagos/Abeokuta Ibadan Road (Govt. College)	8,797
23. Lagos/Abeokuta Ibadan Road (opposite Agip Petrol Station)	11,136
24. Eleiyele Road (opposite Pan Electric)	7,264
25. Ojoo Road (opposite Tinuoye House)	7,446
26. Sabo-Onireke-New Barracks Junction	6,859
27. Amunigun Road-Agbeni (opposite Omos Road)	6,308
28. Okunola Street (opposite Rational Bookshop)	8,194
29. Inalende-Mokola Roundabout	3,382
30. Sabo-Scala Road-Mokola Roundabout	3,451

* Counts done at each point from 0600 to 1900 hours of GMT twice in January and July each year.

Source: Computed after the Oyo State Ministry of Works and Transport, Traffic Division, Ibadan.

APPENDIX II

POPULATION FIGURES FOR IBADAN WARDS (1963 CENSUS)

Ward Area		Population
1.	C1	11,557
2.	C2	18,437
3.	N1	16,307
4.	N2	9,496
5.	N3	20,503
6.	N4	15,964
7.	N5	20,420
8.	E1	48,345
9.	E1	12,856
10.	E2	7,595
11.	E3	9,122
12.	E4	7,028
13.	E5	9,850
14.	E6	9,825
15.	E7	12,045
16.	E8	8,646
17.	E9	9,206
18.	S1	11,391
19.	S2	7,897

APPENDIX II (Contd.)

Ward Area		Population
20.	S3	7,963
21.	S4 and S5	22,928
22.	S6	11,385
23.	S7	11,654
24.	SW1	13,200
25.	SW2	8,132
26.	SW3	20,913
27.	SW4	13,743
28.	Sw5	12,179
29.	SW6	55,214
30.	SW7	70,687
31.	SW8	33,767
32.	SW9	15,362
33.	NW1	6,820
34.	NW2	13,658
35.	NW3	26,859
36.	NW4	6,913
37.	NW5	3,980
38.	NW6	5,602

APPENDIX III

DATA ON TEMPERATURE AND RELATIVE HUMIDITY FOR THE TEST OF THE HYPOTHESIS IN CHAPTER SIX

	Rain				Harmattan			
	Tu°C	Tr°C	Hu%	Hr%	Tu°C	Tr°C	Hu%	Hr%
1.	35.[illegible]	31.8	65	70	33.1	31.5	41	43
2.	31.[illegible]	29.2	70	72	32.1	30.0	50	56
3.	34.[illegible]	32.5	69	72	36.2	32.1	32	36
4.	35.[illegible]	32.8	69	70	35.2	32.5	33	37
5.	28.[illegible]	26.3	80	84	35.2	32.5	36	43
6.	29.[illegible]	23.8	63	65	35.8	33.4	22	36
7.	27.[illegible]	23.4	88	91	34.5	31.5	35	41
8.	28.[illegible]	23.2	81	86	37.5	31.5	28	32

Tu - Temperature Urban

Tr - Temperature Rural

Hu - Relative Humidity Urban

Hr - Relative Humidity Rural

APPENDIX IV

DATA UTILIZED FOR THE SPEARMAN'S RANK CORRELATION COEFFICIENT TEST IN CHAPTER EIGHT

Land-use	% UR	BUL DEN	ZO BUL	ZO TR	Qtq RA	Qtq HA	a HA	a RA	L* HA	L* HA	L* RA	H RA	T RA	T HA	RH RA	RH HA	Rn RA	Rn HA
L Unit	%	km^2	cm	cm	Ly-min^{-1}	Ly min^{-1}	%	%	Ly min^{-1}	Ly min^{-1}	Ly min^{-1}	Ly min^{-1}	°C	°C	%	%	Ly min^{-1}	Ly min^{-1}
1. High density	84.7	8,000	7.4	106	.25	.27	12	14	.14	.13	.120	.020	28.1	29.7	82	29	140	159
2. Medium "	78.3	450	8.2	114	.29	.30	15	16	.17	.16	.116	.020	26.4	27.1	83	32	136	142
3. Low density	87.8	700	109	102	.30	.32	16	17	.19	.17	.107	.013	26.0	26.5	586	35	121	130
4. Rural	24.4	306	46	96	.33	.35	17	16	.22	.20	.095	.006	27.9	25.8	87	38	101	112
5. Commercial	80.5	1800	113	105	.24	.26	12	12	.13	.11	.131	.020	28.3	30.2	80	27	151	163
6. Open Space	0.8	0	0	163	.30	.33	16	16	.20	.18	.101	.009	26.0	26.2	86	36	110	126

UR - Urban
DEN - Density

BUL - Building
TR - Tree
RA - Rain
HA - Harmattan