WORLD CLIMATE PROGRAMME

APPLICATIONS and SERVICES

URBAN CLIMATOLOGY
in
AFRICA

Special issue of the

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(VOLUME FIVE, NUMBERS ONE AND TWO
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Yinka R. Adebayo
Guest Editor

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SETTING AFRICAN SETTLEMENTS AND CLIMATES TO SAME RHYTHM : An Editorial Comment*

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Provision of shelter is an essential preoccupation of human kind. Essentially, buildings are constructed in order to guide against the adverse effect of climate and protect properties. Somehow, through trial and error,"Environmental building conditions and human settlements have evolved with civilization and as such were atuned to the physico-social environment. This means that to a large extent buildings and human settlements were designed in response to environmental demands within available resources and know-how. Available evidences revealed that the situation in Africa was such that buildings and settlements were more amenable to climate than they are today because of the following reasons.

1. The advent of colonization lead to a state of cultural confusion. Mix-up and changes in mode of buildings and settlements layout are products of this confusion. As a result of these problems, the so called modern buildings in Africa today are rather more suitable in temperate climates, than in tropical and subtropical, areas.
2. The direct and indirect control of economic base of Africa by foreign interests leaves nothing for housing financiers and settlements planners, to command, in terms of planning and ultimate decision on what-to-build-where and the materials to be used. By this, estate management and physical planning are fashioned by, and towards the needs and ideas of, financiers and educators in developed temperate countries.

The problems of human settlements are multifarious; part of which have to do with the reckless-abandoned abuse of the atmospheric resources. Another face of the problems as they relate to the atmosphere is that building design and settlement planning and management do not take adequate advantage of the resourcefulness of the atmosphere. Expectedly, these problems are more serious in Africa, wherein lie many of the underdeveloped countries.

The problems of the city are enormous and they have even been increasing over the years. Of particular concern to climatologists are the atmospheric aspects of these problems as they relate to other components of the city. The aspects of urbanization as related to the atmosphere has been identified by United Nations Environment Programme in a report in 1988 titled "Environmental Perspectives to the year 2000 and Beyond" as :

i) Atmospheric characteristics in relation to the houses which include ventilation among others.
ii) Ambient environmental situation which includes air pollution and others.
iii) Environment of the area surrounding the urban centres (for example, microclimate).

Urban climate is a typical product of human activities. Generally, urban climate analysis is considered essential because since urban climate changes the whole equation of mesoscale and microscale atmospheric circulation systems, such analysis will enable us put the man-atmosphere relationship in the right perspectives. Thus urban climatology provides some clues to the problems of human comfort, pollution and energy in the city. Unfortunately, urban climatological researches have not been able to provide adequate solutions. The problem is further complicated by the fact that even the existing urban climatological facts are not rightly channelled to both planning and design communities. As expected, this problem is more serious in the developing countries where scanty evidences of the magnitude and dynamics of urban climates exist. The situation in the developing countries should be of cocern to environmentalists not only because their cities are growing at a very rapid rate but also because climatic modifications in the low latitude regions also affect the climates of other regions; in our common global environment.

In view of the above, therefore, concerned planners, architects and engineers should be prepared to answer the following questions.

1. What is the framework upon which climate-sensitive design and planning can be achieved in the highly populated, activity-loaded and economically sensitive cities?
2. How can climate-sensitive buildings design be achieved in slums and squatter settlements ?

Perhaps an important way of solving part of the climatic problems of the modern city is to lay the climatic advantages of traditional and modernhouses on the drawing board and thereafter integrate the

* This editorial is not reflective or symptomatic of UNEP/GEMS' position. Indeed, opinions expressed here are purely those of the Guest Editor.

advantages of both into the production of new types of designs, bearing in mind the basic causal factors of urban climates. These basic features of urbanization causing the changes in physical environment and alteration in energy exchange and thermal condition have been identified and acknowledged by scientists as :

1. Air Pollution – increased long-wave radiation emitted by the atmosphere due to greater absorption of incoming shortwave and outgoing longwave radiation by pollutants.
2. Anthropogenic Heat – heat released in the process of combustion.
3. Surface 'Waterproofing' – decreased latent heat flux thereby favouring sensitive heat.
4. Thermal Properties of Fabric – increased thermal admittance of surface and building materials favouring daytime uptake and nocturnal release of heat storage.
5. Surface Geometry – increased shortwave absorption due to trapping inside canyons, decreased loss of heat by turbulence due to stagnation in deep canyons; decreased loss of longwave radiation from canyons due to reduction in sky view factor.

At a specific regional level, not much has been done in Africa. It was in awareness of this that the Editor of African Urban Quarterly called upon me, following the resolutions at the First International Conference on Urban Growth and Spatial Planning of Nairobi Dec. 13-17 1988, to Guest-edit this Special Issue on Urban Climatology in Africa.

This issue of African Urban Quarterly covers problems ranging from methodology, through real-life empirical issues to the applied aspects of urban climatology across eco-geographic region of Africa. It took us three years to put this issue together.

The problems of information and grass-roots methodology are put in perspectives by Adebayo in two separate articles. The first one identifies the needs of planners and architects while the second one discusses the real-life experience of the author while carrying out a research on urban climatology of Ibadan, the most populous traditional city in Africa south of Sahara. Both articles suggest ways of managing the problems right from the level of research formulation to the stage of data collection analysis and dove-tailing to policy level.

Ogunsote examines the various forms of data storage and retrieval for urban climatology in Africa. His purely theoretical analysis identifies the needs and problems of data management for operational work in this field.

Ng'ang'a and Ezaza in two independent articles touch on some aspects of atmospheric pollution. Whereas Ng'ang'a examines the management and policy aspects of pollution, Ezaza discusses the problems of atmospheric pollution in Dar es Salaam, a typical African City. Both articles, from different perspectives, identify various dimensions of atmospheric pollution, as it were, in Africa.

The only article which handles the aspect of urban hydrology is that by Oyebande which contains an extensive review of trends and features of African urban centres, causes of hydrological regime of cities and empiric examples of different facets of hydrological problems. In the final analysis the article advocates different possible ways of handling urban hydrological problems.

Concrete case analyses of effects of urbanization on climate are presented by Okoola and Ojo for Nairobi and Lagos respectively. These investigations are typical examples of the magnitude of urban climate in typical tropical cities. On the whole, both studies conclude that the effects of urbanization on the cities are significant. Asante carried out similar investigation in Nima Ghana, albeit from the applied aspects of the problem.

Nieuwolt gives an analysis of climate-sensitive planning and design in humid tropics generally while Oguntoyinbo presents a lucid analysis of the situation in West Africa. Both analyses center on planning and designing for comfort, climatic extremes and energy conservation with reference to available resources and cultural settings. Similar analysis is made by Givoni for hot dry climate, although with more reference to urban design and street orientation. In a related article, Meffert gives an account of historical genesis and contemporary situation in Zanzibar Stonetown which is now being rehabilitated by the United Nations Development Programme (UNDP) and United Nations Centre for Human Settlements (UNCHS-Habitat).

The international responses to the problems of urban and building climatology by the World Meteorological Organization (WMO) are treated from two different perspectives by Olsson and Jauregui. Really, the only coordinated attempt at solving the problems of urban atmosphere in developing countries is being made by WMO through its Tropical Urban Climate Experiment (TRUCE) programme. At the African level, this special issue is a pioneer attempt at bringing together expert-ideas on theoretical and applied aspects of the problems. No doubt, it is going to be a worthwhile document for operational use by architects, planners, policy makers, researchers and students in Africa and abroad. I welcome readers and potential users to this special publication.

African Urban Quarterly *Volume 5 Nos. 1 & 2, February and May, 1990*

ON EFFECTIVE CLIMATOLOGICAL INFORMATION FOR ARCHITECTS AND SETTLEMENT PLANNERS IN AFRICA

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Abstract **Accepted July, 1989**

Planning for better indoor and outdoor climates is a fundamental consideration in architectural practice and urban planning profession. Unfortunately, since the time of colonization, the idea of climate-sensitive planning has hardly been taken seriously by African architects and planners who have entirely taken to Western methodology. Today it is very obvious that it will be necessary to change this situation in view of the growing population size and atmospheric problems of African urban areas which lie mainly in the tropics. In this regard, this article discusses some of the basic climatic design tenets that these professionals would need to adhere to in order to attain environmentally sound climate-sensitive design and planning.

Introduction

Urban climate is a form of man-made climate which is not as conducive as the natural, and undisturbed climate. As such, it is better to plan towards the reduction of the magnitude of urban climate with or without change in global climate system. With the wave of alarm and apprehension about the nature and extent of global change in climate, it is more expedient than hitherto to put the urban areas on the alert.

Unfortunately, it is not easy to revert to the natural form of climate anywhere there is human settlement. This problem is further compounded by the intrinsic vagaries in the atmospheric circulation system. The scarcity of urban climatological data in very many parts of the world introduces another dimension into this problem. Indeed, it is necessary to outline ways of minimizing the extent of climatic modification in the urban areas because the effect of the abusive uses of atmospheric resources in urban centers resulting in climatic modification is not limited to urban areas. According to Oke (1977) climatic modification in urban areas affect areas several kilometres downwind.

The climatological challenges faced by urban planners vary across climatic and cultural regions because of the variations in the nature of urban climate and forms of socio-economic and technological conditions. For example, whereas houses in the temperate regions require indoor energy conservation most time of the year, reverse is the case in tropical areas. Also, the effect of 'heat island' on urban climate varies across these major climatic regions. Socio-economic factors also influence the forms of design and environmental management strategies in different ways from one eco-geographic region to the other.

One key problem of urbanization process relates to the issue of poor indoor and outdoor air pollution. It must be noted that atmospheric pollution relates, closely, with climatic condition. As such, human health and comfort can be in serious danger if climatic conditions are not in favour of good indoor and outdoor air qualities. It is necessary to pay more attention to the climatic condition in urban areas also because of the need to find possible meteorological solutions to the growing quantity of suspended particulate matters in urban areas.

Sources of pollutants, as identified by UNEP/WH0(1988) can be linked with human activities such as forms of buildings and nature of building materials. This points towards the fact that in order to control the urban air quality, conditions of building and their materials should be examined along with meteorological, socio-economic and cultural factors. This observation brings out the multifarious importance of building condition as an important factor in environmental engineering. By extension, the layout and configuration of the urban structure play much more important roles in the meso-scale environment.

One major way of solving the aspect of the environmental problem of the urban area is by combating the problem arising from climatic modification in urban areas.

In order to reduce the impact of urban climates, it is important to first and foremost work out the right formula for reducing its magnitude, since it is not possible to eliminate the phenomenon. A top-down approach will be necessary to such exercise. This approach must begin with climate-sensitive urban planning and then dove-tail to climate-sensitive building design in different sectors of the urban area.

Climate-sensitive Planning

An analysis of urban climatological problem should begin with documentation of the nature of surface texture, extent and types of human activities and urban population distribution. Unfortunately, it is not easy to accomplish this task in the developing countries because of the difficulty in laying hands on basic background detailed information. This problem is so piercing to the extent that at best the option which is usually available to most researchers in the developing countries is to gather such required data from an amalgam of disjointed land-use maps and general records. This is one major cog in the wheel of any task aimed at analysing urban climatological problem in developing countries. But whatever may be the case, researchers should find their ways out of this problem.

Over the years, a few general guidelines for arriving at climate-sensitive urban planning and building design have been established by scientists. Some of these approaches will be discussed later. Adopting a top-down approach, our discussions will begin with relevant aspects of climatological considerations in urban planning.

In working towards a better urban climate, it is always important to bear in mind the features of urbanization that are responsible for changes in the atmospheric environment. Some of these important features include air pollution, anthropogenic heat, surface geometry and building conditions. Unfortunately, it is not possible to take a direct sensus of these urban characteristics. As such the land-use approach is usually adopted.

There are various ways in which the urban land-use could be classified, depending on the goal of such classification and, to a lesser extent, availability of information. For urban climatological purpose, the example by Auer (1978) is acceptable because it takes care of the essential microclimatological factors. After a thorough classification of the urban land-use it will be necessary to make sense out of such classification. The detail procedure can progress as follows:

- Extract information about states of urbanization at different periods over time.
- Collate information on site-to-site condition of urbanization such as the states of road, building, surface cover and population, among others.
- Reproduce maps of the state of urbanization for given periods with same interval as identified above.
- Know the states of pollution and anthropogenic heat from different sources.

The above steps form the essential bedrocks upon which both qualitative and quantitative assessment of the state of urban climate can be made. Upon knowing the actual and/or the expected condition of urban climate, the decision concerning urban renewal or approval for expansion of the urban areas could be taken. For example:

- If an area of high pollution concentration is identified, it will be important to depopulate such sector of the city and possibly restrict expansion of the city in that direction. Another option is to re-locate (if it is industrial) or divert (if it is traffic) the sources of the pollutants.
- If areas of scarce vegetation are identified, massive environmental campaign can be mounted and if need be legislative step can be taken in order to enhance a re-generation of vegetation in such areas.

Planners face the problem of determining the extent and location of greens and lawns as well as the problem of achieving adequate orientation for the buildings in urban areas. As such planners can ask the following:

- Is there an optimum proportion of the urban center to be devoted to vegetation?
- Is there an optimum arrangement of such green spaces?
- Is there a preferred orientation for roads and buildings to maximise solar radiation influences?
- Are there optimal height/width ratio for street canyons to maximize energy conservation or pollutant dispersal? (Oke, 1984).

These questions are very difficult to answer especially because urban areas are located in various climatic regions on different forms of geomorphic configurations. Very importantly because locational theories are governed by different socio-economic and cultural factors which tend to over-shadow physical considerations.

In examining the role of climate in planning, it is necessary to take a systematic step from regional level, through settlement level to the housing design level. Similar strategy has been highlighted by Potcher (1988). Regional planning involves lesser considerations than settlement planning and house design. The most important consideration at regional level is environmental hazard. Considerations are compounded at the level of settlement planning by economic factors such as sub-unit functions and distance optimization. These factors compete with other environmental considerations such as shading, wind shelters and open space uses.

The task of integrating climatological ideas into planning framework is not an easy one. Such exercise is not straight-forward because it is very difficult to predict meteorological factors which influence, for example, pollution and comfort. In this connection, Landsberg (1976) regards the system whereby some sectors of the urban centres are separated downwind as "poor use of meteorological information," and recommends that planning should proceed with the wind direction that are associated with meteorological stagnation conditions. Oke (1984) held a similar view about simplistic application of meteorological factors in urban environmental planning: "The suggestion... to lay our cities according to prevailing wind which are adopted in planning new Russian cities... are now seen to be too simplistic. A better scheme would be to base such plans on the direction and frequency of occurrence of wind during conditions conducive to high ground-level concentration of pollution, if that is the primary concern". One important point arising from this observation is that urban climatological information are necessary tools for result-oriented climate-sensitive planning.

It is difficult to isolate the role of individual climatic element from that of the combined climatic conditions since all climatic parameters act together as one holistic atmospheric condition. However, some climatic parameters play very prominent roles and as such they can be used as surrogates for sensing the influence of climate. Within this category are solar radiation, wind, humidity and precipitation. The first thing to do is to collect adequate information about these parameters for worthwhile operational consumption. Required data are needed in the forms highlighted below.

Solar radiation

Taesler (1981) highlighted the forms in which solar radiation data are required as follows-

- Mean global radiation/month, hour
- Mean direct, diffuse solar radiation/month, hour
- Global, direct and diffuse radiation at different hours of each month for clear skies, overcast, and intermediate cloudiness
- Radiation data as above for vertical and inclined surfaces.

Accumulated solar radiation fluxes over consecutive periods of different length.

Solar radiation data should also be collected across the region of a proposed urban site or over the land-uses of an existing urban area. It is also necessary to collect data on the urban sky view factor within different canyons.

Wind

Wind data are useful inputs for analysing the effectiveness of solar radiation/atmospheric temperature, physiological comfort, pollution concentration and possibility of its disposal, wind loading in engineering design and overall energy conservation. As a result of the multipurpose uses of wind data, it is necessary to collect them in the following forms:

- Speed/hour, day
- Gusts, frequency and magnitude
- Lulls, frequency and magnitude
- Direction associated with average wind speed
- Direction associated with gusts and lulls
- All of the above at an interval of 10 m across a vertical extent of 500 m from the surface.

Rainfall

Rainfall data are needed in the following forms:

- Intensity per unit time
- Frequency per unit time
- Intensities associated with ranges of wind speed and direction
- Intensities associated with humidity and cooling rates.

The above data are needed for the purposes of:

- protecting the indoor from rain,
- monitoring the condition of flood,

- determining the thickness of the basement of a house,
- knowing the types of building materials to use in a specific location, and
- understanding the level of "sporadic" comfort/discomfort associable with certain precipitation characteristics.

Temperature and Humidity

Inverse relationship exists between temperature and humidity. Both parameters are commonly employed in comfort and pollution analyses. Information about the parameters are needed in the following forms:

- Magnitude, hourly
- Extremes, maximum and minimum
- Vertical variation at given interval from the ground surface
- All of the above over different sectors of the urban and aspects of buildings

The climatological parameters which are of strategic importance to planning, and the forms in which their data are required have been highlighted above. Important to remark that same set of data can double-up, to an extent, as input to architectural design. Now, the crucial question which is difficult to answer is, how do we expect planners to consume these data? There are various answers to this question. Let us attempt to prescribe possible options.

1. The planner needs to establish a minimum baseline for the attainment of comfort, and thus concomitant conservation of energy. In other words, it must be decided whether heating or cooling is required. If:

a) heating is required, planning should focus on microscale conservation of energy. A way of attaining this is to shelter the houses from the regionally prevailing cooling breeze. Tall office blocks or recreational centres like stadia could be built upwind.

b) cooling is required, planning should focus on microscale free flow of air. For this purpose, streets could be laid out parallel to the regional wind. In addition, buildings should be separated as much as possible. Also 'cool oasis' may be provided through creation of clean water and well-managed water-pool. Vegetation could be planted on "free" land around residential area. For example it has been confirmed that vegetation can act as thermal regulator in courtyards. See, for example, Wilmer's (1986) study in Hannover, Germany. Similarly Mayer and Hoppe (1987) established the importance of vegetation to different comfort-determining parameters in Munich.

2. The problem of pollution also beclouds the mind of planners. The ideal things is to nip this problem in the bud by eliminating the emission of pollutants from their sources. But since this approach is not yet realistic, more effort should be directed towards pollution control. The following steps can be taken, namely,

a) Vegetation can be planted close to emission sources. This means that it is necessary to plant low-level shrubs by the road sides so that automobile emission can be tapped from the source. In the industrial area, tall trees may be more desirable. Trees planted upwind could have detrimental effect on pollution dispersal.

b) Structures should not be erected along the part of the prevailing wind.

c) It is more desirable to locate industrial centres at the city suburb where the wind axis blows parallel to the urban area.

3. It has been confirmed that urban rainfall increases downwind (Huff and Changnon, 1972). In view of this, it may be necessary to preserve the area downwind for the much-desired urban agriculture. Treated water from industrial and domestic sources could be diverted downwind to boost the water resources for this urban agriculture.

4. An urban area located in a region whose rainfall per unit time is high is highly prone to flooding. In view of this, the development of impervious surfaces should be restricted in such locality.

Climatic reference point

It is necessary to examine the link between climate and urban building design in two ways. Firstly, the basic relevance of each climatic parameter to design should be established. Secondly, the allowances to be given to possible changes/modification in climate must be worked out.

The main subject of climate-sensitive building design depends on building orientation, materials used and internal layout of buildings. The exercise is a very detail and comprehensive one, which is difficult to discuss in one breath. Here, we shall consider some aspects of building orientation and materials. The internal layout will be left to the architects.

Orientation

The issue here concerns the position of building relative to the sun. In any locality, it is important to determine the path of the sun. This could be done by using the solar chart. Since the path of the sun and its angle relative to to the earth's surface vary across the year, it is necessary to determine month-to-month solar path and angle. Whatever should be the ideal orientation of the house in any locality will be guided by whether or not cooling/heating is required.

- if more heating is required than cooling, then the building should be oriented in such a way that its longest axis should face the predominant position of the sun.
- if more cooling is required than heating, the building should be oriented in such a way that its longest axis is turned away from the predominant position of the sun.

Unfortunately, the above suggestions are difficult to implement in the city because of the existence of various degrees of shades which are provided by adjacent buildings.

Material

Thermal conductivity and solar relectivity (albedo) of building materials are important factors which control thermal condition of buildings. When heating is required, materials with high conductivity and low albedo are desirable. Reverse is the case when cooling is required. Unfortunately, it is difficult to attain these objectives because of cost and availability of materials. Building materials, also influence indoor pollution. In view of this, it is always necessary to take the ultimate effect of design on pollution into consideration.

Climatic aspect of design takes note of several factors. Indeed, various factors shape up the building before the end result is achieved.

Fundamentally, the type of building under consideration is a key force... are we designing a cinema hall, a classroom, a church, a factory, a warehouse or a residential house?

It is difficult to isolate the role of individual element of weather in the control of energy and comfort. But somehow, the role of some of them could be isolated, as we shall see below.

Insolation

Isolation plays an important role in indoor illumination and solar heating. Its magnitude and diurnal variation should be known at any locality.

Temperature

Temperature is an important determinant of comfort. The magnitude of urban heat island should also be known so that adequate allowances would be given to temperature increase.

Humidity

Humidity is relevant in comfort and energy considerations. The ultimate effect of the building on indoor condition of humidity should be envisaged so as to minimise negative consequences of humidity change on comfort and energy.

Wind

Indoor wind circulation is easy to control through provision for ventilation. For health reasons, cross-ventilation is always very important. It will be necessary to regulate this indoor ventilation from one locality to the other depending on the need.

One important way through which indoor climate would be regulated is by shading the wall with vegetation. This system can introduce lot of changes into the indoor climate and as such can be employed for the attainment of a desired goal. Degree of shading will vary from one case to another.

Conclusion

Climatic aspect of planning and design has nearly lost all its in recognition in modern day urban areas. This is due to the formidable role of economic consideration. In addition, land availability and adaptation of inappropriate technology complicate the situation.

But the issue is, whatever may be the problems, the need to double-up effort in the direction of attaining adequate indoor and outdoor climate in our settlement cannot be compromised for too long. Global energy crisis, fear of radical change in climatic condition and the increasing rate of growth and expansion of urban centres make the need to integrate appropriate climatological factors into urban planning and design frameworks expedient.

It is not as if urbanologists have not acknowledged the importance of climate all along.

But the problem is that urban forms across climatic regions tend to have common features because urban areas the world over are built upon similar economic and technological platforms. As such traditional designs which have been perfected over the years through experience have been abandoned for modern designs.

The kind of attention that should be given to climate in the urban area is in two major directions. Firstly, it is necessary to minimise the impact of urban structures on natural climate since no other form of artificial climate can be better than the natural one. Secondly, in order to reduce the impact of urban climate on human health, comfort, energy and security of lives and properties, it is necessary to embark on climate-sensitive design.

Adequate adaption of climatological ideas in human settlements can only take a top-down course from the urban planning stage down to the building design level. This top-down strategy becomes necessary because it is possible to anticipate the impact of urban development on climate before the erection of the structures and then plan for the reduction of possible negative consequences.

Today, entirely new settlements hardly emerge while the rapidly growing ones usually take their courses right from the onset. As such, various set-backs beset the top-down strategy. For example, it is always difficult to accomplish climatologically sound street orientation for an emergent urban center which is already radiating towards a given direction. Additionally, factors such as geo-political boundaries and natural barriers further complicate the matter. In the end, the job of a climate-conscious designer graduates to a higher level of methodological sophistication. At this juncture, empirical data analysis, case studies and modelling approach inevitably come into the agenda.

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DATA STORAGE AND RETRIEVAL FOR URBAN AND BUILDING CLIMATOLOGY IN AFRICA.

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Abstract ***Accepted September, 1989***

Data for urban and building climatology include climatic, bibliographic, graphs supplementary as well as materials and elements data. Their storage and retrieval will involve computer database or databanks which should be portable, flexible and relevant. Standardization at the hardware, software and data levels should reflect experience gained from existing databases. Implementing such a system in Africa will be hindered by socio-economic, infrastructural and technical constraints. The key to solving these problems lies in proper organization institutional support, use of non-proprietary system and respect for traditional methods.

Introduction

The principal aim of this paper is to expand the forum for discussion about data storage and retrieval for urban and building climatology in Africa. The subject matter proper is so abstract and technical that a direct treatise may fail to interest the general audience. Orgnisation and standardisation of urban and building climatology in Africa is a fairly recent development. Computing, apart from being new, is rapidly evolving in many directions simultaneously.

The nature of the subject matter and the manner of relation make it difficult to avoid personal opinions. While many statements are based on contact with researchers from several countries, the paper is based mainly on the Nigerian experience. The author's experience with microcomputers is largely restricted to IBM PC/XT/AT and ps/2 compatible computers and the MS-DOS/IBM-DOS operating system. Other standards and operating systems in the industry may, therefore, seem under-discussed.

That paper emphasizes the users as opposed to technicalities is a revealing reflection of the current state of computing. In the words of a leading software publisher and hardware manufacturer (Microsoft corporation], the future of computing now rests on making it all make sense. In other words, the users are being left behind.

The Nature of Data

The world data is an uncountable noun used with plural verbs. However, it is now commonly used as an uncountable noun with singular verbs. Data are facts. For our purposes, however, it is more accurate to see data as units processed [by a computer] to produce information.

Records of air temperature, humidity, wind and radiation are examples of data. These can be analysed and processed to yield information such as comfort condition or degree of thermal stress. Words in scientific articles are data items that can be processed to determine the relevance of the paper to a certain subject area. In both cases the relationship between the data items is examined and established using a logical process. The information obtained may be used as data to produce new information.

One interesting aspect of data is the rate at which they become absolute. Permanent data, such as the contents of back issues of scientific journals or even recorded climatic data do not change. Variable data, however, are subject to periodic changes as in the example of the names and addresses of practising urban and building climatology professionals in Africa.

Data for Urban Building Climatology

A large number of professionals and researchers with differing backgrounds are currently contributing to the improvements of the build environments. While they share a common goal, their particular contributions are influenced by their backgrounds: climatology, building, architecture, planning or engineering. Not only do difference exist between the specific data they require, they also view the common data in different ways. However, the following main categories of data required for urban and building climatology may be identified.

Climate Data

This is the most extensive category of data and the variables include air temperature, humidity, wind speed and direction, radiation, atmospheric pressure, precipitation and illuminance. These data may be minimum, maximum or mean and in additional may be hourly, daily or monthly. Sometimes, the average over a number of years is required at the times, representative days or reference years are used.

Bibliographic Data

These include books, journal articles, conference papers in climatology and in related fields like architecture, planning climatology, solar energy and engineering. Researchers are usually interested in identifying publications that cover or mention specific subjects, for example database;"African: building climatology". The few reference selected are then retrieved for inspection.

Graphic Data

A large portion of materials handled by researcher is in the form of graphic images: maps, illustrations, graphs photographs and drawing. Most current computer databases omit graphic data. This is often due to the need for special equipment to view the graphics and technical difficulties including huge storage requirements.

Supplementary Data

Several reference materials are required by researchers on daily basis even though such materials are not directly related to building climatology. These include encyclopeadias, almanacs, specialized dictionaries, the saurus and various manual and handbooks.

Materials and Elements Data

The properties of various building materials as well as the availability, cost, and supply of building elements are usually required for building projects.

The Nature of Databases

The database, sometimes called a databank, is generally any large integrated collection of data. A database is more precisely defined as a generalised integrated collection of data which is structured on natural data relationships so that it provides all necessary access paths to each unit of data in order to fulfill the differing needs of all users.

A database is conceptually a physical entity, maintained usually in the form of cards and files. Most databases are still maintained in this form. The advent of computer is a relatively recent development but their impact is so tremendous that unless otherwise stated, a database is usually assumed to be implemented as a computer.

A good example of a traditional database is a library catalogue. A library usually maintains several cards indices. A typical card contains, among others, the title, names of the author and publisher, date of publication, International Standard Serial Number (ISSN), Local Accession Number and Class mark. Two indices are commonly maintained for users. The first is arranged by subject matter and alphabetically by authors. The second is arranged alphabetically by authors only. However, the various sections of a large library (collection development, circulation and cataloging) maintain another book indices. The information about each book is duplicated on several cards.

The same library catalogue may be maintained as a computer database. All information about a particular book required by the various users and sections is kept in a central file commonly called main file. This main file with the introduction of relational databases, may be spread over several smaller files. The information content of this main file often exceeds that kept on a traditional database and may include keywords, circulation status, demand, price, agent, readership level, etcetera. In addition this central file is usually very large, randomly organised and infrequently changed. The various sections may however, maintain specified indexes - arranged by author, circulation status, local accession number or agent. A major advantage of computer database is the ease with which complex searches may be conducted. Other advantages include sharing of data, increased data integrity, data consistency, standardisation and control of access to data. On the negative side, specialized equipment and experts are required, costs are higher and new security problems are created.

In general a good or viable database should possess certain characteristics. It should be easy to reorganize (format) the contents as users and their needs change. The database should be portable, that is easily distributed among various locations. Probably the single most important attribute is that the data should be useful. The scope and area of application should be wide enough to ensure that the data will be essential to a large number of researchers.

Hardware for Data Storage and Retrieval

The major distinction that needs to be made in discussing the various equipment and peripheral used for data storage and retrieval systems is whether such systems are based on main frame computers or on micro-computers. For practical purposes, microcomputers are grouped with main frame computers.

A typical main frame system is made up of the central processing unit, disk drives, tape drives, terminals, printers, plotters and infrequently card readers or paper tape readers. Such a system can handle a large number of users simultaneously. The most common means of transferring information between systems is through the use of magnetic tapes. Data may also be transmitted via a modem.

A microcomputer system is basically a single-user work-station, even though several microcomputers may be linked together in a network. A hypothetical workstation may be made up of the system unit, monitor, keyboard, printer, plotter and alternative input device (mouse, digitiser,lightpen, bar code reader and scanner), floppy disk drives, hard disk drives, take drives and CD drives. The system unit may have several specialized cards installed; graphics cards, memory boards, modem, co-processors, etcetera. In practice however, the number of alternative input devices and specialised cards is usually limited. Data may be distributed on floppy disks, tape cartridges, CD-ROM diskettes and via modem.

Software for Data Storage and Retrieval

Computer programs for data storage and retrieval are usually written for particular application and clients, especially on mainframe computer. These programs delete and add records to the main file. they also maintain comprehensive indexes that enable fast data retrieval. These indexes are usually organised as balanced binary trees called B-trees. A relatively new function is the management of an attractive user interface.

The traditional Data Base Management System (DBMS) is a large program running on a mainframe computer, Most large databases are still kept on mainframe computers and data distributed via tapes and remote terminals. The software is usually proprietary to the mainframe manufacturer. Such software is usually flexible enough to allow the creation of specific applications.

Micro-computer programs are inherently easier to use. Specific applications are also easier to create using a specific programming language. The Structured Query Language (SQL) and Query By Example (QBE) are popular "languages" that simplify interaction with databases. The standard database program for the IBM PC/XT/AT is dbase (Version) while competing products include RBASE , Paradox, Oracle Quick silver, R & R, dBXL and Foxbase. These programs emphasize that user interface and report production. Despite the relative ease of use of these programs however, it is advisable to develop customised applications for specific situation. A library catalogue for example may be used by people who know very little about computers and who may find such customised applications easier to use.

Database software may also be categorized as commercial or educational. Commercial software are inherently more reliable and better designed in order to meet the challenge of competing products. Such software is loosely used to describe all non-commercial database software. These are usually written in academic institutions using a high level programming language. Record handling in such cases must be designed practically from scratch. Since such software are rarely widely distributed, they are never fully tested. There is little justification today for writing database software scratch for single applications. It is more practical to use commercial software to develop applications tailored to specific needs of users.

The Need for Standards

The use of a common database by professionals from different institutions even countries will require standardisation at the hardware, software and data levels.

At the hardware level, the medium and mode of distribution must be established. The various computers must be compatible enough at the hard ware level to exchange data. Fortunately, the computer regulates tape formats, diskette sizes, communication protocols and interfaces to a certain extent.

There is also considerable standardisation enforced by the computer industry at the software level. Many database management systems can accept raw data in one form or another from other programs. With source level standardisation, programs and data can be ported after minor modifications. Binary level standardisation enables direct portability.

The major standardisation obstacle that will be faced by African scientists is at the data level. For an international database, the choice between the English , French or Arabic language is a fundamental issue. For very technical data, such as climatic data, the format, units or measurements, duration and even the elements recorded should be agreed upon. It is essential to establish the format or organisation of data items in general.

Existing Databases

There are several existing database that can either serve the purposes of African researchers or on which new database can be based. The International council for Building Research and Documentation (CIB) at a recent seminar on Computers and Climatic Data discussed several databases (Keeble, 1988). Of particular interest are the SERC Meteorological Databaseand the British Research Establishment (BRE) Bibliographic Database "CLIMAX".

The SERC Meteorological Database was developed at the University of sheffield in conjuction with the Rutherford/Appleton Laboratories in Ox-fordshire (Page, Gibbons and Lowe, 1985). It is a subset of the UK Meteorological Office Database. It contains hourly parameters for each of the following sites:

(i) Global solar radiation
(ii) Horizontal diffuse solar radiation
(iii) Sunshine duration
(iv) Dry and wet bulb temperature
(v) Atmospheric pressure
(vi) Wind speed and direction
(vii) Rainfall amount and duration
(viii) Present weather code

The database contains data for 1974-81 in six cases and 1962-81 for the seventh site. It also includes daily, monthly and yearly averaged data. The database is stored on disk and tape on a mainframe computer. The hourly data are stored on tape while the summary data are stored on disk. It can be accessed via the SERONET data network for interactive use (summary data) or text retrieval in barch mode. The retrieval data are stored on disk in selectable formats. The database is available to outside users for a fee.

The "CLIMAX" database provides a detailed record of each source of climatic data relevant to construction in the United Kingdom (Keeble, 1988). It is possible to conduct an interactive search of particular words as well as display, print or data items containing these words. It is possible to narrow down the search by specifying detailed search criteria. CLIMAX uses considerable standardisation to control the vocabulary of entries, especially for meteorological elements and climatic parameters.

CLIDATA is a database of climatic data developed by the author at Ahmedu Bello University, Zaria, Ogunsote and Prucnal-Ogunsote, (1987). The database was initially just a collection of data used by some FORTRAN programs for environmental science and building climatology. As the number of data items grew and the need for direct queries and modification increased, special programs had to be written for data handling. Data security and reliability were of particular concern in the design of CLIDATA since the programs and data were in the public domain. Data validation techniques were therefore, widely used.

CD-ROM Libraries

Compact Disk-Read only Memory (CD-ROM) technology has evolved to the point where CD-ROM Libraries are now found on microcomputers. The storage medium is a 12 centimeter (660 MB) diskette very similar to the one used on Compact Disk Audio players. A single diskette can store approximately 270,000 pages of text (Manes, 1988).

The data on a CD-ROM diskette is permanent and unchangeable under normal operating conditions. The diskette is covered by tough poly-carbonate plastic which anyway, is never touched. The CD-ROM player is installed much like an ordinary disk drive. The player is commonly accessed using an extension of the operating system that treats the player as another drive. Libraries are usually accompanied by search and retrieval software, often on the same diskette.

There are hundred of libraries currently on sale. These libraries are most often electronic equivalents of material already available in print, or through on-line information services. Of interest may be the CD-ROM Science and Technical Reference Set (illustrated) and the New Electronic Enyolopedia. The accompanying search and retrieval software enable complex searches on multiple fields. The data satisfying the research criteria are displayed on screen - they may then be browsed through, printed on paper, saved to disk file or pasted into other reports and applications.

CO-ROM currently possess some video and audio capabilities out CD-ROM libraries tend to omit graphics based data such as photographs, diagrams and illustrations. This is largely due to technical problems. However, work on new CD video standards and media may reduce some of the technical difficulties soon. One of the fruits of successfully integrating this technology is a dictionary that not only pronounces every word, but that also displays an illustration for the word.

The African Aspect

Computing in truly African countries is essentially an imported technology. Despite the inherent reliability of computer systems, their practical installation and operation in African countries has been problematic. These problems are more common with microcomputers than with mainframes probably because of the administrative size, funding and ownership of mainframes.

Lack of adequate infrastructure such as constant and steady electricity supply and reliable telecommunications networks is the first obvious problem. The low computer culture means truly expert operation and maintenance professionals a rarity. Training people to use the computer for even very fundamental tasks can be embarrassingly unsuccessful. This situation has been widened by the current economic depression. Thus, the large user base normally associated with personal computers is practically non-existent, even in academic and commercial institutions.

The impact of these and other problems on electronics data storage and retrieval in Africa is far reaching. The effort that goes into the creation and maintenance of a computer database can only be justified if the database is used by a large number of people. Only a very small percentage of urban and building climatology professionals routinely work with computers. This is despite the fact that a considerable number of them have access to computers. Thus, we face the dilemma encountered with most high technology ventures in African the question volume as creates to efficiency. As in the case of automobiles, efficient production of software is only possible on a large scale. Unfortunately, such a high demand is currently non-existent.

The Open Approach

Harnessing the power of computers for data storage and retrieval for urban and building climatology in Africa on a national and international level will require time, resources and a unified approach. Individuals researchers will normally use any available hardware and software for their work. Sharing data with others however, requires standardisation.

Hardware and software can be generally divided into two groups proprietary and non-proprietary. Proprietary products restrict users to the manufacturer, usually a large corporation such as international Business Machines (IBM). Proprietary products promote monopoly and its attendant negative effects. Non-proprietary products on the other hand give users greater freedom of choice and encourage healthy competition, for example, Open Computing, promoted by Sun Microsystems, is based on non-proprietary systems.

For our purpose, investing in proprietary hardware will be counter-productive in the long run. Unfortunately, non-proprietary products are also not ideal, since by definition they are at least not compatible with proprietary products. Also, someone has to set the standards. And There are several standards in the industry. No matter the standard chosen, keeping the system open is essential.

Access to data can be ensured if data centres are developed in and around institutions, especially institutions of higher learning and research centres. Data should, as much as possible, be made freely available at minimal cost. Work done in the various institutions can be centralised in National Data Centres for easy access, standardisation and administration.

Conclusion

The regular use of computers for data storage and retrieval for urban and building climatology in African is no common. This is partly a result of unfavourable economic and infrastructure conditions. Another reason is the lack of demand for such high technology systems. This lack of demand can be traced to traditional work habits of building climatology professionals in their specific social and economic environments.

Improved efficiency and dissemination of information should be based in research institutions which in turn will be linked to a National Data Centre. Hardware and software system should be open and non-proprietary to enable easy exchange of data. The National Data Centres should play a major role in standardisation and distribution. The distribution of information and data in printed form to those without access to computer is essential since many professionals are reluctant to change their traditional work habits.

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PERISCOPING THE PROBLEM OF DOCUMENTING THE CITY ARTIFACTS FOR THE STUDIES OF URBAN MICROCLIMATOLOGY IN THE LESS DEVELOPED WORLD: THE IBADAN EXPERIENCE

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Abstract

The types of problems which are usually faced by urban researchers in the Less Developed World (LDW), from the perspectives of microclimatological studies, are spelt out in this paper. The empirical example of a study site discussed in this paper reflects the experience of the author while collecting data on surface infrastructure for comprehensive study of urban climates of Ibadan Nigeria. For the benefit of other researchers in the general field of urban and building climatology, the types of data required for microclimatological studies of urban environment are lucidly spelt out. Guided by this philosophy, that 'dearth of data, is a crisis of methodology and hence cog to research progress', the paper advocates the need to regularly document information about urban artifacts, and also the need for policy makers to make the necessary provision for reliable and efficient data bank and retrieval systems in the fast developing urban areas of the LDW.

Introduction

The Dearth of Urban-based Data, the Crisis of Methodology

Quite often, various urban researchers in the LDW, just like their counterparts in the 'north' need to make spatial assessment of surface textural characteristics. Unfortunately, such 'specialised' researchers usually run into a common problem. And that is the problem of easily laying hands on basic, background, detailed information about the urban center surface texture and urban micro-activities. This problem is so piercing to the extent that, at best, the option which is usually available to most urban researchers in the LDW is to gather such background information from an amalgam of land-use maps and general records, as it were, mostly in disjointed form.

Unfortunately, such information are not very reliable because, characteristically, most land-use maps in the LDW are coarse and grossly inadequate. Such maps are not very adequate for scholarly works because they are usually perfunctorily prepared as general-purpose documents for "more pressing" and highly populist administrative, commercial and educational purposes. Even when some of those maps look marginally useful, they are so out-dated that as at the time they are needed, the information which they contain are already seriously misleading. General, archival records with urban planning authorities are perhaps less reliable than land use maps in the sense that they are not only out-dates, but they are also existing in a form that they cannot be easily fixed to their respective point locations in the urban space. For example, what we are given are just raw figures about number of buildings, total length of roads, and general activities of the people in an area. But concretely, such information do not reveal to use the exact microgeography of the surface infrastructures and activities in the areas, such as the building configurations, and micro-activities, among others, which are needed for microclimatological studies.

However, the reasons for the above problems cannot be far fetched. This is so because given the multiplicity of human activities and the

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dynamism of the growth of such activities - owing to increasing impact of socio-economic and technological sophistications and the geometric population growth rate - then the cause of the difficulty in coping with the documentation of such specialized information in the LDW should be clear to us; at least to a reasonable extent. In any case, this is not to rationalise the cog which this constitutes to research progress because indirectly we would then be providing a justification for the apparent retardation of efforts in the area of urban studies in the LDW.

This problem is particularly serious in African countries because of the inherent state of their technological underdevelopment, which makes the availability of sophisticated data a rare thing. Sadly, even in some cases, many African governments do not see the need for such "luxuries" in the faces of prevailing hunger, elusive peace and general financial "constraints". With this general apathy by research financiers, the urban researchers in the LDW are put in a more desperate situation. Unfortunately, because of the headache arising from non-availability of required urban data, lack of adequate funding and lack of ideas about how to solve these problem many researchers are often frustrated out of the business. Some retire to dangerous generalization which are based on scanty data while some engage in active improvisation which make their studies get trapped in serious methodological problem.

The problem of urban-based data also arises in another form, much more different from the problem of non-availability of data on a 'platter of gold'. Another way it could arise is that even if the researcher is lucky to get adequate funding and then later 'summon courage' to document urban characteristics so as to suit the project aimed at, the problem of methodology surfaces in the form of know-how. This time around it is in the nature of lack of adequate knowledge of remote sensing and land cover analysis, on the side of the researcher. Even when the urban researcher has peripheral knowledge to enable him gamble with a few basic things in remote sensing, the problem of real applicability cannot be swept underneath the carpet. Under such circumstances, the desperate researcher has two options. One is forced into an interdisciplinary cooperation with a specialist in remote sensing who also may not be available or even when available may not be interested. The second option is for the researcher to go for an *ad hoc*, brush-up training in remote sensing, surround himself with an army of research assistants and go about it all alone. Here, the problem is that, the researcher runs the risk of committing several errors, while the project is also likely to consume much more money and even run over a longer period of time.

In Ibadan, Nigeria, I was caught in the web of seeking background information about the urban physiognomy of the city, as a basis for carrying out comprehensive studies of the city's microclimates. Let us see how the crisis of methodology was actually reached and resolved.

Aims And Objectives

A comprehensive microclimatic studies of the city was to commence in 1983. As usual, such research requires the detailed information about the surface artifacts, as well as the activities in the city. Expectedly, just like in any city in LDW, there were very inadequate archival records relating to the needs of the project. For example, the most recent, complete, urban serial photographs of Ibadan which were readily available as at that time were flown in 1977. Also, the existing studies, by that time, were either too generalized and/or not up-to-date[1].. To get out of this 'den' of inadequacy, the need then arose for the compilation of information from several sources.

Then, it was at that juncture that, the real problem of expertise arose in the sense that it was not possible to lay hands on a ready-made "package of methodology" that could suit the specific purpose of documenting the surface infrastructure for microclimatic analysis. As a geographer-climatologist, the author's practical knowledge of remote sensing was not too vast. But at that point, the crossroad-whether or not the comprehensive project should be executed - had been passed since there was a manageable financial resource.

More importantly, the project-proposal which led to the whole exercise had been approved, while the more important climatological equipment had been assembled, hence there would not be any excuse for turning back simply because of a "peripheral" problem of inability to get the type of information needed about surface infrastructure to be in conformity with our "taste".

At that point, I had the option of modifying the project-proposal in such a way that the 'peripheral' issue of surface texture would be rendered of marginal importance. But since the escapist option was not taken, a geographer-climatologist thus got caught-up in a methodological crisis; a situation in which any urban researcher could find himself. This paper basically aims at accounting for how this crisis was resolved. In order to do this, adequately, it goes as follows.

1. A picture of the urban character of Ibadan is given, in form of a general description of the study area as it relates to the problem of data collection.
2. The nature of the information required for microclimatological studies of urban areas are presented for the benefit of other researchers.
3. The actual step taken in order to document the required information in the face of the existing constrains and how some compromises were reached to enhance the attainment of the desired goal are accounted for.
4. Finally, the lessons that could be learnt from this kind of experience, for both researchers and policy makers are drawn out at the concluding section.

The City of Ibadan

Ibadan (Figure l) is a well-known Nigeria city, especially because of its socio-cultural significance. Situated around latitude 7° 23' north of Equator and longitude 3° 54' east of the Meridian, the city is inhabited by well-over 2 million people. The spatial extent of Ibadan spans over an almost circular area whose diameter is about 25 km. The city is regarded as the most cosmopolitan city in Yoruba land and the largest truly indigenous urban centre in Africa south of the Sahara[2].

The urban characteristics of the city could be described as features which are amalgams of 'traditional' and 'modern' urban attributes. In other words, the city could be partitioned into 'traditional' and 'modern' areas. While the former covers about 25% of the land area, and is situated towards the eastern end of the city, the latter occupies the remaining 75% of the urban land area. Each area also has its own share of the twin commercial centers of the city. The main Centre Business District (CBD) is in the 'modern' area. Expectedly, whereas the 'traditional' area is occupied by old, mud houses with narrow winding roads separating these houses, the 'modern area is relatively better planned with newer structures and spacious pathways. Nonetheless, the 'modern' area still has its share of shanties which exist in pockets especially in the northern and south-western ends of the city.

No doubt, Ibadan has a political and economic significance since its origin in the early 19th century by war settlers, at its present site, which is at the heartland of Yoruba territory. Apart from being an important station for railway which is linking Lagos in the south and other important Nigerians in the north, it is also a major melting-pot for inter-city roads linking and fueling various business activities of the surrounding urban centers like Abeokuta, Ile-Ife, Iwo, Osogbo and Oyo[3]. The city became the capital of the old Western region in the Colonial days, till 1975, and has since turned capital of Oyo state, one of the largest and most significant states in Nigeria. Owing to all of the above, the population and economic conditions have not only increased phenomenally, but have also done so at the expense of the surrounding urban center.

Physically, the topography of the city is rugged with a major ridge, whose altitude averages about 250m above sea level, traversing the city; north-south. The city's elevation rises from about 160m in the south to around 275 towards the north central. Stream drainage in the city runs southwards. Ibadan occupies the boundary between the forest and the Savannah zones. Owing to human impact, the vegetation surrounding the city, as of now, could be described as a derived form of the Savannah type.

Typical of West African moonsoon climate, the climate is characterized by two distinct wet and dry seasons which are, respectively, governed by the southwest and north-east winds[4]. The impact of urbanization is so much felt in Ibadan to the extent that the human modification of the geo-physical environment has made flooding a recurring phenomenon[5]

There are a few reasons to justify the choice of Ibadan as a case study. Firstly, the social-political importance of the city calls for proper monitoring of the urban environment and the effect of the environment on climate. Secondly, the need to carry out a comprehensive study of the urban climate of tropical urban centers[6] like Ibadan. Thirdly, the significance of studying a city whose characteristics are typical of 'traditional' and modern types; for effective comparison with 'modern' industrial urban centers.

Nature of Information Required

The Target-data

Urban and building climatology is an aspect of applied microclimatology which examines the relationship between climate, on one hand, and building and urbanization, on the other. In examining these relationships, enhancement of

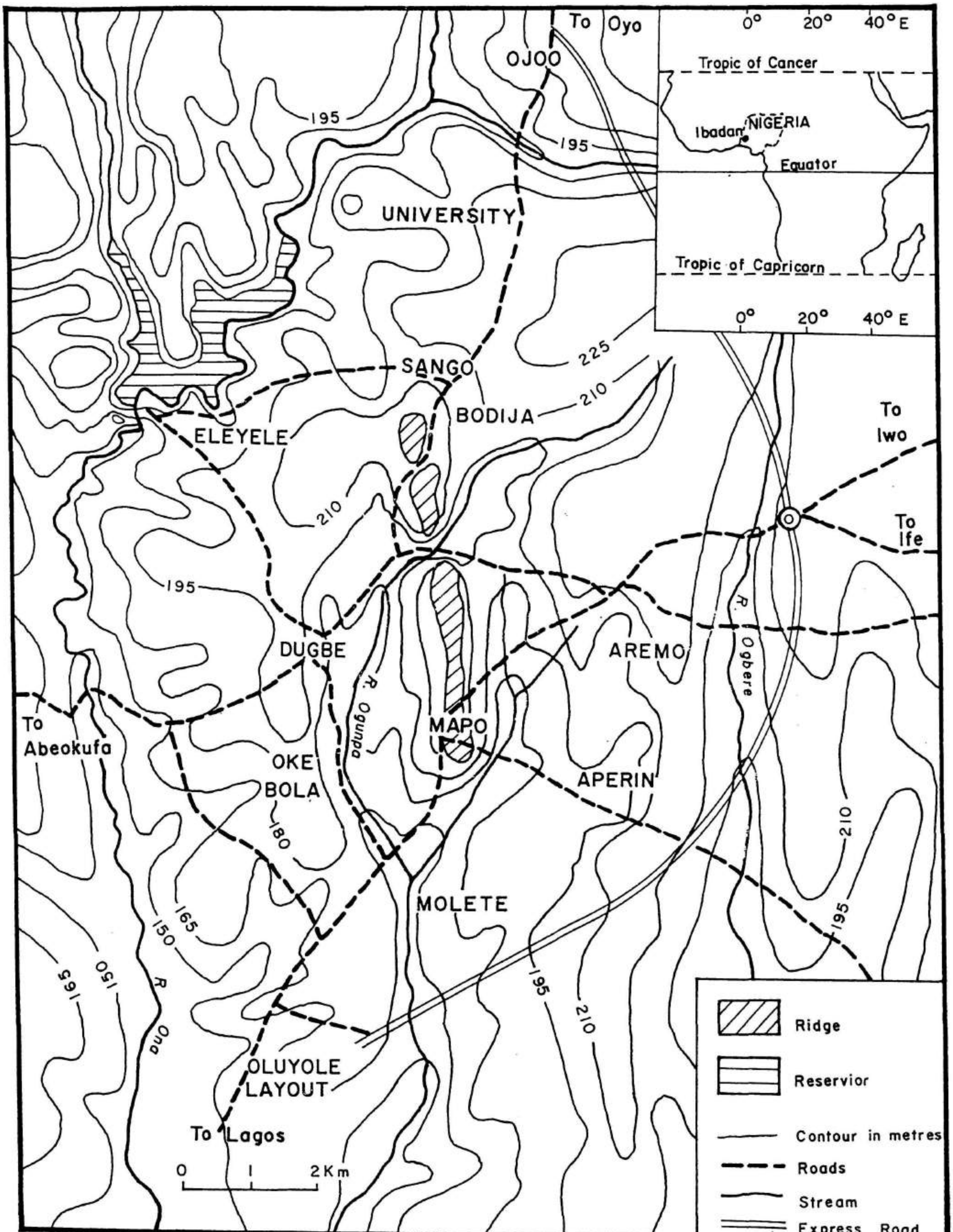

Fig. I: Ibadan, site characteristics, inset is Ibadan within the tropics.

human physiological comfort and minimization of climatic modification are the target goals. Usually, urban and building climatology pays attention to the effects of atmospheric pollution, human cultural artifacts and artificial combustion on climate. In short, the study deals with the examination of the effect of total presence, and impact, of mankind on atmospheric environment in our urban centers.

Because of the sensitive nature of climate at the micro-level, there is a variation with every bit of change in the surface composition. In order to be able to adequately monitor and study urban climate, therefore, it will be necessary to document the surface texture, human activities and population for different sectors of the city. Herein lies the problem, which could be summarized in form of two questions. First, how do we go about the documentation of the surface infrastructure, human activities and population in the vast urban area? Second; which way could the microclimates of the extensive, highly heterogenous urban centers, and even these days of mega-cities, be effectively monitored?

Before we attempt to answer these questions, it is important to point out that there are various approaches to investigation in urban and building climatology, all of which can be collapsed into two, namely; spatial and temporal. Whereas the spatial approach examines the heterogeneity of the urban center in the sense that it considers the microclimates of every sector of the urban landscape, the temporal approach takes the city as a holistic entity; and, therefore, its effect, overtime, on the modification of meso-climate is isolated. Whichever method is used, the effect of local topography should be separated from those of human artifacts. Moreover, and very importantly, the fundamental input for both methods is the documentation of the man-made cultural characteristics of the urban center for the purpose of explaining the conditions of the climatic variables within a man-made urban environment.

Having thrown a general light on the nature of some data which are required for studies of urban climatology we can go further into being more specific about them. The features of urbanization which change the physical environment and lead to alteration in surface energy and radiation budgets were identified[7] as; (a) air pollution; (b) anthropogenic (artificial) heat; (c) surface 'water proofing'; d) thermal properties of fabric and (e) surface geometry. The causes of these features have been classified[8] into three namely; (a) alteration in surface cover such as surface configuration and characteristics of materials used in building places of habitat and activities; (b) changes in the biosphere like composition increase, change on animal composition and reduction in plant cover; and (c) increase in the uses of technical equipment, like industrial plant for space heating and as means of transportation.

In view of the high-heterogeneity of the character and composition of the city, it will be important, therefore, to collect microclimatic data not only from different urban surfaces as was done in Hannover[9] but also in different corners of the city as was the case in Mexico City[10]. Hence, before the right decision could be taken as regards microclimatic analysis in the urban area, it is important to be specific about the type of information which should be gathered. In summary, the types needed are categorised in Table 1. In a way, it could be aptly put that, all the information required could amount to documenting the whole of the urban infrastructure and activities. This makes the data-collection process difficult, but of course a very necessary exercise. Necessary because it could lead to the building of a worth-while data bank for environmental monitoring and planning purposes.

Whatever the case, the ultimate goal was to arrive at a way of coming up with a rational basis for categorising the city's artifacts in a way that would help the researcher to understand the relationship between microclimate and the man-made structures. Ideally, one should wish to emerge with a result such as that of Metropolitan St. Louis[11] (Table 2). Unfortunately, the problem is that most urban land-uses in the LDW such as in Ibadan are difficult to decifer. This is so because most of them originated as pre-colonial urban centers which later metarmorphosed to modern post-colonial urban centers. Slums and illegal structures are obvious characteristics of these amalgam urban centers. Hence, the documentation of their infrastructures would perhaps require much more considerable leg-walks, for site-to-site ascertainment of different features than people can ever imagine.

Getting Our Best

A target was set for the project. The set-goal was in line with what has been highlighted in the above, which formed the core of the objective of the research. However, needless to emphasize that for any project work there are always discrepancies between expectations and experiences. In other words, for a realistic researcher, particularly because of various

Table 1 Urban Microclimatology : Data Collection Guide

Category of information	Parameters	Forms required
A. Activities	1. Domestic 2. Industrial 3. Transportation	1. Energy consumption (electrical) 2. Energy consumption (fossil fuel) 3. Pollution exhaust (industrial) 4. Pollution exhaust (domestic and traffic)
B. Biological	1. Vegetation 2. Population 3. Water	1. Vegetation density 2. Mean height of vegetation 3. Colour of vegetation 4. Area covered by vegetation 5. Total population 6. Area covered by water
C. Configuration	Relief	1. Altitude 2. Aspect
D. Man made	1. Building 2. Road 3. Surface	1. Height of building 2. Orientation of building 3. Area covered by building 4. Building material 5. Length and width of roads 6. Nature of cover for road 7. Extent and type of surface (whether lawn bare or paved)

Source: Compiled by the Author.

limitations, setting a 'utopian' goal is the best way to set towards a successful journey so that after making all compromises as dictated by various handicaps, the most realistic objective could be accomplished. Guided by this research philosophy, the project took off aiming at achieving the vital goals. The data was required in the form that would enable us establish quantitative relationship between components of urban surface texture and the microclimatic parameters. In view of the fact that the climatological analysis were to be done on both temporal and spatial bases, it became necessary to accordingly collect data on surface components over time and space. But all in all, the target-data was in the line of up-dating and hence obtaining a comprehensive data bank for urban artifacts. This would include documentation of the temporal change in the spatial extent of the city and the intra-urban variations in the surface texture.

The ideal path towards the attainment of the enumerated goal would be to harness information from all possible sources and also utilise the necessary human skills in order to: (a) extract information about states of urbanization at different periods over time from mosaics of aerial photographs; (b) collate information about site-to-site condition of urbanization like states of road, building, surface cover, population, among others; at given interval of time; (c) reproduce maps of the states of urbanization for given time periods, with same interval as (b) above; and (d) know the conditions of atmospheric pollution and artificial heat in the atmosphere, from different sources. But, as expected, a lot of limitations handicapped the concrete attainment of these goals.

Firstly, we could only lay our hands on aerial photographs for just a few years, which were not even regularly interspaced. Specially, the first photography was flown in 1964 on a scale of 1:40,000; another in 1965 on a scale of 1:25,000; also in 1973,1975 and 1977. The irregularity of the scale of which they were produced was another handicap to note. Secondly, the constraint of

Table 2, Land-use in Metropolitan St. Louis, as Identified and Classified by Auer (1978)*

Description Use and structures		Vegetation
1	Heavy industrial Major chemical, steel and fabrication industries; generally 3-5 storey buildings, flat roofs.	Grass and tree growth extremely rare; <5% vegetation
2	Light-moderate industrial Rail yards, trucks depots, warehouses, industrial parks, minor fabrications generally 1-3 storey buildings, flat fabrications; roofs.	Very limited grass, trees almost total absent; <5% vegetation
3	Commercial Office and apartment buildings, hotels; >10 storey heights, flat roofs.	Limited grass and trees; <5% vegetation.
4.	Common residential Single family dwelling with normal easements; generally one storey, pitched roof structures; frequent drive-ways.	Abundant grass lawns and light-moderately wooded; 70% vegetation.
5.	Compact residential Single, some multiple, family dwelling with close spacing; generally <2 storey, pitched roof structures; garages (via akket, no driveways)	Limited lawn sizes and shade trees; <30% vegetation.
6.	Compact residential Old multi-family dwellings with close (<2m) lateral separation; generally 2 storey, flat roof structures; garages (via alley) and ashpits, no driveways.	Limited lawn sizes, old established shade trees; <35% vegetation.
7.	Estate residential Expansive family dwelling on multi-acre tracts.	Abundant grass lawns and lightly wooded; <80% vegetation.
8.	Metropolitan natural Major municipal, state, or federal parks, golf courses, cemeteries, campuses; occasional single storey structures.	Nearly total grass and lightly wooded; <80% vegetation.
9.	Agricultural rural	Local crops 9e.g. corn, sobean); >95% vegetation.
10.	Under-developed Cultivated; wasteland.	Mostly wild grasses and weeds, lightly wooded; >90% vegetation.
11.	Under-developed rural	Heavily wooded; 95% vegetation.
12.	Water surfaces Rivers, lakes	

Source: Compiled by the Author.

*Difficult to arrive at this type of lucid classification and correct spatial identification in most cities of LDW because of the existence of slums, erection of illegal structures and provision of wrong statistics, even through official records.

getting exact records about roads and buildings as official statistics were grossly inadequate while even the existing ones were in chaotic form. Thirdly, irregularity of national population census activity. For example, the only reliable census in Nigeria as at 1982 was that of 1963! The story is the same all over the LDW. Fourthly, the time and monetary constraints, because doing so much work within such a limited time would require a lot of expenditure. Fifthly, the question of expertise. In other words, there is no way a geographer-climatologist can claim to know so much about remote sensing. As a matter of fact remote sensing is just a step towards the attainment of exact documentation of surface characteristics and activities. No doubt a multi-disciplinary approach is the ideal way of carrying out a proper documentation of the urban artifacts. But the problem here is that, interests rarely overlap, especially in the LDW where the few experts in different fields are saddled with "enough" to chew as their various contributions towards "more pressing" problems than the "little known" problem of inadvertent modification of climate by urbanization. This situation if further worsened by the fact that agencies and governments rarely pay attention to the encouragement of such cooperative effort for the studies of urban climate by experts. Rather it is erroneously felt that problems of urbanization should be left solely with urban and regional planners. Paradoxically, orthodox planners know very little about urban microclimatology except at a general level!

With all of the above constraints, it becomes necessary for researchers in the LDW to retire to "compromises" as well as optimum utilization of what is available. That was the position this author had to adopt in solving the Ibadan problem. A way we could do it was to re-trace the steps towards a 'utopian' project; since over-ambitiousness could lead to an over-kill and even make the fieldwork an almost endless, aimless exercise. Hence healthy compromises were arrived at by upgrading census data, analysing the available photographs, consulting urban planning maps, making references to existing works and doing follow-up field surveys.

The Concrete Steps and Output: Identifying the 'bedrock' (Land-use identification)

The way it started was through consultations with some published works and maps. As earlier envisaged, adequate information could not be collected from these works. For example, the most relevant work was published over a decade before the take-off the project.[12]. Information on growth and geographical character of the city were also collected[13]. The work that came in handy on the spatial extent and growth of the city up to most recent period was published in 1982[14]. It shows the approximate sizes of Ibadan in 1963,1973 and 1981.

Perhaps the most appropriate place to collect data about the city artifacts was the Ibadan Municipal Planning Authority (IMPA). But the following interwoven shortcomings were identified with the IMPA. Firstly, the IMPA was more pre-occupied with bureaucratic land allocation for public and private projects. Unfortunately, placing the available information on land-use in a spatial context were not readily available to the researchers. Secondly, even when some coarse, skeletal maps were produced for some years, these maps were produced based on approved plans whereas there were discrepancies between approved plans and erected structures - both in nature and number. This could be attributed to corruption. Thirdly, tied to the above was the difficulty in getting correct information about project development (especially private properties) approved because it was either that some approved plans for development of structures were left undeveloped for years by their owners or that the plots which were officially approved for specific purposes were fraudulently converted to other uses without official documentation, in collusion with unscrupulous officials of the IMPA.

However, inspite of all the problems and shortcomings, it was still possible to get some useful information from the IMPA. The information collection formed part of what was used in modifying the land-use map shown as figure 3 which was adapted from figure 2. With the production of this land-use map, a 'bedrock' was, therefore, established for a thorough analysis of the city surface infrastructure. Now, can we say the 'bedrock' was really a solid one?

Digging the 'bedrock'

Having identified the land-use pattern, the next step was to dig the character of the microgeography of the different land-uses. In other words, this was a stage at which the information required for micro-climatological studies were documented, as specified in Table 1. Perhaps it would be important to recall that the 'utopian' goal was set to obtain information in the nature of what is shown in Table 1, over a number of years.

However, this was not possible because of the non-availability of adequate aerial photographs and even the problem of embarking on massive real-life ground cross-checking of these facts at the sites. It is vital to emphasise that a complete and accurate micro-analysis of features on aerial photographs cannot be done without physical ascertainment of these features.

With the above constraints, perhaps the most useful thing which could be obtained from the aerial photograph was an estimate of the real extent and general land-use conditions of the city. Unfortunately, the most recent, readily-available aerial photographs as at that time were flown in 1977, hence we had no option than to use them as bases for carrying out the infrastructural analysis in 1983.

Agreeably, the inter-gap in time was six-year period, but then the difference in surface infrastructure was still not as much as to prevent the concrete identification and ascertainment of the features as at that period. Be it as it may, it should be pointed out that this constituted part of the huge problems of infrastructure studies in the LDW because having to make do with aerial photographs taken six years earlier was not the ideal situation. Obtaining photographs taken that same year should be the normal thing. This story is the same all over in the LDW.

Usually, sampling is involved in any data collection exercise which covers extensive space and time dimensions. But before we identify the problem with this particular project, let us observe as follows:

(1) As at 1983, the spatial extent of Ibadan was about 25 km in diameter. Actually, the city size was put at about 44,000 hectares of diversified land-uses. With this, therefore, the fieldwork had to contend with an extensive study area.

(2) Although some meaningful arrays could be brought into the chaotic pattern of land-uses, a preliminary observation revealed that almost all types of activities could be found everywhere - like industries and markets found in pockets in residential area. The point here is that this added to the cities in the LDW, especially those ones that are mixtures of 'traditional' and 'modern' features. But beyond this, the real problem here is that whereas the first observation justifies the reason for carrying out sampling, the second observation on the other hand restricts the kind of sampling which could be carried out especially if the real characteristics of the chaotic city were to be adequately documented. Ideally, what should have been done was to sample according to land-uses. But with extensive internal hetrogeneity of the city, it became necessary to, on a general basis, somehow ignore the land-uses as the only basis for sampling. In other words, a strictly stratified sampling approach could not be adopted for use.

In solving this problem, the approach employed in carrying out the micro-climatic analysis in Sacramento, was adapted[15]. Whereas that approach was used basically for climatological recordings, this author went further by adapting it for both micro-textural and micro-climatological analyses.

The weighted-average approach was used in the following order: (a) identifying the land uses in Sacramento; (b) this was then followed up with climatological recordings, on different land-uses, to know the average climatic characteristics of each of the land-uses, and (c) they then went ahead to impose regular grid squares on the theoretical explanation that since each land-use generates its individual microclimate, then it should be possible to carry out a spatial analysis of the urban microclimate by using the grid systems to impose isolines on the whole city.

In Sacramento, grids were nine smaller ones as well. More explicitly, the idea was to estimate the microclimate of each of the large grids as follows. Firstly, know the proportion of the different land-use types, then go ahead to estimate the microclimate of the larger grid by multiplying the fractional representation of each land-use by its established average climatic condition and then sum up the figures to arrive at the microclimate of the larger grid. This procedure was adopted for all the grids and with the emergent figures, dotted all over, isolines were imposed over the city of Sacramento. Let us not waste some time here by giving empirical example of this weighted-average method, as it has been implicitly done before[16].

The other way in which the grid-system was used was in the course of designing the sampling procedure for collecting data on surface infrastructure. One km2 grids were uniformly imposed on a mosaic of aerial photographs of the city. 10% of each of the land-uses was then selected for an analysis. The grid served the purpose of demarcating areas for the analysis. For example, in order to know the building density, the census of buildings, within the grids over 10% of the different land-uses, was taken. The same thing was done to estimate the average building height, building orientation, types of building materials, number of occupants, activities, estimation of domestic and industrial combustions, analyses of characteristics of surface cover for different land-uses, etc. Important to point out that the analysis began with stereoscopic analysis of aerial photographs, then followed by ground-checks, in-house empirical checks and then distribution of questionnaires.

Climate, Land-use And Planning Implications

The analysis of land-use pattern in Ibadan enabled us to get an adequate bed-rock for collecting microclimatic data. Part of this has been reported earlier[17]. Table 3 shows that the temperature condition varied from one land-use to the other. This confirms the theoretical premise that each land-use generates its own microclimates. In Ibadan the highest degree of modification was recorded in the high density area.

Table 3 Increase in Temperature in Ibadan City, Compared to the Rural Surrounding (^{o}C)

Land-use	Temperature wet season	Increase Harmattan season
High density	3.5	7.0
Medium density	2.0	3.0
Low density	1.5	2.5
Commercial	2.8	5.0
Open space	2.0	3.0

Source: Adebayo, 1987 : 14

The lesson to learn from this result is that urban landuses should be planned in such a way that microclimatic modification would be minimised. Since high density areas generate high temperatures, it will be necessary for planners to engage in extensive decongestion of the crowded parts of our cities. Doing so will minimize the contribution, by cities, to global increase in temperatures.

Conclusion

The problem of collecting data on surface infrastructure in a city in the LDW has been discussed. The account was in the nature of the experience of the author while collecting data for microclimatological analysis in Ibadan, Nigeria. In order to get a theoretical basis for the critique, the target data on surface infrastructure which are needed for general analysis in urban and building climatology were clearly stated.

Although the target-data were regarded naturally as 'utopia' yet, unlike in more condusive situations which are found in the Developed World, it emerged that poor record keeping and inconsistency of environmental monitoring coupled with the heterogeneity of the poorly planned urban territory are the major factors which are making it difficult for researchers to collect adequate data on surface artifacts. These affect research methodology and hence hampering, as well, research progress.

It is being recommended that owing to its importance for research purpose, and environmental monitoring in particular, adequate aerial photographs of urban areas should be taken on an annual basis. Detailed land-use analysis should also be done, regularly, to enhance the production of more reliable land-use maps. Provision of adequate data bank and retrieval system is a necessary thing to be done by appropriate planning agencies. It is also important for urban researchers to make efforts to equip themselves with appropriate knowledge of remote sensing.

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THE PROBLEM OF ATMOSPHERIC POLLUTION IN AFRICAN CITIES

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Abstract

In the past, the problem of atmospheric pollution in African urban areas has received little attention perhaps because it was widely believed by policy makers and planners that air pollution was not a problem in African countries and hence the development issues. It is, however, now becoming increasingly clear that industrial development in many of the major African urban areas is taking place rapidly and with it more and more pollutants finding their way into atmosphere. It is, therefore, evident that the impact of this development on the atmospheric environment can no longer be ignored. For example, studies that have been carried out in Nairobi have shown that suspended particulate pollutants and motor vehicle emitted carbon monotide have reached concentration levels that are higher than those generally accepted for human welfare. In this paper, the factors leading to increased air pollution in Africa's major urban areas and the constraints to the management of the pollution problem are discussed. The transfer of obsolete technology from the point of view of air pollution control and management is viewed as the major factor that economic planners and policy makers will have to contend with. Furthermore, urban planning for industries is carried out often with little consideration for potential environment impact. The above two factors become constraints in any efforts to control air pollution in urban areas. The main solution in the effective control seem to lie in the adaptation of modern and appropriate technologies ,in the industrial development, establishment of air quality standards and in the proper land use planning taking into account the climatology of the area among other factors.

Introduction

The degradation of air quality through pollution from industrial sources in urban areas has attracted considerable attention around the world in recent years. One of the main reasons for this concern is that the infrastructures that are needed for industrial development are to be found in urban areas and as a consequence these areas have the highest concentration of industries. Secondly, urban areas maintain large population of people often concentrated in large residential areas and thirdly epidemiological studies have consistently linked a variety of health effects in urban are residents to air pollutants originating from industrial sources (Goldsmith and Breslow, 1959; Dohan et. al., 1962 and Ferris et. al., 1979).

The problem of air pollution in Less Developed Countries especially in African urban centers has yet to draw similar attention perhaps because it is widely believed that industrial development in these countries has not reached such a stage as to have a significant impact on the environment. However, some recent studies have shown that contrary to such belief, particulate pollutants in some African urban centers have reached significant concentration levels. For example, in Nairobi's industrial area concentrations in excess of 300 micrograms per cubic metre (μgm^{-3}) have been observed while in other areas of the cities lower concentrations but still significant levels were evident (Ngugi, 1984). Abdel Salaam et. al. (1981) carried out measurements of total particulates in Cairo, Egypt and concluded that the high levels of the particulate pollutants were associated with industrial activities in that city.

A study that was made about ten years ago showed that motor traffic in Nairobi had increased to a stage where it became a major source of carbon monoxide (CO) in the city (Ng'ang'a, 1980). Obviously the number of motor vehicles has at present increased considerably and the situation is now quite different from that time. Studies of precipitation chemistry conducted over East Africa showed that the rainfall samples taken near urban centres contained more sulphates and nitrates indicating that these compounds were of industrial origin (Rodhe et. al. 1981). Similar conclusion was reached in a study of rainwater samples collected in Nigeria, (Bromfield, 1974).

Recent investigation of the acidification of rain water in Kenya has shown that those samples taken near Nairobi urban area were often more acidic than those from other remote areas, (Nganga, 1989). The significance of this finding is that high levels of acidity in rain water is a strong indication of high levels of air pollutants from industrial sources. From the examples given above, it is clear that the problem of air pollution resulting from industrial development and other related activities in African cities has in some cases reached significant proportion and can no longer be ignored.

Air Pollution Management

It is now accepted that industrial development must bring with it the problem of air pollution. However, several strategies can be applied to effectively manage air pollution in order to minimise its effects on urban population and on the urban environment in general. Some of those strategies are outlined below.

Air Pollution Control At the Source

Perhaps the most effective strategy of management of air pollution is by controlling its emission at the source. It requires that emission control devices or systems be installed for the purpose of removing most or all of the air pollutants before they reach the atmosphere. Installation of such systems is the main stay of any meaningful air pollution management effort and has been adopted by many industrialised countries. There is a large variety of gas cleaning systems in use today with variable degree of removal efficiency, (Hesketh, 1979).

The main constraints associated with source control systems are, firstly, some of them are not efficient to the required standards; secondly, installation of such systems demands increasing the initial cost of establishment of an industry and thirdly, even if some of those systems have low capital inputs they require high operating costs which raises the cost of manufacturing and hence the cost of goods to the consumer. For developing countries, the main consideration may be to provide manufactured goods at the cost most consumers can afford.

In spite of the fact that most of the industrial machinery and technology now in use in the developing countries have been supplied from the industrialised countries, there is no evidence that any source control systems have been incorporated into such machinery. In addition the choice of the process of disposal of the effluents is made with little regard for the subsequent environmental degradation. As a result of the constraints outlined above, the management of air pollution through source controls becomes an almost impossible task in most developing countries.

Urban Land Use Planning

The objective of urban land use planning from the point of view of air pollution management is to locate the industrial area in such a way that it is far enough from the residential areas so that the residents are not adversely affected by the industrial air pollution. The location of the industries is done taking into account the prevailing meteorological factors mainly the average wind speeds and direction. The strategy behind the above consideration is to site the sources of potentially harmful pollutants down wind of the residential areas so that the pollutants are transported away from the residents. Wind speed is an important factor in estimating the ability of the atmosphere to disperse air pollutants are transported away from the residents.

Wind speed is an important factor in estimating the ability of the atmosphere to disperse air pollutants (Gifford 1961 and Pasquill 1961).

Those urban areas located within the tropical easterly winds regime have the advantage that these winds are highly constant in direction and the speeds are generally high (Ng'ang'a 1981). Therefore, when prevailing meteorological conditions are taken into account in the long term urban planning, then residential areas can be assured of long periods of unpolluted air. However, for urban centers located on the fringes of the tropical belt and beyond, the winds are not so steady and planning takes on a more complicated form if meteorological conditions are to be taken into account. A good example is those countries in the Southern and North-Western Africa where seasons bring on different wind regumes.

The objectives outlined above are often not considered during urban planning for the reason that in most African countries the main consideration is to utilise all land in urban areas and it becomes impractical to leave large tracks of land for the sole purpose of separating residents from sources of harmful pollutants. Therefore in deciding on the location of the industries the primary factor that is considered is the availability of land regardless of its position with respect to existing residential areas.

Development of Air Quality Standards

The objective of developing air quality standards is to control the amount of pollutants that industries emit into the atmosphere in order to keep the concentrations to permissible levels. Many industrialised countries have established air quality standards which are based on the current knowledge of the effects of various air pollutants on human health, materials and plants. One of the difficulties that will be faced by cities in African countries in their effort to manage air pollution is lack of air quality standards perhaps due to the already explained reason that air pollution is not yet a priority in most African Countries.

In the absence of any standards most industrial enterprises have little concern for the possible impact of their emissions on the environment except in the cases where such emissions are obvious public nuisance or danger. Even when such impacts are later noticed and the concerned industry is asked to take remediable action, it becomes difficult to take any effective measures because it often requires that the machinery or the operation system be redesigned or source control devices be installed which may often be too expensive.

If the air pollution management in African countries is to be effective, then there must be air quality standards which can be used as a basis for pollution control regulations. However, if such standards are to be enforced, there must also be trained personnel in the field of air pollution who will ensure compliance with these regulations. It is, therefore, seen that well trained personnel for monitoring-and assessing air pollution impacts are an essential part of any effective air pollution management strategies.

Conclusion

As a summary it has been shown in this paper that contrary to widely held belief, air pollution in many African cities has reached significant levels and therefore there is need to start taking the necessary measures for its control and management. The main problems that affect effective air pollution management strategies will be lack of:

a) air pollution control systems in the industrial operations;
b) long term urban land use planning;
c) air quality standards and regulations;
d) trained air pollution monitoring and control personnel; and
e) air pollution awareness and concern on the part of industries and urban planners.

In conclusion air pollution due to industrialisation has been and continues to be a major environmental problem in the developed countries of the world and there is reason to believe that African urban centers will experience a similar trend. What is necessary now is for the policy makers and urban planners in African urban centers to adopt appropriate strategies to contain air pollution to the levels that will not have adverse effects on the environment.

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A GENERAL VIEW OF ATMOSPHERIC POLLUTION IN DAR ES SALAAM CITY TANZANIA.

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Abstract

Air pollution in Dar Es Salaam, Tanzania is not a new phenomena. Anthropogenic combustion from shifting cultivation, cooking fires, and odours from organic wastes such as garbage, sewage, farm manure etc plus natural dust storms, and sea-salt sprays among others have been characteristic of Dar es Salaam ever since the latter became established as a port city. However, industrial and transportation activities which require energy from fossil combustion have now changed the traditional forms of air pollution in Dar es Salaam. This article gives a general view of the atmospheric Pollution in Dar es Salaam.

Introduction

Dar Es Salaam is the only city in Tanzania (Figure 1). With its present growth rate of 14% per annum, it is expected that about 4.6 million people will be living in the city by the end of this century (Banyikwa, 1986 and World Commission on Environment Development, 1987). Regarded as one of the least developed countries, Tanzania is also experiencing serious environmental pollution. This problem seems to have come about as a result of the country's effort towards agricultural and industrial modernization since the early 1970's. Being the only city in Tanzania, Dar Es Salaam could be regarded as the biggest centre of environmental pollution in the country. Like many African countries, Tanzania's policy of industrialization by transfer of technology from abroad and of its rural poverty into Dar es Salaam is putting a lot of pressure on the Dar es Salaam City Council (DCC). The result of this is the increasing need for the provision of the necessary services such as sewers, roads, dumping places, health and educational facilities. Expectedly, all of the above facilities, one way or another, constitute sources of environmental pollution, and in particular atmospheric pollution. Let us take a look at the geography of Dar es Salaam and then proceed to document the various, actual, sources of atmospheric pollution in the city.

Dar es Salaam is a coastal city which lies 10 metres above sea level. It is located around 7° 0'N and longitude 39°0'E. The climate of the city is influenced by its altitude and by the effect of the ocean currents. Thus the hydrography of the Indian Ocean is strongly influenced by seasonal variations of the monsoon winds (Bliss, 1983:290-295). The city experiences rainfalls between December and February and between May and September. While the former rainy period is controlled by the north-east monsoon, the latter comes under the influence of the south-east monsoon. The mean annual rainfall is about 1041 mm.

Table 1: **Composition and Percentage of the Pure Atmospheric Air**

Pure air compostion	Percentage composition
Nitrogen	78.1
Oxygen	20.1
Argon	0.9
Carbondioxide	0.03 - 0.04
Krypton	0.0001
Neon	0.002
Helium	0.0005
Xenon	0.00001
Trace elements	Under 0.0001
Total	99.93271

Source: Leith (1974) Quoted in Wohlrab (1980: 1)

The author would like to thank the National Environmental Management Council (NEMC) of Tanzania for providing a background information about Environmental Problems in Tanzania. The UNEP has also provided some general information about the state of the environment in African cities. Lastly, my thanks to Dr. Adebayo for his valuable comments and discussion about the theme of this paper and to Miss Makato for assisting in the drawing of the figures and to the Secretaries of the Department of Geography, Kenyatta University for the typing.

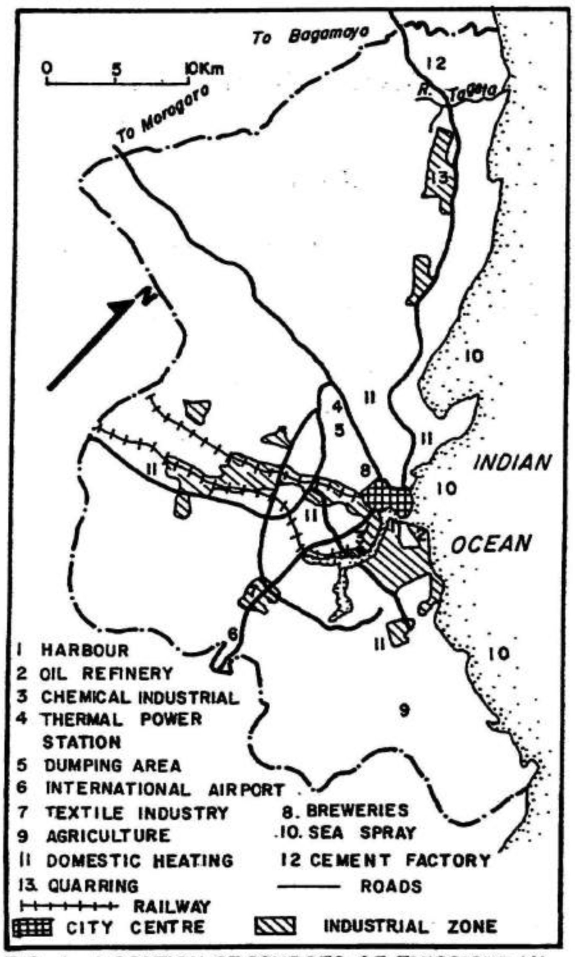


FIG. 1 LOCATION OF SOURCES OF EMISSIONS IN DAR ES SALAAM

Mean daily sunshine is 717 hours, while the mean maximum and mean minimum temperatures are 30.5°C and 21.0°C, respectively.

Sources of Atmospheric Pollution

The atmosphere can be regarded as polluted when it contains, to a considerable content, some extraneous gases and/or solids, other than as defined on table 1. (Wohlrab, 1980:1-28) All over there are two ways in which we can view air pollution. These are in-door and out-door. The city is characterised by both types of pollution.

The main sources of air pollution in Dar es Salaam are: (a) industrial combustion including oil refinery, manufacture of chemicals, iron foundries, quarrying, electricity power stations, solid waste treatment, textiles mills, oceanic evaporation and continental aerosols; (b) vehicular traffic; and (c) Agricultural activities within the fringes of the Dar es Salaam city and domestic heating, cooling and biomass combustion. Table 2 and Figure 1 give the type of industry and their locations in Dar es Salaam (Tanzania, 1988:1-8).

The spectrum of the industrial pollution especially through chemical manufacturing in Dar es Salaam is diverse. It includes both organic and inorganic products such as: (a) fertilizers, mixture of pesticides, fungicides, insectcides, and herbicides, (b) plastic (PVC) products; (c) chemical fibres; (d) pastes and paints; (e) dyes and sprays; (f) photo-chemical material; (g) washing detergents and (h) cosmetics among others. The main pollutants from the above sources occur mainly in form of gas, steam or vapour of organo-chemical composition such as hydrocarbons, and its halogen-derivates, aldehyde, carbonic acid and sulphur combinations. There are also some inorganic chemical gases and vapour such as sulphurdioxide hydrochloric acid, gaseous fluoride, and phosphorus hydrogen plus toxic elements including fluorides carbides, and dust from asbestos among others.

Table 2: Industrial Sources of Air Pollution in Dar es Salaam

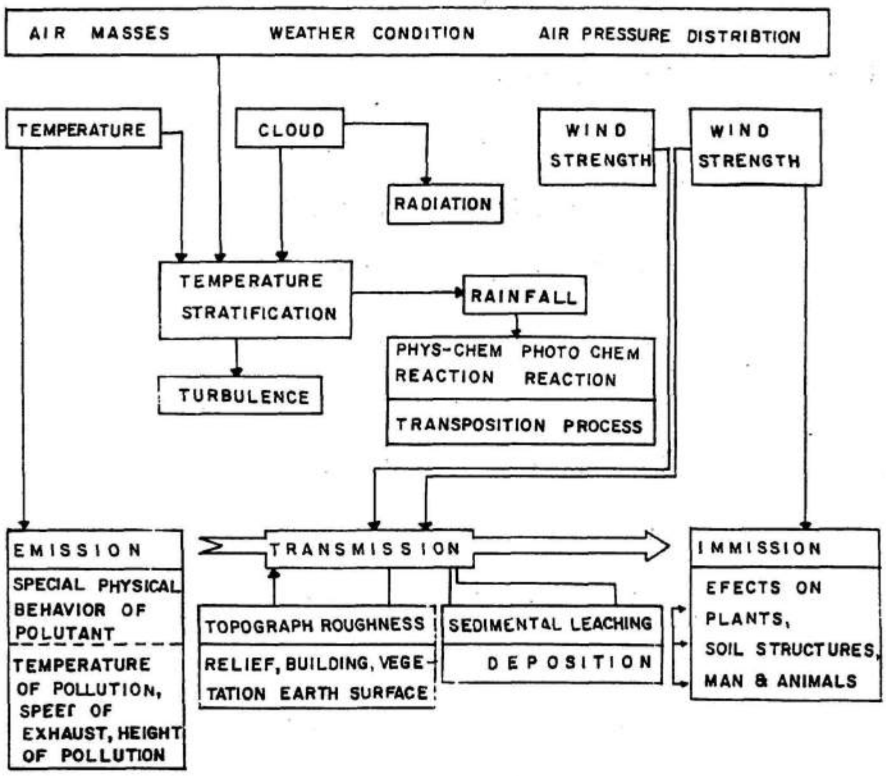
Type of Industry	Location of Industry in Dar es Salaam City
Cement Works	Wazo-Hill in Kunduchi area 22 km North of Dar es salaam city.
Pharmaceutical Works	Keko, 4 km West of Dar es Salaam city.
Breweries	Kariakoo area 2 km North-west of the city.
Oil Refinery	Kigamboni area, 4 km South-east of Dar es Salaam.
Quarrying	Kunduchi area, 20 km north of Dar es Salaam.
Solid Waste Treatment	Tabata - 5 km North-west of Dar es Salaam.
Power Plant	Ubugo - 9 km North of Dar es Salaam.
Textile Mills	Ubungo - 8 km North of Dar es Salaam.
International Air Port	Ukonga Area 15 km North-west of Dar es Salaam.
Dar Harbour	One kilometre South of city centre.

Source: Tanzania, 1988: 1-8

Industrial (Oil Refinery)

The growth of chemical industry and transportation in Dar es Salaam has led to the high demand of fossil-energy for the running of automobile, pumps, compressors, and power mains, among others. This has also led to the establishment of the Tanzania - Italian Petroleum Oil Refinery situated just 4 km south east of the city surrounded by residential and agricultural areas. The petro-chemical processes supplies not only petrol, diesel and oil to the industries but serves *a hoard* of other industries with such chemicals as Ethylen which is used in the production of Synthetic (Polyethylen, Poly Vinyl Cloride (PVC), Polysty-

APPENDIX II


AIR MASSES WEATHER CONDITION AIR PRESSURE DISTRIBTION
TEMPERATURE
CLOUD
RADIATION
WIND STRENGTH
WIND STRENGTH
TEMPERATURE STRATIFICATION
RAINFALL
TURBULENCE
PHYS-CHEM REACTION PHOTO CHEM REACTION
TRANSPOSITION PROCESS
EMISSION
SPECIAL PHYSICAL BEHAVIOR OF POLUTANT
TEMPERATURE OF POLLUTION, SPEEr OF EXHAUST, HEIGHT OF POLLUTION
TRANSMISSION
TOPOGRAPH ROUGHNESS
RELIEF, BUILDING, VEGE-TATION EARTH SURFACE
SEDIMENTAL LEACHING
DEPOSITION
IMMISSION
EFECTS ON PLANTS, SOIL STRUCTURES, MAN & ANIMALS

rol etc.); dissolvents and extractors such as Alcohol, Ether, Ketone etc. These chemicals have very strong undesirable odours and are corrosive to materials.

The synthetic industrial chemicals used as propellants, refrigerants, solvents and working fluids or as foam-blowing agents emit chlorofluro-carbons (CFCS), hydrogen sulphide and methane into the atmosphere which propel to form partial energy shield around the earth. (World Resources, 1989:163-178). These elements are also found to influence average air temperatures, precipitation and the regional climate. It is believed that if these processes are not controlled, they could lead to changes in agricultural production patterns and influence changes in the sea-levels (World Resources: 1989).

Cement Production

One of the main sources of air pollution in Dar es Salaam is The Coral Limestone works situated some 22 km north of the city (figure 1). This factory emits particulates such as dust, Co_2,SO_2 through three kilns operating at high temperatures of 1480°C to produce cement. However, due to some leakages and poor performance of the electro-participators, an estimated loss of 100 tons/day of cement is incurred from the three kilns on full production capacity. (Yhdego,1988). An interview during a field excursion with the mines manager revealed that the State Mining Corperation (STAMICO) does not consider any environmetal measures in its mining activities.

While mining by its very nature lays waste thousands of agricultural land, this activity is causing serious environmental pollution not only to the residents through the air but to the ocean and vegetation around. Close observation and measurement by the second year Geography students, University of Dar es Salaam in September, 1988, showed some 4 cm - thick dust which lies over the ground near the factory. The dust covered the leaf surface which reduced normal photosynthesis. Also the whole area around the factory was dotted with 'heaps and pits'; the underground water table has been sunk to 10 m depth and the salty sea water appears now to mix with the fresh underground water especially during the high tide. But the most serious effect of the cement works is the puffing of Dust by the kilns whose filters went default some years ago. Dust, noise, headaches, chest-pains, sleeplessness are some of the main complaints of the employees. Added to this suffering is the whole operation of earth-movements by the use of dynamites, bull-dozers and lorries. This activity has partially led to the siltation of the rivers such as Tageta (Figure 1) which can no longer reach the Indian Ocean.

Domestic Heating, Cooling and Biomass Combustion

Dar es Salaam city is characterized by poor and low income population which has transfered its poverty into the city. Many people living in Dar es Salaam are either self-employed or under-employed. In fact many factories have closed down because of lack of spare parts, raw materials and high-level expertise. Under such conditions, one would expect a low level of economic activity and a high level of poverty which is leading to pollution. Thus, where income levels are low, biomass (Woodfuel) becomes the primary source of fuel energy which causes indoor air pollution especially in the urban periphery. Wood in form of charcoal, logs, twigs, and leaves among others have different combustion characteristics. Combustion of wood and other agricultural wastes under peri-urban conditions produce large quantities of smoke and purgent gases indoors (de Honing,1988: 2-23). A study conducted by the World Health Organization (WHO) in Kenya in 1986 and in Gambia in 1987 measured indoor concentrations of different pollutants in peri-urban settlements and arrived at result shown in table 3.

According to the WHO, Tanzania's per capita use of wood energy for cooking and heating per year is about 1.0 tons of dry wood per capita per year. The demand of fuel wood in Tanzania and especially in Dar es Salaam has lead to the gradual depletion of vegetation of the area between the city and Morogoro - a distance of about 200 km away.

Another aspect of urbanization and air pollution in Dar es Salaam is the intensive agricultural activities within the city area. The practice of burning biomass creates hazy clouds over the city and reduces the morning and evening visibility and this has sometimes caused road accidents especially on the Port Access Road. Cloud formation affects both precipitation and the atmospheric reflectivity. The updrafts in storm clouds can also carry particles into the strotosphere (Landesberg, 1970:130-140).

Treatment of Solid Wastes at Tabata

The disposal site for Dar es Salaam is located some 5 kms north-west of the city. Waste solids treated here in Tabata area include rubber, paper, rags, metals, leather, paints, dyes etc and agricultural wastes such as kitchen refuse, garden cuttings and animal carcasses, among others. The burning of wastes causes a permanent air pollution since it burns day and night. Ever since the area started burning, some residents of Tabata have been complaining bitterly to the DCC about the dumping and burning of refuse in their area. Virtually all the solid wastes are treated by uncontrolled burning which is not covered. This releases obnoxious odours and attracts vermin. It also releases toxic gases such as HCl, SO_2, H_2S, CO which all go to contaminate the air, underground water and the soil. The strong winds from the Indian Ocean drive the smoke and smell across the area and it makes life for Tabata residents unpleasant. As Yhdego (1988:1-7) noted that: "the present condition of the Tabata site is unacceptable from an environmental and a public health point of view ... The site is unhygienic and is a nuisance to the environment surrounding the vicinity of Tabata."

Some prevalent diseases such as typhoid fever, di-

Table 3: **Results of Indoor Concentations of Different Pollutants in African Houses (Kenya and Gambia)**

Pollution range	Average Concentration	WHO - Guideline
Respirable particulate	Matter .... 400-2300 mg/m³	100-150 μg/m³
Nitrogen dioxide	.... 80-140 μg/m³	150 μg/m³
Carbonmonoxide	.... 0-100 mg/m³	30 mg/m³
Polycydic aromatic hydrocarbons	.... 40-800 μg/m³	No guidelines
Formaldeyde	.... 25-100 μg/m³	100 μg/m³

(Tanzania's household energy consumption as percentage of total energy consumption has been estimated at 85.0 (1981) and Biomass fuel as percentage of household consumption is 98.8 (1981).

Source: World Health Organization (WHO) PEP/88.8.

arrhoea, tuberclosis, dysentry, coughing and eye-pains have been found to be common diseases among Tabata residents. So far, the DCC has not yet located another dumping site but a recent Nairobi Newspaper indicated that the Residents at Tabata have now won the case they filed against the DCC.

Vehicular Traffic

Road vehicles, both private and commercial, in Dar es Salaam could account for nearly all the pollutants (carbon monoxide hydrocarbons and nitrogen oxides) emitted in Dar es Salaam. There are, however, no studies done in the study area to confirm actual pollution rates. However, the main source of pollution from vehicular traffic include those numerous reconditioned vehicles which have recently been imported from Japan as a result of the Trade Liberalization Policy of 1986. Most of the vehicles are old and their operation characteristics, especially the engines, contribute immensely to the quantity of pollutants. Over 15,000 vehicles which use both petrol and diesel have

Table 4: **Vehicle Types and Pollutant Emissions for Various Engine Fuel Combustions in Glasgow, Scotland.**

Engine type	Fuel type	Vehicle type	Major emission
Otto cycle	Petrol	Cars (also buses, lorries/trucks, aircraft, motocycle tractors)	HC, CO, NOx Pb.
Diesel	Diesel oil	Lorries, trucks buses, trains, ships, tractors, cars.	NOx, SOx Soot particulate
Two-stroke cycle	Petrol	Motorcycles, outboard motors	HC, CO, NOx Particulates
Gas turbine (jet)	Turbine	Aircraft, marine (also rail)	NOx, particulates
Steam	Oil, coal	Marine	NOx, SOx, Particulates

Source: Henderson-Sellers 1984: 155.

Table 5: **Appendix (i)**

Industrial Processes

Source	Emission	Location	Effect
Oil Refinery:	Hydrogen sulphide Hydro Carbon vapour Nitrous Oxide Nitric Oxide Sulphur dioxide	Dar es Salaam Harbour	
Cement Production: Quarrying Brick Production	Dust, Organic Sulphur,fumes,gases mercaptons, chlorides Heavy metals	Wazo Hills Kunduchi Kisarawe	- Damage on human health,plants and materials - Nuisance
Textile Mills	Dyes, Bleaching, Heavy metals (Cr, Zn, Str.).	Ubungo Ukonga	- Partial Energy shield around Earth
Thermal Power Generarion	Sulphurdioxide Dust	Ubungo Dar es Salaam	
Chemical works: (agric. fertilizers, pigments for paints, fabrics, fibres rubber, plastics)	Sulphuric acid, costic soda, hydrogen fluoride	Pugu Road Chango'mbe	- Changes in average air temperature, precipitation and regional climate
Pharmaceutical		Keko	- Change in agricultural patterns
Chemicals		Keko	- Stress.

Source: Compiled by the author

recently been registered in Dar es Salaam alone. Table 4 is a general study showing a list of engine types, fuels and associated pollutants taken from Glasgow, Scotland which is used as a comparison to those imported in Dar es Salaam. (Henderson, 1984 : 55)

Other similar sources of air pollution come from the International Airport situated some 15 km North west of Dar es Salaam, from the Cargo ships and Oil tankers; from the trains etc. Like automobile, these non-stationary sources also contribute to the amount of pollutants in Dar es Salaam in form of unburnt gases as shown in table 4.

Pollution and Urban Climates

Studies on air pollution and urban climatology are becoming increasingly important subjects, especially because of anthropogenic emissions of pollutants accumulate sufficiently to influence the global climate. Although the effects of human activities on the global climate is a controversial subject, there is general consensus that these activities are having an effect on the climate of the urban centers. (Lenihan and Herchers 1978: 1-25). For example, studies done in European and in North American urban centers have shown that differences do occur between rural and city temperature, wind speeds near the ground surface, humidity, and rainfall, among others. While there is not yet enough evidence to show the extent to which pollutants interfere with the global and urban climates, studies done by the WHO have established that weather conditions often conspire to create cumulative effects in urban areas and subsequently promote cumulative clouds of pollutants. This general statement could also apply to the many emerging urban centers in Africa like Dar es Salaam. For example, Dar es Salaam is a coastal city situated 10m above the sea level and experiences some inversion of air and wind disturbances from the South Equatorial Currents and the North east Monsoon Currents

(Pettantyus, 1988: 7-9). The city also creates its own 'wind field' and 'heat island' as a result of the surface changes and gaseous and particulate pollution from the industrial, vehicular and domestic combustion (Strauss and Mainwaring; 1984: 1-7).

Wind is known to be the most important agent for the dispersal of pollutants. In Dar es Salaam, this role is played by the pressure induced monsoon winds from the Northeast monsoon winds which are sometimes disturbed and which tend to flow from the Indian Ocean towards the centre of the Dar es Salaam in January (Niewolt; 1979: 193-200). This occurs because the built-up environment of Dar es Salaam absorbs its own heat. Urban centers have been known to trap and recirculate pollutants within the heat dome. In July, for example, the dry monsoon winds from the Indian Northeast Monsoon currents blow dust and fine sand particles into the air which attenuates the solar radiation. This has sometimes produced more radiative cooling of the air afloat, causing it to sink by gravity. Sometimes when this happens, the air warms diabatically so that it retains the moisture and prevents precipitation in Dar es Salaam. This makes the city very hot and uncomfortable to the residents.

Planning Implications

Different urban centers have different air pollution problems which means that planning attitudes by the concerned governments will depend on the country's ability to assimilate the social costs of pollution. In developing countries like Tanzania, environment protection legistlations are given lower priority than other pressing demands such as fuel problems or food shortages (Ezaza; 1989). Many urban centers in Africa, including Dar es Salaam, are not only growing fast but are immitating western industrialization perhaps even faster than the former has actually developed. Thus, there is need for comprehensive air pollution control strategies in the many mushrooming African urban centers. For Tanzania, the selection of options and their adoptation by the National Environmental Management Council (NEMC) for better environmental quality in Dar es Salaam will depend on the country's aspirations, goals and national priority. Judging from the type of air pollution Dar es Salaam , Tanzania may be forced to adopt expensive technical strategies which she can not afford. Already the NEMC is facing a lot of

Table 6: Vehicular Traffic

Source	Emission	Location	Effect
Transportation and shortage of fossil fuels	Chloroflur carbons (CFCS) Carbon monoxide Carbon dioxide Hydrogen carbons	Dar es Salaam City Centre	- Inhibits plant photosynthesis and respiration - Inhibits blood's absorption of Oxygen
Automobiles, Cargo ships and Aeroplanes	Tropospheric Ozone	Dar es Salaam Habour	- Stress
Incomplete Combustion of fossil fuels	Photochemical Oxidants		- Impaired vision
Solvent evaporation	Carcinogens Mutagens or tetatogens	Dar es Salaam Railways Dar es Salaam International Airport	- Poor physical and mental coordination - Tropospheric oxidation
Natural Gas Flaming	Methane (CH_4) Dust, smell, noise	Songo Songo in Indian Ocean	- Green house gases - Toxic to neurological system, kidneys and effects total development and immune system.

Source: Compiled by the author

problems in trying to control and manage pollution problems in Dar es Salaam. For example, the responsible body lacks monitoring devices, funds and equipment and qualified personnel to implement its goals. Another obstacle towards better planning and development of Dar es Salaam is the fact that there is very little cooperation between the industrialists, businessmen, scientists, politicians and environmentalists. This has weakened the environmental legislation so that many development projects do not consider environmental issues in their planning strategies. Moreover, some of the heavy industries which are sources of emission are still under the Ministry of Trade and Industry so that the real responsibility of controlling urban pollution by the industries or NEMC still rests with the Ministry of Industry. There is, therefore, no environmental protection law which would give legal powers to the concerned authority.

Even if there was a law to control environmental pollution, it would be foreign to Tanzania since most of the sources of pollution have been imported. The only way Tanzania may be able to assimilate the costs of industrialization could be through: (a) public environmental literacy; (b) interdisciplinary action involving all industrialists, businessmen, politicians, scientists and the general public; (c) environmental appraisal of all development projects in their planning stages and incorperating these into the overall national development process; (d) enacting an Environment Protection Act; (e) provision of guidelines to industrialists and local government; (f) supervision of polluters and monitoring of the effects on the environment; (g) collaboration with International Agencies such as WHO, UNEP, and IIED among others.

Conclusion

The above discussion reveals that the adverse air pollution sources in Dar es Salaam relate to a diverse range of urban activities which have been largely imported. The problem is aggravated by a general poverty and lack of enviromental awareness. While efforts have already been made to reduce air pollution problems in the developed world, very little if any steps, have been made to contain the social costs of industrialization in African urban centers. This is because African countries are faced with adverse balance of payments, hunger and fuel problems which put environment protection issues at a lower priority. But some solutions have to be found . Any pollution programme has to start from identification of the pollution sources and the establishment of criteria on which the control decisions are to be based. In case of Dar es Salaam, it would require a bold political decision and social

Table 7. **Anthropogenic - Domestic Household**

Source	Emission	Location	Effect
Biomass combustion Decomposition of organic matter	Nitrogen Oxide	- Dar es Salaam City periphery - Tabata	- Impaired vision - Partial Energy Shield around the Earth
Wet lands and livestock management	Carbon dioxide Dust, smell		
Forest clearing and burning		- Pugu area	- Inhibits photosynthesis and plant respiration
Dumping and treatment of solid-wastes		- Vingunguti - Indian Ocean	
Sea spray/evaporation		- Dar es Salaam City Centre	- Regional climate changes
Domestic cooking, heating and cooling			- Greenhouse effect.

Source: Compiled by the author

sacrifice plus a substantial technical support from various international agencies. For example, solutions likely to reduce air pollution in Dar es Salaam will have to involve restriction of rural-urban migration, improvement of and planning of settlement sites, improvement of quality of fuel energy consumption, land use planning, training of mechanics in the transport and commercial traffic section and a general environmental literacy at a national level.

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ASPECTS OF URBAN HYDROLOGY AND THE CHALLENGES FOR AFRICAN URBAN ENVIRONMENTS

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URBAN HYDROLOGY AND ITS EMERGENCE

Urban hydrology has emerged as a distinct branch of the broad field of hydrology with its own focus and method of investigations, thanks to the complex interactions of human population and activities with air, water and land in concentrated settlements. The peculiarities of the urban environments and the changes they induce in the water cycles subdivide the urban hydrology into two parts, namely, hydrology of urban centres and industrial areas and the hydrology of the some of urban effects on the environments, water resources and water cycle in general[1]. The changes induced in the pre-urban landscapes often make urban environments vulnerable to pollution and drainage/flood hazards, two major concerns of urban hydrology. For a long time the solution of the problems arising from urbanization and industrial impacts such as water supply and drainage protection were considered purely engineering problems. The result of the attitude is that scientific evaluation of the impacts on the hydrological cycle, regime and quantity of water is one of the least developed in hydrology.

Urban hydrology is indeed inter-disciplinary science of water and its relationship with the urbanite and the urban management which team includes, or should include urban hydrologists, engineers, architects, planners, economists, ecologists, and sociologists among others. As it happens, in Africa and other less Developing Countries (LCDCs), the priorities for urban development are for food including drinking water, shelter, clothing, domestic sanitation, health and education. Urban hydrology is considered a marginal problem and urban drainage is generally not taken into consideration except when it affects significantly any of the above priority needs. However, as urbanization intensifies it usually becomes obvious that the attainment of the primary objectives are closely linked to water quality and storm water drainage as part of the more general problem of flooding and environmental health and welfare in urban areas.

Almost fifteen years ago it was noted that urban hydrology was still, in the absence of an adequate body of field data, more of an art than a science, and that the choice of a model for a given application was largely a matter of taste[2]. In most of Africa the observation is still valid, for urban hydrology in many cases is indeed an imperfect art. There is no doubt, however, that urban hydrology has come a long way. According to McPherson[3] as cited by Delleur (1983)[4] the period 1967-1974, in urban hydrology was called the period of "tool making" and was followed by the 1975-1978 period of "tool welding". The immediate post-1978 era witnessed greater attention being accorded runoff quality by the use of comprehensive computer models to stimulate several aspects of pollution. The period was also one of acquisition of extensive data base both on the quality and quantity of urban rainfall and runoff. Urban hydrology was maturing rapidly as a distinct branch of hydrology as easily evidenced by the number of book publications on the subject.

The historical perspective and antecedents of urban hydrology, of course, predate 1967 and some of its vital tools-raw as they might be- such as the rational formula with its modifications and improvements were long developed and were applied between 1950 and 1960 to urban areas. Important landmarks in the development of the early tools in urban hydrology were established in 1850 when Mulvaney formulated[5] the rational formula; and in 1889 when it was first applied in the USA by Kiuchling[6]. Lloyd-Davies[7] later formulated its UK equivalent. Other land marks include the introduction of the zone principle; of the general rational formula; the Los Angeles hydrograph; the inlet hydrograph method; and the Chicago hydrograph. In 1964 Jens and McPherson[8] wrote a state-of-the-art review of urban hydrology, and during 1965-1966 Eagleson and March[9] and Viessman[10] applied the well known unit hydrograph theory proposed by Sherman more than three decades earlier to urban hydrology.

Few investigation considered the possibilities of urban flood abatement before 1978 as the hazardous phenomenon was almost considered to be an inevitable consequence of urbanization. The last ten years have, however, witnessed increased effort in that direction as the urban hydrologic picture broadened to encompass the urban watershed in its entirety. Much work has been done on both on-site and regional detention basins for storm runoff peak rate reduction which are now operational in many urban areas.

Trends and Features of Urbanization in Africa

The qualification put forward by different African countries in respect of their urban communities vary. For instance, in Madagascar communities between 200 and 5000 inhabitants are considered as urban centres. In Ghana each Locality with a population of 5,000 and over was defined in 1960 as an urban centre; such localities with over 10,000 persons are regarded as large urban centres[11]. The fast growth of population of Africa and other LDCs against the background of limited physical resources in rural areas and the centralizing force of commerce and industry in urban areas have made the former unattractive and resulted in dramatic expansion of the urban areas for better way of life. Urbanization which is characterized by clustering of people, activities and infrastructural facilities in relatively small areas is recognized as an inevitable historic process. In 1950, one third of the world's population lived in urban centres. By 1985, the population in urban centres had tripled from 734 million to 1,983 million, and by the year 2000 half of the world's population is expected to live in urban centres. In the More Developed Countries (MDCs), about 75% of the population would be concentrated in urban areas[12]. Already by 1985, each of 270 urban centres housed more than one million persons while 35 of these housed over 5 million persons.

Urban development in sub-saharan Africa (that is not including North Africa countries of Egypt, Libya, Tunisia, Algeria) is a recent phenomenon. Most traditional communities were small in size and dependent on agriculture. The Yoruba of Western Nigeria are outstanding example of a people that evolved an urban culture with urban centres based on royal courts, crafts and peasantry that commuted daily to nearby fields, or came regularly to urban centres for major socio-religious events[13]. The Republic of South Africa had by far the highest level of urbanization by 1970 and had three out of the biggest urban centres of sub-saharan Africa. One of the main features of urbanization in the region is that Nigeria and Republic of South Africa were most urbanized countries. In 1963, Nigeria had 23 urban centres each with more than 100,000 persons while Republic of South Africa had 16 such urban centres. Another feature of urbanization is the coastal concentration of large urban centres. Of the 80 urban centres housing more than 100,000 people, 21 are so situated, and if Nigeria and Republic of South Africa are excluded 15 out of 38 of such large urban centres are located on the coast. Yet the massive continent has a very short coastline in relation to its area.

Table 1 shows that in most African countries between 4 and 14% of the population lived in urban centres housing 50,000 more inhabitants in 1969; the figure for Republic of South Africa exceeded 30%. Lesotho, Rwanda, Botswana and Mauritania had no urban centres of this size. The percentage living in urban centres in Africa is lower than in any other continent or major world region, but rapid changes in the size and proportion of urban population are taking place and will change this position of Africa before long. Between 1965-1975 the urban population increased from 60 to almost 100 million and its proportion from 20 to 24%. Growth has been particularly rapid in the larger urban centres, notably the capital urban centres, many of which demonstrate a high degree of urban primacy[14], Spatial differences in the percentage and growth of urban population within the continent are high, but in general higher levels of urban population prevail in the Northern and southern parts of Africa (Table 2). Table 3 shows the rate at which the largest African urban centres outgrow their initial boundaries.

The United Nation projections in 1969 suggested that the annual rate of population growth in urban African centres, which was then 5.4% in urban centres over 20,000 inhabitants and 8% in large urban centres; was likely to be faster than any other region. By the date, 30 million people were housed in the urban centres of more than 100,000 inhabitants. Also in Africa, urbanization has been

Table 1: Percentage of Population Living in Large African Towns of over 50,000 Inhabitants (1969)

COUNTRY/ PERCENTAGE	PERCENTAGE	COUNTRY/COUNTRIES COUNTRIES	
South Africa	32	Liberia, Somalia	10
Congo	28	Benin, C.A.R., Sierra Leon	8
Zambia	22	Angola, Cameroon, Kenya	7
Senegal	21	Chad, Ethiopia, Mali	4
Ghana	16	Tanzania, Uganda	4
Nigeria, Zimbabwe	13	Malawi, Upper Volta	3
Gabon, Ivory Coast	12	Burundi, Niger	2
Zaire	11		

SOURCE : Gugler[13]

marked by high density. Further estimates by UNESCO in 1979 concluded that urban population of Africa in 1970 would have been increased fourthfold by the year 2000 (table 4). Such a figure indicates that, on the average, urban population in the continent would increase by 5% annually with likely increases higher than 10% in some urban centres.[15]

Apart from the gradual decline in death rates, the major factor of population explosion in the LDCs is the total fertility rate, defined as the average number of children a woman will bear at prevailing level of fertility. LDCs fall into two categories in this respect. In the first, fertility rates have declined since 1960 by more than 20% although very few have reached the so-called replacement-level fertility of about 2.1 births per woman. In this group are some countries of Asia and Latin America, but the dramatic change took place in East Asia and Cuba, were fertility levels dropped by such as 75 per cent[16].

In Africa, only Egypt and Tunisia experienced fertility decline of more than 20% between 1960 and 1987. Indeed pockets of extremely high fertility of above 6 children per woman still exist throughout Africa. Figures in 1987 for some of them are Kenya 8.0, Ethiopia and Senegal 6.7, Nigeria 6.6, Sudan and Zimbabwe 6.5, and Zaire 6.1; all with consequent high population growth rates of 2.3 to 3.9 per annum. When such high rates are applied to medium to large population figures as in

Table 2: Urban Population Size and Changes in Africa Population in 1975

REGION		TOTAL (Million)	URBAN (Million)	URBAN %	ANNUAL GROWTH RATE 1970-1975 (%) TOTAL	URBAN
1. E. Africa (18 countries)	Ave/Total	114.5	14.0	12.2[a]	2.7	5.7
	Max			36.6	3.4 Zimb.	6.6 Uganda
	Min			3.7 Burundi	4.3 Kenya	5.4 Ethio.
2. Middle Africa (9 countries including Angola and Cameroon	Ave/Total	45.3	10.4	23	2.3	4.6
	Max			45 Eq. Guinea	2.4 congo	6.0 Angola
	Min			14 Chad	1.0 Gabon	3.9 Zaire
3. Northern Africa (7 countries including Sudan and Western sahara)	Ave/Total	98.2	38.9	39.9	2.7	4.5
	Max			50.0 Algeria	3.2 Alger	5.6 Alger.
	Min			13,2 (38.0)[b]	2.3 (0.9)[c]	3.8 Egypt
4. Southern Africa (5 countries)	Ave/ Total	27.8	12.80	45.9	2.7	3.7
	Max			50.0 S. africa	2.8	–
	Min			3.1 Lesotho	2.3	–
5. Western Africa (17 countries)	Ave/Total	115.5	12.4	18.6	2.6	5.0
	Max			33 Ghana	2.7 (Nig.)	5.4 Ghana
	Min			8.3	1.5	4.5
6. Africa Total	Ave/ Total	401.3	97.6	24.3	2.6	4.7
	Max			50.0	3.4	6.6
	Min			3.1	1.0	3.6

a. Countries of Mauritius and Reunion have 48% and 51% of their population in urban areas, but the total population of each country is less than a million. Zambia with 36.6% is more representative.
b. Sudan which does not really belong to this group has 13.2% but the minimum for the other five is 38.0 % urbanization. Information is not available for Western Sahara.
c. Western Sahara has 0.9% annual population growth, but Tunisia with 2.3% is more representative.

SOURCE: Extracted from Clarke & Kosinske [14]

Table 3: Some Characteristics of the largest African Urban Centres

Urban Centre	Date of (Census)	Administrative Area (km^2)	Built Up Area (km^2)	1969 Estimates of Built -up Area (km^2)
Johannesburg	1960	595	1153	1350
Lagos	1963	665	1089	1200
Cape Town	1960	508	807	920
Kinshasha	1959	402	—	920
Durban	1960	560	681	780
Ibadan	1963	627	627	700
Addis Ababa	1967	644	—	700
Accra	1960	338	388	650
Darkar	1955	186	231	600
Pretoria	1960	304	423	520
Khartoum	1956	93	246	500
Nairobi	1969	478	—	480
Abidja	1955	—	128	400
Salisbury	1969	—	386	390

SOURCE : Gugler[13]

Table 4: Growth Factor of Urban Population for the Period 1970-2000(% p.a.)

Europe	1.5	East Asia	2.7
North America	1.7	Latin America	3.1
USSR	1.8	South Asia	3.3
South Sea Islands	1.9	Africa	4.2

SOURCE: Lindh[15]

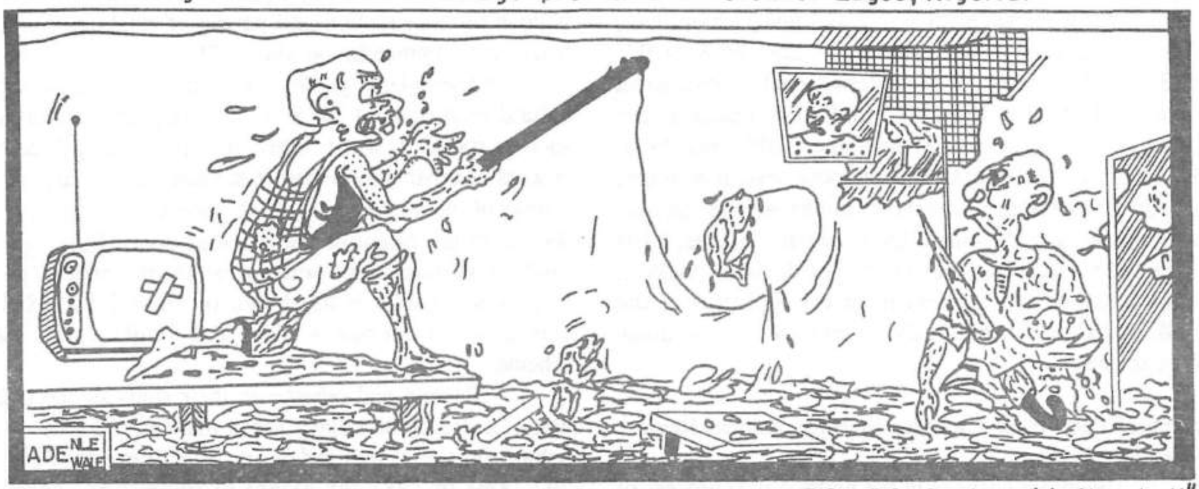
Nigeria, Kenya and others, the result is a large future population which far outstrips available infrastructural facilities and resources. This is especially true of urban environment where rural out-migration has accentuated the concentration of people.

Estimates of the continent's population for the year 2000 and the year 2025 are 826 and 1427 million, respectively.[17] If the estimates prove accurate and if the present trend of urban population growth continues or declines only slightly not less than 248 and 428 million inhabitants would be housed in Africa's urban environments in those respective years.

Unfortunately only few African countries have developed policies to check the problem of explosive population growth and particularly of over concentration of people in a few urban centres by restricting development of largeurban centres. Instruments such as villagization, a vehicle of rural transformation as well as licensing and heavy taxation have been used by Tanzania since 1967 for redistributing the population. There is no doubt that African countries need well articulated population redistribution policies formulated within the context of overall population policy, and not mere *ad hoc* measures, aimed at stemming rural out migration - a major factor in exacerbating existing population distribution and natural growth.

Such urban rates lead to strong changes in the natural space, with some damages to the water cycle components (quantity and quality), and with grave consequences for the health and welfare of the urbanities. It has been estimated that as much as one-third of the population in the urban centres of the LDCs live in slum or squatter settlements on the fringes of the urban centres, in appalling conditions of deprivation as exemplified by Khartoum and Lagos Metropolitan areas.[18] The "fisherman" in Figure. 1 retorts "of course, this is my room during the dry season and my fish pond when it's flooded". The cartoon aptly depicts the plight of many urban dwellers who inhabit the slums and flood plains which abound near the urban centre and periphery of

Fig. 1: Reactions to drainage problems in Greater Lagos, Nigeria.



"Of course!, this is my room during the dry season and my FISH POND when it's flooded!"

Source Daily Times of Nigeria (July 21-1989 P.8) By I.O. Mahiri.

many bursting urban environments in Africa.

The world-wide process of urbanization and industrialization and the deficiencies in the knowledge of urban hydrological process and its implications for adequate water resources planning and management have led to international action and cooperation since 1970.[19] Within the framework of the International Hydrological Decade (IHD) in 1965-1974 and its successor, the International Hydrological Programme (IHP) since 1975, UNESCO took the initiative to promote several activities such as symposia and workshops and to prepare state-of-the-art reports and manuals. Through such activities, it has succeeded in arousing the interest of decision makers, technicians and researchers in many countries of the world, including Africa, in the hydrology of their urban environments.

Principal Factors of Changes in Hydrological Regime of Urban Areas

The major changes in the hydrological process of urbanizing areas are due generally to three principal factors namely.

(a) covering of parts of the urban catchment with impervious surfaces, and compaction of the remaining non-paved surfaces;

(b) Increased hydraulic conveyance of both natural (stream) and artificial drainage networks;

(c) intakes of surface and groundwater and introduction into the network of streams through utilization and consumption of the imported water.

There is, however, a fourth factor which serves to exacerbate the already complex problems of urban hydrology in LDCs such as Africa, the aspects of poor planning of land use for the various urban functions. These four factors are discussed with respect to changes which they induce and illustrated with examples from urban environments in Africa.

Extent of Impervious Areas

The replacement of previous surfaces by impervious ones is a major process of urbanization. This is done by construction and paving of roads by building house and commercial buildings. Thus in the place of the forest and grassland, gardens or swamps of the pre-urban natural environment we now have impervious surfaces such as rooftops, street, sidewalks and parking lots. The process of urbanization manifests itself most clearly in the growth of the relative size of the impervious areas and the decline in the extent of the pervious areas. Each type of landuse is associated with a range of percentage of impervious surfaces as shown in table 5 by US Soil Conservation Service in 1971 and Stankowski's 1972 scheme.

Benetin and others[22] in their study of the USSR urban centre of Bratislava noted that as the area of the urban centre expanded from 39.25km^2 in 1945 to 292.1km^2 in 1985 the extent of impervious surfaces increased drastically. They used the same sample area of 77km2 for both 1945 and 1985 to evaluate the changes. The proportion of impervious surfaces increased from 21% to 47%, while that part of pervious surfaces covered with gardens, lawns and recreational parks increased only slightly from 44.1 to 45%. However, most of the gains in impervious surfaces was derived from former field which decreased from 31.4% to 3.5% while water areas increased from 3.5 to 4.5%.

In Tunis, Tunisia, as the urban development intensified, the area of impervious surfaces increased rapidly and by 1988 the percentage of impervious surfaces was up to 60%, but only part of it contributes to quick storm runoff.[23] Also, almost all the houses have flat roofs with elevated edges to delay runoff, and roof drainage is rarely connected to the storm water system. In addition, some paved surfaces are undulating or cracked. Studies

Table 5: Percent of Impervious Surface Associated with Land ise Types

LAND USE	PERCENTAGE OF US SOIL CONSERVATION SERVICE 197120	IMPERVIOUSNESS STANKOWSKI 1972[21]
Low Density Residential	20 – 30	12 – 40
Medium Density Residential	25 – 35	(30 - 60)
High Density Residential	30 – 40	60 – 80
Business		
Commercial	40 – 90	80 – 100
Light Industrial	45 – 65	(40 – 70)
Heavy Industrial	50 – 70	70 – 90
Public and Quasi Public	____	50 –75

Such figures are useful indicators but should not be applied without verification, especially in LDCs.

reported in West African countries of Niger, Burkina Faso and Cote d'Ivore by Bouvier [24] indicate that the area of impervious surfaces do not exceed 30%, generally. It is also reported that only about a third of the impervious surfaces are connected directly to the sewer system thus contributing to an earlier peak.

However, for the urban centre of Aba, the important commercial capital of Imo State in the south-eastern Nigeria, the situation is somewhat different. The urban centre covers an area of about 8 km^2 but the metropolitan area is over 18km^2 and the urban centre is traversed by Aba River from the North-East to the South-East. According to Okoye[25], in its early stage of development the built up area was contained within the urban centre boundaries (figure 2). But by 1960, the urban centre was some 90% built up. During the early 1970s after the civil war further population concentration led to the extension of urbanised area beyond the boundaries into the village settlements around Aba, particularly Ndiegoro and Umuokpoji both in the South West, Eziuku (West), Osusu(North-East), Ogbor hill region (East) and Ohuru area. By the late 1970s the whole of these areas had become heavily built up. The houses were huddled together such that the roofs of adjacent houses are almost touching, especially in Ndiegoro area. A consequence of this crowded housing was the covering of a high percentage of the urban centre with impervious surfaces. Table 6 shows the extent of impervious surfaces in various section of the urban centre as ranging from 76 to 92% with average of 84.6%, in 1980 [25].

Much work has been done to evaluate the effect of urbanization, particularly of the extent of imperviousness on storm runoff peak and volume. But as noted above imperviousness though a very significant factor hydrologically is only one of the factors influencing storm runoff. In Africa's urban land use planning have been found to be very conveyance and poor urban land use planning have been found to be very important. Moreover, it is difficult to separate the effects of the various factors without detailed data gathering and rigorous statistical analysis. Nevertheless, different workers have observed some quantitative relationships between different levels of imperviousness and urban storm runoff. For instance, Bigwood and Thomas[26] found in 1955 that for a Connecticut watershed 20% of imperviousness resulted in 300% increase of flood peak, while Espey and others[27] observed in 1960 a 590% increase in storm peak flow as the paving of the watershed under study reached 50% of the total surface area. In 1980, Alvarez and Sanchez [28] in their study of the 80 km^2 Duluvo Creek basin of Porto Allegre, Brazil applied the Kraijenhoff's model to 10-year 30-minutes rainstorm and noted that as a result of increases of up to 27% in the impervious area discharge increased 3.3 times (330%). The workers indeed concluded that the first phases of urbanization (up to 20% imperviousness) are responsible for the biggest change in the hydrological regime whereas the development of previously urbanized areas creates less dramatic changes, although they may be equally dangerous since the increases in volume of runoff will overload the drainage network which are generally old and deficient.

Thus peak flows may increase by a factor of 3 to 8 as urbanization progresses[29], depending largely on the proportion of urban watershed covered by impervious surfaces. Runoff volumes too have been similarly observed to be 2 to 2.5 greater than in a natural environment, even though the increase in surface runoff volume will cause a reduction in runoff downstream of the urban watershed due to lower infiltration and hence groundwater discharged to rivers. The dramatic effects that the unchecked growth of imperviousness can have in African urban centre on erosive force and land sculpturing is exemplified in Durban South Africa.

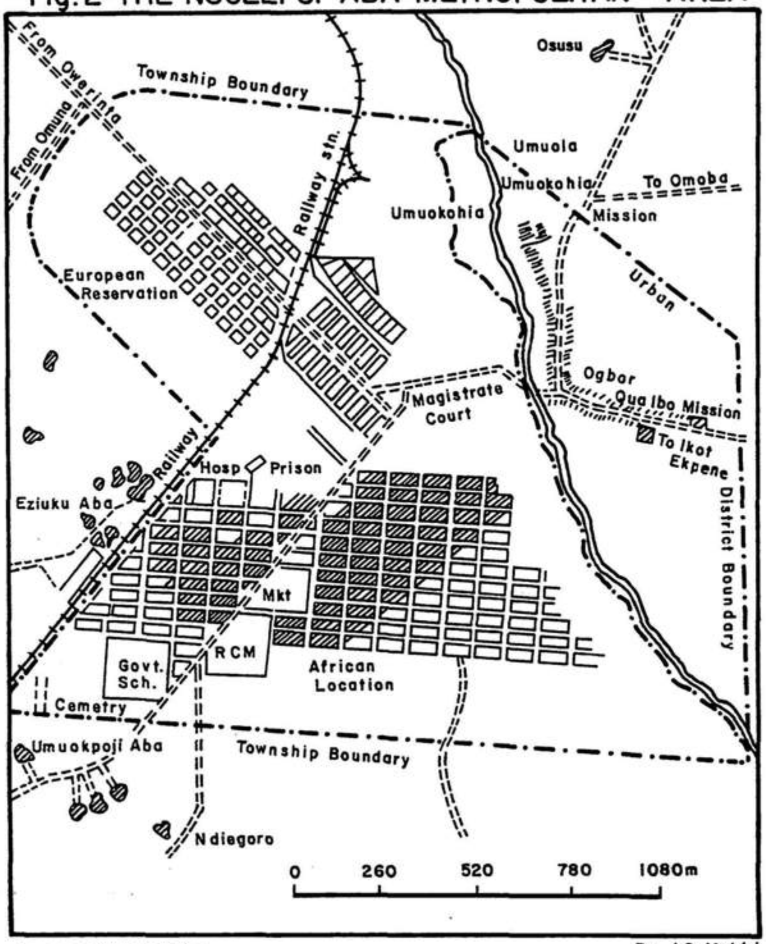
The reasons for observed increases in the rates and volumes of storm runoff are perhaps obvious. Rainfall abstractions are smaller, hence rainfall excess produced in a given storm is greater for the impervious than for the pervious parts due mainly to lower infiltration rates and smaller depression storage capacity of the impervious

Table 6: Extent of Impervious Areas in ABA 1980

CATCHMENT AREA SURVEYED	IMPERVIOUS AREA (ha)	PERCENTAGE OF IMPERVIOUS AREA
Umuacham	52.3	78
Eziama	49.8	76
Eziukwu	41.1	80
Ndiegoro	95.6	92
Igbo National Area	65.3	91
Igbor Hill	37.7	78
Ministry of Agriculture	58.3	83
School Road Area	54.5	92
Azikiwe Road	99.4	91
Total/Average of Partial Area Survey	554	84.6

SOURCE: T. O. OKOYE[25]

Fig. 2: THE NUCLEI OF ABA METROPOLITAN AREA



Source: Okoye 25

By I.O. Mahiri.

areas. One would then expect runoff hydrograph of the impervious area to have shorter characteristic time parameters such as time to peak or time of concentration, and time base than the corresponding hydrograph for the natural or pervious areas. Generally, this is also due to higher flow of velocities and, often, shorter for paths in the paved area[30]. The work of de Villers[31] on the small fully urbanized Palmiet watershed in metropolitan Durban, Republic of South Africa illustrates the impact of intense urbanization on flow velocity. The Pinetown subcatchment in the west is relatively flat, but industrial development there increased considerably during the last decade making Pinetown the most industrialized urban centre not only in Natal but also in Republic of South Africa. Flow velocities for the 50-year flow event were calculated upstream and downstream of Pinetown Central Business District (CBD). In the upstream section with a slope of 1:50, the velocities varied around 3 $msec^{-1}$, whilst they doubled to about 6 $msec^{-1}$ downstream of the CBD where the slope is only 1:80, but the imperviousness in the upstream catchment exceeded 80%. Velocity dropped to 5 $msec^{-1}$ in the eastern part of the catchment in spite of the relatively steep slope of 1: 60 because the effect of urbanization there is less pronounced. It makes sense therefore, that often the recurrence intervals of floods resulting from storms on such surfaces are increased significantly.

The other type of surface in urban areas consists mainly of the unpaved areas of undeveloped land, lawns, nature parks cemeteries and unpaved streets,among others. We also noted earlier that the intense utilization of the unpaved surfaces in urban area, particularly in may African urban centres where the proportion of gardens, nature parks and other open spaces are very limited more than often than not results in compaction of such surfaces such that they may be more impervious than expected. A number of streets in many urban centres in Africa are indeed unpaved, yet these are often so compacted that for the most part are largely impervious, particularly the compacted laterite surface streets. Bouvier[24] gave report of a three-year study of 24 urban watersheds in six metropolitan areas of West Africa (Niamey, Ougadougou, Bamako, Lome, Cotonou and Abidjan). He observed that in traditional African urban landscape which predominates in may Africanurban centres, runoff is contributed from both natural surfaces and impervious ares that are not directly connected to the sewer system. The results also show runoff coefficient of 75-85% on dry soils; 91-95% on wet soils given a 40 mm high rainfall. Niamey's and Cotonou's watersheds have the same ratio of imperviousness area of 30% but composite runoff coefficients of 60% and 20%, respectively, for one year rainfall. The result imply that in any meaningful evaluation of urban storm runoff volumes and peaks in African urban area, both types of surfaces should be carefully considered as sources of runoff contribution.

Hydraulic Conveyance

This is regarded as the second major factor in the urban runoff process. Urbanization creates radical changes in the drainage network by adding a great number of channels to the natural network and thus creating a mixed natural-artificial system with substantially different characteristics. Natural channels are often straightened, deepened and lined. On the other hand, additional (artificial) network of gutters, storm sewers and drains are installed. A distinctive characteristic of the man-made pathways be they surface or underground(e.g.sewers) is that they are usually impervious. There are cases, however, in urban areas of LDCs when some gutters are unpaved and are therefore subjected to severe gullying. The hydraulic conveyance efficiency resulting from the above improvements, modifications and additions combine with changes in the impervious fraction to change the urban hydrological regimen, particularly runoff peak and volume and their time distribution as already noted earlier. It is not surprising therefore, that urbanization has come to be accepted as a flood-intensifying land use change. The increase of urban storm runoff may cause flooding and disrupt traffic, flooding of underpasses, damage to houses and properties as well as costly interruptions of urban activities. In many urban environments of Africa such as Lagos, Ibadan and Aba in Nigeria[25], Tunisia[23], Nairobi, Dar-es-Salaam[33] and Addis Ababa [32], to mention a few, flooding and associated damage problems occur several times in a year and have intensified over the years as urbanization progressed. This is largely because the existing network of drainage channels and sewer together with the associated culverts and bridge openings are often inadequate to contain or pass the storm flow. In some of theurban centres, particularly in flattish coastal areas, sheet flood water may remain on the urban land days after storm rainfall had ended. The increased velocities of flow enhance the transport of suspended solid and of pollutants which aggravate the scouring of channels.

Let us conclude this section with a brief consideration of the severe storm water management problem which metropolitan Tunis once experienced. The annual precipitation was only 450 mm, most of which falls during November to January as short convective storms. The urban centre is surrounded by hills which slope steeply towards the central part of the Tunis, thus creating serious drainage problems as the existing drainage system was not adequate to convey the flow during intensive rain storms[23]. The excess capacity thus flooded the streets and properties several times a year. But during the last ten years, huge water conduits have been constructed to evacuate storm water from the central areas of predominantly impervious surfaces to the nearby lagoon-Lac de Tunis. As the Tunis gets further urbanized and the area of impervious surfaces increases rapidly, it is feared that the present drainage capacity may soon become inadequate once again. The need to forestall such problems led to the initiation of three storm water management projects.

Water Demand

Extensive urbanization phenomenon is itself the result of increasing demands of man himself. Modern man increasingly demands more water, more energy, more land space for buildings and more consumer goods. The results are that more wastes of all kinds are produced and in many cases more water is needed to dispose of them. This is largely because in large urban centres where local land occupancy has become sufficiently extensive septic tanks and cesspools for individual buildings give way to community sewerage. This water borne carriage of wastes in public systems of waste sewers, a creation of urbanization, is practised extensively in MDCs of Europe and North America.

The rate of water use and of the water supply system is thus one of the vehicles for the major changes that urbanization produces. For instance, the discharge of Leningrad, USSR aqueduct is over $20m^2$ sec^{-1} and that of Moscow, about $40m^3$ sec^{-1}. In other words, each day Leningrad empties a lake about 12,000m in diameter and 2m deep. By the same token, the water discharge into the aqueduct feeding urban agglomerations with millions of people will be enormous and such communities will consume large rivers for their domestic needs alone. An example in Africa is the Metropolitan Cairo, Egypt whose population rose from 482 million in 1960 to 10.27 million in 1981. During the period per capital water demand increased from 127 litres per day to 240 ld^{-1}; so that the total water demand in 1981 was 2.46 million m3 d^{-1} and is expected to rise to 6.7 million m3 d^{-1} by the year 2000[35]. Some 60% (i.e. 548 x 10^6 m^3 yr^{-1}) of the water pumped into the supply system networks is lost by leakage. This amount is said to exceed the sewage capacity originally designed to serve a half million inhabitants by nearly 0.5 x 10^6 m^3 d^{-1}, an amount which goes to recharge the aquifer. And altogether, it is estimated that some 800 x 10^6 m^3 represents the total vertical recharge per year in the 1200-km^2 Greater Cairo which receives less than 40 mm of annual rainfall on the average.

The hydrological features of an urban area also depends on the extent of its catchment area. In a number of Africanurban centres, the amount of water available locally cannot meet the rapidly increasing demand of the human and industrial needs. The water resources have to be increased by water transportation or by storage.

The evolution of the hydrological system of the Metropolitan Area of Mexico City (MAMC) from 1325 to 1983 has revealed some features of interests and relevance to Africa, particularly African urban centres in coastal and arid zones. As Mexico City grew , its hydrological system extended from the valley of Mexico to cover three other watersheds. Boreholes were drilled from 5 million in the 1950s to the present figure of some 18 million and water supply of 76 m^3 / sec (6,57 million m^3 per day). 67% of the water supply for the urban centre comes from ground water sources so that ground water mining and falling water table have been continued for more than 30 years. More than 9 meters of land subsidence has occurred in some areas of the city and caused severe flooding, making part of the drainage system obsolete and resulting in poor water quality due to withdrawal of fossil waters. Consequently, a new artificial outlet was completed to reduce the floods[36].

It is envisaged that as more water is demanded to cover seven watersheds by 2010 or thereabout. Meanwhile measures being taken to reduce ground water mining include interregional transfer of both groundwater and surface water and increase of water reuse from the present level of $3m^3$/sec (0.26 million m^3 per day).

In flat, dry areas urbanization presents a particular problem of water supply shortage. Evenurban centres situated near large rivers may be faced with both water shortage as well as flooding. Niamey in Niger is a case in point. During the Sahelian drought the urban centre consumed half of the flow of the River Niger during a few days in 1974 and the river flow stopped completely during a short period in 1985[37]. The water supply system was thrown in jeopardy and transport of effluents was adversely affected. In many cases the hydrological cycle may involve transport of huge water masses often transferred from beyond the local basin or drawn from aquifers drained or recharged by other rivers. This means that other areas of basins participate in the hydrological regime Lagos metropolis some $1200km^2$, for instance, obtains most of its raw water from the Ogun River with an area of 22,370 km^2 with its headwaters rising some 310 km upstream in Oyo State of Nigeria. The water is pumped from the Ogun River channel whose flow is regulated by releases from Oyan Dam located 95 km upstream in yet Ogun State of Nigeria. The Federal Authority which which takes charge of the dam has a standing agreement to release certain quantities of water from the reservoir to Lagos and Abeokuta (Ogun State) urban water supply systems.[38]

Thus in a real sense water management includes the whole of urban watershed and has to integrate drainage and regulation of the flow conditions, flood protection, waste water transport and waste water treatment; all these under the prevailing physical condition, and water supply is an essential, integral part of it.

In highly urbanized areas, e.g. Hong Kong, and in arid or semi-arid climates, e.g. Doha and Lima, flows in water supply network exceeded those in the natural system[39]. Even in temperate moderate densityurban centres (Vancouver, Birmingham) flows in the two systems are comparable in size (Table 7).

The increase in water use- both domestic and

Table 7: Relative Size of Imported Water in the Urban Drainage Networks.

URBAN CENTRE	AREA (Km2)	DATE	PRECIPITATION	IMPORTS	LOCAL GROUND-WATER	UNITS
Mexico City	—	1980	86	14	—	%
Hong Kong	1046	1971	1912	1310	64	mm
Hong Kong (Part)	0.16–0.35	1980	2000	650 - 7500	0	mm
ydney	1035	1962-72	1100	333	16	mm
Vancouver	0.21	1982	1215	576	0	mm
Lima	400	1978	10	1650	950	mm
Doha, Qatar	294	1981/82	1671	175	27	mm
Birmingham	500	1985	730	675	30	mm

SOURCE: David N. Lerner

industrial- within the urbanized area leads unavoidably to the increase in the quantities of waste water

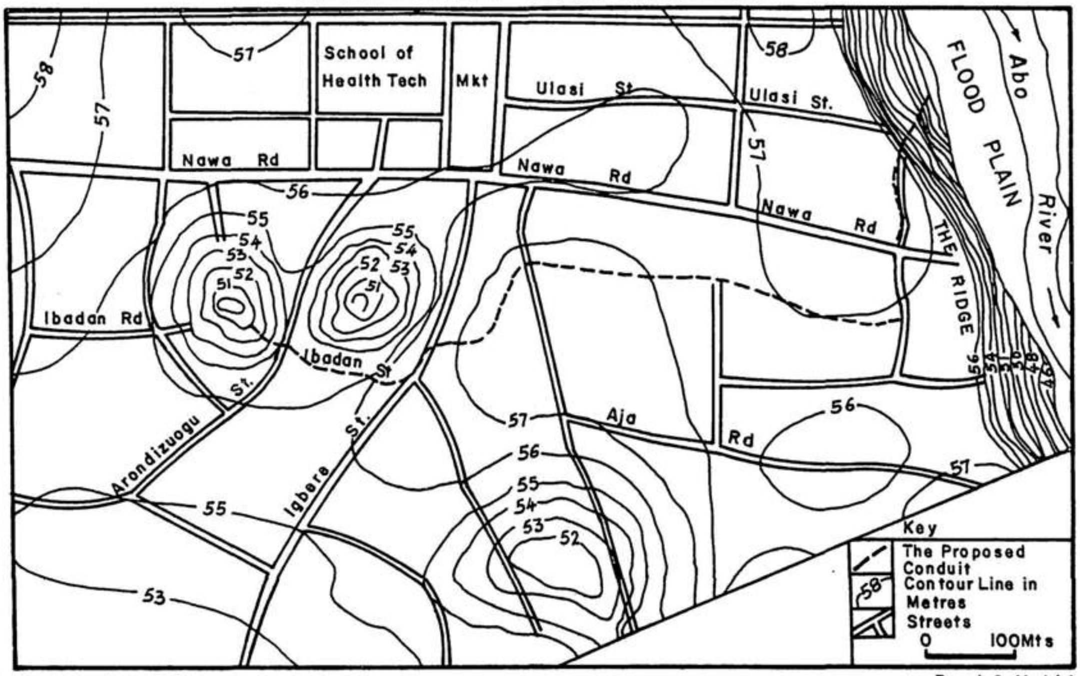
Inadequate Landuse Planning and Maintenance of Facilities

Cases of poor land use planning and failure to maintain drainage and other urban facilities in good conditions abound in Africanurban centres and often aggravate flooding and pollution hazards. We have seen how unplanned expansion of Aba, Nigeria and the failure to adhere to building and health regulations led to haphazard construction of buildings. There was no orderly layout and streets were not constructed, access was only through footpaths and there were no drains. The area of Ndiegoro west of the ridge (Figure.3) has no natural drainage outlet to Aba River, but a series of shallow depressions 3 or 4m deep in which runoff collects to form ponds. Even parts of these depressions were built up while streets traverse them in places. Given the poor planning the inadequate drainage system and the high percent of impervious surfaces (table 6), a high coefficient of runoff was prevalent with frequent flooding. In 1980, a series of high intensity short duration rain storms occurred in Aba which flooded streets and houses, causing large scale damage to property and disrupting traffic flow. The Imo State government declared Aba a disaster area and solicited for federal assistance. The urban area has since continued to suffer perennial flooding and upwards of 50 houses are threatened or rendered uninhabitable every rainy season. The short-term solution of pumping the depression storages to Aba River 3 km away costs 0.2 million monthly. A permanent solution lies in the construction of an adequately sized conduct at a cost of over 20 million with 60% federal assistance.

The case of Ibadan, the second largest urban centre in Nigeria and West Africa is similar. The shortage of urban land, in the absence of any strict flood plain zoning regulation encouraged people to build right on to the bank of river channels, thus occupying flood plains. Ogunpa and Kudeti rivers traverse the urban centre from North-west and north-east directions, respectively, before forming a confluence within the metropolis to the south. Over the years, extension if urban land use has restricted the flow of the two rivers within artificial channels. According to Akintola[40], the mean distance of buildings along the Ogunpa River in 1978 was only 11 metres whereas the mean width of the flood-prone land was 90 metres. To further aggravate the condition, the increased generation of solid wastes[41] and inadequate sanitation facilities resulted in dumping of the wastes in the stream channels obstructing the flow of water and partially damming the river. The consequence of this land abuse and insanitary conditions were catastrophic floods which affected the built-up parts of the Ogunpa flood plain in 1984 causing loss of life and property. Several destructive foods of similar magnitude have recurred since 1984, and all efforts at channelization and other control measures have not proved successful since the political will to enforce land use zoning and watershed protection has not been made manifest.

Such examples can be multiplied in African urban environments; we shall conclude this section by citing three cases from eastern, northern and western Africa. Dar es Salaam, in Tanzania had a population if 1.5 million and was growing at 8% per annum as at the last census in 1978. The urban centre has stressed the provision of utilities including the drainage system. During the rainy season parts of the urban centre gets flooded to the point of disrupting economic activities and causing loses of revenue. In 1987, the President had to intervene personally by directing that the maintenance work on the sewer network and drains be effected immediately[42]. As at that time, much of the sewer network and drainage channels were completely blocked by various materials and only two of the 17 sewage pumping stations were functional. Indeed only 12% of the dar-es-salaam's population had access to the chocked sewers by the early 1980s while 8% used septic tanks and 80% had

Fig.3: LANDUSE AND DRAINAGE PROBLEMS IN NDIEGORO SECTION OF ABA METROPOLITAN AREA (NIGERIA).



Source: Okoye 25

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pit-latrines.

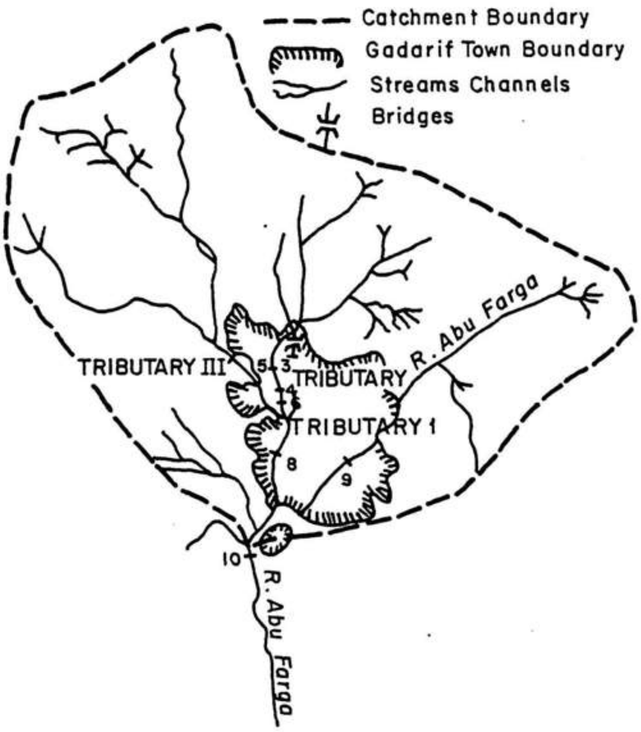
The case of Gadarif Sudan is a real catastrophe. The urban centre is located within a 100-km^2 catchment of Khor Abu Farga River with its numerous tributaries (Figure.4) deriving their headwaters from the sorruonding highlands within a radius of 4-10 km from the Gadarif is the most important sorghum centre and the wealthiest urban centre in the country and had thus experienced population explosion through in-migration[43]. Unfortunately, no proper planning was made to absorb the urban development. Errors galore were made in the haphazard expansion of urban land use that followed:bridges, railway crossings and embarkments, storm drains and modification and shifting of natural channels were done without conformity to hydrological conditions or hydraulic principles. Houses were also built in the flood plains. On September 9, 1973 a storm rainfall amounting to 90 mm, with the first falling during 45 minutes occurred. The 5- year storm in a 25- year flood which caused the worst damage over reported in the Sudan up to that date. Official records put the losses at 30 dead persons and over US $ 1 million loss in properties. The Antecedent Precipitation Index (API) would be high for the damaging storm was preceded by a fall of 76 mm five days earlier. The co-efficient of runoff was thus high being 0.46, double the value for the records of comparable precious storms. Severe damages were reported in six areas of the urban centre (Figure.4 & 5). One of such areas is area (1) (Figure.5), enclosed by Tributary (II), Artificial Drain (I), Elmufargat Bridge (3), the railway embankment, railway bridge (5) and Tributary (III). Fast flowing tributary (III) had washed off houses sited in the flood plain to block the railway bridge completely (5). The Elmufargat bridge(3) is on the sharp bends of Tributary

Table 8: Extent and Causes of Flooding in Metropolitan Area

	Flooded area (ha)		Causes
Zone	Natural	Man-made	
1	3,400		No natural outlet
2.		740	Inadequate cross-drains in Streets plus illegal building in drainage ways
3.		1,220	construction of Apapa – Oworonshoki Expressway, illegal construction, inadequate size and lack of maintenance of the twin Surelere drains.
4.		300	Construction of Apapa – Oworonshoki Expressway and improper Street construction near the University Hospital
		90	Inadequate drains in the Apapa–Oworonshoki Expressway, Agege Motor Road and Nigerian Railway
5.		320	Natural lowland with little gradient and to Lagos
		140	Inadequate Street drains and culverts
6.	170		Natural lowland with inadequate gradient and obstructed channels.
		260	Inadequate cross drains under the Agege Motor road and railroad, improper grading of streets and illegal building construction blocking drainage ways.
7.		170	Improper reclamation, subsidence, blocking of existing drains by the Ring Road.
8.	310		Natural Lowland bordering and subject to tidal and other variations of level of Lagos Lagoon.
		163	Lowland subject to level and inadequate outlet of Ebute-Metta Creek.
9.		154	Lowland behind National Stadium – flooding aggravated by landfill reclamation on Western Avenue.
		37	Inadequate Street drains
		180	Inadequate road cross drains, building in drainage ways.

SOURCE: Lagos State Ministry of Works and Transport:
Master Plan Project Map August, 1979.

Fig. 4 : KHOR ABU FARGA CATCHMENT

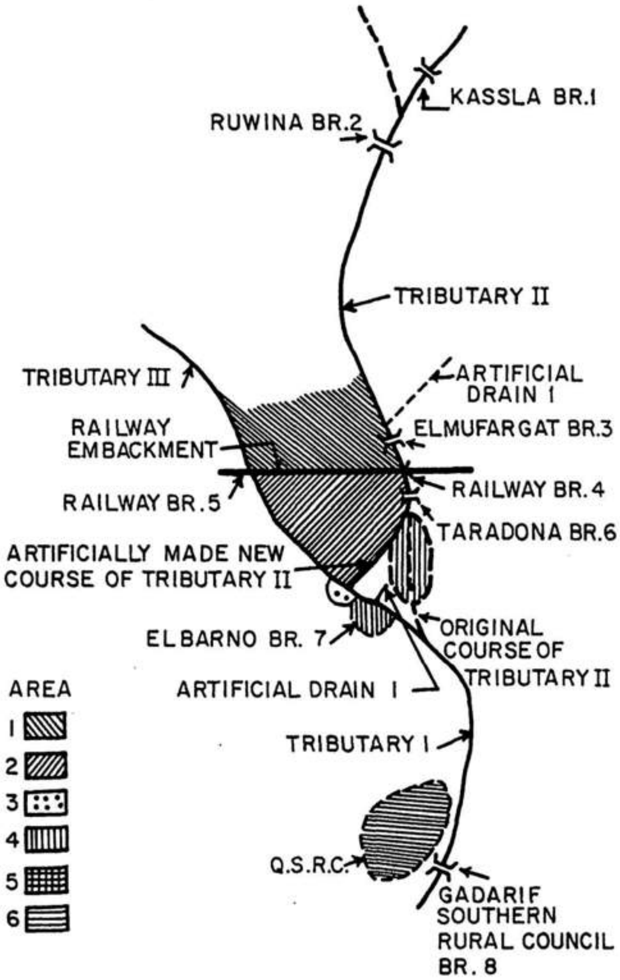


KEY:-

1. Kassala Bridge
2. Ruwina Bridge
3. Elmufargat Bridge
4. Railway Bridge
5. Railway Bridge
6. Taradona Bridge
7. El Brano Bridge
8. Rural Council Bridge
9. Railway Bridge
10. El Sofi Stream Gauging Station

Source: A.M.A. Salih[42]

Fig. 5 : 1973 FLOOD DISASTER IN GARDARIF SUDAN



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(II), so that more than half of its openings were also blocked. The artificial drain (I) constructed at right angle to the bend just upstream of Elmufargat bridge together with Tributary (II) completely blocked the remaining openings of the bridge with debris. The blocking of the two bridges (3) and (5) converted the 2m high railway embankment into a dam which collected and stored water from Tributaries (II) and (III) as well as artificial drain (1) behind it. The flooding waves or surges that occurred following the ponding and subsequent spillage were reported to be frightening,[43] and did much damage to bridge hand rails and concrete blocks were moved far away from their original positions.

It is believed that without the errors in man-made activities within the Khor Abu Farga catchment, the flood would have caused very little damage as other parts of the urban centre where land use and construction of structures were done in a rational manner did not suffer such damages. A survey of flood-prone areas of Lagos in August 1977 shows that 81% of the flooded ares were man-made. Inadequate cross drains accounted for 1180 ha or 28% and inadequate street drain some ha or 6% (table 8).

Hydrologic Process in Urban Areas

The hydrologic process which the input precipitation undergoes in urban areas include precipitation, and the abstractions such as interception, infiltration and evaporation as well as runoff. Interception by vegetation is not normally significant in urban areas, while roof tops are usually included as impervious surfaces in urban environments. Interception splits precipitation into that delivered to the land and water surfaces and that caught on the forest canopy and returned to the atmosphere by evaporation. Figure 6 illustrates the major hydrologic process and components of the urban hydrologic sub-system. It is also known that water does not often follow a cycle in the urban environments because it enters and leaves across the urban boundary[39]. Rather it follows either of the two networks of pathways which are interlinked at many points. We have referred to them as modified natural pathways and the water supply - supply - sewage pathways. The main pathways of the natural network are precipitation, interception, evaporation, infiltration, runoff, ground water recharge and flow.

Precipitation

The intensity of tropical rainfalls with a duration of 15 minutes and a frequency of a year is often 2.5 to 4 times higher than that of rainfalls of similar duration and frequency in Western Europe[44]. According to Geiger, for 60- minute rainfall, the factor is gathered by Bouvier[24] in someurban centres of West Africa confirm that African rainstorms are very intense. As table 9 shows, 2-year rainfall intensities for different durations are much higher in African urban centres than in the four Europeanurban centres. Since drainage systems are designed for rainstorms of short duration, models and model parameters used for Europeanurban centres may not fit the specific conditions of the African urban watersheds, especially with respect to drain/pipe sizing. For similar reason of high rainfall intensity, combined sewers have been considered impractical in tropical areas. This aspects is discussed further below.

Rainfall studies thus form one of the basic items

Table 9: Rainfall intensities of 2-year return period

Duration (Δ t)	5 min	15 min	30min	60 min	source
Urban Area					
Niamey (Niger)	160	110	79		Bouvier[24]
Ouagadougou (Burkina Faso)	184	128	92		"
Abidjan (Cote D'Ivoire)	171	142	104		
Lagos (Nigeria)	150	105	95	60	Oyebande[45,46]
Port Haracourt (Nigeria)	160	121	80	62	"
Montpellier (South France)	126	69	48		Bouvier [24]
Paris (france)	82	41	27		"
Gothenburgh(Sweden, West Coast)	80		20	18	Lindh [47]
Stockholm (Sweden, East Coast)	60		25	18	"

of data needed to understand urban hydrologic system and to design urban drainage. It is needed in form of chart, or formula giving the rainfall intensity - duration frequency data for the area under consideration. The temporal patterns of rainfall are also of importance in many urban drainage problems, especially those including retarding basins.

In general thunderstorms create critical flood conditions over most urban catchments in Africa. A dense network of rainfall stations is required to determine the amount and spatial variability. Delleur[4] reported a hydrometeorological study in the Chicago area, which made use of 317 recording rain-gauge over 11,700 km^2, i.e. a density of one gauge per 37 km^2. The study demonstrated that adjusted radar measurements indicated the rainfall pattern accurately in most storms and they were successful in providing 30, 60 and 120 minute forecasts over urban areas. The use of radar similarly showed that there are preferred tracks for heavy (larger than 12.5 mm) rain storms across the Denver metropolitan area.

where T = duration in hours, I is intensity per hour, a, b, and n are constants and $b = \frac{1}{3}$ hr. is the best fit for all the data. Fifty of the largest storms recorded at each urban network during the 4-year study were analysed for storm profiles using storms which produced 20 mm of rain. For typical large storms 90% of the precipitation occurred during 46-64% of the duration. The percentage duration is 46% in Kampala and 54% in Nairobi. Half of the storms occurred in only 13-15% of the duration. In the case of the more concentrated storms 90% of the fall occurred in 19-22% of the duration in Kampala and Dar es Salaam and 31% in Nairobi. Maximum falls generally occur during the first 30 minutes of the onset of the storms.

The storm profile, together with the depth-duration relationships and area-reduction factor provide design data input to the TRRL Hydrograph model in the tropical urban environments studied.

Results reported by Jeje[49] for a typical rainfall intensity frequency distribution of thunderstorm-dominated rainfall in areas of southern Nigeria receiving over 2000 mm (Ondo and Bendel States) further indicated the effectiveness of tropical rain storms in generating large storm flow and eroding deep channels (table 10)

Table 10. Some Characteristics of African Storm rainfall

(a) West Africa

Class Interval of intensity (mm/hr)	Percent of Rainfall
< 25.4	60
25.4 – 50.8	22
50.9 – 76.2	11
> 76.2	7

Source: Jeje[49]

(b) East Africa

Urban area	Local Relief (m)	No. of Recording Rain Gauges	Rain gauge Density (Km^2)	n – Value *
Kampala (Uganda)	100	25	1.35	0.95
Nairobi (Kenya)	160	20	4	0.79
Dar se Salaam (Tanzania)	40	25	2.5	0.89

* n in $I = \frac{a}{(T+b)^n}$

Source: Jones & Pugh[48]

Jones and Pugh[48] have reported a joint research programme aimed at obtaining relationships between mean rainfall intensity and the duration of intense storms for the purpose of gaining insight into design factors for surface drainage in urban centres of East Africa. Data from 100 recording gauges in 3 urban areas of Kampala, Nairobi and Dar es Salaam were gathered for the period 1969 to 1972. Table 10 gives details of the rainfall network density and the n value in the formula:

$$I = \frac{a}{(T+b)^n}$$

Rainfall Abstractions.

In modelling urban basins, it is usually found that abstractions from impervious surfaces are insignificant in size and their effect on runoff peak or volume. Interception is not expected to be high in urban areas as a rule since its magnitude is directly related to the proportion of the area covered by vegetation, which we have noted tends to increase drastically particularly in LDCs as urbanization intensifies. Similarly evapotranspiration tends to be intensely used and fairly consolidated pervious surfaces in African urban areas. However, where cultured ground-growth is extensively irrigated evaporation may be significant, and such areas are usually rather limited in urban areas of Africa. Depression storage neither infiltrates nor runs off immediately but is detained for varying lengths of time. Unfortunately, it has been less measured than even interception, and more or less empirical values based on land cover types are used to determine its value. In African urban environments depression storage may account for significant portion of the water in the networks of pathways of water particularly in flat coastal areas-and there is a marked coastal concentration of urban centres in Africa as we had earlier noted in where sheet flow may remain in many depressed parts of the metropolis. We have also noted the role of such unplanned depressions in Aba, in Nigeria[25] (Figure. 3).

Infiltration is a complex phenomenon because both infiltration rates and capacity of soils vary with time, and is influenced by diverse factors which include pedalogical and slope conditions. The topic of infiltration has been the subject of numerous publications, resulting in a variety of equations which express the function, or soil storage capacity. But as Aron[50] noted, estimates of infiltration parameters in most cases remain largely a guess work except perhaps where site-specific infiltration test data become available.

There are two basic deterministic approaches to determination of infiltration: the soil physics approach exemplified by Green and Ampt [51] model together with its more or less general variations and the hydrological approach. According to Overton and Meadows, the soil physics approach appears to be more reliable model of infiltration, but the requirement of very data and extensive computations represents a major drawback for its application in Africa. Furthermore, infiltration is more complex than the assumed one dimensional vertical flow as it also depends on surface slope and conductivity. Hydrologic models of infiltration include Horton's [53] model derived from energy-work principle as a function of time. It is of the form $f = fc + (fo - fc)e^{-kt}$, where f= infiltration rate at time t in mm/hr, fo and fc are initial and final rates and k is a constant and a function of soil and vegetation cover. Like all hydrologic models of infiltration, Horton's model is based on concept of die-away of f until a final rate is reached - the saturation rate. Watson's 1965[54] experiments on silty clay loam to heavy clay resulted in the following best fit values of the parameters : fo = 44 mm/hr (with initial dry -grassy surface), fc= 12.5 mm/hr and k = 4.23 per hr. The parameter/ values vary with soil type and initial soil moisture condition. Niemczynowicz[23] observes that Hortons's infiltration formula/model does not reflect the real infiltration process in Tunisia as it probably did in Europe. The laterite clay cracks during the dry season and attains high infiltration capacity. However, after the first rains, the clay swells and the cracks close, drastically reducing infiltration capacity. Such soil conditions obviously occur extensively in Africa, and point to the need for carefully designed research experiments on this important hydrological process.

Holtan's 1961[55] conceptual infiltration models is backed by substantial field experimentation and was formulated to relate the volume of water remaining, to infiltration capacity and the two parameters a and n determined experimentally from the relationship f=af pn + fc. n was found to be 1.4 for all plots studied and coefficient a varied from 0.2 to 0.8 for the soil cover complexes. It was overton who showed three years later that integration was permitted by using n=2 without much loss of accuracy. Thus the model became known as the Holtan - Overton model. The model has a couple of advantages over the Horton's model[56].

Infiltration is a very important hydrologic process, because it has runoff on the other side of the same coin, as the water that does not infiltrate runs off in the absence of any detention or depression storage, either as overland flow or as channel flow. In spite of the emphasis on the pervious areas in urban environments, the role of the pervious areas may be significant. Aitken[57] noted that over large land areas, such as Australia (and Africa), the nature of urban catchments varies very substantially, for instance, 5 year storm water drainage system for a 3000 ha catchment in Darwin would be designed for rainfall intensities ranging from 55 mm /hr up to 60 mm/hr. In particular, Aitken noted that much of some urban centres has been built on very pervious soils where infiltration rates after steady rains remain as high as 10 mm/hr whereas in some others, the relatively impervious basaltic clays have low infiltration rates of the order of 1mm/hr when saturated.

Bouvier[24] concluded that the ratio of impervious area in the largely traditional African urban landscape of West Africa which he studied does not exceed 30%. Furthermore he observed that two urban watersheds, - Niamey and Cotonou, have the same ratio of impervious area of 30%, but composite runoff coefficient of 60% and 20%, respectively, for 1 year rainfall. Obviously the effects of climate and infiltration characteristics of pervious areas are important factors of the differences. The results of the study by Bouvier show that a permanent regime of infiltration (saturation rate) is quickly reached from 20 to 40 minutes on dry soils and from 10 to 25 minutes on wet soils with corresponding infiltration rates of 4 to 6 mm/hr, respectively. His model was based on a Horton type function applied to rainfall intensity of more than 5 mm/hr, and Kohler index for initial soil moisture conditions.

Again, Bonell [58] and others find the surfaces soils(0-0.lm) to be so highly permeable (with mean coefficeout of permeability, k = 20.1m per day) that they can absorb even peak monsoonal intensities during short rainfall events in Queensland, Australia. Similar soils conditions may be found in urban environments of Africa built on very permeable soils or perhaps in the faulted zones of Eastern and Northern Africa.[59]

Urban Storm Runoff

There is increasing interest in urban runoff problems, one of the most important hydrological consequences of urbanization in Africa. The problem may be devided into three, namely, the purely hydrological problems of calculation of the quantity of the storm runoff, the collection of urban storm water and the treatment of the wastewater. It is the first aspect that receives our attention in this section. We have observed earlier that a predominant characteristic of an urban drainage system is the man-made impervious pathways for guiding the flow of water over the land surface and underground. According to Roesner[60], the system is an array or assemblage of subsystems which can be characterised by three basic subsystems: surface runoff, transport through sewer and major drainage facilities, and receiving water. These subsystems may be represented as in figure 6 by boxes marked I &Ia, II & IIa & IV, respectively.

The surface runoff subsystem consists of flow from catchments area tributary to sewer inlets as well as flow over unsewered land (I and Ia, respectively, of figure 6). Each catchment is characterised by its area, imperviousness, hydraulic roughness, slope and certain coefficients related to water quality aspects. Overland flow transforms excess rainfall hyetograph into the observed inlet hydrograph and pollutograph and the corresponding graphs for unsewered land.

As already noted, however, in many Africa urban areas much of the impervious ares is not sewered. For instance, in many West African urban area, particularly the more traditional ones, ratio of impervious areas may reach 30%, but often not more than 10% of this is connected to the collection system and thus contributes to surface runoff peak. Also in North Africanurban centres such as Tunis, while the percentage of impervious surface may be as high as 60%, only part contributes to runoff peak. The flows eventually reach surface storage, natural or man made channels or receiving bodies of water, often after resulting in local flooding.

The transport subsystem is made up of the physical works for conveying storm water and associated pollution loads from all of the inlets in the system through a network of storm channels and /or underground conduits to a point of disposal. In African urban centres, part of the urban runoff problems deals with the question of the engineering computation of pipe size and the type system preferred or most suitable. Very often wrong sizing of pipes conveying water from inlets or from detention storage ponds has resulted in flooding of the area surrounding the ponds, as noted in Aba[25], (Nigeria) and a major pond near the Lagos University Teaching Hospital Surulere Lagos, Nigeria.

It has been observed also that Manning's roughness factor for storm water conduit which is assumed constant with respect to time for a given conduit in MDCs varies in many African urban centres including Tunis[23]. This is because the channels or drains get clogged up with garbage during the dry season, but during the rainy season, running water gradually removes them from the channels changing the flow conditions drastically.

An important question of hydrological character deals with the problem of conduit leakages through conduit walls and joints. Such leakages are known to make the volume of sewage water received at treatment plants much higher than the water distribution from the water in the ratio of 2:1 to 7.5:1. Leakages may also occur from conduit to the surrounding soil.61

In Greater Lagos the drainage network or the transport system consists of (i) the street drains (the tertiary drains) (ii) collector drains subdivided into secondary and main collectors and may be open drains or conduit: and (iii) canal/outfall channels referred to as primary channels.

The receiving water subsystem may be of several forms:stream, river, lake, estuary Lagoon or ocean. A direct consequences of improper landuse planning in a number of African urban environments is the use of swamps as receiving waters so that when such wetlands are eventually reclaimed, the unplanned buildings already erected all around them, constitute severe obstacles to effective drainage planning and construction.

Discharge of storm water and waste water is expected to have impact on the quality of receiving waters. Quantitative aspects of the storm hydrology of Pinetown[31] in metropolitan Durban which have been discused shows the results of the chemical analyses of the Palmiet river water which de Villers carried out for the period September 1982 to December, 1984, both for the macro- analytes and the micro-analytes (table 10). The pattern of chemical water quality seem to show clearly the effect of urbanization for instance, in the case of the dissolved solid content at six sampling sites 1,2,4,6,9 and 11. At sites 2 and 4 below the Pinetown CBD, the effect of industrial pollution appears quite obvious. Sites 1 and 7 are situated just in residential areas and high No3. values at these sites were attributed to use of fertilizer or seepage from French drains or septic tanks into the river system. The generally high k+ values are also supposed to be due to excessive use of fertilizers. along the entire river by gardeners to upgrade the poor K^+ content of the sandy soil of the Palmiet River Catchment in order to support healthy lawns. In general the various tributaries (at sites 3, 5, 7, 8 and 10) were observed not to pollute the main river significantly (table 11a).

Similar pattern is exhibited by the trace elements in table b. The impact of Pinetown CBD is clearly illustrated by the relatively high values for nine of the elements, some of which are high compared to the rest of the Rebublic of South Africa .

Hydrological Aspects of Erosion and Sedimentation.

Erosion is a very important hydro-geomorphic process which affects drainage design in urban areas, particularly in mountainous areas, where large quantities of sediments enter the drainage system. The sediments are eventually deposited in sewer sections with low velocities, especially during low flow periods, and may reduce the capacity of the drainage system and thus cause flooding.

The dramatic growth in cross-sectional area of the river Palmiet system in metropolitan Durban has been discussed. It is observed that the channel width/depth ratio is close to zero, whereas a ratio less than 12 is regarded as erosive. Thus in most of the tributaries of the River Palmiet, strong indication of the erosive power of increased discharge due to urbanization is clearly stamped on the landscape. The resulting sediments are subsequently deposited in downstream areas and interfere with both natural and manmade drainage channels.

Indeed accelerated erosion has became a feature of urbanization in Africanurban centres, and gullying appears to be an urban phenomenon in south western Nigeria,[49] where a number of intra-urban roads have been destroyed by the hazard. In Auchi urban centre of Bendel state, for example, local relief is 60m, and valley slopes are 5° - 10°, yet steep slopes are covered with buildings having densities of 800 units per km^2 in the government reservation areas of low density and up tp 11,800 units per km^2 at Akpekpe quarters where overcrowded slums abound. Here gully networks developed on the southern slopes of the spur on which most of the urban centre is located attaining depths of 1.6 m to 8.5 metres and widths of 20 m to 7.6 m in a third order system. All the gullies were eventually channelled into concrete open drains.

On exposed surfaces, high intensity storms can compact the soils and decreases, infiltration capacity and hence generate large overland flows which are capable of eroding deep channels and produce spectacular gullying. In some urban centres as in Aba.[25] the storm drains terminate before reaching any receiving water some times in a low ridge or just after it. The concentrated runoff initiates rills and gullies and grow headward toward built up areas, constituting serious threat to several houses in the affected areas.

Storm Water Modelling

Categories of Models.

We may revisit the important problems of storm runoff computation for drainage and sewer system projects in urban rainfall-runoff or rainfall-runoff-quality can be divided into three distinct categories: panning models, design/analysis models and operation models.

Planning models are used in macroscale applications such as for metropolitan or urban-wide master plans and may deal with many components e.g hundreds of catchments. A model dealing with such a system must of necessity be as simple and as flexible as possible. Data requirements would include estimates of runoff hydrographs at a relatively few locations at road bridges or structures. Hourly rainfall data will be appropriate for flow simulations in the larger urban streams and models can be used to determine the size of future floodways and the frequency for design of the drainage systems.[2] Planning models include the Storage, Treatment, Overflow and Runoff Model (STORM) and the Hydrocomp Simulation Programme Model (HSP).

Design/analysis models, on the other hand are more sophisticated hydrologically as individual catchments and sub-catchments for sewered system are analysed, using suitable models and appropriate storm intervals as short as 5 minutes. The size of pipe required to convey stormwater through the system must be determined and separate estimate of runoff made at every entry point in the system i.e hundreds of estimates for every 100 ha of catchment. Analysis/design models include the following:-

(i) MIT Catchment Model (complex, non-linear, not continuous and no water quality component
(ii) Hydrocomp Simulation Programme Model (also used for planning small scale catchments).
(iii) The Road Laboratory Method (US adaptation of the British Road Research Laboratory Hydrograph Model)
(iv) Versions of the Environmental Protection Agency (1971) Storm Water Management Model (SWWM) for simulating flow and quantity of receiving waters.

For details of the structure, flowchart or subroutines of the above planning and design analysis models helpful references include Aitken[62] McPherson,[63] Dendrou[64] and Delleur.[4] Operation models are apt to be more application specific than planning or analysis models because of the wide diversities in management practices, operating problems and individual service system configurations. Data requirements of operation models include precise catchments moisture conditions prior to flood-producing rainfalls. In this category of models is the group of continuous accounting of the movements of all water through the various catchment stores, e.g. HSP. STORM model is also suitable but it includes water quality component. Urban Waste Water Management Model Developed by the University of Minnesota is for simulating major components of a sewer system and can evaluate the performance of a planned or existing sewerage system during a variety of rainfall conditions.[64]

There are other hydrologic models that are

Table 11: Chemical Analyses of the Palmiet River Water
(a) Annual Geometric mean values for the macro-analytes (mg), September 1982 - December 1984

Sample Site No	pH	Conductivity (mSm^{-1})	Ca^{2+}	K^+	Mg^{2+}	Na^+	Cl^-	PO_4^{3-}-P	SO_4^{2-}	NO_3^{2}N	NH_4^{1}-N	Si	F-	Total Phosphorus	TDS
1.	6.6	29.0	9.1	2.75	6.9	30.5	48.4	0.013	17.3	1.82	0.18	8.1	0.35	0.020	160
2.	7.5	65.6	31.0	5.70	9.9	78.1	93.1	0.059	56.5	0.92	0.32	8.4	0.35	0.108	420
3.	7.5	59.0	32.7	6.45	10.9	60.0	65.2	0.023	37.2	1.66	0.41	9.9	0.38	0.044	363
4.	7.5	60.0	31.6	5.50	10.1	66.2	80.8	0.041	52.5	0.78	0.34	9.1	0.35	0.067	357
5.	6.7	31.3	9.9	3.03	6.9	33.4	48.8	0.019	20.5	1.60	0.17	8.2	0.35	0.030	166
6.	7.4	48.8	24.0	4.53	9.0	51.2	65.8	0.043	41.4	1.56	0.14	8.7	0.35	0.062	272
7.	7.2	44.3	18.1	4.10	11.0	44.2	63.2	0.62	29.0	2.78	0.09	9.1	0.35	0.074	247
8.	7.7	59.5	25.7	3.35	16.5	63.1	77.1	0.082	40.0	1.61	0.24	12.1	0.35	0.097	339
9.	7.4	53.4	22.0	3.86	12.4	58.0	74.9	0.036	41.7	1.52	0.13	8.4	0.35	0.054	301
10.	7.4	60.3	19.5	2.50	16.0	69.7	90.0	0.023	54.0	0.93	7.27	7.2	0.35	0.031	369
11.	7.5	60.8	24.0	3.71	13.6	58.5	74.5	0.029	44.8	1.14	0.14	8.4	0.40	0.045	324
Mean	7.3	52.1	22.5	4.13	11.2	55.7	71.1	0.039	39.5	1.48	0.22	8.9	0.36	0.057	302
	0.4	12.4	8.0	1.29	3.2	14.8	14.6	0.021	12.9	0.56	0.10	1.3	0.02	0.028	83
Umgeni	7.3	44.0	15.5	3.57	9.2	42.9	58.7	0.038	23.5	1.64	0.31	5.7	0.35	0.089	223

S CaCo
S = Total disolved solids SD = Standard Deviation.

(b) Annual Geometric mean values for the macro - analytes (mg), September 1982 - December 1984

Sample Site No.	Al	As	B	Be	Be	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	St	Ti	V	Zn	Zz
1.	151	28	39	64	1	3	11	5	3	1082	36	–	8	12	62	2	2	21	–
2.	280	28	444	92	1	4	9	8	–	1682	141	–	11	22	196	3	6	143	8
3.	190	39	253	81	1	10	10	8	13	1572	100	9	11	24	199	2	3	291	8
4.	170	31	366	83	1	5	9	7	3	1215	82	8	9	32	158	1	5	37	8
5.	153	22	72	56	1	5	10	6	3	974	29	7	10	8	62	2	5	10	6
6.	161	30	228	93	1	5	10	6	4	757	32	8	10	13	124	2	3	54	6
7.	82	25	76	90	1	3	10	5	4	235	9	8	8	12	84	1	5	10	6
8.	536	55	74	167	2	5	14	8	6	1779	503	13	12	20	138	7	6	22	6
9.	346	30	146	111	1	4	12	6	5	1436	107	12	11	28	181	8	4	33	8
10.	224	46	81	78	1	5	11	6	5	1262	512	9	9	30	102	2	8	17	7
11.	283	24	148	92	1	4	10	4	5	1077	147	10		14	138	2	6	22	9
Mean	234	33	175	92	1	5	11	6	5	1183	154	9	10	20	124	2	5	64	–
SD	126	10	133	29	0	2	1	1	3	444	181	2	2	8	44	2	1	85	1
Umgeni	754	26	96	92	1	3	9	5	7	1597	216	7	8	18		5	5	17	6

SD= Standard Deviation

Source:de Villiers31 Tables 1 and 2, p. 576

widely used in urban hydrologic studies, but which are also suitable for other uses such as large watershed studies of flood control or mitigation. Those models include the original Stanford model (for a complete watershed water balance), European models (for detailed hydraulic behaviour of sewer systems) such as CAREDAS(by SORGREAH) and HVM-QQS model (by DORSCH CONSULT).

Model Applications

According to Pilgrim,[65] a great deal of work has been done in recent years on the development and testing of computer models of urban drainage. In a survey by the Institution of Engineers of Australia published in 1986, 32% of the respondents reported use of such models, about 86% of the respondents reported use of the rational method in practice, despite the wealth of research literature on sophisticated models. Similar use patterns apply in many other countries including the USA where several agents use the same simple methods in order to be sure of obtaining the results not different from the one another, so as to avoid the who is right and who is not The report of a survey inRepublic of South Africa shows that although computer applications are increasing, 95% of respondents use the rational method for urban drainage design.[66] James Mclaren Limited earlier reported that at least 90% of design work in Canada involved the rational method and its continued widespread use has been reported in 1982 by Roads and Transportation Association of Canada.[67] The predominant use of the rational method or variants of its was reported in the state- of - the art report for several countries by UNESCO[68] in 1977 and 1978. The situation in the design work as at 1976 involved the rational method. And in spite of the adoption of computer modelling, modified versions of the rational method are still used for watersheds smaller than 1.5 km^2 which actually account for much of the detailed design works.

Early surveys in 1969 indicate that the rational method was used for almost all urban drainage design in the USA. This situation still applied in 1977 although computer models were gaining ground, and an overwhelming majority of storm sewer designs utilised the rational method by 1978.[68] However, by 1982, a rapid decrease in the use of the rational formula for urban runoff modelling was reported in the USA, but it is still the most frequently used design as at date, the reason being that it is considered to be particularly adequate for straightforward and residential design applications.

The rational formula is generally used in India,[69] adopting use of deterministic interpretation to the estimate the design peak flow in urban watersheds. Drains are sized for the design flow in the use of the rational formula, $Q_T = CI_TA$, where Q_T is peak flow rate for specified frequency, C is coefficient of runoff dependent on land use, I_T is design rainfall intensity for the frequency and duration specified, and A is drainage are the terms of the RHS as defined.

Linsley[70] observed that when using the rational formula, there is tendency to assume an excessively high fraction of impervious area. He noted that effectively impervious areas can rarely exceed 30% in urban residential areas except in high density housing without open space. Inlet times are frequently assumed to be 5 minutes or less, although flow across the depth of a typical house lot may take much longer. Linsley suggested that when the rational formula is applied to areas of 13 km^2 and larger adjustments be made for conduit storage to prevent gross over estimate.

It is clear from the short review of urban hydrologic model applications that the sophisticated models which abound in literature are yet to be widely adopted in design practice even in the MDCs. Yet in LDCs, there is tendency to adopt advanced models, procedures and design values from MDCs. There is design in consultant experts fromMDCs doing so in order to bring practice to a higher level, like that in their countries. Design practice will be much better served by adopting simpler procedures and developing design values from local observed data. For example, Dar Al Handasah Consultants and Others between 1973 and 1977 used the rational method for Lagos mainland and Lagos Islands storm water drainage comprehensive design to estimate storm runoff and decided the degree of protection required as well as the detailed design of the channels and their apputenances. The consultants used the following design rainfall frequencies for different land uses in the metropolitan area to design[71] namely: (a) storm channels in low and medium density residential areas-2 years; (b) storm channels in high density residential and low cost commercial areas-5 years; (c) storm channels in high cost commercial and industrial areas-10 years; and (d) major structures such as bridges and culverts - 10 years. They believed that selection of higher frequencies might result in unjustifiably larger channels and expensive systems. Runoff coefficients were based on the projected future use of various land units. The whole project area was then divided into 86 catchment areas and weighted runoff coefficients computed for each of them.

Rodier has also reported the application of the French variant of the rational method in three watersheds (Mfoa 6.3 km^2, Ouenze 6.7 km^2 and Makelekele 3 km^2) in 1953 - 1954. The results show that the first two basins were discharging on average 6m3 S-1 instead of 0.2 to 0.3 $m^3 S^{-1} km^{-2}$ if the soils had remained in their natural conditions. Also reported by Rodier[72] is the study by ORSTOM in three watersheds in the Gounti Yena basin in Niamey in 1966. The watersheds were under three different land uses. The results show that the French variant of the rational method, the CAQUOT formula underestimated the 10-year runoff in the Niamey watersheds (areas are 0.56km^2, 1.6 km^2 and 1.54 km^2) by a factor of 5 and 2, respectively, for the first two watersheds. Attempt was made to adapt the CAQUOT formula to the conditions in West Africa through experimental studies.The following formulae were derived for four zones into which Cote d'Ivoire was divided:

Coastal zone	$Q= 12601^{0.18}\ C^{1.10}\ A^{0.84}$
Central Easter Zone	$Q= 22701^{0.27}\ C^{1.15}\ A^{0.80}$
Central Western Zone	$Q = 18001^{0.25}\ C^{1.14}\ A^{0.84}$
Northern Zone	$Q = 12501^{0.18}\ C^{i.10}\ A^{0.87}$

In the formulae, C= Coefficient of runoff in %, A is area in ha, and I is 10 -years design rainfall.

Thus the rational method and its variants continue to enjoy widespread use for urban drainage design, but when detention storage is contemplated; the shape and volume of the design hydrograph may be more important than the peak flow rate. And, unfortunatel, no simple relation exists between peaks and runoff volumes. This explains why the use of the rational method is often complemented by that the unit hydrograph method.

Some of the more sophisticated models have also been applied in parts of Africa with varying measures of success. The RRL Hydrograph model developed in England by the DSIR Road Research Laboratory was applied to an urban catchment in Kenya in 1971. The model was found deficient when applied to Nairobi and such areas of higher rainfall intensity for it ignored previously the previous areas[73]. Recognizing this deficiency, a relation was developed between antecedent precipitation index and a volume runoff coefficient for the previous areas.[74]

Also, one of the projects reported for Tunisia by Nienczynowicz is the application of the Storm Water Management Model (SWMM) to planning, anylysis and design of sewer systems in a part of metropolitan Tunis,[75] the Guereb-Ruriche catchment, 20km^2 in area. The objective was to ensure a meaningful water management in the urban area. The data requirements for the model were met from the network of 8 rain gauges, 5 discharge measuring stations and one water quality sampling station. Recorded rainfall-runoff events during 1979-82 were used to calibrate the model. Villiers reported the application of a version of the Watershed Storm Hydrograph Multiple Options (WASHMO) model developed in the Agricultural Engineering Department of University of Kentucky to generate hydrographs for the Palmiet River in Metropolitan Durban. The catchment was divided into nine sub-catchments based on drainage pattern, land use, channel characteristics, overland slope, soils and geology and model variables were calculated for each sub-catchment. The analysis indicates that increase in runoff volume due to urbanization would be mainly from smaller storms rather than the largest less frequent ones such as the 50-year event. This is because the initial abstraction is less than 20 mm in all cases. However, the increase in peak discharge rates were substantially higher, varying from just less than 4 times to more than 5 times. At the same time, decrease in time to peak varied from 4 to 6 times.

Research Need

We have noted earlier that in the absence of an adequate body of field data, urban hydrology will remain more of an art than a science, and the choice of a model for a given application will be largely a matter of taste. The data include current and projected land use through full period of implementation and may require decades for complex projects. Application of STORM and SWMM type models, for example, require similar landuse information, differing mostly in the amount and detail. Such needs include percentage of total tributary area of imperviousness by each land use category, which is related to pollutant loading. Simultaneous measurement of rainfalls , runoff and quality at inlets and at various collections system points in a catchment is, of course, a major research need.

With the objective of compiling a list of major research and development needs in urban hydrology a questionnaire survey was conducted among all national committees of the International hydrological Decade (IHD), as the precursor of the International Hydrological Programme (IHP) was known during 1965-1974. The respondents were requested to indicate the topics which represented research priority from a list of thirteen topics 76. The replies indicate the following four priority topics, abridged and with percentage score added:-

(a) Changes in surface runoff caused by urbanization (amount & quantity) - 86%
(b) Soils moisture and groundwater relationships and effects - 79%
(c) Runoff in terms of precipitation occurrences in experimental catchment areas - 75%
(d) Water Demand forecasting (including technical, social political aspects) Others top priority topics include:
(e) measurement of discharge in sewer,
(f) air pollution-water quality relationships,
(g) application of remote sensing and isotope techniques, and
(h) the effects of waste water and sludge on the natural purification capacity of receiving waters and their aquatic life.

The above topics are of high priority to African urban environment, but not necessarily in the order listed. Topic (h) is especially important for African countries, because the hydraulic and self-purification capacities and water level variations also affect the sewer design. In particular, the hygienic conditions of surface waters are often considered to be the most important water quality criterion. This is because surface water from rivers and drains is more often than not used for household purposes because of lack of public water supply or water wells.

Appropriate Approach to Urban Drainage in Africa

The objective of drainage is to remove excess water from an area to be protected by surface or subsurface means. If appropriately designed, operated and maintained such disposal systems should contribute to human well-being and proper functioning of urban communities. In someurban centres storm drainage does not prevent damage, but merely abates the nuisance of flooded streets. In this case it is appropriate for the political authority to decide what level of protection the community can afford or is willing to pay for. If damage is negligibly small, then a design level a design level of rather high probability is appropriate.

There are several concepts of urban drainage which deserve close examination with respect to developing economies of the tropical and sub-tropical Africa. The following concepts from the basis of the discussion in this section because of their appropriateness to the African situation:

(i) Use of urban streets and roads as components of storm drainage system;
(ii) Use of detention ponds and infiltration facilities;
(iii) Storm drainage by ditches and channels discharging to the nearest receiving waters;
(iv) separate sewer systems, conveyingseparately domestic and industrial wastewater and storm water;
(v) Combined sewer system which conveythe wastewater and stormwater in the pipes or channels;
(vi) Use of Open channels and closed conduits; and
(Vii) Use of Single or double street channels

In many African urban areas streets are deliberately used to carry off runoff laterally from the area being protected and thus become the fist step in landuse planning. Some workers have rightly proposed in a study of the urban centre of Tahoua, Niger paved streets for storm drainage. [76] The advantages of such compared to a classical sewer system include simplicity of construction, maintenance works are limited to pavement repairing, local availability of construction, maintenance works are limited to pavement repairing, local availability of construction materials and required labour, and lesser expense of paving than asphalt streets and classical drainage system of open or sewer system, in the socio-economic environment of Tohoua and similar Africanurban centres. The technique may be profitably combined with the classical drainage system to take advantage of slopes and shortage of urban land space.

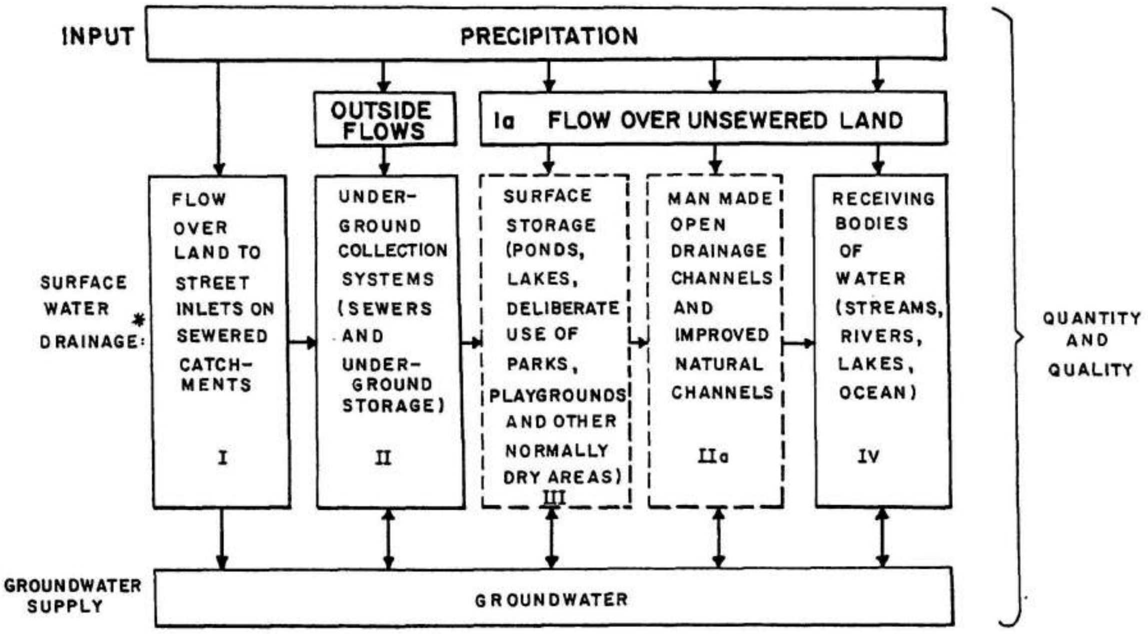
Some new concepts based on storm runoff delay urban catchment have been developed in the last 15 years. Detention ponds and infiltration facilities have been studied in the Africa Sahel[77] with respect to three areas to be controlled: a group of housing parcel and large catchments outside theurban centres. The device was indeed proposed for Zinder, Niger and considered capable of reducing the investment for collectors on account of lower discharges to be evacuated, but also of limiting the damages resulting from runoff, erosion and flooding. In such a case, detention ponds as a solution will become a major component of land use planning since such sites must be chosen before the area becomes urbanized, in order to be effective and efficient. Other areas that have been used for temporary runoff storage on catchment surface include such public areas as parking lots, permeable streets, playgrounds, public gardens, parks and special floods plains. Underground storage is a common runoff control measure used in densely built-up ares especially of MDCs (figure. 6).

According to Geiger,[78] the discharge of stormwater into the nearest water course and on-site or off-site sanitation, if applied properly, may represent an accepatale method of runoff and wastewater disposal in some urban areas with lower population densities. However, in largeurban centres drainage by separate or combined sewer systems is recommended. Separate sewers may, however, discharge stormwater directly into receiving waters. A major dis-advantage of this approach is that pollutants are also discharged directly into the water body and its water quality may be severely downgraded. The approach also tends to reduce recharge of groundwater aquifers.

The controversy surrounding the advantages and disadvantages of separate and combined sewer system is still continuing. The characteristics of rainstorms in Africa is still continuing. The combined systems, because the major stormwater channels have to be extremely large to handle the expected combined flows that it would not be economically feasible to cover them. Also in a combined system since all homes should be served by gravity, the sewer network must be placed at considerable depth with consequent higher cost and putting homes at greater flooding risks. In most African urban environments, it is advisable to set the separate system as the first concept of design. In these same environments, however, one finds that the distinction between combined and separate systems is more of an academic exercise because the existing networks, combined or separate, are generally used for disposal of all kinds of urban wastes, particularly in the case of open channels. The result is that even the so -called separate storm sewers may cause similar pollution problems as combined systems do.

The example of Greater Lagos provides an interesting illustration of the question of using open or covered drains/conduits. The original network of road side drains was constructed having concrete cover slabs with

Fig.6: Subsystem of urban storm water disposal



(* EVAPOTRANSPIRATION NEGLIGIBLE DURING PRECIPITATION)

Source: American Society of Civil Engineers

By I.O. Mahiri.

removable sections to facilitate maintenance. The drains were periodically flushed with public water supply and when flushing was not sufficient the covers would be removed and the drains cleaned manually as no mechanical cleaning equipment was available. In time, the population growth and water outstripped the available water supply. Flushing of drains had to be discontinued in order to save badly needed water for domestic use. In order to reduce the drudgery of manual labour, the drain covers were removed permanently to facilitate cleaning work. The choice between open channels and closed conduit thus depends on local conditions. Open channels are used more frequently in Africa and other LDCs. Obviously closed conduits and covered drains are preferable for hygienic, aesthetic and safety as well as operational reasons. Local availability and cost of pipe materials represent a major constraint, and cleaning of open channels can be done easily without use of special equipment or trained staff as is the case of maintenance of closed conduits. In spite of the above benefits of closed conduits (plus their self-cleansing), open channels and ditches are favoured as the more practical options in low and medium density areas of African urban centres because of construction costs and maintenance reasons. In heavily built-up areas and where land value is very high a compromise solution is to cover open channels and gutters with concrete slabs to reduce the risk of accidents and wrong use for disposal of solid wastes. The cost of replacing the concrete slabs must be considered and included in the operational costs at the planning or design/construction stage.

An important consideration in the use of street drains is whether to use single or double street channels. The decision may not be generalised, but selection based on individual street conditions-its width, underground structures and runoff, among others. A single channel system leaves enough space for other utilities such as sanitary sewers, water and underground power lines, and is less expensive to construct. However, the high rainfall intensities in Africanurban centres would necessitate the use of comparatively large channels that may not be feasibly accommodated on one side of the street.

Whether or not open storm drains are used in African urban centres, intensive educative programmes dealing with storm drainage and drainage control components (detention ponds, channels, and infiltration facilities, among others) Similar to those developed for sanitary purposed, would provide better knowledge of urban storm drainage and associated flood hazards to the urbanities, particularly the new arrivals and help them to settle down in their new environment conformably

Conclusion

Appropriate disposal of wastewater and storm runoff contributes to human well-being and to proper functioning of urban communities. Konotey-Ahulu[78] told the Edinburgh Medical Missionary Society in 1985 that the three constraints of health care delivery in the LDCs are the three P's of poverty, population and politics. These same three P's which make the sides of the welfare triangle are effective constraints of storm water management in Africa's urban environments. but also by the inadequacy of funds for implementing and maintaining necessary urban drainage projects and services. Unfortunately, the current world wide economic depression has further exacerbated the already frustrating level of poverty. It has been said that economic recovery has three dimensions: speed, magnitude and durability. The explosive population growth and overcrowding which we have noted in Africa, particularly its urban centres is opposed to all three dimensions of economic recovery. But how do we restrict population growth, and how do we redistribute population so as to check overcrowding in the urban areas in order to forestall the continual over-straining of urban infrastructural facilities? The answers lie largely in political action, the third P of the triangle. All national,regional and local governments of African countries should demonstrate necessary initiative and political will by giving adequate political leadership that will enable hydrologists and other members of the urban environment team to use available technology and methods of inquiry to contribute to hydrological knowledge and practice in their urban areas.

A master plan is necessary fist step toward urban drainage system. It will indicate the existing conditions and future development and implementation stage throughout the planning horizon. Alternative drainage concepts can be designed most effectively prior to urban development, while it is often difficult to incorporate such alternatives into existing urban areas. It is important to take into consideration in the planning, design and construction of drainage the local ecological, social financial and political conditions. As Geiger[79] has emphasized appropriate technology is not mere transfer of the technologies of MDCs, but proper adaptations of these to match the available labour skills and related services as well as existing system and traditions.

It is now obvious to many African urban centres that drainage systems however well designed and constructed can be operated successfully only if at the same time, adequate solid waste disposal services are provided[80]. In addition, public information and education programmes should be provided on a continuing basis on the consequences of proper and improper use of the facilities. Citizen participation and involvement at various stages of decision making would go long way to help them see the projects and facilities as theirs and to feel responsible for them.

Urban drainage systems very often involve consideration of temporary and permanent storage, inter-basin diversion, pumping installations and silting of drains. This requires a knowledge of flood hydrographs, rather than just single design flood peak values. Awareness of these needs should result in initiation or extension of programme for hydrological data collection such as rainfall, water quality and continuous discharge data and in the use of appropriate mathematical models for analysing and designing of urban drainage systems.

Wright[81] has stated that urban runoff is a resource out of place and "should not be treated as a common enemy to be sent downstream as fast as possible". On the other hand, urban flooding should no longer be accepted as inevitable hazard to be tolerated calmly. Instead the planner and the hydrologist should be involved in considering water reuse, water quality, upstream ponding schemes and improvements of the urban environment, among others. Indeed, because of the increase in complexity of water problems brought about by urbanization in Africa, there is need for more comprehensive and more systematic investigation of hydrological changes in Africa's urban areas. More metropolitan-scale water balance inventories and their analysis should be undertaken as a means of improving overall water resources planning and management[82]. Subsequent periodic inventories would then serve to document changes, if any, and provide a better understanding of the hydrological effects of progressive urbanization. Fortunately, such a total - resource systems approach will also accommodate the constantly changing urban land use. The days should be past when drainage systems are not well adapted to fast urban growth. Urban hydrology and particularly urban storm drainage should be a major factor of urban planning in Africa. For as Gloyna[83] pleaded, water (and drainage) must become a stepchild in resource management; it is a basic resource and as such must not be neglected in the planning process.

Innovative institutional framework, part of the political action, is needed in African nation's urban areas. Such may include programmes which make provision for joint funding by private enterprises and governments. All newly developed urban areas may also be made to incorporate appropriate devices to moderate flood discharges. Legislation is, of course, required to empower use of not only individual sites, but especially the more effective regional approach to storm water management.

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THE INFLUENCE OF URBANIZATION ON ATMOSPHERIC CIRCULATION IN NAIROBI, KENYA

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Abstract

Many types of human activity among them urbanization result in inadvertent modification of the local and regional weather. The heat island phenomenon in Nairobi city has been well established from the studies of Nakamura (1966) and Okoola (1980). It has been shown that the heat island is most intense during the dry months of January and February. The highest mean monthly urban-rural temperature contrast reaches 2.5%C for the minimum temperature time and is -0.5%C for the maximum temperature time. But the disturbing effect of Nairobi City on the regional airflow has not been reported. Studies in many cities (Oke, 1979; Bornstein et al, 1977) have shown that average wind speeds are generally lower in built-up areas than over the rural areas. In this study surface wind data at five locations within Nairobi City, for the period 1982-1986 inclusive, will be used to document the various influences of urbanization on the regional wind circulation. Also upper air wind and temperature at Dagoretti Corner (1° 18' s, 35° 45'E) will be studied. Nairobi Airport will be used to represent the rural airflow particularly for the wind with an easterly component while Eastleigh station will represent the city center conditions. Particular attention will be given to wind directed and wind speed using windflow near 0600 hours Local Zone Time (LZT), at 1500 LZT and the vectorial wind differences between these.

Introduction

Many types of human activity such as urbanization, industrialization, power plant operations, irrigation and changes in land-use practices, in general result in inadvertent modification of the local and regional weather. Chief among the impacts of urbanization is the high temperature within the urban centers compared with the suburban regions. The Nairobi heat island phenomenon has been well established from the studies of Nakamura (1966) Okoola (1980). It has been shown that the Nairobi heat island is most intense during the dry months of January and February. The highest mean monthly urban to rural temperature contrast reaches 2.5°C for the minimum temperature and is -0.5°C for the maximum temperature. A similar case of a cooler urban zone area for the afternoon hours (from 1200 to 1600 hours Local Zone Time) over Mexico City (Jauregui 1986) was about 1°C lower than the suburbs. But the effect of urbanization on the regional airflow has not yet been reported.

Studies in many urban centers (Oke 1979, Chandler 1976, Bornstein et. al, 1977) have shown that average wind speeds are generally lower in built-up areas than their surrounding rural areas. In this study, surface wind data at five locations within Nairobi City (Fig.1), for the period 1982-1986 inclusive, are used to document the various influences of urbanization on the regional wind circulation. Nairobi Airport (Embakasi) will be used to represent the rural airflow, particularly for the wind with an easterly component, while Eastleigh station will represent the City centre conditions. Particular attention will be paid to the study of the influence of the heat island on wind speed using windflow at 0300 hours, at 0600 hours, at 0900 hours, at 1200 hours and at 1500 hours GMT (Local Zone Time (LZT) = Greenwich Mean Time (GMT) + 3 hours). Also the vectorial wind differences between the above hours will be studied.

ANALYSIS AND RESULTS

Urban Heat Island

For the period 1982 to 1986 the 'heat island' intensity (Eastleigh-Embakasi temperature) for minimum temperature was 2.1°C during the month of January and 1.8°C during July. However for maximum temperature time the intensity was -0.3°C during July and -0.2°C during January. The lower 'heat island' intensity (near minimum temperature time) in the city during July may be accounted for by the observed increased cloudiness in July with lower net long wave radiational loss over the city and its suburbs.

The diurnal variation of the 'heat island' intensity has been studied (Figure 2). It is observed that for the time between 0300 and 2100 hours (GMT) the heat island intensity is maximum near 0400 hours (time of minimum temperature in the region) and is a minimum between 0800 and 1200 hours (maximum temperature time). These results compare favourably with those of Jauregui (1986) for Mexico City.

The 'heat island' intensity also varies with seasons being stronger (large difference) during the drier and less cloudy months of December to February and September, and weak in the cooler and more cloudy months of June to August.

Urban Wind Flow

Regional Scale Wind

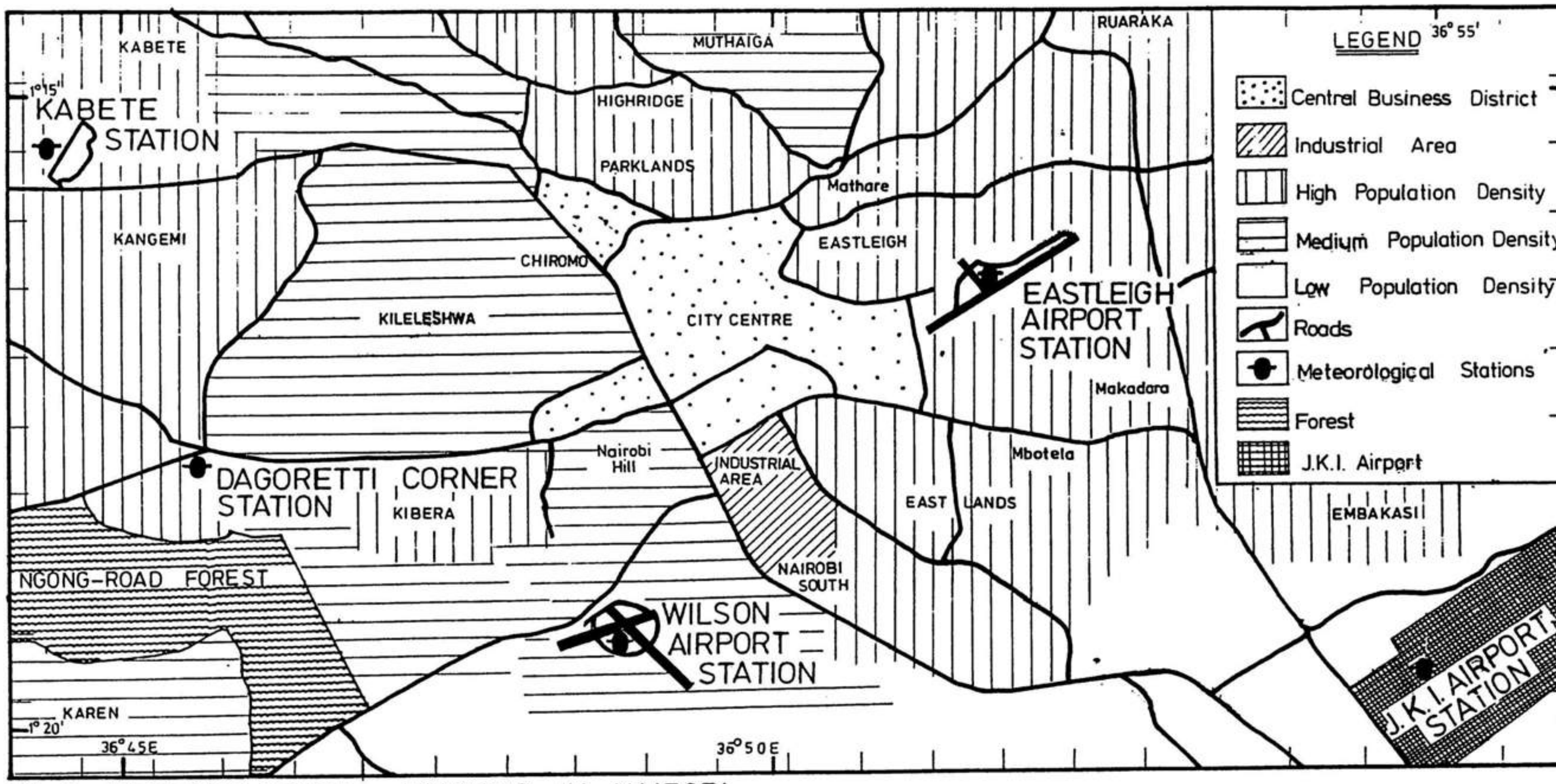

Fig. 1. METEOROLOGICAL STATIONS IN NAIROBI

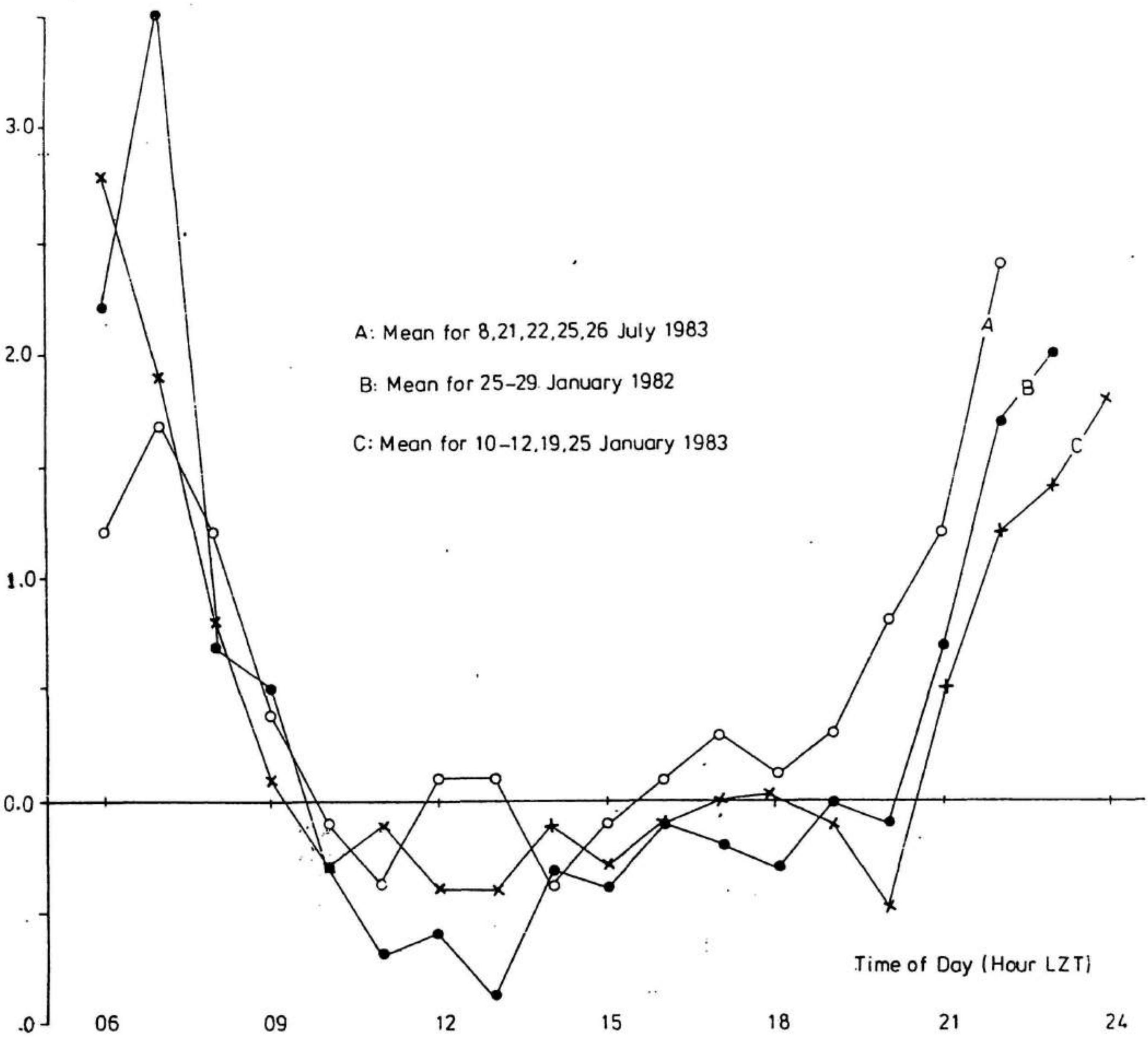

Fig. 2: Hourly Variation of Heat Island Intensity for Nairobi City
Hour is Local Zone Time (LZT)

Nairobi City is located on the east-facing slopes (altitude 1600-1800m asl) of the eastern highlands of Kenya. It is affected by two large scale wind regimes: the northeast monsoons and the southeast monsoons.

The northeast monsoons begin in October and continue until the end of April. These winds are characterised by a veering and increase in wind speed as the day warms up, followed by a backing and decreasing wind after sunset (Table 1). Ramsey (1966) has noted that the greatest increase in wind speed were associated with the greatest hourly temperature fall which occurs just before sunset.

The Southeast/Southwest monsoons last from May to the end of September. These winds are characterised by a backing and increasing of surface wind speed (from a Southwest to a Southeast direction) as the day warms up followed by a veering and decreasing in speed after sunset.

Local Winds

Various studies (Chandler, 1976 ; 1965) have shown that at the time of calm or weak (<4 meters per second) regional winds, urban "heat islands" will set up a rural to urban airflow system which is in many ways similar to the land- and sea-breeze. Then, there is a surface inflow towards the centre of the warm air. However, due to the heat island effect, the change in surface roughness and the valley (up\down slope) wind effect, the urban wind field for Nairobi City is rarely simple. We have used the three-hourly surface wind observations at five stations (Fig. 1) in the Nairobi area to study some characteristics of the urban wind flow. Two cases were selected for detailed study: the period 25-29 January 1982, a period of little cloud (< 3 Oktas cloud), and the period 8,21-22,25-26 July 1983, generally cloudy (> 4 Oktas cloud) per period.

The daily surface wind data for 0300, 0600, 0900, 1200, 1500, and 1800 hours GMT were extracted from the original tabulation records of the Kenya Meteorological Department for the months of January and July for a five year period (1982 - 86). Hourly wind averages at these three-hourly periods were calculated. V_3 represents the wind flow at 0300 GMT, that is 0600 hours Local Zone Time (LZT). Similarly V_{12} represents the flow at 1200 GMT, that is 1500 hours LZT. V_3 represents morning conditions close to the time of maximum heat island intensity and (urban-cool island). Thus, $1/2\ (V_3 + V_{12})$. When these perturbations are subtracted from the undisturbed flow we obtain the morning flow and the afternoon flow respectively. Table 2 gives these components of the local flow for some Nairobi stations.

it is observed (Table 2) that the undisturbed flow is stronger and is from northeasterly direction during January, while during July the flow is weaker and predominantly southeasterly. These results compare favourably with those of Ramsey (1966) for Embakasi.

It is necessary to look at the impact of the morning and the after perturbations due to the heat-island/cool-island effects:

The Morning Flow

The land in the vicinity of Nairobi, slopes gently eastwards. After long night-time cooling of the high ground to the west of Nairobi City, a down slope flow (Katabatic flow) sets in. During this time, as soon as the katabatic wind sets in, the katabatic flow is at first reinforced by the heat island induced winds from the western edge to the City-warm centre beyond which they start decelerating (due to the opposing heat island induced winds from the east) until they come to a virtual standstill. Some evidence for the declaration of this down slope flow is provided by Table 3 which shows the frequency of calms at Eastleigh and Embakasi.

It is further shown (Table 3) that for the year 1982 at Embakasi and at Eastleigh there were more calms during July than during January. This may be due to the cloudy and therefore more stable atmospheric conditions at this time. January with more cases of clear skies and the attendant high temperatures, has no calms between 0900 and 1800 hours (GMT) at Embakasi in 1982. At both stations the maximum number of calms occurs near 0300 GMT and the minimum number is at 1500 GMT. These times are near sunrise and sunset in Nairobi area and are associated with rapid temperature changes.

Ramsey (1966)has studied vector mean winds for each hour and month at Nairobi Airport for the period 1959-63. His study has shown that nocturnal westerlies occurred during seven months in a year and they were all associated with speeds of less than 3 knots (1 knot + 0,515 Meters per second). It is noteworthy that during July these westerly winds were stronger than during the other months and they were from a more southwesterly direction. Table 1 further indicates that, contrary to expectations, the rural wind speeds were stronger than the urban ones at this time.

After sunrise the eastern side (of the N-S oriented highlands to the west of the city) begins to be heated up by the sun and upslope winds (from the East/Southeast) tend to develop and reinforce the heat-island induced flow from the east of the City-warm center.

Table 1 offers an example of the above with the wind speeds at Embakasi being stronger than those for Eastleigh throughout the morning.

The Afternoon Flow

In the afternoon the stable layer is completely eroded by turbulent mixing from its bottom upwards, until convective coupling with the regional wind is achieved. It is observed (Table 1) that the urban wind

Table 1: Urban to Rural Hourly Wind Speed Differences for Nairobi City (Eastleigh (Es) - Embakasi (Em)) for 25-29 January 1982

HOUR (GMT)	WIND AT Es	WIND AT Em	WIND SPEED Es-Em
	(dddff.f)	(dddff.f)	(f_{es} - f_{em})
03	320012	335035	-2.3
04	300010	300031	-2.1
05	355018	359045	-2.7
06	009067	030067	0.0
07	037098	058118	-2.0
08	028109	045125	-1.6
09	046158	055160	-0.2
10	048162	038135	2.6
11	047145	054133	1.2
12	060142	069138	0.4
13	050154	080139	1.5
14	051167	080155	1.2
15	050160	072180	-2.0
16	038161	062149	1.2
17	034130	052118	1.2
18	027115	051102	1.3
19	018071	046082	-1.1
20	360025	040059	-3.4
21	050050	036070	-2.0

f_{es} = Wind Speed at Eastleigh.
f_{em} = Wind Speed at Embakasi
Local Zone Time (LZT) = Greenwich Mean Time (GMT) + 3 Hours.

speeds during the afternoon are generally stronger than the rural wind speeds. This result is contrary to expectation in that we would expect that the increase in surface roughness within the city would cause a reduction in the urban wind speeds. However, this result may be due to the observed cooler city at this time with the cool-city island causing a wind flow from the city cool centre towards the rural areas and thus tending to decelerate the rural winds. Also it is expected that the city environment would be unstable and turbulent at this time with positive interaction with this city induced turbulent regional flow. This positive urban-rural wind speed difference is a welcome situation that tends to ameliorate human discomfort during these hours.

It has been observed (Table 3) that the most number of calms (wind speed less than 3 knots) were at 0300 GMT while the least number of calms were experienced at 1500 GMT.

CONCLUSIONS

The heat island intensity displays a diurnal variation from a maximum near minimum temperature time (0400 hours GMT) to a minimum near maximum temperature time (1200 hours GMT). The wind speed difference (Eastleigh minus Embakasi) has an inverse relationship to that of the heat island intensity. The temperature difference changed from positive to negative between the hours 0600 and 0700 hours GMT while the wind-speed difference changes from negative to positive about one hour later. For the late afternoon the above changes occur between 1700 and 1800 hours GMT for temperature and between 1800 and 1900 hours for the wind-speed.

As may be expected the most number of calms occurred during the night and morning. Also it has been shown that the more cloudy and cooler months (typified by July) showed a higher frequency of calms. Further, we have shown that the percentage calms was higher over the urban areas when compared to the rural surroundings.

Further work will be carried out on the diurnal variation in the stability of the urban atmosphere in order to offer some explanation for the observed direction changes and the speed differences in the wind flow within the city.

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Table 2: Components of the urban flow for different time of the day.

Period Station	Flow undisturbed by heat-island effects ($V_{12} + V_3$)	Afternoon perturbation (V_{12}-V_3)	Morning perturbation (V_3-V_{12})	(V_{12}+V_3)- (V_{12}-V_3) Morning flow	(V_{12}+V_3) - (V_3-V_{12}) Afternoon flow
Period A Eastleigh	055/07	065/07	245/07	315/1.5	050/15
Period A Embakasi	055/07	080/07	260/07	340/03	070/14
Period A Dagoretti	080/06	090/06	270/06	360/03	080/14
Period A Wilson	065/07	100/08	260/08	315/03	075/15
Period B Eastleigh	095/1.5	050/02	235/02	175/01	070/04
Period B Embakasi	185/1.5	095/02	280/02	235/2.5	145/03
Period B Wilson	130/2.5	080/06	260/06	240/06	095/08
Period B Dagoretti	080/2.5	080/2.5	260/2.5	CALM	080/05

Period A=25-29 January 1982
Period B = 8, 21-22, 25-26 July 1983

Table 3: Variation of Calms (Percent) with time of day at two Stations within Nairobi city, Kenya

Hour (GMT)	Eastleigh 1982-86 July January	Embakasi 1982-86 July January	Embakasi 1982 July	Embakasi 1982 Year	Embakasi 1982 January
00			61.3	41.1	32.3
03	50.4 50.0	44.3 27.7	74.2	53.2	51.6
06	42.1 16.2	28.3 6.1	45.2	25.7	3.2
09	31.3 3.5	17.0 2.1	35.5	13.5	0.0
12	19.7 2.2	8.8 0.7	19.4	4.7	0.0
15	3.8 1.5	0.8 0.8	0.0	1.4	0.0
18		29.0	15.4	0.0	
21		48.4	31.1	3.2	

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ASPECTS OF THE URBAN CLIMATE OF LAGOS, NIGERIA

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Abstract
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Lagos, Nigeria is regarded as the fastest growing urban center in Africa. Accompanying its growth and development is a serious modification in its climate. This paper examines the aspects of urban climate of Lagos; looking at the problem from energy balance approach. Some other evidence of climatic modification are also discussed. The implications of all these to physiological comfort and over-all planning of the city are analysed.

Introduction

The creation of urban centers provides the modes of man's greatest impact in destroying the existing microclimates and creating new ones which are of great complexity depending on the design of the urban center structures, the density and functions of the buildings and the various activities performed by man in the urban center. Thus, the urban center represents the area, where man has altered the essential resources of the land, air and water and thus, provided the most extreme microclimate modifications that have ever been created. Indeed, it has been well known for several years that urban center create their own climate (Howard,1833). Moreover, the meteorological and climatological consequences of urbanization have been noted in many parts of the world since the early part of the 19th century (Howard, 1833), although it is only in the last few decades that there have been hundreds of studies in urban climatology. Particularly in recent years, scientists have become increasingly aware of the significance of urban and building climates as far as planning of new towns; and re-development of old ones are concerned. There is, also an increasing awareness of the fact that in urban centers, layouts and designs can often turn microclimatic liabilities into assets.

Thus, in many parts of the world, there have been studies which take and analyse observations of air temperature and humidity parameters (Sunborg, 1950; Mitchell, 1961; and Oke, 1963). It is only in the last two decades that pure observations are complementing and some cases, being replaced by theoretical studies involving energy and water balances. This is particularly the case in the middle latitudes where studies such as those by Terjung and Louise (1973); Terjung , Garnett and Bach (1965) and Terjung (1970) have emphasized the need to apply the energy balance approach to studies on climate of urban centers.

Unfortunately, most of the studies available have been on the mid-latitude urban centers. In the tropical areas, in general and Africa, in particular, not much attempts have been made to study the urban climates. Among the few studies available on urban climates of Africa are the works of Nakamura (1967); Ojo (1981); and Adebayo (1985); which like many other available approaches concentrated on temperature and humidity. Although such studies which emphasize temperature and humidity may be important in the urban climatology, it is important that increasing attention must be placed on the energy and water balances which form the basis of understanding the fundamental processes of the varied geometries and composition of the urban centers fabrics. As already noted in some previous studies, it is only the energy balance approach which can entangle the complex web of microclimates in urban areas, (Terjung and Louie, 1973, and Ojo 1981).

As for many other urban centres, in the tropical areas, Lagos, Nigeria represents a typical urban center whose location, growth and development have been determined by some combination of strategic, social and economic considerations and whose effects have been considerable on the urban climates. Specifically, the urban structures of Lagos, the changes in the characteristics of the urban 'active surface' and the various activities in the urban centre have had considerable impacts on the characteristics of the climate and the climatic components of the urban center. Thus, the composition of the atmosphere, the energy and water budgets components of the urban center and the composition and roughness of the surface have become modified. At present, there has been no comprehensive study of the analysis of the various climatic modifications which have taken place in Lagos. It is, therefore, the purpose of this paper to make such analysis. The paper not only examines individual climatic elements or components of the energy and water budget, but an analysis is also be made of the concepts of energy and water budgets as they apply to the urban center. The paper also examine the concept of the applications of urban climates to urban and regional planning.

Lagos Metropolitan Area

The Lagos metropolitan area with a surface area of about half a million hectares and an estimated population of more than six million is generally a low lying area mostly characterized by depositional landform features (Figure 1). The urban center comprises many islands, which are separated from one another as well as from the mainland, by intricate network of lagoons, which are of great importance in the amelioration of the microclimates of the different parts of the urban center. The lagoons also constitute a threat to the health of the people in many parts of the metropolitan area and are still used as dumping grounds for refuse which cause a lot of water and air pollution in the area concerned.

The rise and development of Lagos have been comprehensively discussed by many writers (Mabogunje, 1968 and Adalemo 1981). From these studies, it is evident (a) that Lagos did not start as an urban settlement; rather, it has grown from an aggregation of a number of non-urban settlement which were established long before the present role as an urban centre was perceived (Adalemo, 1981); (b) since the acquisition of an urban role, Lagos has grown by expanding and absorbing the existing non-urban settlements located at its growing edges. The names of these former non-urban settlements are still borne by the areas which they formerly occupied; and (c) the urban center is the most spectacular of that class of Nigerian urban center which owe their growth and development to European influence (Mabogunje, 1968).

These characteristics of Lagos are in part, the result of landuse and landuse changes which have occurred, although they also form important factors of landuse changes. From the traditional centre of development over Lagos Island, the metropolis have grown into an urban center characterized by many structural changes which significantly affect the micro and meso-climates of the urban center and which should be of concern not only to the climatologists, meteorologists or geographers, but also to other scientists in related fields such as architecture and urban and regional planning. The need to be concerned with the relationship between climate and the structural characteristics arises from their effects on man, particularly with regards to high health and productivity.

Radiation and the Energy Balance

The basic equation which expresses the energy budget model as an input can be expressed in the form:

$$Rn = (Q + q) \quad (1 - d) \quad - I \qquad \text{(Equation 1)}$$

Where Q is the direct beam solar radiation, q is the diffuse solar radiation, d is the albedo of the surface and I is the effective outgoing radiation or the net infrared radiation which is the infrared radiation lost by a particular surface (I) minus that gained by the surface from the atmosphere,ie. counterradiation (I). Thus, symbolically, the effective outgoing radiation (I) can be expressed in the form:

$$I = r - IØ \qquad \text{(Equation 2)}$$

In terms of disposition, net radiation can be expressed in the form:

$$Rn = LE + H + G \qquad \text{(Equation 3)}$$

where LE is the latent heat flux (L is the latent heat of vaporization and E is the rate of evaporation), H is the convective heat loss and G is the heat flux into the pavement. Equation 3, however, assumes that no other major fluxes of energy exist in the system.

Not much has been done on the city of Lagos as regards the computation of the energy budget. The only work available is that by Ojo (1981) in which the net radiation was measured by using a model 603 portable miniature net radiometer manufactured by C.W. Thornthwaite Associates. The study was conducted on May 17, 1980, on which date the atmospheric conditions showed variable cloudiness in the morning hours and complete cloud cover in the evening hours. From approximately noon on that date, there was a heavy downpour of rain which lasted about one and half hours. The intensity of solar radiation was relatively small during the morning hours while direct solar radiation was completely cut off during the evening hours.

Evaporative heat losses were computed by using the following equation:

$$LE = \frac{Rn - G}{1 + B} \quad Le = f\,(Rn\text{-}G,\ 1\text{=}B) \quad \text{(Equation 4)}$$

Where B is the Bowen ration. Similarly the conductive-convective heat losses were computed by using the following equation:

$$H = \frac{Rn - G}{I + B^{-1}} \quad H = f\,(Rn\text{-}G,\ HB^{-1}) \quad \text{(Equation 5)}$$

Further details of the measurements and computations of the various components of the energy budget are contained in the paper by Ojo (1981).

Figure 2 shows the net radiation for 1000 hours, 1200 hours, 1500 hours and 1800 hours, respectively, for the study. At 1000 hours, the values of net radiation varied between less than 0.260 ly min^{-1} and more than 0.280 ly min^{-1}. The highest values of more than 0.280 ly min^{-1} are found on mainland Lagos, around the Ikeja Airport and Mushin-Oshodi areas. The situation around Ikeja Airport is not surprising in view of the fact that the "greenhouse" effects which result from the impacts of pollution ejected into the atmosphere reduce the effective out-going radia-

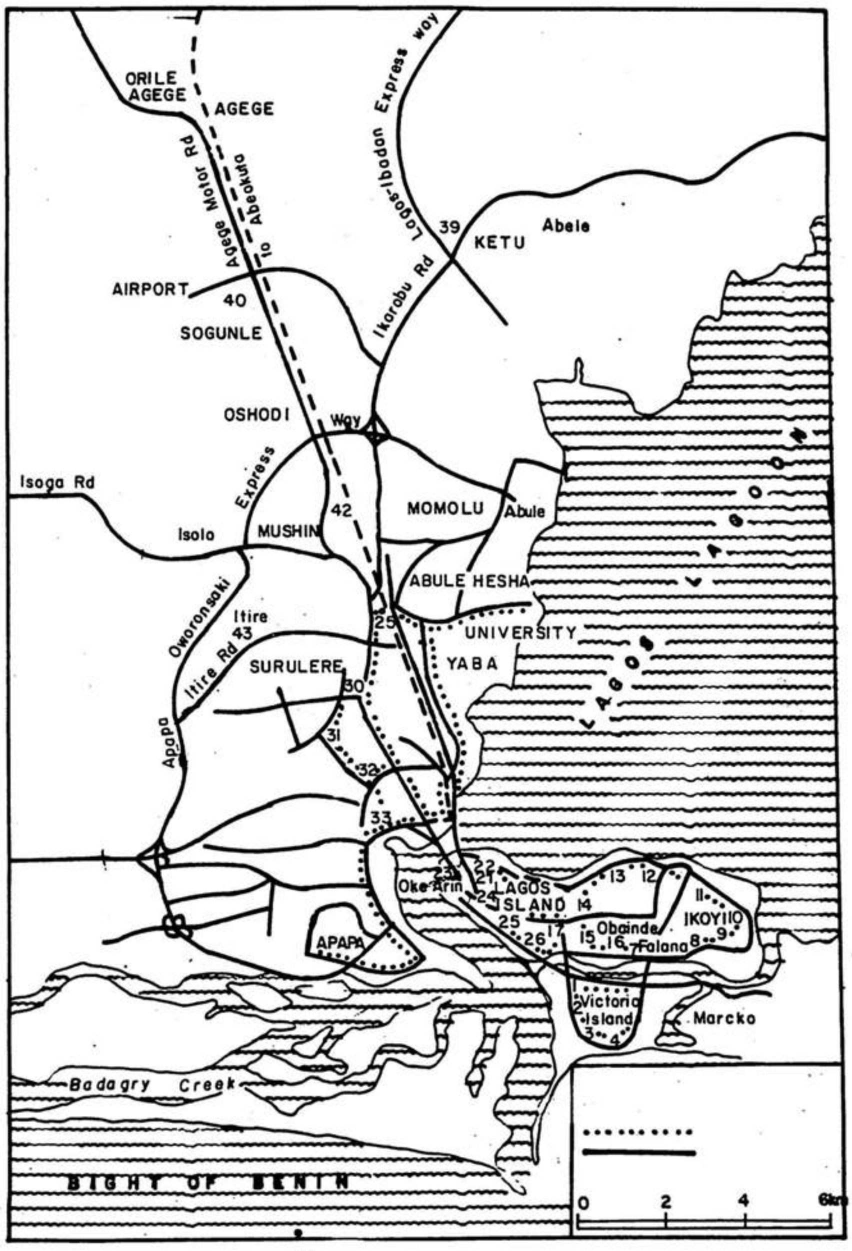
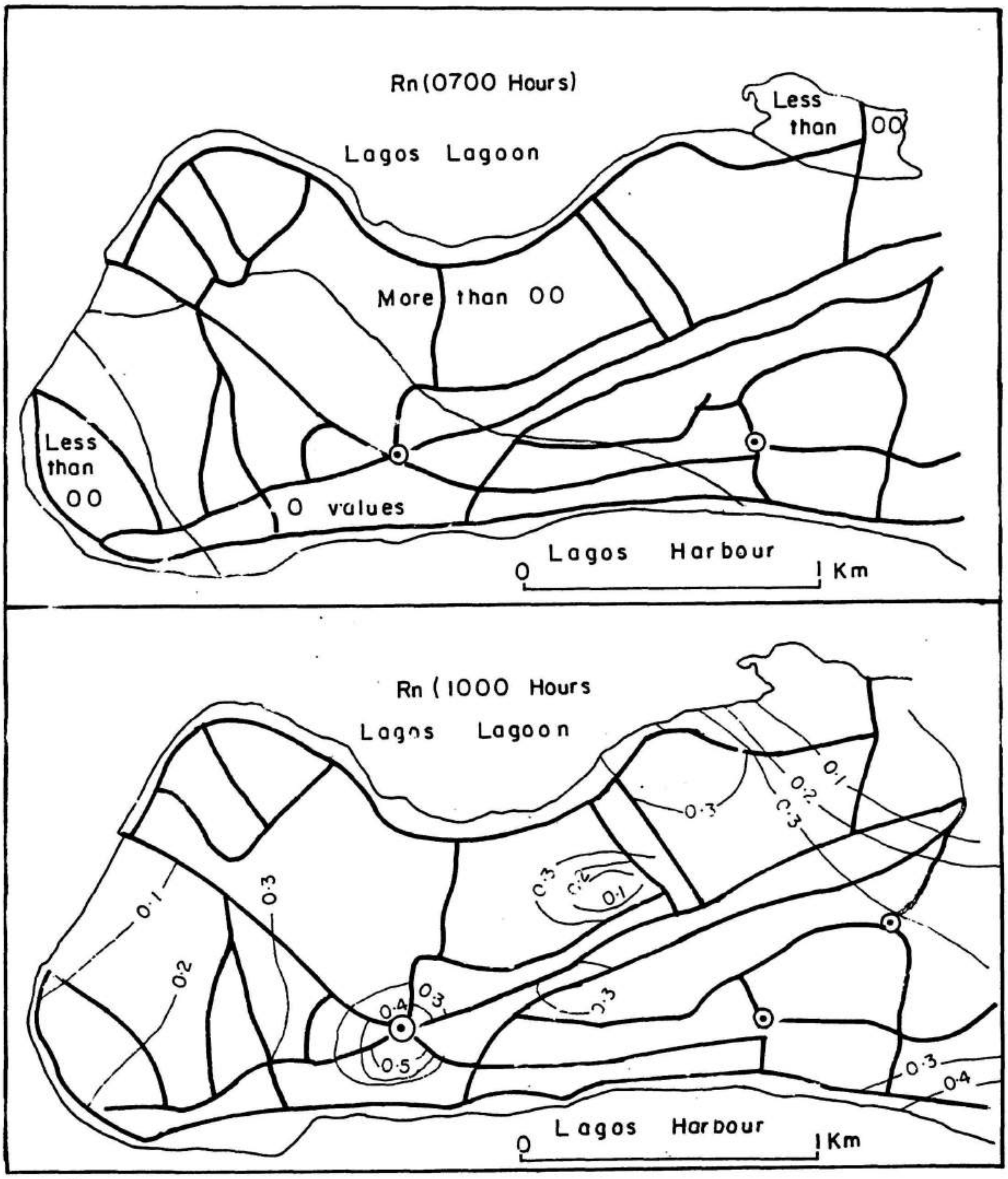


FIG: I: TRAVERSED ROUTES AND OBSERVATION POINTS.



FIG·2· RADIATION OVER LAGOS (Ly min⁻¹)·

tion and consequently increase the net radiation available over a particular surface. Mushin area is a congested low income house area, with relatively higher density of houses and greater "artificial heating" of the environment. In addition, Mushin and Oshodi are bus-stop areas characterized by pollution from the various buses plying the routes in the areas. As for the airport, these pollutions considerably reduce the effective outgoing radiation in the areas. Values of net radiation are also relatively high in Apapa, which is a major industrial centre of Lagos. Outside the built-up areas of Lagos to the West and North, and over the coastal islands, net radiation values are lower than over the build-up area.

At 1200 hours, net radiation values have increased particularly outside the built up areas where the values are greater than 0.370 ly min^{-1}. This is for example the case to the West and North of Mainland Lagos, where greater amounts of solar radiation are able to reach the surface than in the built-up areas along the coast, where built-up are few. Values are also relative high, with approximately 0.380 ly min^{-1} over Lagos and Victoria Island. This is mainly due to the fact that much of the incoming isolation is able to get to the surface because of the characteristics of the open spaces which allow much of the solar radiation to reach the surface. The built-up areas of the Mainland have the lowest values which vary between less than 0.310 $lymin^{-1}$ and approximately 0.0340 be min^{-1}.

As already noted, there was rain on the study date and the afternoon and evening periods were characterized by heavy clouds. It is, therefore, not surprising to find that values of net radiation at 1500 hours (local time), are negative all over the metropolitan area. Effects of some local factors over the area can also be observed from the distributional map in Figure 2d. For example, the University of Lagos area whose values are between approximately -0.25 ly min^{-1} and less than -0.40 min^{-1}, is a relatively open area, less built up than a lot of the other parts of Mainland Lagos. The same thing applies to the Iganmu areas where the newly built express roads join the Lagos Island. Relatively low values also occur in the Northcentral parts of the Mainland, over Ikeja reservations which are also relatively open areas with lots of tree shades.

An analysis of another study conducted over the Lagos Island in February 28, 1976 shows that variations can occur in time and space even over a relatively micro area (Figure 2). The study shows that over the Lagos Island area at 0700 hours (local time) the values of Rn were negative to the Southwest and zero to the Southwest-central parts of the Island; which are the most built-up areas of the Island. The values were also less than zero to the Northeast areas. By 1000 hours, the values of Rn have risen all over the island. The highest values, however, occur around Tinubu area where transportation is mostly concentrated. The patterns of Rn at 1300 hours also show that the highest values are around Tinubu as well as along Broad Street with more than 0.8 min^{-1}. These values decrease particularly to the Northeast and Northwest, which are characterized by the heaviest transportation and the highest density of tall buildings on the Island. The values of net radiation have decreased by between approximately 40-50% at 1600 hours. This is not surprising in view of the fact that the solar radiation intensity has decreased all over the Island. As for the other periods already discussed, the highest values of Rn occur in the areas with heavy transportation systems and the highest density of tall buildings.

Temperature

Figure 3 shows the distribution of temperatures at 0700 and 1500 hours over the Lagos metropolitan area on May 17, 1980. Surprisingly, the Island areas which were adjacent to the Atlantic Ocean have relatively high values of about 28°C at 0700 hours. This partly reflects the oceanic influence of the waters of the Atlantic Ocean and the Lagoons moderating the temperatures and reducing the diurnal temperature ranges. Thus, on the morning of the study date, the ocean and the lagoons were still relatively warm so that temperatures of the lands immediately adjacent to them were relatively high during the early morning hours. Moreover, the Islands were already exposed to the incoming solar radiation which results to increase in air temperatures. Over the mainland areas, particularly over the built-up areas, temperatures were much less with values varying from about 22°C and 26°C. Outside the built-up areas on Mainland Lagos, temperature values were also relatively high than over the built-up areas, mainly because of the warming effects of the incoming insolation.

At 1500 hours, the temperatures have been considerably reduced by thick cloud cover which prevailed over the metropolitan area after the heavy downpours. In general, the temperatures varied between less than 20°c over the relatively "cool spot" in the Ikeja Government Reservation Area (GRA) and more than 20°C over the "heat island" airport of the metropolitan area. Outside the city, temperatures were between approximately 21°C and 23°C.

Conductive-Convective and Evaporative Heat Losses

Figure 4 shows the distribution of conductive-convective and evaporative heat losses for 1200 and 1500 hours (local time). As for net radiation, the pattern of distribution generally run from North to South. At 1200 hours, the values of H are positive throughout the metropolitan area. Relatively high values of more than 0.0035 ly min^{-1} occur over areas with relatively low density of buildings where insolation received at the surface was relatively high. In areas such as Mushin, Oshodi and Ebute Metta, which have relatively high density of houses, values of conductive-convective heat losses are lower. Relatively high evaporative heat losses also occur in areas where the density of houses are relatively low. *In the lower than 0.003 ly* min^{-1}. In general, the pattern of distribution of LE is relatively more uniform than that for H.

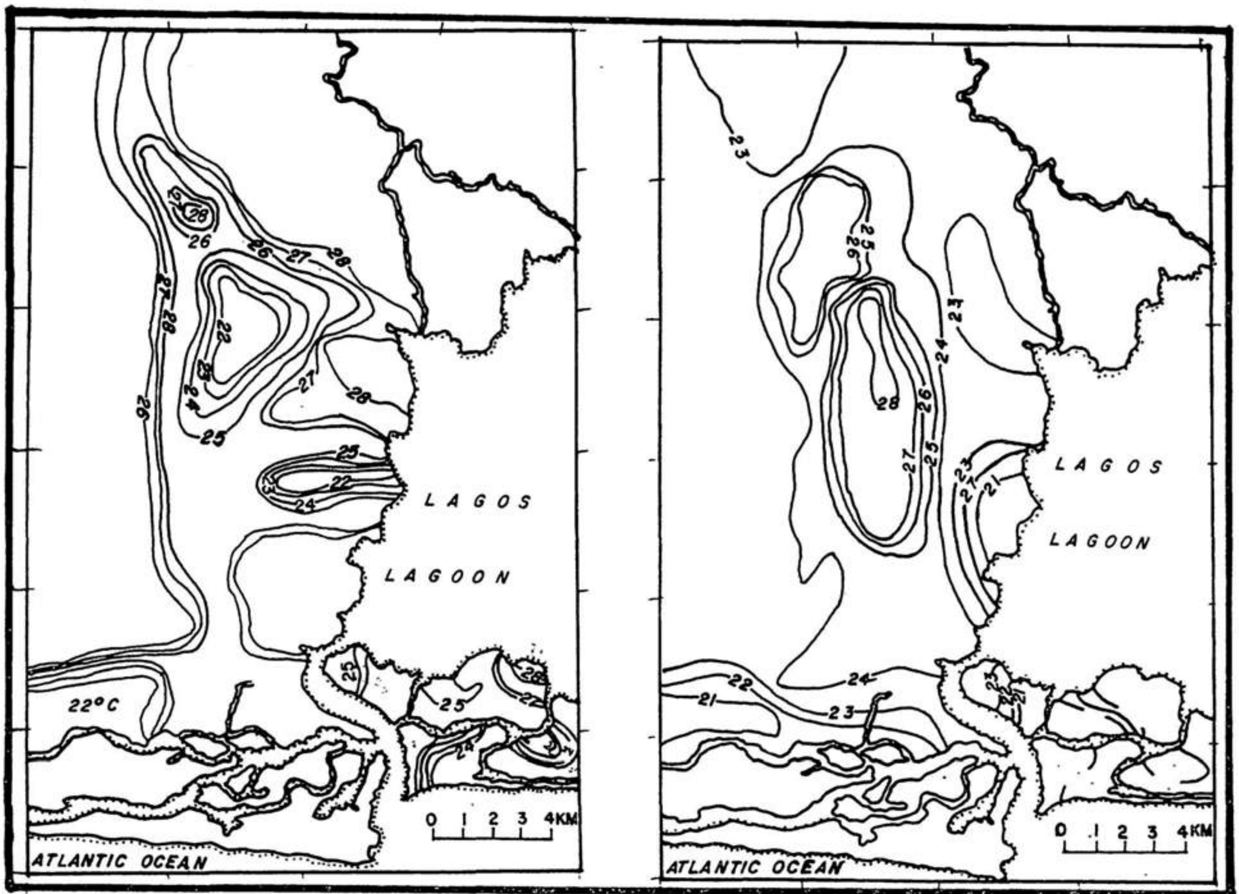


Fig. 3 TEMPERATURE CONDITIONS(°C)

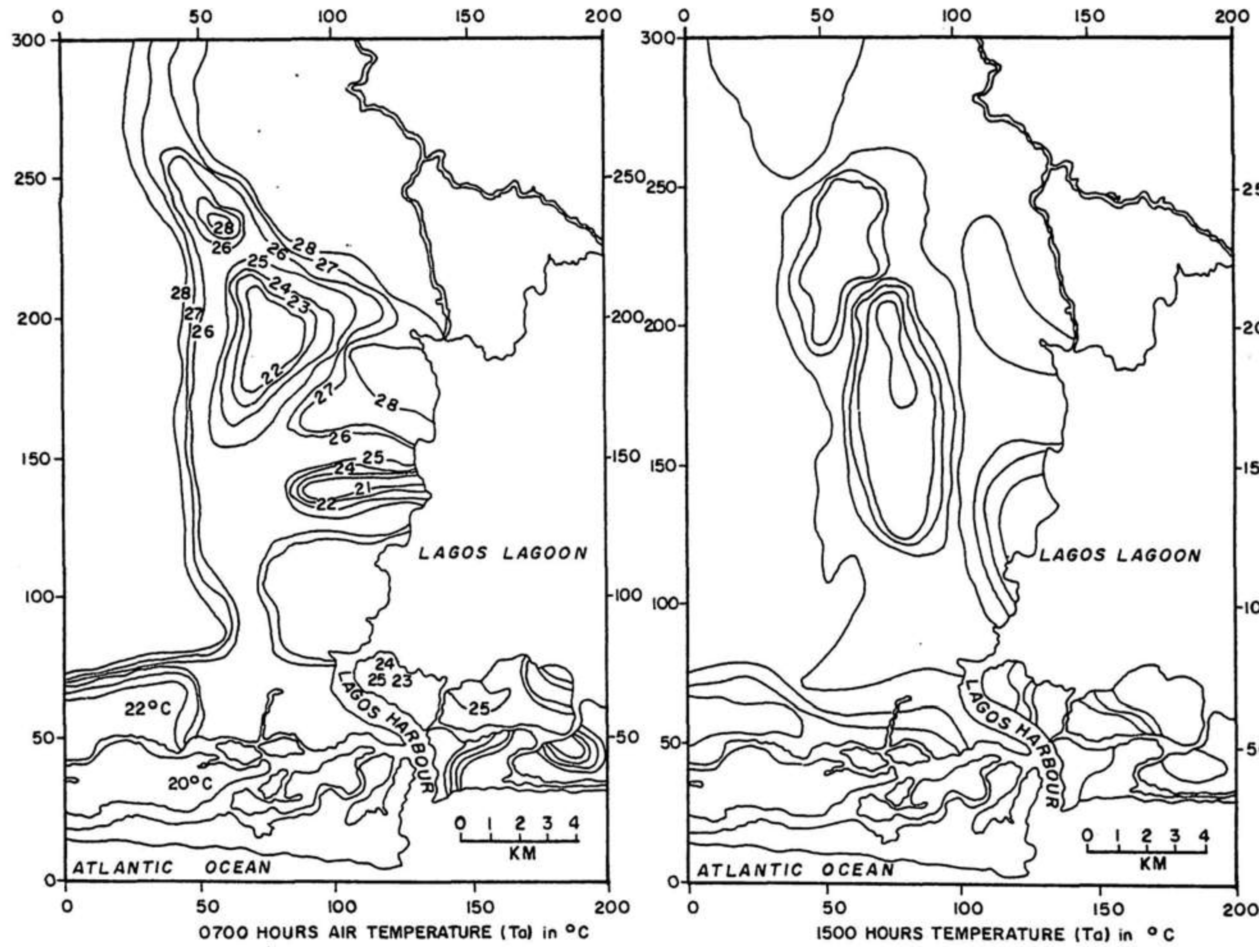


Fig. 4 : CONDUCTIVE-CONVECTIVE AND EVAPORATIVE HEAT LOSSES

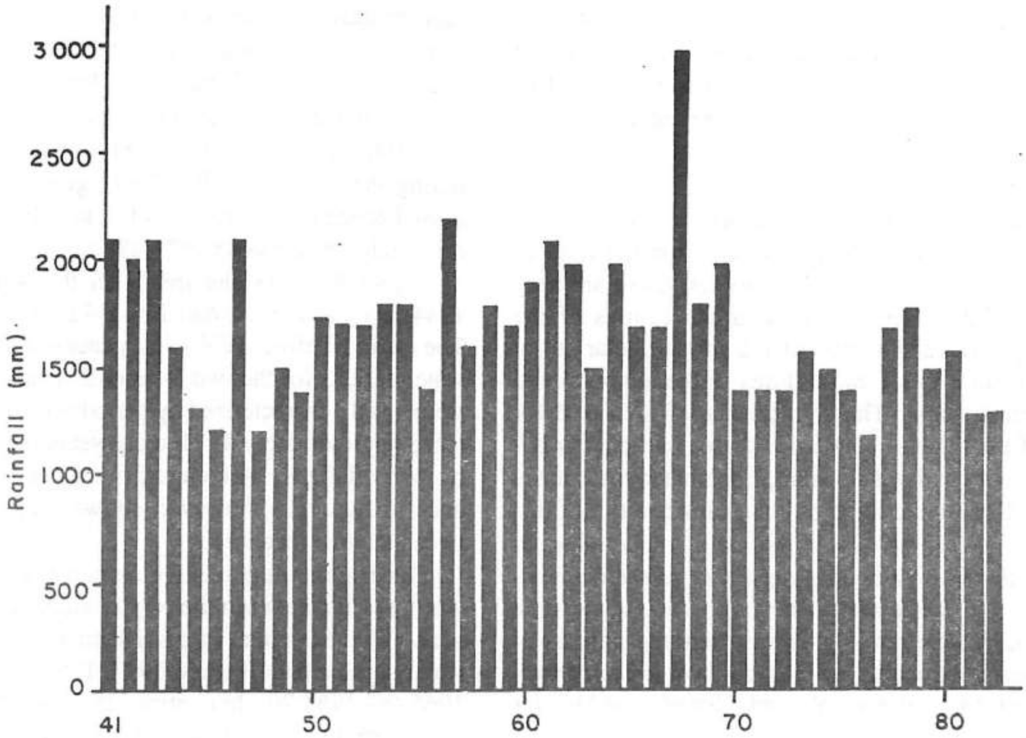


FIG: 5: AVERAGE PRECIPITATION TRENDS IN LAGOS (1941–84).

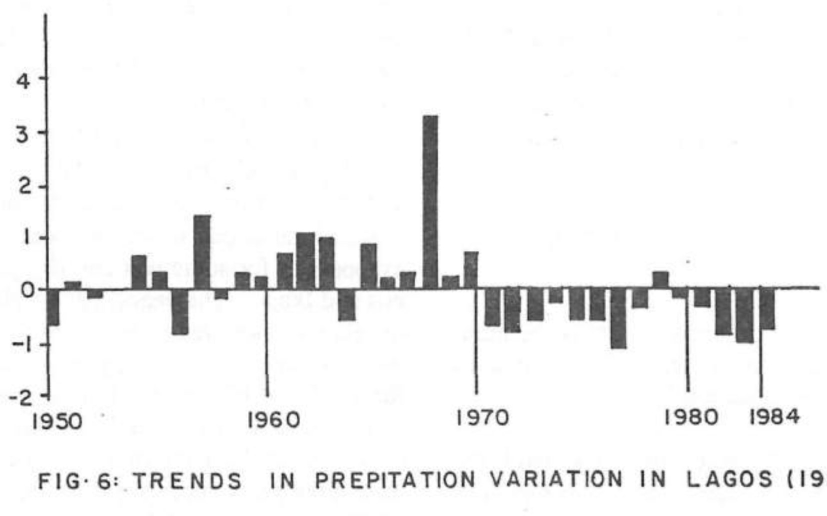


FIG. 6: TRENDS IN PREPITATION VARIATION IN LAGOS (1951–85)

At 1500 hours (local time) the values of H have been considerably reduced particularly outside the built-up areas, where values less than zero ly min^{-1} have been recorded. The values increased towards Mushin, Oshodi, Surulere and Ebute Metta where the values were generally more than 0.002 ly min^{-1}. In contrast to H, values of *LE have* increased considerably over the built up areas. This is not surprising because of the relatively high values of net radiation over the built-up areas and because of the relatively higher vapour pressure gradient, created between the surface and the atmosphere over these areas in contrast to the less developed part of the city where relatively low values which are less than 0.0001 ly min^{-1} occur.

Precipitation

Another major component of the urban climate is precipitation, which in West Africa is mainly in the form of rainfall. As in many parts of the tropics, there are very few studies of this component for urban centres of the tropics in general and West Africa in particular, even though there are a lot of variabilities in the temporal and spatial characteristics. The significance of and need for the study of the urban precipitation arises particularly because the energy and water balance characteristics of the urban areas depend mainly upon the characteristics of this component. For example, it is the main source of water supply and, therefore, a controlling factor of the demand-supply system in the urban centres. This is for example the case in Lagos metropolitan area where the impacts of the recent variabilities in precipitation have led to considerable shortages in water supply and a lot of hardships for the urban population.

Figure 5, for example, shows the average precipitation trends in Lagos between 1941-84. The figure was drawn by computing the average precipitation trends for ten locations. It can be noted from the figure that the 1961-70 decade was generally wetter than the previous two decades (1941-50) and (1950-60) and the more recent period (1971-84). Figure 6 shows the annual trends of the normalized precipitation departures for the Lagos metropolitan area (1950-84). The figure drawn by using the equation which can be expressed in the form:

$$I_{ij} = 1 \underset{j=1}{\underline{N}} - = \quad Iij = f\,(j = 1, N, Pij - Pi) \quad \text{(Equation 6)}$$

Where Iij is the normalized departures, N is the number of stations available during the year j, *is the standard* P_i is the mean precipitation at station i.

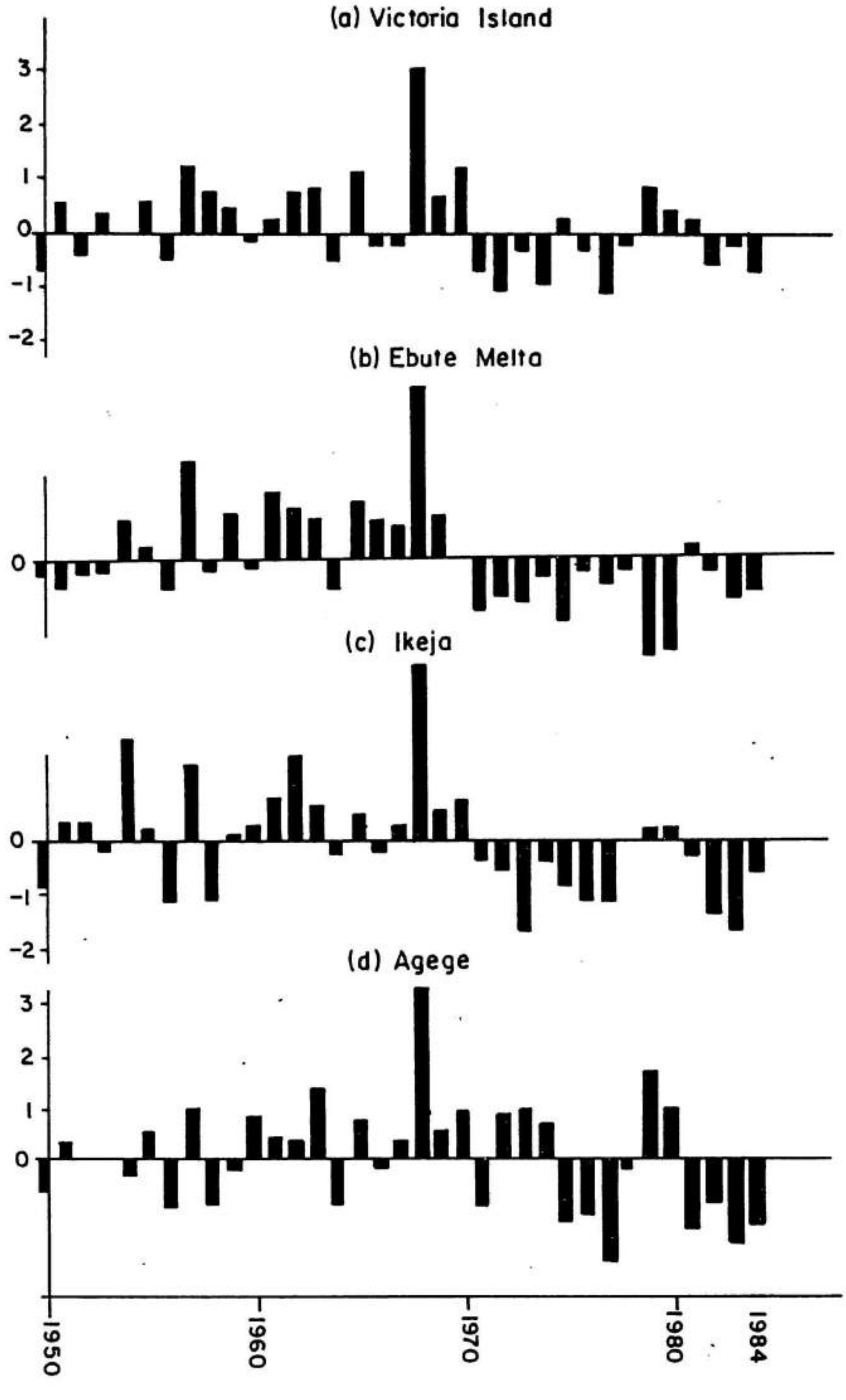
From this figure, it can be noted that in general, the decade 1952-1960 showed characteristics of normal conditions with most of the indices between ± . Only one year (1957) had an index which is more than + , while no year had an index below -0. The following decade (1961-70) was relatively wetter than the 1951-60 decade, while the period since 1971 shows that conditions have been persistently dry with negative indices.

A comparison of the average trends in rainfall and rainfall variabilities with the locational trends (Fig 7) shows that there are some differences between the average trends for individual locations within Lagos. For example, a detailed analysis shows that in 1960, both Ikeja and Agege have positive values, whereas Ebute Metta had slightly negative values. In more recent years, the values of the indices show positive variability conditions in 1975 and 1979-80) for Victoria Island, whereas conditions show negative values for Ebute and Metta in these years. In general, however, the average trends for individual locations show similar patterns, with fairly normal conditions during the decade of 1951-1960, generally wetter conditions between 1961-1970 and generally persistently dry conditions between 1971-1984.

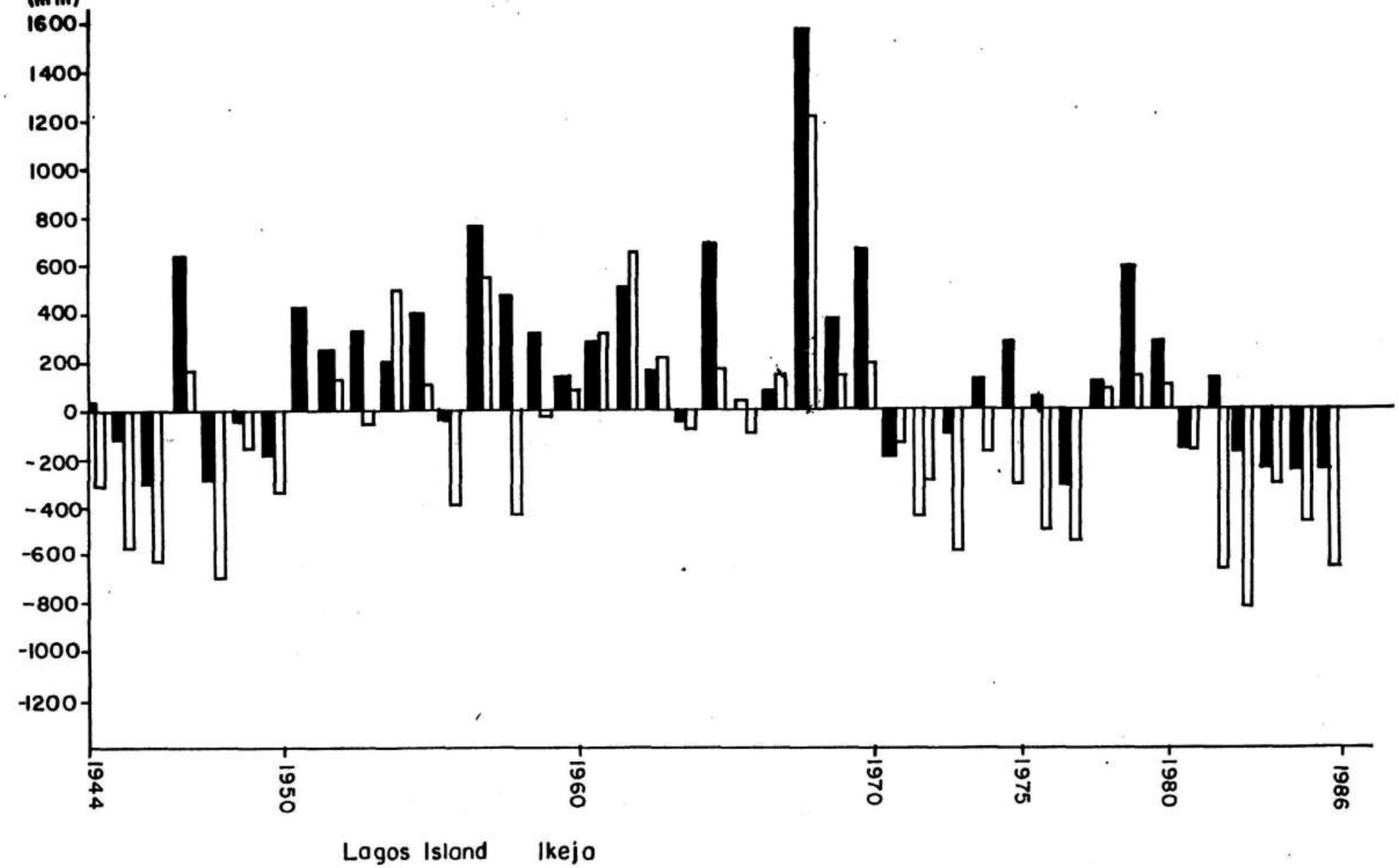
Figure 8 shows the trends in the water balance for 1944-1985 as approximated by P-PE for Lagos and Ikeja. The period before 1950 was generally characterized by water deficits for the two locations. The next two decades were mostly characterized by periods of water surplus while since approximately 1971 most years were characterized by water deficits. A comparison of the annual water balance in figure 10, however, shows some differences between the two locations.

For example, the relative amounts of water surplus or water deficits between the two locations vary from year to year. For example, Lagos Island has higher values of water surplus than Ikeja in 1947, 1952, 1952, 1954, 1955, 1965 and 1968-70. In contrast, Ikeja had higher values of water surplus than Lagos in 1951 and 1961-1963. Similarly, Lagos Island had higher values of water deficits in 1971, while for most of the other years, the values of the water deficits in Ikeja are greater. There were even greater contrasts between the two locations in some years when one location had water surplus, while the other had water deficits. For example, in 1944, 1951, 1953, 1958 and 1975-1976, Lagos Island had water surpluses while Ikeja had water deficients.

Probably of greater importance for urban areas are the monthly, weekly, or even daily variations in precipitation and the water balance. Figure 9, for example, shows the seasonal variations which may occur in precipitation and evaporation for some wet and dry years and for both Lagos and Ikeja. The years, 1957 and 1958 were examples of relatively wet years, while 1946, 1958, 1972 and 1973 were examples of relatively dry years. As can be noted for 1957, the highest rainfall occurred in July for Lagos Island whereas it occurred in June for Ikeja. Moreover, the two double maximum normally characteristic of Lagos were more pronounced for Ikeja than for Lagos Island. In 1968, the main rainfall maximum occurred in July for both Ikeja and Lagos Island instead of June, which is the normal month when this maximum is expected to occur. In both years, however, variations in evaporation show



FIG·7: LOCATIONAL VARIABILITIES IN RAINFALL IN LAGOS



FIG·8: THE WATER BALANCE FOR LAGOS ISLAND AND IKEJA

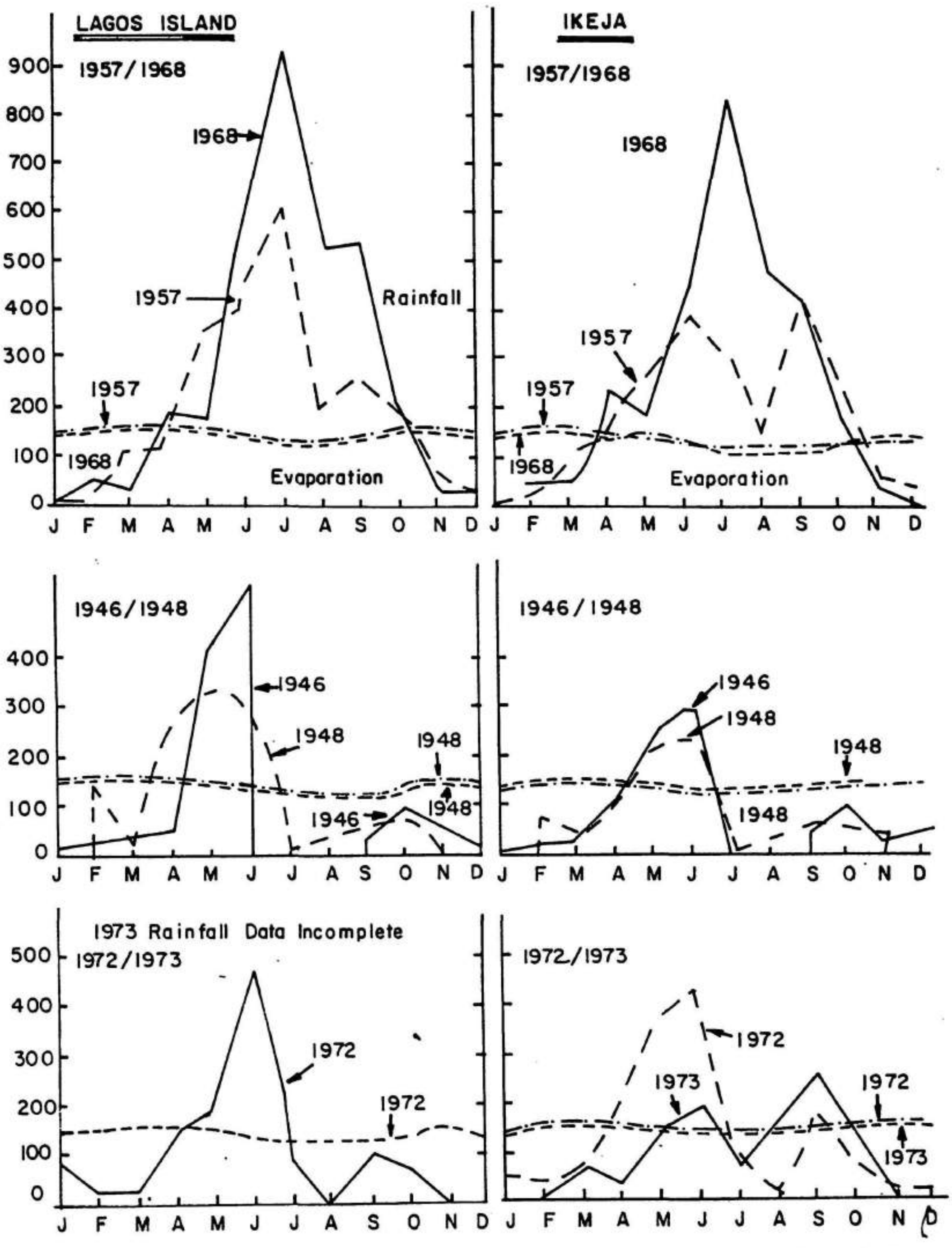


FIG 9: Monthly Distribution Rainfall and Evaporation for Selected Years in Lagos

similar patterns and much less variations with seasons than rainfall variations. Typically dry year conditions as represented by 1946, 1958, 1972 and 1973 show contrasting characteristics compared with 1957 and 1968. For example, 1973 had the highest rainfall in September in Ikeja in contrast to 1964 and 1948 which had the highest rainfall in June and 1968 which had the highest rainfall in July for the same location. Also the highest monthly rainfall for the wet years are usually more than 500mm, compared with the dry years whose highest monthly rainfall are usually less and which in some years, are less than 250mm as was the case in 1973.

Planning Implications

As already noted in previous studies, Page (1976) and Ojo (1981), the application of urban climatology to urban planning arises for three main reasons. Firstly, it is intended to provide information on ambient atmospheric conditions as a basis for studying the interraction between the different urban units. Secondly, it is intended to provide information for proper design of areas of urban renewal or expansion. Finally, it is intended to provide information input to the selection of site and design of new urban centers and to achieve the optimum landuse zoning bearing in mind, the different funtions and activities in relation to the distribution of climatic parameters. The first two of the above mentioned reasons are no doubt quite applicable to the studies of urban climates of Lagos Metropolitan areas. As already noted, there are very few studies on ambient atmospheric conditions over the metropolitan area and, therefore, the present study is important for providing some information on atmospheric conditions which may be useful for future researches on the interraction between the different urban units and consequently on the planning and redevelopment of the urban center.

Probably a more significant aspect of papers such as this is that they can be used to provide information for proper re-designing of the metropolitan area, particularly for the purpose of urban expansion and renewal, as already noted by the present writer, radiation studies are basic to the analysis of thermal conditions in the urban boundary layer. Thus, the influence of heat load within an urban environment must be of concern to planners. Yet in tropical areas in general, and Nigeria, in particular, there is very little emphasis placed on the need to reduce heat load to a comfortable level in planning and re-designing of old cities.

There is considerable literature on the comfort, discomfort and thermal stress indices in relation to the climatic environment (Landserg 1970). Moreover, as noted by LaFleur (1971) the general principles underlying the evaluation of thermal stress indices is to recognize that human health and comfort depend upon the maintenance of a stable internal body temperature of 37°C and skin temperature ay 33°C. To maintain these temperatures, heat gains must balance heat losses between the man and the environment and these depend on the nature of the environment and are intimately connected with radiation processes, temperature, humidity and wind. Thus, for planning purpose, the present paper is significant for determining climatic stresses particularly as far as thermal sensation is concerned.

Among the already developed thermal stress indices, probably the most commonly employed for determining thermal sensation is the Effective Temperature (ET) index which is calculated from an empirical formula:

$$ET = 0.4\,(Td+Tw) + 4.8 \quad \text{(Equation)}$$

Where Td and Tw are wet and dry bulb temperatures respectively in °C. The resulting values are related to a subjected scale on reported sensations of people in different experimental groups. A rather more sophisticated approach to the treatment of feelings of comfort is given by the relative strain index (RS) which is represented as:

$$Rs = 10.7 + \frac{0.74\,(Ta - 35)}{44 - 3a} \quad \text{(Equation 8)}$$

Where Ta is the air temperature and Rs is the vapour pressure of the air. For a healthy person, the scale of sensa tion indicates comfortable conditions for all people when RS is less than 0.2, discomfortable conditions when RS is more than 0.3, distress conditions when RS is more than 0.4 and complete failure when RS is more than 0.5.

It may be noted that RS can be obtained for various values of M, Rn and wind speed, and that this had been done after careful examination of published physiological data on heat stress (Munn, 1970). It is also important to note that the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) continues to sponsor programmes of research in this field.

Equation 7 and 8 were computed for seven stations which were representative of the major land uses the Lagos Metropolitan area in order to examine the relationships between landuse and the physiological climatic environment over the metropolitan area. The stations used include (a) Tinubu Square (CBD), the bar beach (Victoria Island - high residential area influenced by the oceanic influence), (b) Ikoyi Hotel (high class residential area with a lot of tree shades), (c) the Ikeja airport, (d) Mushin Bus Stop (with pollution effects of transportation), (c) Surulere (middle income class residential areas) and Ketu (around the express road junction - newly developed low income and middle income class area).

In general, the diurnal-seasonal pattern of both the ET and RS indices follow the patterns of temperatures with the highest occurring in the afternoon and the lowest occurring in the morning and evening hours. The values of ET vary between less than 23-24°C during the morning hours of July to October and more than 26-28°C during the afternoon hours of January - May and October -

December. The RS values also vary between 5-10% during the night and morning hours and rise to more than 35% between February and April and more than 30% between November and December. During the mid-rainy season of July-August, RS values decrease in the afternoons to less than 15%.

Both the ET and RS values show different distributional characteristics for the different locations. The ET values vary between approximately 23°C and 30°C over the Tinubu Square, 22°C and 29°C at the Bar Beach, 22.5C and 29°C at Surulere and 22.5°C and 28°C at Ketu-Expressway Junction. Notice that relatively high values occur at Tinube Square and Mushin Bus Stop reflecting the significance of transportational pollution which concentrated over the areas. In contrast to these relatively lower values occur at the Bar Beach and the Ketu Expressway Junction which are less affected by these pollution effects.

The RS values show greater contrasting conditions over the locations than the ET values. Over Tinubu Square, for instance, the RS values varied between about 0.1. and more than 0.5. Over the Bar Beach, the values varied between about 0.04 and 0.42. Over the Ikeja Airport, Mush Bus Stop and Surulere, RS values varied between about 0.1 and more than 0.7 in each case. As expected the lowest values occurred over the Bar Beach while the highest values occurred at Tinubu square and Mushin Bus Stops.

In terms.of thermal sensation using the convectional ET scale, the ET diagrams indicate that none of the locations would be thermally comfortable during the study period while some people would experience some discomfort in most of the locations between about 1400 and 1800 hours using the RS scale. Judge from the subjective reactions of the people who took part in this study, however it would appear that the RS index gives a more accurate assessment of the sensation during the study period. As already noted, the afternoon conditions were relatively cool and comfortable for most of the students who did not appear to show any sign of discomfort or give a negative answer when asked if they felt comfortable. For the morning and early afternoon hours on the other hand, both indices appear to give fairly accurate assessment of the situation as reflected by the students' responses to the questions posed to them on how they felt during these hours.

The relatively cool and comfortable conditions which occurred over most parts of metropolitan area during the evening hours of the study period, as indicated by the RS values, reflect the effects of the rain showers which cooled the atmosphere during these hours. This indicates that under normal conditions, the atmospheric environment over Lagos during these hours of the day are usually thermally uncomfortable.

Conclusion

The creation of cities provides places, where man has created the most extreme alteration of the original covers of the land and the greatest alteration of the characteristics of land, air, water and organisms. Urban climates, therefore, provide the most extreme micro-climatic modifications which man has created. In the present paper, the distribution of net radiation, temperatures, evaporative and conductive-convective heat losses have been examined. The pattern of distribution of these parameters closely demonstrate the relative significance of man's modification of the active surface on the energy and water exchanges over the city. The Ikeje airport and Mushin-Oshodi areas which are important bus stops for example provide the "heat Islands" of the city whole relatively open spaces such as the Ikeje GRA, and the adjacent lands to the west of the city provide the "cool spots". Thus, in relative terms, the influence of industrialand transportational pollution concentration provides the most significant factor for the major differences between the heat Islands and the cool spots. However, the significance of the physical environment, particularly the ocean and the lagoons can be observed for the patterns of the diurnal variations of the climatic parameters, for example, as shown by the diagrams of temperatures and humidities along the Bar Beach and the Marina, compared with the mainland areas. In general, temperature ranges during the study period are relatively lower along the ocean (the Bar Beach) and the lagoons (Marina) than in locations farther away from the oceans or lagoons.

The significance of the study of urban center climates arises from the need to apply climatology to city planning. A historical review of the urban centers in the tropical areas shows that most urban center sites and their plans have been determined by some combinations of strategic, social or economic considerations. Lagos is not an exception in this regard. For example, as noted by Mabogunje (1968), the most important single reason for settling on Lagos Island was defence although its growth and development was largely due to European influence particularly with the construction of railways in 1895 and the latter improvement of the port facilities in 1941. Thus, as for many other tropical cities, most parts of Lagos are poorly planned, with no consideration for the climatic environment. The present study provides initial information which could be used in the application of urban climatology to planning the city of Lagos.

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REDUCTION OF URBAN HEAT ISLAND EFFECTS : A CASE STUDY OF NIMA, GHANA

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Abstract

The high percentage of built-up area and over-crowding in Nima, a sub-standard residential area in Accra, have contributed to the creation of an urban heat island. A development approach has been suggested which applies knowledge of the existing climate to improve indoor thermal conditions and alleviate the unfavourable effects of urbanization as well as ensuring the best possible outdoor climate

Introduction

Nima is a sub-standard residential area only 6 km from the commercial centre of Accra, the capital city of Ghana. The area was first settled in 1931. It was then outside the city boundaries and so the settlers were able to build sub-standard houses without violating building codes or sanitary regulations. The area was between a military base and a largely upper income residential area and therefore, there were job opportunities for the settlers. People from the city centre as well as migrants flocked to the area to work as cooks, stewards and labourers, among others.

After World War II, there was an influx of many disbanded soldiers, and with the acceleration of economic development in the mid-fifties, there was another influx of migrants from rural areas. These provided unskilled and semi-skilled labour in Accra, especially in the construction industry. The uncontrolled development, however, continued. Plans drawn up to control development in 1945 could not be implemented because areas earmakred for roads and public amenities had been encroached upon.

The deterioration continued until 1951 when the boundaries of Accra municipality were extended to include Nima, but attempts to implement any development plans were frustrated by the uncooperative attitude of the settlers.

By 1968, nearly all the available spaces had been built upon. More people had moved into the area because of cheap rents but adequate facilities and amenities such as water, electricity, public toilets, vehicular access roads and schools could not be provided because there was not enough space. Today the houses are over-crowded, with a net population density of about 500 persons per hectare. In addition to the over-crowding, the insanitary conditions remain. The uncontrolled growth coupled with the lack of basic amenities and facilities have all contributed to make Nima a sub-standard residential area.

The high percentage of built-up area, mostly in a haphazard manner has exerted a pronounced influence on the climate of Nima relative to the surrounding suburbs of Accra. The mass of building structures absorb and trap extra heat; there is also a reduction in evaporative cooling because there is less vegetation. These factors have contributed to the creation of an urban heat island in Nima.

Redevelopment Approaches

For redevelopment of Nima, two main approaches had been proposed at different times. One approach favoured extensive demolition of most of the buildings. The area would then be re-developed for a new social group consisting mainly of middle and upper income groups. The other approach involved minimal demolition and provision of access roads and more open spaces for essential services and other community development facilities. For either re-development approach it was recognised that many improvements in the quality and function of the built-up area as well as of individual buildings could be achieved on the basis of a good knowledge of the climatic conditions in the area.

Micro-Climatic Studies in Nima

Micro-climatic studies were, therefore, carried out by Asante (1974 and 1978). The studies were to establish the indoor thermal conditions in

Acknowledgement

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the houses and to document the nature of prevailing climatic conditions; this knowledge would give an indication of the modification required to achieve the desired indoor environmental conditions. Then design procedures and the physical properties of materials could be utilized to ensure the desired control of the indoor environment.

The indoor climatic observations were made in rooms of a typical court-yard house and outdoor air temperature and wind measurements were made in the court-yard of the house and outside the house. Observations were made at 0900 hours and 1500 hours, daily, of ourdoor shade dry-bulb temperatures from a whirling hygrometer; the outdoor maximum and minimum dry-bulb temperatures were also recorded from maximum and minimum thermometers installed in a Stevenson's screen.

For air movement, a cup anemometer installed at a height of 2m was used to measure the total wind-run during a 24-hour period. Twice daily, at 0900 and 1500 hours, the instrument was also used to measure the wind speed by taking a count over a given period with a stop watch. The wind direction indicated by a wind-vane was also noted each time the wind speed was determined.

Results of Micro-Climatic Studies

The results of the studies showed that the local external climatic conditions influenced the indoor micro-climate. There was a continuous high incidence of thermal discomfort due to warmth. The results also revealed the formation of a heat island in Nima. The main climatic elements that showed urban effects were air temperature and wind. The average temperature differences between the target area and the airport, 8 km away, was between 1.2°C and 1.9°C at 0900 hours. The highest difference in temperature is most likely to exceed this average figure.

a comparison of wind-run recorded with a cup-counter anemometer at a height of 2m showed that the wind-run per day, for a period of about 6 weeks was 116 km for Nima while at Legon, an open area 12 km away the figure was 183 km. The predominant wind direction for the two areas was however, the same - south-west.

Other Studies

In studies carried out elsewhere moving observation techniques were used; cars and bcycles were used ot make climatic observations, including vertical temperature profiles up to 24m, over whole districts (Sekisuh, 1972 and Gajzago, 1977). Oke (1976) has listed some of the studies on urban heat islands of cities.

Ventilation and Design of Urban Layout

Givoni and Pacuik used models in a wind tunnel to study the influence of tall buildings above a lower built-up area in relation to their shape and size. The researchers observed that when the buildings were of uniform height neither the change in the height of the buildings nor in the distance between the rows of buildings have any significant difference in the average wind velocity in the built-up area.

However, when different arrangements of high-rise buildings were added to the layout of uniform height buildings, changes in flow pattern and an increase in the air velocity were observed. The increase in the mean velocity of the entire built-up area was greater than 100 per cent when four or nine high-rise buildings were added, and the increase in the mean velocity for the street in between the rows reached, in some cases, 300 per cent.

It can be seen, therefore, that by suitable arrangement of high-rise buildings in the neighbourhood of low-rise buildings, it is possible to improve the ventilation conditions in the low-rise buildings. These findings suggested a development approach in Nima which applied knowledge of the existing climate to improve indoor thermal conditions. Consideration of climate in planning would also alleviate the unfavourable effects of urbanization as well as ensure the best possible outdoor climate.

Reduction of Heat Island Effect Through Vertical Development

For the re-development of Nima, it was decided to adopt a vertical development approach. It had been recognised that it would be possible to exert a definite influence on the climatic conditions in Nima through the layout of the built-up area and the design of the individual buildings. It was, therefore, decided to influence the ventilation conditions through the addition of another storey on one wind of a court-yard house. This development approach required a limited demolition of some of the buildings to make it possible to provide a network of roads and open spaces (Figures 1 and 2).

To determine whether the "vertical development had produced improved indoor conditions", temperatures in the upper-storey

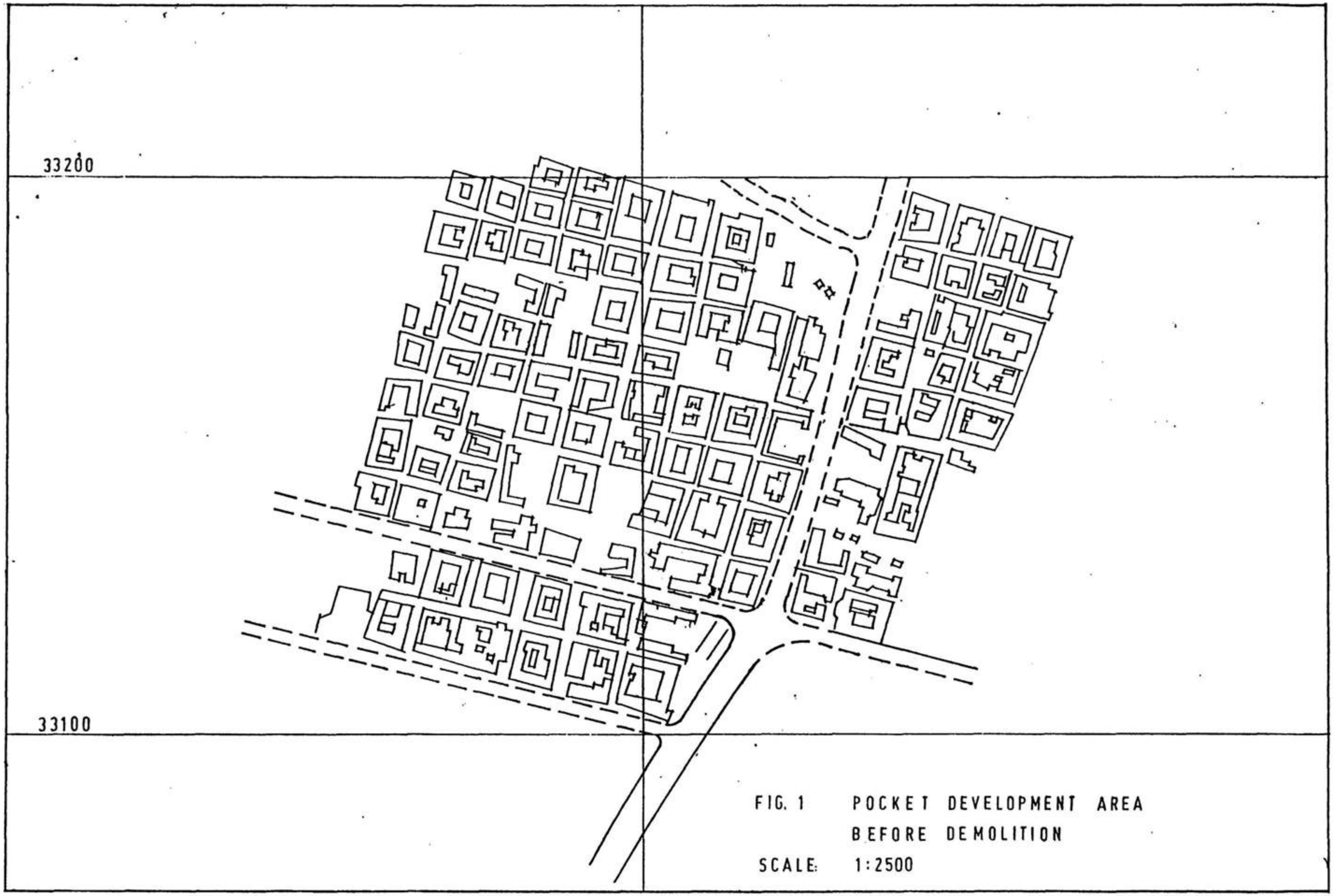

FIG. 1 POCKET DEVELOPMENT AREA BEFORE DEMOLITION

SCALE: 1:2500

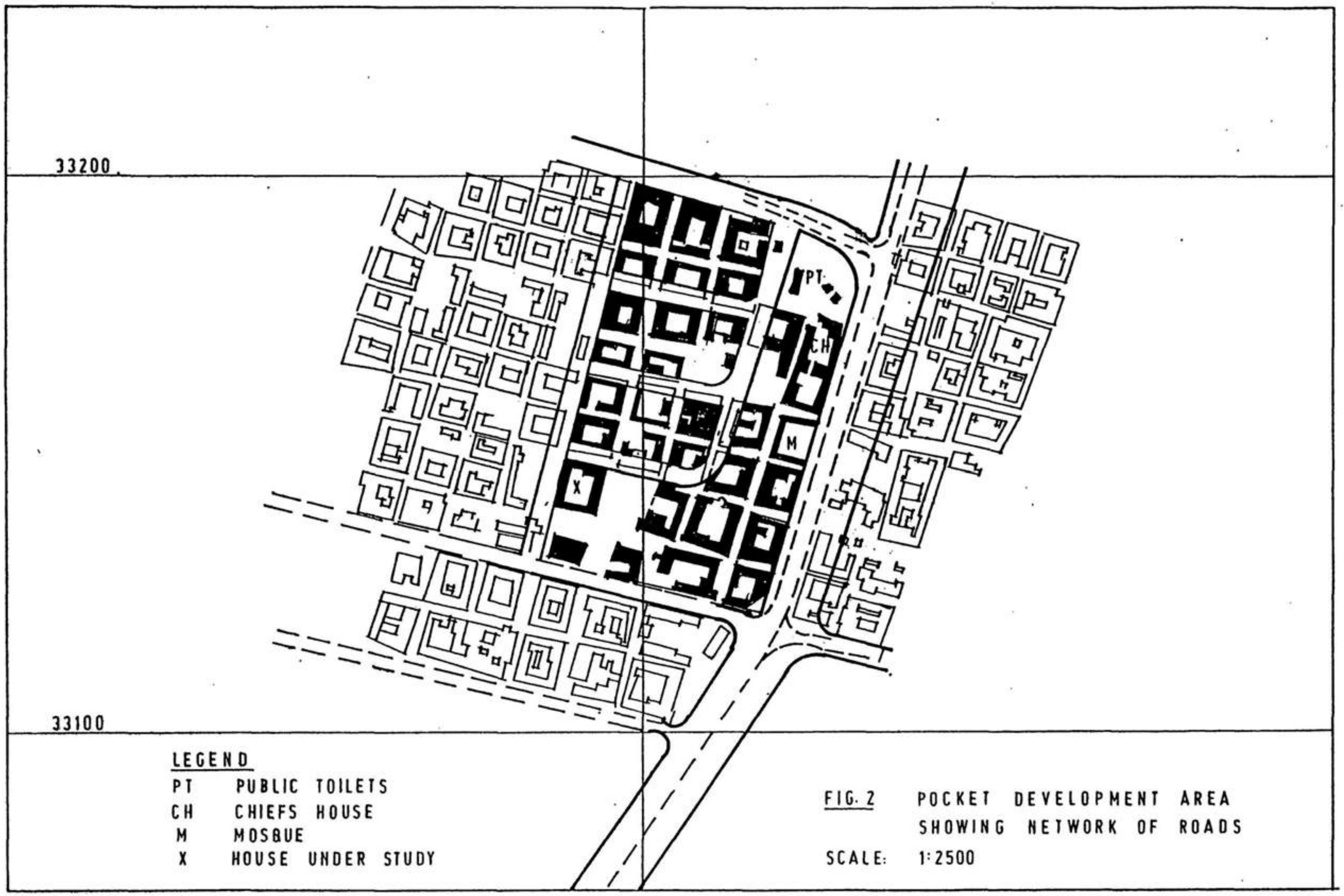

FIG. 2 POCKET DEVELOPMENT AREA SHOWING NETWORK OF ROADS

SCALE: 1:2500

rooms were measured, and the results compared with previous measurements made in rooms in single-storey court-yard houses. These measurements showed lower indoor temperatures in the "lifted-up" rooms. The construction of drains to carry waste and storm water away from the area also considerably improved environmental sanitation.

Conclusion

The lower indoor air temperatures recorded in the "lifted-up" rooms would seem to suggest that ventilation conditions in the area had improved. It is reasonable to assume that the improved ventilation conditions had been due to the "lifting-up" of one wing of the court-yard house and the open spaces created by the limited demolition. It may, therefore, be concluded that the vertical development has led not only to improved indoor conditions but also to better outdoor conditions due to the higher ventilation rates both indoors and outdoors.

This means that vertical development of selected buildings in Nima could provide the desired arrangement of tall buildings above a lower built-up area. Such a lay-out would result in changes in air flow pattern and an increase in the air velocity with consequent benefit to improved indoor thermal conditions and better outdoor environment. The heat island effect would then be reduced and more open spaces would be made available for the provision of roads, essential services and other community development facilities.

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URBAN PLANNING AND BUILDING DESIGN FOR URBAN CENTERS IN THE HUMID TROPICS

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Abstract

In humid tropical climates the combination of high temperatures and high humidity often causes heat stress in human beings. This will be particularly serious in Urban Heat Islands over large urban centers also because the natural ventilation in urban centers is usually reduced by lower wind velocities. Climatic statistics obtained outside an urban center can indicate when the heat stress situation is most dangerous. A consideration of the prevailing wind direction during these hours allows urban planners to orientate new residential buildings so that they can have maximum benefits of ventilation. As wind speeds increase rapidly with elevation, the construction of high buildings is advisable and economical. The high rainfall intensity frequently experienced in tropical climates requires careful planning of surplus water disposal in new development schemes. Rainfall statistics provide a fair estimate of the amounts likely to be received during rainstorms. A few simple rules help to design residential buildings so that they offer advantage of cross-ventilation and adequate protection against solar radiation.

Introduction

Urban Heat Island (HI) are caused by human activities, like manufacturing, transportation, domestic cooking and heating, and by man-made changes in the characteristics of the earth's surface: reduced areas of vegetation and water surfaces, increased resistance to winds, removal of surplus rain water and strong absorption and storage of solar energy by houses and road surfaces (Oke, 1982:1-24 and 1987:273-303). These changes occur in the humid tropics, as everywhere else. Here, domestic heating is (of course not a cause,) but the reduced evapotranspiration, owing to the lack of vegetation and water surfaces, which normally uses much solar energy, as an important factor (Daniel and Krishnamyrty, 1973:407-412; Giacottino, 1979:22-38: Hannel, 1976:95-109: and Nieuwolt, 1966:95-109).

In climates where heat stress for humans is a frequent occurrence, an increase of temperature by a few degrees, as in urban (HI), can be of grave consequences for human health and comfort. Thermal stress not only affects the work efficiency, but it can also be a danger to health, particularly for the very young and old (Pagney and Besancenot, 1982:158-163).

Heat stress is usually indicated by sensible, effective of physiological temperatures, which reflect the combined effects of air temperature and humidity (Ellis, 1953:386; Ilyas at al, 1981; Penicaud, 1978; Smith, 1955; Tom, 1959:57-60; and Wycherley, 1967:73-77). In large urban centers temperatures tend to be higher, but the humidity of the air is often lower than in rural areas. However, this lower humidity usually does not, compensate for the effects of temperature (Nieuwolt, 1966:36).

An added disadvantage for urban dwellers is that the natural ventilation is often impeded by buildings and this is especially the case near ground level, where most people work and live.

Therefore, inhabitants of tropical urban centers may suffer much more frequently from high sensible temperatures than people in the surrounding rural areas. The effects of the urban HI are particularly strong in areas of dense settlement, where the majority of the urban population is concentrated. Planners and architects should be made aware of this danger, because they can do much to reduce it in future buildings for residential purposes.

A major problem is that detailed information about thermal stress is not available for most urban centers in the tropics. Climatic information is usually recorded at the airport, located far from the Central Business District (CBD) and outside the urban heat island. An airport does not represent the rural areas around an urban center either, as the vegetation cover is reduced to grass and bushes, and partly replaced by paved surfaces of runaways and aprons. Microclimatic differences between airport and CBD are often recorded only for a short period during special research projects (Ilyas, et al, 1981; Sham, 1977:65-83; and Turner, 1978:334-338).

A solution to this problem is to use airport statistics to determine the most critical periods of the year. Hourly temperature and relative humidity data can be used to compute the temperature-humidity index or similar indicators which quantify thermal stress (Figure 1).

These data provide an indication of the periods when the combined effects of temperature and air humidity are most likely to cause thermal stress for the inhabitants of the nearby urban center. For the temperature - humidity

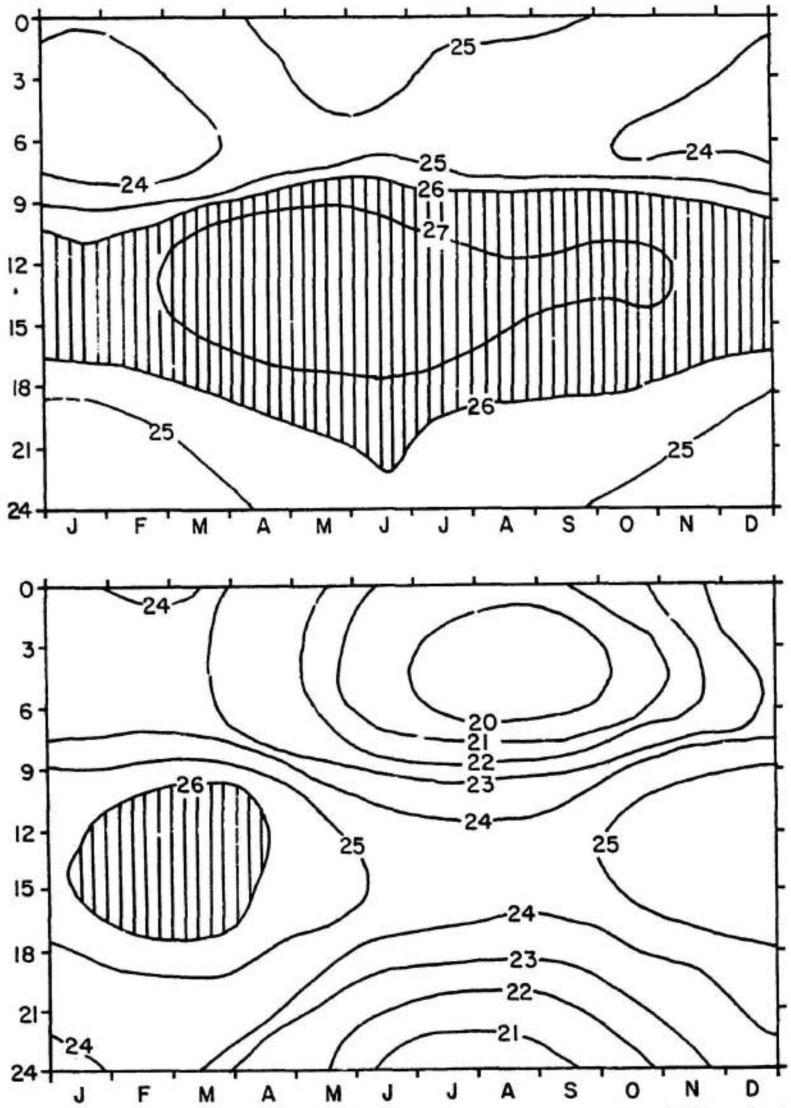

Fig. I — Hourly means of the Temperature—Humidity—Index at Singapore (above) and Dar es Salaam (below) Shaded: periods when heat stress is likely

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index used here, this is the case when it reached values of 26 and higher. In Singapore, the critical period is, obviously, from about 10 to 18 hours throughout the year, but in Dar-es-Salaam Tanzania only the afternoons from January to March are perilous. It should be emphasized that these data are based on hourly means, and that actual temperatures may reach much higher values, especially during sunny afternoons (Figure 2).

Most indicators of thermal stress disregard the cooling effect of natural ventilation by the wind because wind speeds are very variable over time and place. Also, natural ventilation does not reduce thermal stress when the air temperature is close to that of the human skin (Court, 1948:487-493; and Thomas and Boyd, 1957:29-39). For the purpose of identifying critical periods the neglect of the effects of winds is not a serious disadvantage, because winds in an urban center are usually much weaker than at the airport. Also, ventilation can be provided at low cost by electric ventilators, although this is normally not as effective as the natural ventilation because the hot air within a room is circulated rather than being renewed by fresh air from outside.

Once the critical periods for thermal stress have been recognized, it is possible to provide planners with information about the prevailing wind direction and the position of the sun during these periods. In Dar-es-Salaam, for instance, winds during January afternoon are mainly from the northeast (Figure 3). It is really a reinforced sea breeze which brings relatively cool air from the Indian Ocean (Nieuwolt, 1973:189-206). At the same time, the sun's position is between south and southwest, but it reaches a direct overhead position at noon in early March. Planners can, therefore, calculate the correct exposure and size of shading surfaces needed to bring residents natural ventilation by the sea breezes and shade during these periods.

In Singapore, prevailing winds during the afternoon are mainly from the northeast between December and March, from the southwest in May to September, and from very variable directions during intermediate seasons (Nieuwolt, 1964:164-167). Here, planners should try to take advantage of the sea breezes, which are quite regular within a few miles from the coast, and of local wind variations, which are not indicated by the official wind statistics recorded at the airport. Being at a latitude of only 1°20' North, Singapore has a high sun throughout the year, so shade can be applied mainly by overhanging roofs or vertical shading devices.

Another climatic problem facing planners of tropical urban center is the high rainfall intensity. A large proportion of tropical rainfall comes during rainstorms, short periods of very intensive precipitation (Nieuwolt, 1977:122-126 and Riehl, 1979:108-114). In rural areas, the dense vegetation cover and deep soil act as an efficient reservoir for surplus rainwater, releasing it relatively slowly. Only continuous heavy rainfall will cause flooding. In urban areas, however, large parts of the surface, like houses, streets, paved surfaces, are impermeable and the storage capacity for surplus rainfall is small. As a consequences, runoff is very fast and direct and flash floods can occur even after a short rainstorm, as demonstrated by their frequent occurrence in urban centers like Kuala Lumpur, Malaysia.

Planners, therefore, need statistical information about the maximum rainfall intensities that can be expected (Figure 4). If the surface area of a catchment basin can be estimated, a good idea of the total water masses that must be dealt with by the drainage facilities is obtained. This may mean that low-lying areas in residential development schemes must be reserved exclusively for temporary water storage. Planning authorities should have the power to enforce these rules in the interest of future inhabitants. Illegal settlements, which tend to develop spontaneously along water- courses, should also be cleared when the danger of sudden floods becomes obvious, as the risks tend to increase dramatically wherever the urban population is growing, as in many tropical urban centers is presently the case.

Urban Planning

When the areas of urban development have been designated, and sufficient care has been taken to allow proper drainage of rainstorms, most attention by planners should be directed to residential buildings. New industrial, commercial and public buildings are usually designed for use of air-conditioning, the only way to improve work efficiency and comfort for workers and customers. Climatic factors should be considered in their design, to reduce the cost and need for air-conditioning, but they are often disregarded as one can observe many modern buildings with large unshaded windows exposed to the sun, or dark materials which readily absorb solar radiation.

Most urban centers in the tropics have experienced a very rapid population growth during the last 40 years or so. Crowding in existing buildings and unsanitary conditions in squatter settlements, combined with the continued influx of new migrants, have created an enormous demand for residential accommodation at reasonable cost. It is the task of the urban planner to design new parts of the urban center that may provide maximum comfort to the new settlers. The use of air-conditioning must be considered as beyond their means.

Fortunately, thermal stress can be reduced to some degree by natural ventilation. Residential apartment blocks or houses should be directed with their long sides approximately perpendicular to the main wind direction observed during periods of potentially high sensible temperatures. Even if wind directions are somewhat variable, natural ventilation is ensured as oblique winds are also quite effective (Givoni, 1976:289-191).

A second way to provide ventilation is to design high buildings, with large free spaces between them to allow a

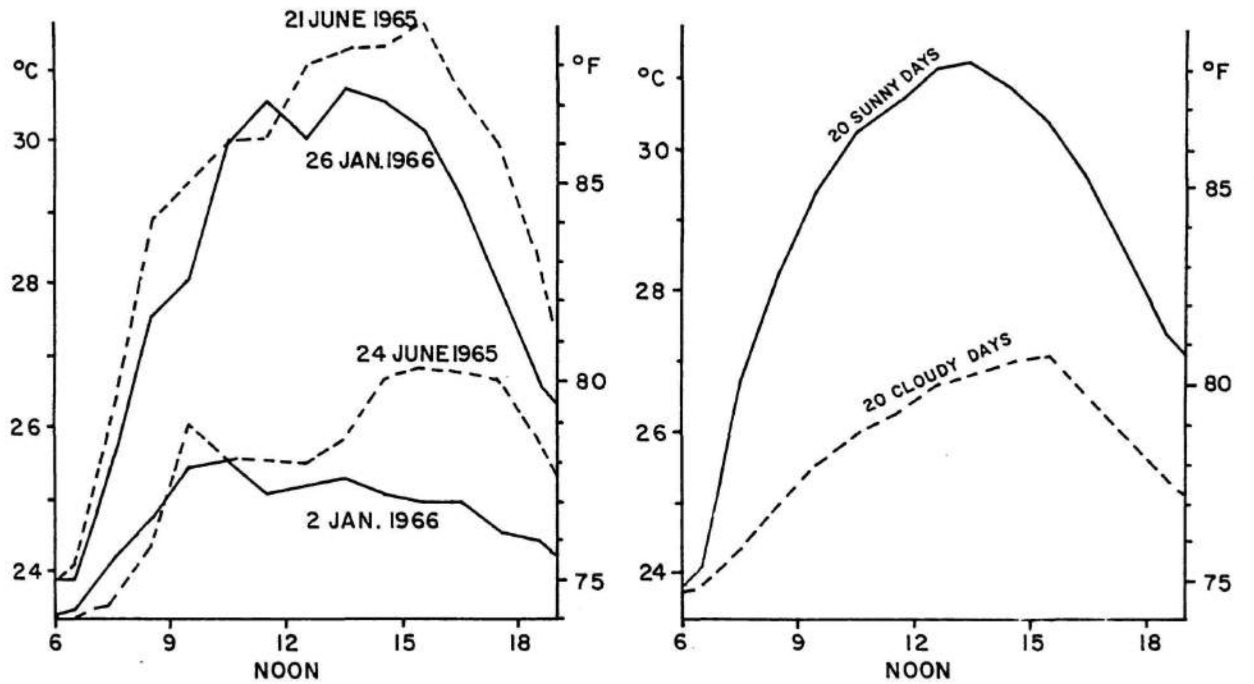

Fig. 2-Temperatures during sunny and cloudy days in Singapore.

Left: 21 June, 1965: 10.45 hours of sunshine.
24 " " : 0 " " "
2 Jan., 1966: 0 " " "
26 " " : 11.00 " " "

Right: 20 sunny days: more than 9 hours of sunshine each day (1965) } means for each hour
20 cloudy days: less than 1 hour of sunshine each day (1965) }
The two groups were equally distributed over the different months of the year.

(after : Nieuwolt, 1966)

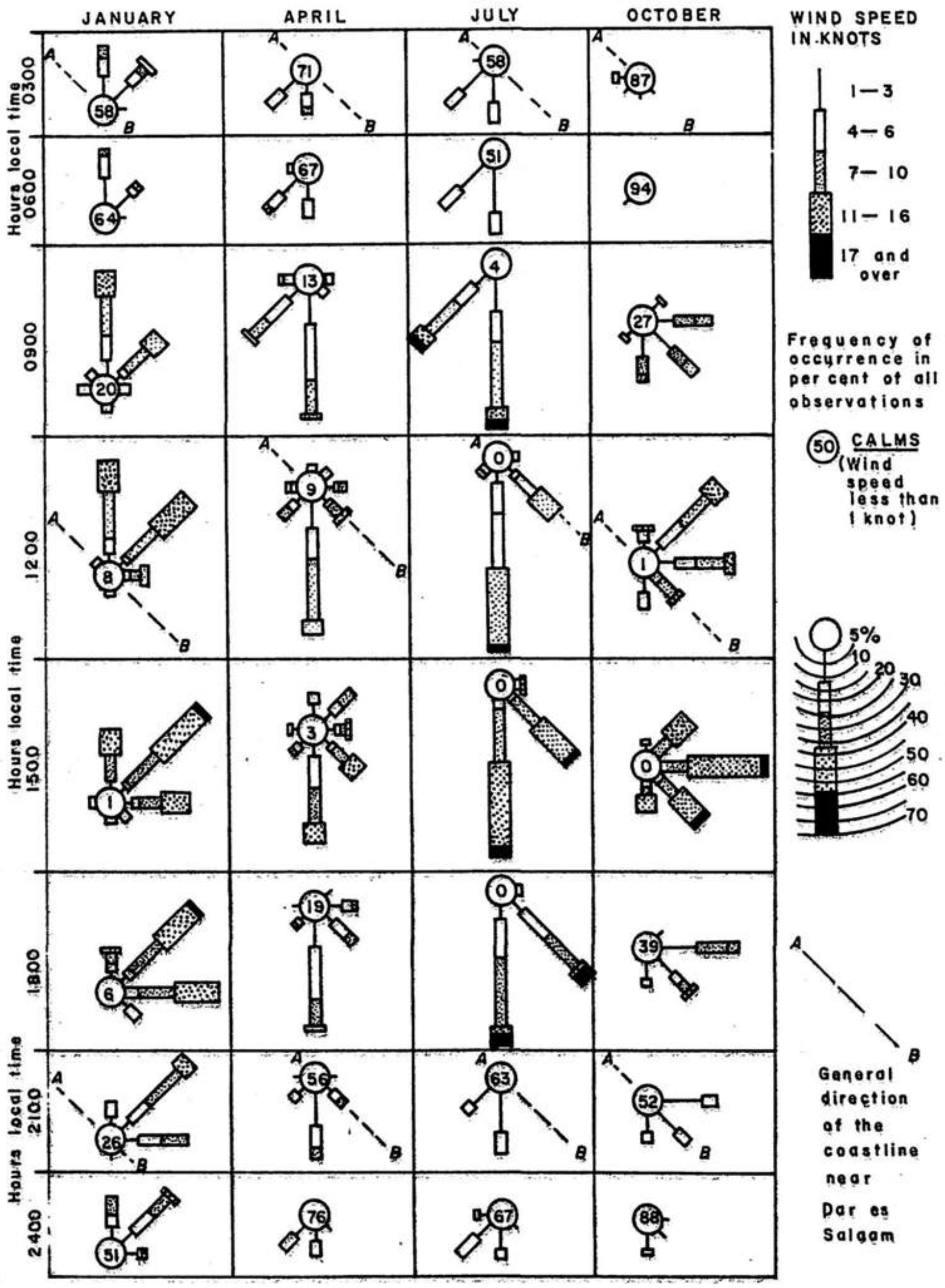

Fig.3- Wind directions and -speeds at Dar es Salaam (1955—1958)
(from: Nieuwolt, 1973)

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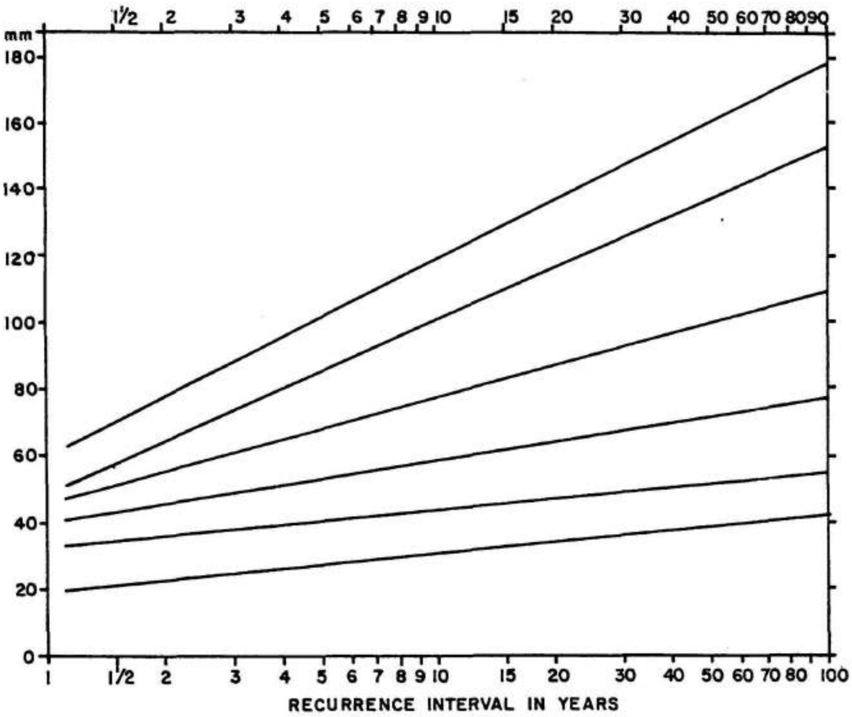

Fig. 4 — Maximum rainfall intensities at Dar es Salaam for various recurrence intervals (21 years) (from: Nieuwolt, S— Rainstorm distribution in Tanzania, Geogr. Annaler, Vol. 56A, 1974, p. 245)

free flow of air. In most urban centers wind speeds increase rapidly with elevation above the ground (Oke, 1987:299). Moreover, the relative humidity of the air decreases with altitude, but this has only a minor effect on sensible temperatures.

The concept of large and high blocks of apartment buildings is easily accepted by government and private construction firms, because the cost of construction and maintenance compares favourably to those of more widespread and lower buildings. The skyscrapers of many large tropical urban centers for instance Singapore, demonstrate their viability as low-cost housing units.

The open space between the high residential blocks should be reserved for parks and sportsfields. The vegetation in these areas will help in the absorption an transpiration of rainfall, and this will use much solar energy, reducing the surface temperature. Trees will also provide welcome shade for pedestrians and cyclists and promote outdoor activities, such as shopping and light services. Where not enough shaded space can be made available under trees, shading should be provided by awnings and little roofs over footpaths.

However, often new residential buildings will be constructed as urban renewal projects in older parts of the urban center, where street patterns are already established. A solution might be to designate whole blocks of land as parks, creating thereby free space between the new and higher buildings. A proper orientation of the new apartment blocks may not always be possible. An effective advantage of natural ventilation can only be gained by designing a number of smaller blocks. It might also be desirable to allocate the lower floors to offices and workshops, with air-conditioning, and reserve the higher storeys, where winds have free access as they rise above the surrounding buildings, for residential purposes.

Architectural Design

Residential buildings in the humid tropics should have the maximum possibilities of cross-ventilation. This requires not only a high, but also a very open type of construction, with large openings on both the windward and the leeward side of the building. The lower storeys, which are at a disadvantage regarding ventilation, can be used as garages or workshops, possibly with air-conditioning. Where flooding is possible, residential blocks can be constructed on stilts, a method which can be observed in many traditional buildings, both in rural and urban areas. In most humid tropical climates the nights can be rather cool, so shutters must be provided to stop ventilation when required. Shutters will also help to give more privacy indoors.

Protection against flying insects, particularly mosquitoes, will make the use of fly screens necessary, but they reduce ventilation by as much as 50%. It is possible to use fly screens only for bedrooms, or to use mosquito nets over beds only.

A great disadvantage of open construction of residential buildings is the noise pollution. Only strict rules regarding the use of radio's etc. can help, but this is a matter of information and education. Where people congregate in large numbers, consideration of others becomes more essential than in the traditional way of living in rural areas, to which many new urban-dwellers are accustomed.

A second requirement is proper shading. Large overhanging roofs, window overhangs or ownings, balconies and vertical shading devices should be incorporated in the residential buildings at least on the sides exposed to the mid-day sun. It is important that shading devices do not interfere with the free circulation of air around the building.

Horizontal extensions over windows and doors also provide protection against rain and they may allow a low sun to bring its warmth into the house, which may be welcome in the early morning or during the low-sun season. On west-facing walls vertical shading may be most efficient to keep the sun out in the late afternoon, when temperatures are still high. Where ventilation allows, it may be preferable to keep openings on the west side of residential buildings to a minimum.

A third need is to reflect as much solar radiation as possible. This can be achieved by using light colours, preferably white, on all outside surfaces and particularly on roofs of residential buildings. Materials with a low heat storage capacity , like straw, wood and modern insulating materials which contain much air, will help to reduce the absorption of solar heat during the day, so that buildings will cool off rapidly after sunset. Galvanized metal sheets, a cheap and widely used material for roofs, can be made more effective in reflecting solar radiation by regular whitewashing (Givoni, 1976:353-355).

A good separation between roof and living areas, in the form of a well-ventilated attic with good insulating material, and the construction of high-pitched roofs will help to reduce indoor temperature during the day. Flat roofs, though cheap in construction and design, should be avoided in the humid tropics. They absorb much solar energy and may be covered by pools of stagnant water when the surface is no longer absolutely flat. These can become breeding grounds for mosquitoes and other insects.

Finally, all internal sources of heat, like kitchens and bathrooms, should be planned on the leeward side of the building, so that the heat is rapidly removed from the residential quarters. Outside kitchens, or verandahs, are widely used in the tropics. These few simple rules can do much to reduce thermal stress for the inhabitants of low-cost housing estates in the humid tropics.

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CLIMATOLOGY AND BUILDING DESIGN IN WEST AFRICA

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Abstract **Accepted July, 1989**

West Africa extends from an area covered by the hot humid equatorial climate in the south to the hot and arid continental climate in the Sahara Desert. Along with these climatic conditions are variations in traditional architectural design. These days, modern building types ranging from simple bungalows to office tower block or modern presidential palace have virtually replaced the traditional simple architecture. This paper examines the basic climatic conditions (out door and indoor) across the West Africa sub-region. These climatological factors are examined within the framework of urban and building climatology. The impact of modern technological innovations on building design in the context of the prevailing climate are also discussed. In the final analysis, concrete suggestions are given as to the best way to use climatology in building design and urban planning.

Introduction

Building for people in West Africa range from the simplest grass hut to the office tower block or modern presidential palace. They are essentially constructed for shelter, work, comfort, storage or cultural requirements. It follows, therefore, that in designing buildings, there are three main considerations: first the people and their needs; second, the environment in which the people live especially the microclimate; and third, the available, affordable building materials. In addition, the site on which the building is to be erected should be considered and, probably, the cost and level of upkeep (Hayward and Oguntoyinbo, 1987).

For most people, the most crucial building is the house which is used mainly for shelter from weather elements, for privacy and storage. The availability of construction materials usually reflects the climate, from the skin or cloth-tent of desert to clay and mud, wood and grass in the seasonally of more permanently humid areas as doesn't the way in which the materials are used. Some level of physiological comfort, given the environmental constraints, has been achieved to a fair extent by indigenous architecture. In recent years, however, pressure to abandon the old methods of building and to substitute "modern" alternatives has had some regrettable consequences, a fact to which many school children and office workers will attest.

It is, therefore, pertinent to review the major climatological factors affecting building design in West Africa, such a review will highlight the climate and its effects on traditional architecture and the recent trends in modern technology as they affect building design in West Africa. To achieve this objective, the succeeding paragraphs will review first the major climatological factors affecting building design in West Africa, this will be followed by a discusssion on traditional rural house types in the region; next will be a discussion on modern trends in architectural designs in the hot humid, arid and semi-arid urban centres of West Africa. In the final section we shall consider the impact of modern technological innovations on building design in the context of the prevailing climate.

Climatic Information

West Africa lies within the tropics from about latitude 2°N to 24°N. It therefore extends over an area characterized by the hot humid equatorial climate in the south to the hot and arid continental climate in the Sahara Desert; in between these two regions lies the seasonally arid zone characterized by the savanna vegetation (Table 1 and Figure 1).

The most important information for building climatology include temperature, relative humidity and wind; others include rainfall and insolation. In West Africa, the interannual hourly values can be based on relatively short periods of observation and still be reasonably representative. (Nieuwolt, 1968, 23-29) Figure 1 shows the pattern of seasonal and spatial variations of the main climatic parameters over West Africa.

In West Africa, rainfall is highly variable both in time and space. The length of the rainy season ranges from over 10 months in the Niger Delta to less than 3 months on the desert margin; the mean annual rainfall varies from over 4000 mm in the south to less than 200 mm on the desert margin. The start and end of the rains are generally marked by strong winds and rainfall of high intensity associated with the east-west moving siqual lines. (Adefolalu 1984; 359-368). The strong winds and heavy rainfall cause severe damage to life and property through thunder and lightning and flashfloods (Ogunrala and Ogun-

Figure 1, Seasonal variations of temperature and humidity in West Africa.

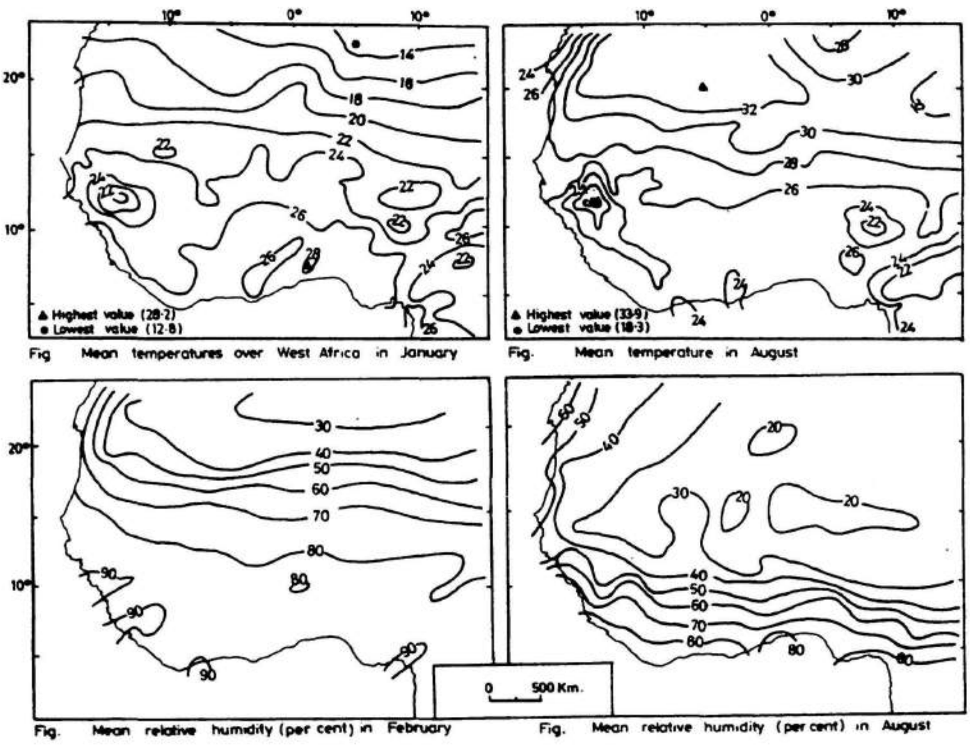
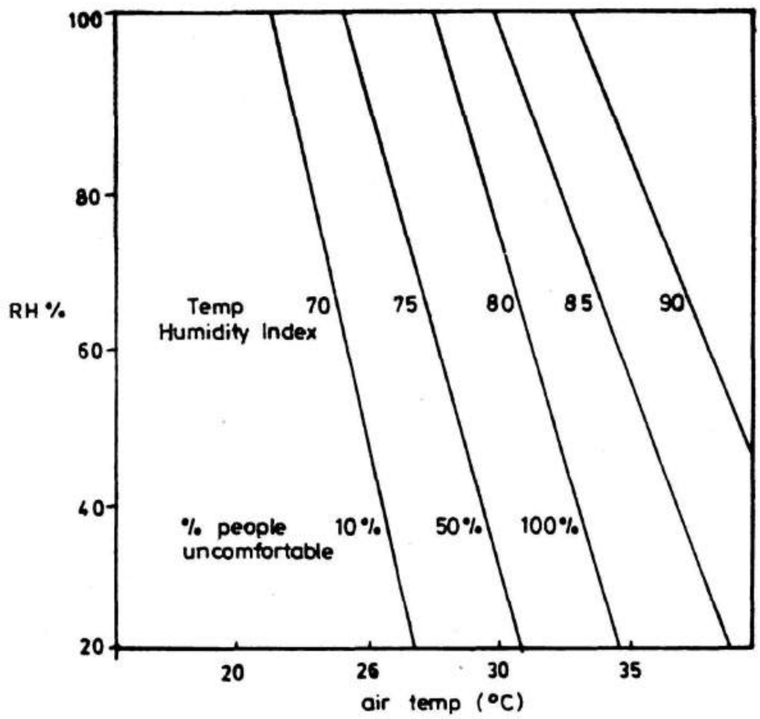


Figure 2, A temperature-humidity index (after Gates, 1972).



royinbo, 1968: 39-46). Urban planners and architects need information on these phenomena in the prices of designing drainage systems and culverts to cope with flashfloods and reinforcement of buildings to cope with strong winds. In the areas close to the desert, planners and architects must take cognisance of dust storms, thunderstorms and strong winds in their designs.

Temperature is affected by radiation efficiency, evaporation and evapotranspiration and advection. In the coastal areas of West Africa, the dense cloud cover which occurs over an appreciable part of the year reduces the radiation efficiency. This, together with the constantly high relative humidity and advective heat fluxes from the marine winds, helps to keep the temperature in the coastal area more uniform and relatively lower than in the interior part of the region. The mean annual temperature over the area south of latitude 10°N hovers around 26° to 28°C and the mean diurnal range is about 4° to 6°C.

Further inland, the highly reduced amount of cloud cover and relative humidity and the increased distance from the marine influence all combine to increase the radiation efficiency; mean temperatures are much higher and the diurnal and seasonal variations equally so. The mean annual temperature increases to over 30°C and the range to between 18° and 20° at latitude 20°N.

In January, the 26°C isotherm covers most of the area south of latitude 10°N. The highest temperature value of 28.2oC in this zone occurs in Bohicon, Benin Republic. North of this zone there occurs a zonal decrease in temperature. The zonal decrease in temperature is, however, disrupted by local altitudinal influences in Fouta Djalon highlands, Jos Plateau and Adamawa highlands between latitudes 10° and 15°N. Beyond this zone, the parallel pattern is well marked; the lowest mean temperature of 12.8oC; for the region is recorded at Tamanrasset. The hottest month occurs in April when a large part of the region between latitude 12°N encloses the 32°C isotherm.

In August, which is the coolest month, the 26°C isotherm now extends inland to cover most of the land area south of latitude 12°N. North of this zone the temperature increases rapidly inland reaching a mean maximum of 33.90C for the month of March.

From the early works of Houghton and Yaglou (1923: 163-176) temperature and humidity data have been used to deduce a Discomfort Index (DI); their experiments led to the development of what became known as Effective Temperature (ET) index:

$$ET = 0.4\,(T_d + T_w) + 15 \quad \text{.............................(1)}$$

where T_d is the dry bulb and T_w the wet bulb temperature in °F.

Modifications to this methodology have continued ever since. Thom re-evaluated in 1923 formula and produced alternative indices as follows:

$$\text{THI (Temperature-Humidity Index)} = 0.55T_d + 0.2Td_p + 17.5$$

or

$$THI = T_d\,(0.55 - 0.0055rh)\,(Td - 58) \quad \text{..................(2)}$$

where Tdp is the dewpoint temperature (°F), and rh is the relative humidity.

Cates (1972) expressed the US THI as in Figure 2. For instance, at a relative humidity of 100% and a temperature of 70°F (21.1°C) or relative humidity of 20% and a temperature of 80°F (26.7°C) or connections of relative humidity and temperature on the straight line joining these two points on the graph, the THI will be 70. It is suggested that 10% of the normally healthy adults will feel uncomfortable with a THI of 70, 50% will feel discomfort with a THI of 75, and all people will be uncomfortable if the THI reaches 80.

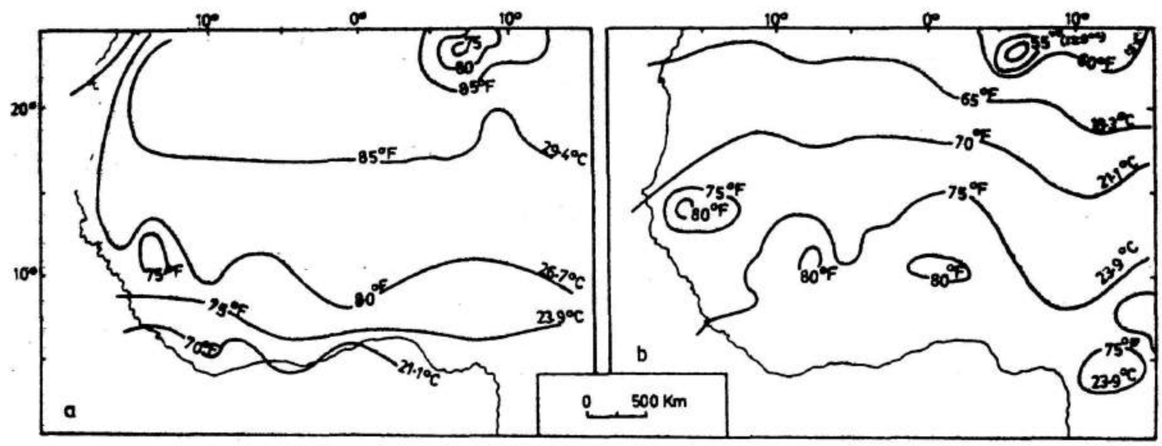
Terjung (1967: 5-19) using the relevant climatic parameters adopted the procedures after Thom (1959: 57-60) and produced the Temperature Effective Index (ETI) map of Africa. The outcome for West Africa is shown in Figures 3 a and b. An activity level of 175 K cal m^{-2} hr^{-1} was used as base. The maximum Et was then calculated to be 82.6°F (28.1°C). above which all people could feel uncomfortable.

In the map for July (Figure. 3a) it would be seen that nearly all parts of West Africa north of latitude 14°N have values above this suggested critical value of 28.1°C. (At 85°F (29.4°C) the work rate should be reduced to 125 K cal m^{-2} hr^{-1}). In January (Figure. 3b) pockets of high ET values occur in eastern Gambia and Senegal, in Southern Mali and Northern Benin. Values over Southern West Africa do not vary significantly from July, indicating that uniformity of climate which some people find enervating.

Wind is another parameter of importance on the effect of climate on building; its intensity can influence the orientation of buildings, while its speed can influence the selection of materials for, and structure of, the building. In West Africa, winds of high speed damage buildings particularly at the beginning and end of the rainy season when thunderstorm activities are characteristic. Except for these thunderstorm activities, windspeeds are generally light to moderate. The direction and intensity are dictated by the surface location of the Intertropical Discontinuity (ITD). When the surface location of the ITD is in the south in January, the easterly and north easterly winds predominate over most of the region except the coastal areas where a shallow depth of mT air mass prevails. Being of continental origin the NET are dry and dust laden. In July/August when the ITD has advanced to its northernmost limit, the westerly and south westerly winds predominate; this air mass is moisture laden and rain bearing.

The effect of natural ventilation by wind can be identified when hourly mean wind speeds are known. Formulae for this purpose indicate that the cooling effect

Figure 3, Effective temperature over West Africa (a) July (b) January.



of the wind is approximately proportional to $v^{0.3}$ or $v^{0.5}$, (v being the wind speed) and to the difference between the temperature of the air and that of the skin (35°C). (Siple and Passat, 1945; 177-199; Cairr, 1948; 487-493 and Thomas and Bayd, 1957: 29-39) Therefore, natural ventilation becomes much less effective in reducing thermal stress when the air temperature reaches a value around 35°C. Temperatures of that order occur in most regions of West Africa during the hottest hours of the day particularly during the dry season between November and March/April.

Wind speeds within cities are generally only about one half of those recorded at rural airports. There are, however, exceptional situations where much higher wind velocities can be expected due to local factors such as shape and height of buildings. But normally a strong reduction of winds speed can be expected within a city.

Indoor wind speeds are again reduced by about half compared to those outside, even with good ventilation. But the effects of ventilation are important; at higher floor levels outside winds may have speeds comparable to those recorded at airports. The combination of mean wind-directions and speeds for a few typical months can be of assistance to designers. They allow the detection of local variations in the wind pattern and thereby offer a good prospect of potential natural ventilation at the construction site (Figure. 4).

Traditional Rural House Types in West Africa

The hot humid environments of West Africa are characterized by high levels of humidity and cloudiness with prolific vegetation growth and abundant animal and insect life. It is, therefore, desirable to insulate buildings against the incoming insolation and to facilitate air movement, to counter the thermal stress and protect against the rainfall and insect. Roofs are more important than walls. They are usually made of palm or grass thatch thus reducing heat and re-radiation into the living space below. The round or rectangular hut of lattice polework is infilled with mud with or without a clay or chalk plaster, or hut of moulded mud block. The hut is rapidly giving way to the rectangular dwelling made from concrete blocks with corrugated roof (Figure. 5).

Something of the variation in the interior climate that can occur in these various buildings can be deduced from observations made in Sierra Leone (Peel, 1954; 125-143) and Nigeria (Oguntoyinbo, 1974). In both cases windows were closed at night primarily for fear of thieves, snakes and insects. This lack of natural ventilation plus the inward radiation from the thick mud walls caused temperature between 2000 hrs and 0800 hrs to be 3-5°C higher inside of the walls than on the outside while the relative humidity was 20.8% higher in the rural building over the same period. Experimental results (Holmes, 1951) show that the cheap metal roof, more durable than thatch and less of a fire risk and harbouring fewer snakes and insects, is probably the most suitable roofing material, especially if treated or ventilated, and provided the rooms beneath are fitted with ceilings.

On the Baouchi Plateau in Nigeria at lat. 101/2°N and at an elevation of over 600m where uncomfortable cool nights can be experienced in the dry (harmattan) season, some traditional huts are clearly constructed with two roofs, an immer one of clay to conserve the heat absorbed by day and to re-radiate it downwards at night, and an outer one of thatch to shed the rain and to protect the clay. Between the two roofs is an insulating air space to further reduce daytime temperature in the rooms beneath. Small doors and windows help this purpose (Huyword and Oguntoyinbo, 1987).

In the arid northern West Africa the requirements for building design are different from those in the south. The basic environmental conditions include low humidity, a lack of cloud and vegetation, much glare and dust. Breezes are here not beneficial as the flowing air is too warm, dry and dust laden (Firch Pase et al 1963). It is therefore advantageous to have enclosed, compact, inward-facing buildings, close together to decrease radiation on the walls and to maximize shade aided by verandahs and trees. Inner courtyards also help to reduce air turbulence and dust. Temperatures under shade can be 20°C lower than in direct sunlight. The labyrinth between houses provides shade.

Roofs are now less important than walls and can be flat as rainfall is limited, providing additional space for storage for drying clothes and food. Like the walls they are constructured of thick earth, stone or brick so as to absorb heat over a prolonged period before passing it to the interior of the building. This provided cooler day time conditions therefore, but hot nights as the stored energy is re-radiated inwards at the same time (Firch and Brand, 1960: 134-144). During which time people can retire to the flat roof tops until the cool hours of the morning (Figure. 6).

Windows are few and are kept to a minimum especially on the outer walls and are placed high up to reduce glare and dust. The poor ventilation that results is, however, not good for health especially in crowded family units. Buildings are light coloured to inverse reflection.

In the Sudan/Sahel zone with its seasonal alternation of intensely hot, dry and hot, wet conditions, a mixure of building designs of both the humid south and the arid north is characteristic, involving courtyards, day and night rooms, overhanging roofs, verandahs and sorrounding foliage. Dwellings on the coastal north west are advantageously open to the ameliorating sea breezes from the west by day but closed to the chilling night winds from the east.

Climate and Urban Development

In considering the effect of climate on building designs in urban centres, one needs to visualize the problem from two angles: first, the impact of climate on individual

Figure 4, Mean wind speed and direction over selected stations in Nigeria.

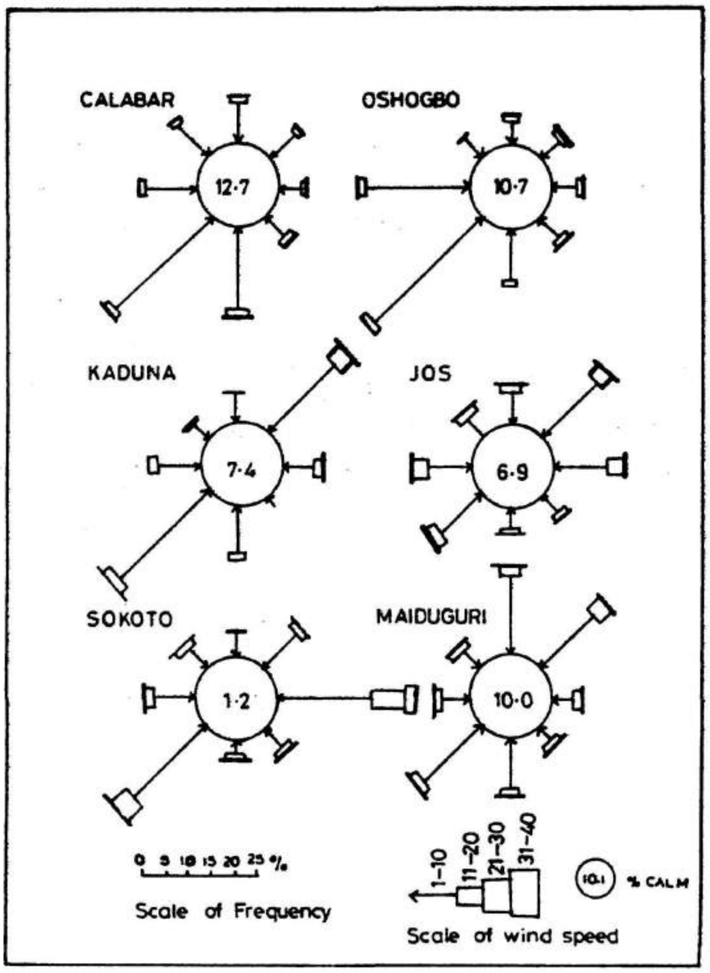


Figure 5, Traditional house types in West Africa.

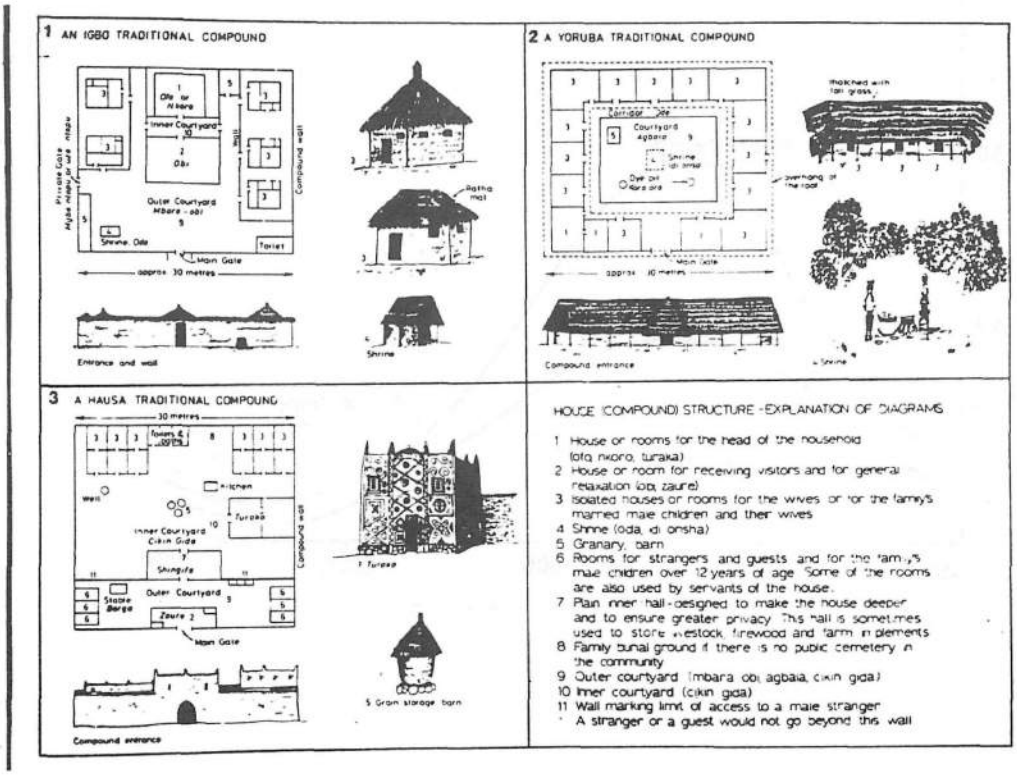
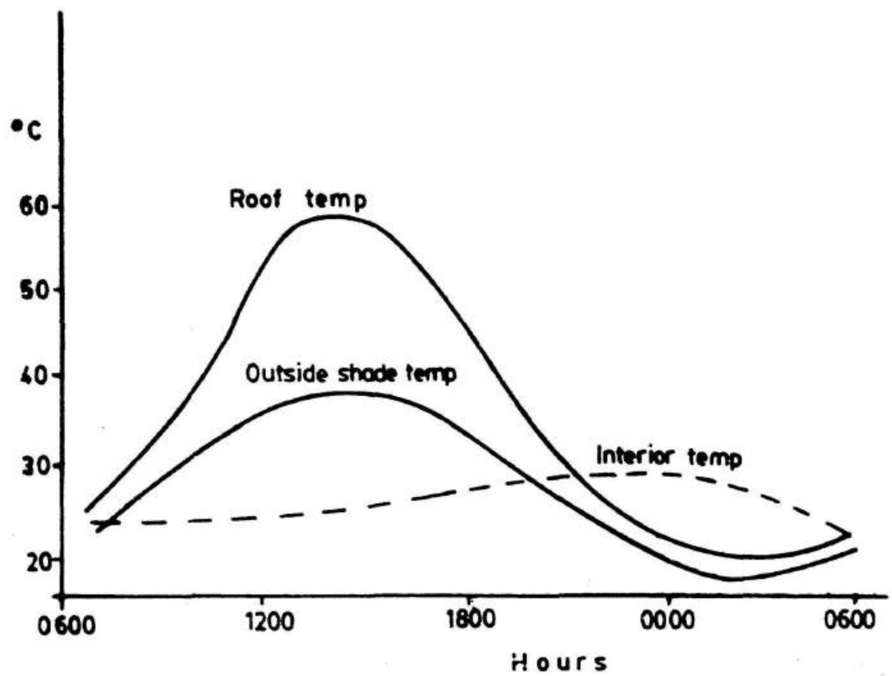


Figure 6, External and internal temperature of an adobe desert dwelling (after Fitch and Branch, 1960).



buildings and the impact of climate on the location of facilities within the city. While the former may involve predominantly the microclimate of the building environment, the latter should tale cognisance of both the global and the micro-climate of the urban centre. It is, therefore, appropriate to consider this aspect under two sub-sections, viz: (a) architectural design and urban climate and (b) climate and urban planning.

Architectural Design and Urban Climate

The function of building is basically to provide shelter; but in urban areas where a variety of activities take place, apart from shelter the functions of buildings include provision of facilities for undertaking commercial, industrial and administrative activities. The requirements of each activity imply that the micro-climate within each structure will vary according to the service the building provides. In addition to that, the location of each function within the urban complex in relation to the local and macro-climate of the larger region is fundamental to the variation in the microclimate (and, therefore, level of the atmospheric pollution) and health hazard prevailing over the city.

The climatic factors related to housing design are insolation, temperature, wind and moisture. Insolation provides heat and light and has certain health giving factors. Traditional housing style in the zone prefers a rectangular or square shape; however, an L-shaped house can be oriented to provide much more sunny exposure than a square or rectangular one covering the same area.

Unwanted bright sunlight can be controlled from the interior by means of curtains or blinds over openings and overhanging roofs. Translucent windows also reduce glare while admitting light.

Wind causes convective cooling, intensifies precipitation effects and exerts direct force upon a house. Therefore house design should provide for insulation against too much cooling, tight construction to prevent the entrance of cold air or wind-driven precipitation, and overall strength to withstand wind pressure. The lack of adequate reinforcement in buildings often cause severe damage due either to squall lines or floods in many cities.

Modern building designs in cities take less advantage of the prevailing climatic conditions and rely more on the provision of artificial facilities, such as air conditioning, for improving the microclimatic conditions within the building. This situation is only satisfactory where the supporting facilities - electricity and water supply to operate the machines - are uninterrupted and the cost per unit is not prohibitive; but this is invariably not the case in most West African cities. Power cuts are regular and pope borne water is in short supply. Consequently, the interior of buildings, designed with air conditioning facilities, is rendered very uncomfortable especially during the hot dry season. The use of mosquito netting on windows also reduces free air movement by 30 to 70% thus compounding the problem of unsatisfactory air ventilation.

One noticeable characteristic in the hot humid cities of West Africa is the creation of high rise buildings. Such buildings take advantage of higher wind speeds, particularly above the roofs of surrounding buildings; furthermore, distance from dust and noise at street level and the free view of the urban landscape all contribute to the preference for high rise buildings.

In the northern cities of West Africa where the climate tends towards aridity, the air is less humid, insolation is higher and more intense due to less cloud cover; dry and dust laden continental air mass prevails for a greater part of the year. Modern architecture has had to adopt the traditional building designs and incorporate the modern technological facilities. For instance, where bungalows are preferred these are provided with large courtyards to which people retire when the interior of the building is uncomfortable.

The building design is such as to keep out the heat of the day, so that shades and small windows act as a protection when sand and dust storms hit the area. The narrow shaded streets also provide resting place in the late afternoon when the interior of the building is hot and uncomfortable.

Urban Planning and Climate

The major pre-occupation of early urban growth in West Africa was to provide shelter and protection against enemy attach. Consequently certain locations were oftem preferred for siting settlements; such included hillslopes as in the case of Ibadan, plains surrounded by inselbergs as in the case of Kano. Buildings within the cities are packed closely together in the inner core of the city where a high density of housing is sorrounded by a city wall. The modern appendages like planned housing estates, industrial and commercial centres have developed on the periphery outside the city walls of such cities. The case of Ibadan, the largest traditional urban centre in tropical Africa is typical. As can be seen from Figure 7, the urban core is marked by a high density of houses these are generally the compound type, rectangular in shape with very narrow spaces between buildings, lacking in open spaces and covered with corrugated iron sheets which have lost their reflective ability. This close density of buildings with poor ventilation and of high heat absorbing capacity accounts for the urban heat island phenomenon most strongly developed in this part of the city (Adebayo, 1985). As can be seen on the map most of the low density housing zones are located outside the old city wall. Here buildings are widely spaced, thus allowing for good ventilation, green lawns and trees abound to aid the free circulation of heat and moisture and reduce the level of noise pollution.

Considering the fact that the predominant wind over Ibadan city is the southwest monsoon wind, the location of some industrial estates in the southwestern part of the city is ill-advised as this will increase the level of atmos-

Figure 7, Urban land use in Ibadan, Nigeria.

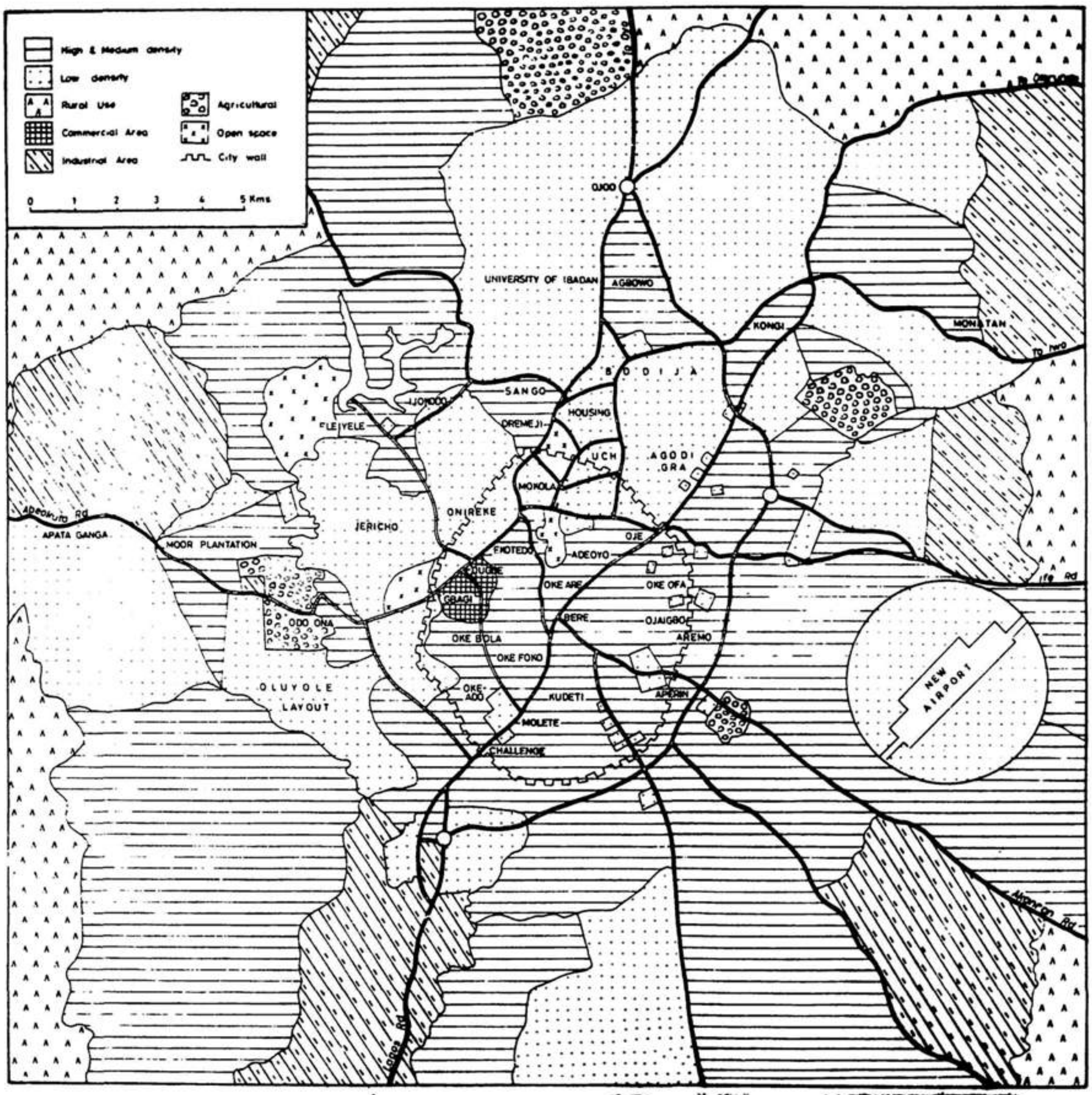
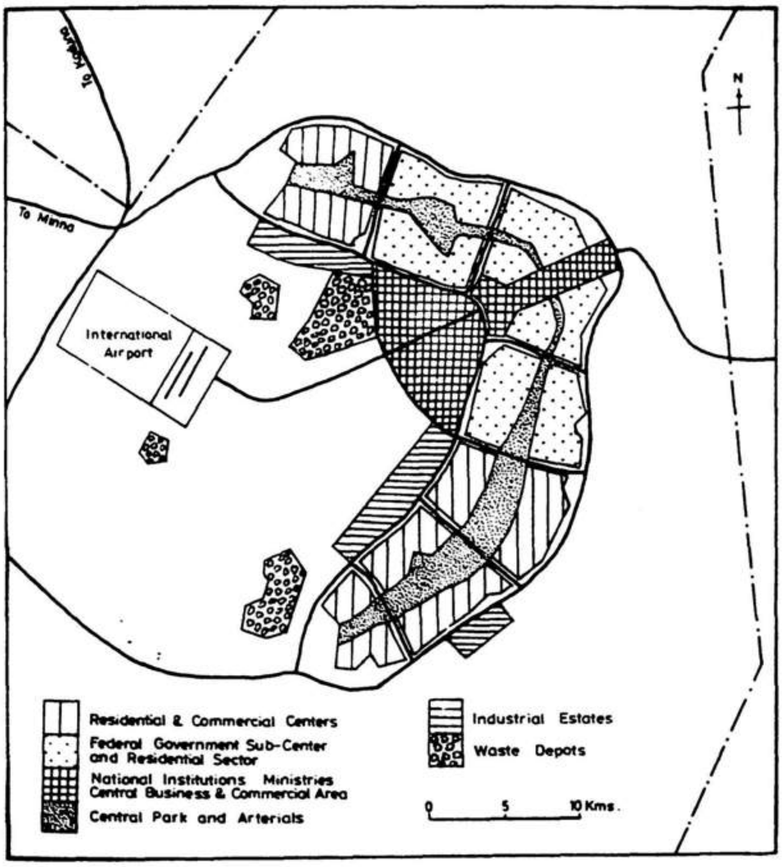


Figure 8, Urban land use inAbuja, Nigeria.



pheric pollution within the city.

A major problem in the hot humid climates is the prevention of floods and inundations caused by the high intensity of rainfall. This is particularly serious in urban areas because surface run off is much higher than in the rural areas where the vegetation and the soil cover constitute a larger reservoir of rainwater. Drainage systems which are quite sufficient in rural areas therefore become too small when urban development takes place.

The danger is particularly acute in the cities like Lagos located on the coastal plans where, under relatively dry conditions, regular drainage is necessary to prevent flooding or cities like Ibadan located on hill slopes astride flood plains. (Giacotting, 1979) Here unfortunately, the indiscriminate clearance of hillslopes for building purposes has accelerated the rate of run off from the hillsides and, the uncontrolled erection of illegal structures in the flood plain has hindered free drainage; these two processes have combined to increase the frequency and intensity of flash floods in Ibadan (Oguntola and Oguntoyinbo, 1986: 39-46).

Building Design and Air Conditioning

With the rapid increase in urbanization in West Africa within the past thirty years, new buildings have been designed to accommodate the urban population. Usually, houses in the low coast housing units are still closely packed and do not include the use of air conditioning. Comfort and health of inhabitants is, therefore, strongly impaired by the planning and design of buildings, the upper class residential areas occur in low density areas and have air conditioning systems installed in the building design.

New industrial, administrative and public buildings are usually designed with air conditioning. Air conditioning appears to be the only way to prevent climatic stress and improve work efficiency and productivity in modern architecture, as ventilation disturbs paper work in schools, banks and other offices. Nevertheless, climatic factors should be considered in their design for, there are many instances of quite unsuitable architecture in this respect in the hot humid cities. Glass walls or large unshaded windows on sides exposed to the afternoon sun, and the use of dark building materials which absorb too much solar radiation come to mind. Such construction of materials increase the cost of energy consumption of the air conditioning system and render the interior of the buildings disfunctional during power cuts which are not frequent in these urban centres.

Rarely can site selection, orientation, materials and design create the 'desired' indoor climate at all times. Air conditioning is, therefore, the last resort in the overall attempt to provide a suitable indoor climate. In the popular usage, air conditioning has sometimes been restricted to the artificial cooling of the interior of buildings. In the broader sense, it includes all attempts to modify indoor temperature, humidity, air movements and composition of the air by artificial means. The demands placed upon the controls of these elements depend on the outdoor climate, building design and its related factors and the kind of indoor climate which is wanted. Though many of the principles remain the same, air conditioning of the hospital operating theaters is quite a different problem from refrigerating a cold storage locker.

In residential buildings, the functions of different rooms influence requirements for comfort. Most importantly, individuals differ widely in their conception of comfort. Furthermore, the method of air conditioning applied depends on the type and functions of the building. In an office block of several storeys, it is more economical to install a central air conditioning system, whereas in houses and small buildings, single units are preferred. However, the efficiency of the system used depends largely on the regular supply of electricity and water. Incessant power cuts can lead to frequent breakdown and malfunctioning of the units, thus incurring unnecessary repair costs or rendering the whole system ineffective.

Conclusion

Most buildings are required to perform two basic functions: the first is to provide some protection against direct atmospheric conditions and create an artificial climate suitable for linging accommodation, storage, or some other specific purpose; second, buildings must be structurally safe and able to withstand the stresses of the prevailing climatic environment during the anticipated lifetime of the structure. These requirements, and the ways in which they are fulfilled in West Africa indicate that while traditional building designs have attempted to incorporate the climatic characteristics in the different environments, modern architecture has introduced materials, shapes and structures which have not been fully integrated into the climatic environment.

If we take the basic differences imposed on architectural design by climatic conditions into account diversity of expression can result (Gropivs, 1956). Le Corbusier (1946: 163-113) wrote: "the materials of town planning are the sun, the space, the vegetation and concrete in that precise order and hierarchy but tropical housing and planning have reversed the offer in such a way that space, steel and concrete are the predominant factors while the occupiers are left to combat the effects of vegetation and the sun on the completed structure. The so-called modern buildings are coated on the outside with solar absorbers making substantial solar heat gains - the effect is sometimes referred to as "double sun" effects. Thus climatically inappropriate forms are often used when cultural symbolic or social factors are potent crucial ones". One needs to visit the 1970-80 modern housing estates in many urban centres to corroborate this statement. Here urban and public buildings are still constructed to the specifications of foreign appointed specialists (Albeti; 1955 chapter 1). They are rendered uninhabitable without the support of energy operated cooling systems.

In the planning of new residential areas in the peripheral parts of a city natural ventilation is probably the most efficient way to reduce the thermal stress. Local wind conditions are needed to decide where the best wind conditions prevail during periods of potential climatic discomfort caused by hot and humid/dry environment. If there is a dominant wind during critical periods, the orientation of the buildings should taste cognisance in the location of urban activities (residential, commercial industrial and recreational).

The foregoing discussion has helped to illustrate the role of a climatologist in building design and urban planning; the advantages derivable from such a co-operation between urban planners, architects and climatologists are best illustrated by the co-operation amongst these professionals in the restructuring of cities the like Stuttgart in West Germany (Banmuller, 1984: 451-460), and Volgograd in the USSR. The input of climatological expertise in the planning of the city of Abuja is noteworthy (Figure 8); it resulted in the location of industries and waste disposal sites in the south western and north western parts of the city and the airport is aligned in a north east-south west direction. The rationale behind this is that since the prevailing winds for a major part of the year is the north-east trade winds, the pollutants from industries, and waste disposal sites would be blown south westwards into the rural areas and thus keep the city air relatively clean; the alignment of the airstrip also considers the take off and landing facilities of an air craft. This trend shows an increasing awareness of the role of weather and climate as a resource whose input into the development of our living environment should not be underestimated.

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URBAN DESIGN FOR HOT DRY REGIONS

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Abstract

The article discusses the climatic characteristics of hot-dry regions, urban design objectives and the design elements which affect the urban micro-climate. The design elements discussed in the article are location of an urban centre in a region; density of the built-up areas; orientation and width of streets; and design details of "green" areas.

Climatic Characteristics of Hot Dry Regions

Hot dry regions are defined in this article as arid regions in which the summer conditions are more severe from the comfort viewpoint than the winters. Such regions are found in the sub-tropical latitudes approximately between 15 and 30 degrees north and south of the Equator in central and western Asia, the middle East Africa, North and South America, and in central and north Australia. These regions are characterized mainly by their aridity, high summer daytime temperatures, large diurnal temperature range and high solar radiation. In some arid regions typical daytime summer temperatures are in the 32-36^0 range while in hotter regions they may be well above 40 and up to 45^0 C. Some regions which are hot in summer may experience comfortable winters while others may have winter temperatures well below freezing. Because winter temperatures vary from place to place, heating requirements may vary greatly in different hot dry regions of the world.

Urban design in hot-dry regions, from the climatic point of view should aim to achieve the following objectives, namely; (a) choosing locations with the most favourable climate, mainly lower summer temperatures; (b) avoiding areas prone to severe natural hazards (e.g valley floors where flash floods from far away rains occur; (c) minimizing urban temperature elevation above the surrounding level (the "heat island"); (d) enabling good ventilation potential for the buildings and in the open spaces; (e) providing shade in summer in the streets, over side walks and in open spaces, especially in regions with cold winters; (f) providing "access" to the sun in the winter for the buildings and in open spaces; (g) minimizing the dust level; and (h) providing protection from winter winds (in regions with hot summers but cold winters).

Some of the urban design features which can affect the urban climate in hot dry regions and which are discussed in this paper are locations of an urban centre in a region; density of the built-up area; orientation and width of streets; and design details of "green" areas.

Urban Center Location Within a Region

In choosing a location for an urban center or a neighborhood in hot region one should look for places with lower summer temperatures and good ventilation conditions mainly in the evenings and at night. Different locations within a given region may differ in their temperature and wind conditions, among others. Variations in altitude, in particular, may cause appreciable differences in temperature over short distances.

Local variations in topography may affect greatly the wind conditions. Thus windward slopes of a hill experience much higher wind speeds that the leeward slopes. Similarly, windward slopes of mountains may be more moist and experience higher precipitation that the leeward slopes.

Valleys experience different wind conditions, depending on the relationship between the valley and the prevailing wind conditions. Valleys parallel to the prevailing winds may have good ventilation potential. On the other hand, valleys on the leeward of and parallel to a mountain range extending perpendicular to the wind direction usually experience poor ventilation.

A common opinion is that wind is not important, or even undesirable, in dry regions because the outdoor air temperature is above skin temperature and the wind increase the convective heat gain of the body. However, it is the personal experience of the author that, even with air temperature of about 40°C, a light wind actually reduces discomfort by reducing the wetness of the skin, especially when one stays outdoors and is exposed to the sun.

Good building ventilation, which depends on the availability of wind in the area is essential in the evenings for indoor comfort and for enhancing the cooling rate of the building's interior.

Urban Density Considerations in Hot-Dry Regions

The density of the built up area (land coverage by buildings) in hot-dry climate may have both positive and negative effects on human comfort outdoors and on the indoor climate of the buildings. With a given building's height increasing urban density means smaller open spaces between and around the buildings. The effect of the reduced distances in hot-dry regions to a large extent on the orientation of the walls in question.

With proper design of the individual dwelling units a building can be cross -ventilated even when openings are provided only in the northern and southern walls. In this case, the distance between the buildings along the east/west axis can be eliminated altogether. This creates "roughhouses" or "townhouses instead of individual detached houses.

Consequently, when the main orientation of the building is the north and south it is possible to increase the density of the built up area by reducing the side distance between neighbouring buildings without causing deterioration in the thermal quality of the urban environment.

The effect of distance between buildings along the north/south axis is quite different. In winter it may reduce the possibilities of utilizing solar energy for heating, which has great potential in hot-dry regions, because of the altitude of the sun in the sky. Solar radiation on a southern wall (in the Northern Hemisphere) of one building may be blocked by another building in front of it.

Untreated urban land in a hot-dry region is often a source of dust while land covered by plants helps in filtering out the dust from the air. The lack of rain in hot-dry regions and the high cost of "imported" water limit the capability of urban center landscape to open land . In developing countries most of population cannot afford the expenses of planting and maintaining the open areas between buildings. Therefore appropriate urban design policy in hot-dry regions would be to limit the distances between buildings (set backs regulations) to the sizes which can be expected to be landscaped by the individual inhabitants. This consideration leads to higher urban densities than in other types of climate, e.g a hot-humid ones.

Density and Urban Air Temperature In Hot-Dry Regions

The temperature modifications by an urban center mainly in the "heat island" phenomenon, especially during calm and clear nights, when the urban air temperature is usually higher that the temperature of the surrounding open country.

Regarding the day-time conditions, it is commonly assumed that urban temperatures are higher than rural ones, due to lack of vegetation and heat generated in the urban center, although the differences observed are smaller than at night. Part of the incoming solar radiation is absorbed during daytime hours in the mass of the buildings. Part of it is absorbed at walls of high floors, far above the level. These factors reduce daytime temperatures at the street level where "urban temperatures' are measured, although they are on the average still higher than in the countryside.

It is possible to infer from theoretical considerations as well as from actual measurements in and around buildings that in hot dry regions it might be possible to plan urban center so that the ambient daytime air temperatures would be lower than those of the surrounding country. The main planning approach by which such a modification of the urban temperature seems possible is a combination of urban density, building heights and an average albedo of the whole area of the urban centers which will reduce significantly the solar radiation absorbed in the urban fabric.

High density of buildings can ensure that most of the radiation exchange will take place at the roof surfaces and not at the ground level and and at walls. By assuring that all the roofs are coloured white - by yearly repainting, for example - it is possible to achieve a negative radiation balance: the longwave radiant loss can substantially exceed the absorbed solar radiation even on a clear day in mid-summer. Under these conditions, the average temperature of the roof surfaces will be lower than the average regional air temperature. As cool air is heavier than warm air, it will sink into the urban center's streets if suitable details of the roof are provided. If the urban centre is large enough, and built densely enough it can be assumed that it will be possible to achieve a daytime air temperature at the street level that is a great deal lower than in the surrounding areas.

Urban Density and Ventilation Potential in Hot-Dry Regions

Hot dry regions commonly have strong winds during daytime but the winds usually subside in the evenings. Furthermore, during the daytime hours building ventilation is not desirable, while in the evening it is essential for indoor comfort. Therefore, as related to urban density and building design, the main concern in hot dry regions is how to provide the potential for evening and night ventilation for the buildings.

In high density neighborhoods, where streets are narrow, distances between buildings small and buildings are of about the same height, there is a sharp drop in the wind speed below the roof's level. Below the roofs the wind is very light while above the roofs it is much stronger. Under these conditions it is difficult to provide good indoor ventilation, especially when the ambient importance for the rooms where the inhabitants sleep.

When the same family occupies the whole vertical section of the building it is also possible to make us of "wind catchers" to catch the wind blowing above the roofs level and to direct it downward. Such "devices" can be an integral part of the functional design of the building, such as stairwells leading to the (flat) roof, or to a second storey extending only over part of the roof. The open part of the roof can be used as a private open space.

In neighborhoods with high rise apartment buildings, higher overall urban densities (total Floor Area Rational) can be maintained with adequate potential for natural ventilation. Reasonable distances between the building blocks should be insured, and long buildings should not form "walls" perpendicular to the wind direction. The wind can then "negotiate" between the buildings so that the potential for natural ventilation exists. The extent to which an individual apartment will actually have adequate ventilation depends on its design details.

Orientation and Width of Streets

The orientation of streets affects the urban climate in several ways, namely; (a) wind conditions in the urban area as a whole; (b) sun and shade in the streets and the sidewalks; (c) solar exposure of buildings along the street; and (d) ventilation potential of the buildings along the streets. The width of the streets determines the distance between the buildings on both sides of the street with impacts both on the ventilation and solar utilization potential.

In a hot dry climate the main objectives related to the street's layout are to provide maximum shade in summer for pedestrians on sidewalks than wide streets.

A north-south orientation of a street may result in an east-west orientation of buildings along and parallel to the street, which will cause unfavourable solar exposure for these buildings. From the solar exposure viewpoint an east-west street orientation is preferable.

In hot dry regions the main concern with regard to ventilation is to insure the potential for ventilating the buildings during the evenings. To the extent that such ventilation can be insured by the design of the buildings themselves (e.g. by use of wind catchers of some type) the street ventilation is of secondary importance, although light winds of desirable in the streets and open spaces, to mitigate the effect of the sun. In fact, during the hot daytime hours strong winds are not desirable, as they promote dust generation. This problem is more common in many developing countries, where many roads may be unpaved

Special Details of Buildings affecting Outdoor Condition

Protection against sun for pedestrians on the sidewalks is very desirable in hot dry regions. It can be provided by buildings with overhanging roofs, or colonnades in which the ground floor is set from the edge of the road, with the upper stories jutting out, supported by pillars (or other means).

The color of the building walls not only affects the interior climatic conditions, but also the lighting and glare in the streets. In this respect, in many instances, contradiction may exist between the requirements for comfortable indoor climate and those necessary to reduce the glare in the streets. In a hot dry climate a white color of the walls will reduce indoor heat load but will increase outdoor glare. These conflicting requirements can be often resolved by horizontal overhangs projecting from the walls which not only protect the windows from solar radiation but also extend; over the entire length of the wall.

Such overhangs cast shade on the section of the wall below them and also block from pedestrian view part of the sunlighted section above them. In this way they can greatly reduce the glare for the pedestrians.

Reducing Dust by Town Planning

Dust storms in desert regions are of two types; namely (a) regional storms, in which dust extends to great heights (hundreds of meters) and covers very large areas (hundred or thousands of kilometers). Such dust storms occur from time to time but are not a daily phenomenon; and (b) local dust "waves", originating in the local area and extending in height to several meters and in distance covered to several hundred meters. Such "storm" are in many places a daily phenomenon.

Nothing can be done on the neighborhood scale to stop or even minimize the impact of regional dust storms outdoors, although it is possible to minimize the penetration of dust indoors. On the other hand, much can be done in neighborhood planning to reduce the occurrence and minimize the impact of local, more frequent, dust "wave".

The main factors affecting the frequency, intensity and range of local dust storms are ground cover and the wind speed near ground level. Both these factors can be affected by neighborhood design features.

In hot dry regions, especially within an urban area, the soil without irrigation is practically exposed and provides a source of dust. In many urban centres, especially in developing countries, the individual citizen and the municipalities cannot landscape private open spaces between buildings or even large public open spaces.

Therefore, as a planning policy, the density of the built up area (land coverage) should avoid unbuilt areas that the private citizen and the municipality cannot realistically keep up as landscaped areas.

In view of the fact that water is scarce and expensive in most arid areas, private plot sizes should be such that the owners can easily plant and cultivate, or take care in other ways, of all the area belonging to them. This calls, in the case of individual houses, for rather small lot areas for low cost housing, which are sufficient for small gardens and can be kept efficiently well by the inhabitants.

Public areas within the neighborhood borders should also be limited in size to areas which can be well kept. Large public bare land is frequently the source of dust nuisance for the built-up area around it. In land reserved for future development the natural vegetation cover should be kept and protected.

In the development of new neighborhoods in desert regions, special attention should be paid to the treatment of the windward borders. The land should be kept in its natural conditions as far as possible, so that the natural ground cover of desert plants will limit the generation of dust.

"Green" Parks in Hot Dry Regions

Urban public and private green areas, to the extent that they can be kept properly (mainly irrigated), are a great asset in a hot dry region. Water evaporation from the leaves minimizes their heating by the absorbed solar radiation, and lowers significantly also the temperature of the air in contact with them. The evaporation from the leaves elevates the air humidity. In arid climates the evaporation rate is high and the effect of the higher humidity on comfort is welcome. As a result of the lower temperature of the leaves and the air passing by them, the temperatures in green areas are significantly lower than above hard surfaces such as along roads or in a hard surfaces open area (e.g. parking areas).

In hot dry regions parks and playgrounds should provide ample shade and protection from dust in summer, as well as protection from cold winds in winter. Large lawns and flower beds without shade contribute little to the recreation possibilities of the inhabitants - ordinary citizens, elderly, and children alike - to rest, relax, or play on a hot sunny day. Thus, plenty of places to sit in the shade should be provided along roads and trails in public parks, and in children's playgrounds. Shaded spaces for play and rest thus minimize the danger of over-stress and heat strokes.

Provisions for wind protection in urban parks is of particular importance in arid regions with cold winters. The availability of sunshine and the absence of much rain in winter can enhance greatly the attraction of settlements in these regions as winter resorts. This factor may be of significant economic value to the community. Protection from cold winds will help greatly in enjoying these qualities in the public urban parks.

ZANZIBAR STONETOWN - A PLACE OF MANY SEASONS

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Rehabilitation Zanzibar Stonetown

Zanzibar Stonetown, is an Arab colonial settlement founded by Sayid Said, Imam of Muscat and Sultan of Oman, when he moved his residence in 1832 to the long admired island of Unguja, better known as Zanzibar.

The stonetown developed rapidly on a strategic site at the western seafront of the Island, close to the protective guns to an older Omani fort.

Even when the Sultan himself resided first outside at Mtoni, his subjects took, immediately, the opportunity to build solid Stonehouses around the fort in Shangani and Forodhani; first of Arab character and style, later with an increasing influx of Indian administrators and traders, also in Indian style.

The applied technology was simple and well executed by foreign Craftsmen. There was massive lime/corral-stone walling with boriti (mangrove poles) limestone floor slabs. The early roofs were flat lime-screed slabs, similar to the one found in this dry Arab homelands. The layout of the house was of the courtyard type, its airy design corresponding well to the warm-humid island climate.

However, soon the disadvantages of the massive flat roof slabs were recognized. For Zanzibar, at the time the most advanced trading place in East Africa, it was no problem to apply the then most modern Western roof technology, i.e. corrugated mild steel sheets. Still, today, one can see the old traditional solid boriti/corral-stone roof slab of the first generation topped by a wooden roof structure covered with iron sheets.

With time, they use to turn rather unattractive in appearance, and corrode heavily. But one cannot deny them a genuine place in Zanzibar architecture.

With building ground becoming scarce at the more favoured locations, the compact Indian house type took more and more over, its more luxurious representations furnished with generously decorated verandahs, facing the main street. It does not require imagination to understand their climatic advantage.

The Indians were also the ones who introduced burnt clay tiles for roofing, climatically improved alternatively towards heat and rain protection. However, any of the more modest town houses could neither afford a courtyard nor a verandah. And this is perhaps the most adverse aspect of a model township transplanted by settlers into an unfamiliar foreign climate.

There are no early statistics as far as life expectations of town folk are concerned, in particular for women who under Muslim rules had rather to stay indoors. This meant being restricted for most time of the day to a damp poorly ventilated houses, a situation favouring tuberculosis and other diseases of the respiratory track. The densely built houses of the bazaar quarters are generally missing adequate ventilation, i.e. the access of the refreshing sea breeze blowing periodically sea and land-wards.

When possible, houses were often extended upwards with covered rood tops. But the majority of the houses had to go without such extravagances.

For more than 150 years after Sultan said's arrival in Zanzibar the stonetown went through many changes of social, economical, political and cultural nature. One of the most severe one was African Revolution in 1964.

An outcome of this was that many houses were taken over by a rural population without solid economic base. The result was a high degree of negligence and accelerated decay, leading to incidents of collapsing structures, killing people under their rubbles.

Reading through old descriptions of Zanzibar, one has to recognize that the collapse of houses is nothing new to the town. There were always neglected buildings, and if water has access to the lime masonry, the walls turn soft and lose their structural strength, leading to the consequent collapse. But these were single cases, and they did not constitute a general threat to the town as a whole.

When the imminent danger was realized, means of defense were identified. It was decided that some of the nationalized property had to be reprivatized in order to reencourage private initiative and responsibility. However, this is a rather slow process within an economy struggling for its survival. And still, the experience of the recent years proved that the attempt was the right policy.

Reprivatization was done through the sales of houses, not at market price but for an amount considering a degree of social justice.

The incoming funds were set aside by the Government. An Agency was created, the Stonetown Conservation & Development Authority (STCDA), which was charged with the rehabilitation of the stonetown.

Together with bilateral and multilateral support, the programme took off, and is now in its early stage, trying to develop various solutions for urgent demands;

To show public simple but effective maintenance and repair techniques;

To save badly affected building from getting completely lost;

To identify architectural values and to demonstrate their preservation.

It is an ambitious undertaking and the programmes should be careful not to raise expectations too high.

The attempt of rehabilitation reaches far into the operation of legislative and executive bodies charged with specific responsibilities towards the future of the stonetown. One of the issues is planning.

At the early stages of the town the situation was rather simple. A familiar model was transplanted with little concern for the consequences later, with increasing knowledge if the complexity of urban fabric and environment, corrections and improvement were designed, but often not implemented due to prevailing constraints. Today a new chance is offered.

There is ample knowledge and expertise in urban developments, and its control, also in urban climatology. The political will for implementations is required, the art of setting the right priorities has to be exercised, often against too numerous day-to-day temptations.

Land-use densities, physical scale, the economics of materials, distribution of plant cover, communication standards, life style, urban aesthetics, communal health, technical and artistic issues, all moving along the same line dividing planning from design. They are the ones which finally tame the suicidal tendencies of an uncontrolled urban organism, turning it into a living cultural asset-let us call it a humane environment.

Since the natural resources of the earth are becoming more scarce, the future generations might measure with a yardstick less generous than the one used by us and our forefathers. We should keep this in mind.

WORLD METEOROLOGICAL ORGANIZATION (WMO) ACTIVITIES IN URBAN AND BUILDING CLIMATOLOGY

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Commentary **Accepted May, 1990**

Accelerated urban growth, some call it "the urban explosion", especially in the developing countries is placing a severe strain on the urban environment. For good or bad, man has manipulated climate over the ages. Significant climate change was probably first observed with urbanization. Urban developments mean changes in surface roughness and sometimes, even in the topography, altered surface characteristics with regard to radiation, permeability and thermal inertia, among others, and urban activities produce heat, air pollution and other disturbances relative to an uninhabited natural environment. All these changes and alterations also contribute to a change in the local climate which generates an urban climate.

The urban fabric consists, to a large extent, of man-made constructions and buildings. These are dependent on the prevailing climate for their functions and they influence and alter the local climate, at least in their immediate neighbourhood. One well known climate alteration is the "Urban Heat Island" (UHI), which has obtained special attention in connection with the debate on global and large scale climate change. In this case the UHI effect is considered noise in the temperature records and has to be filtered out before any true possible climate change signal can be detected. The most important reason for concern over local/urban climate change, however, is that this is the change which has the immediate and most direct impact on large populations. Climate and its relation to human health and comfort is thus closely related to the urban climate. WMO has a long record of activities in the area of Urban and Building Climatology (UBC) as well as in the area related to Climate and Human Health (CHH).

The first Congress of WMO, in April, adopted Resolution 33, which established Technical Commissions. Included in the terms of reference of the Commission for Climatology (CCI) was the item "(h) Application of *climatological data to man, his comfort and his activities;*". In March 1953, the first session of CCI established a working group on the subject and in December 1960, CCI established a Working Group on Human Biometeorology. After the UN Conference on the Human Environment held in Stockholm in June 1972, a WMO Working Group on Applications of Meteorology and Climatology to Environment Problems was established. During its meeting in December 1972, the group included Human Biometeorology as a major topic.

UBC has been in the focus at several meetings within WMO since the fifties. A major breakthrough came with the Symposium on Urban Climates and Building Climatology held in Brussels in 1968, which was organized jointly by WHO and WMO. Since then, several meetings have been organized by WMO on topics related to UBC, in some cases jointly with other organizations. Guidance material and reviews have been published by WMO, e.g. as Technical Notes and other Technical Documents (see below).

A popular information pamphlet on "Climate, Urbanization and Man" was prepared and widely distributed by WMO. New or updated sets of guidance material are continuously being prepared. Emphasis is also placed on education and training in the UBC area and several regional training seminars are planned. A not-uncommon problem is the lack of sufficient financial resources.

It should be obvious that climatology and meteorology are important components in Urban Building activities. Emphasis is now placed on the definition of user requirements and evaluation of potential economic benefits in specific climate applications. This is a continuous process as climate applications have to be adjusted to meet changing conditions and experience, keeping in mind the local physical, social and economic context.

Assistance will be given to National Meteorological Services to develop project-oriented activities with planners, designers and decision-makers. In particular, techniques will be developed to estimate climatic parameters at locations where standard meteorological observations are not available. A focus in the years to come will be on a major project.

The major goals of Tropical Urban Climate Experiment (TRUCE) are to improve our understanding of urban climates in especially tropical areas and then to use this knowledge to help improve the environment, and thus the living conditions in the fast growing low attitude urban centers. A true challenge for the future, but this is discussed in more detail in another paper in this issue of African Urban Quarterly (AUQ).

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TROPICAL URBAN CLIMATOLOGY AND THE TRUCE PROJECT

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Abstract

Rapid urbanization is taking place in the tropical world even though Africa is now the least urbanized region in developing countries, its rate of population growth is the highest. By the end of the century, more than 340 million will be living in cities. The accelerated urban growth has been putting pressure on such high priority services as sewage, water supply, education. Also, the mainly chaotic urbanization is leading to environmental degredation, e.g. air pollution, heat stress, poor ventilation. In order to address the climate-related problems in tropical cities, the World Meteorological Organization is endorsing the development of an international meteorological experiment (the TRUCE project) to better understand the urban tropical atmosphere. In this article the highlights of this project are described.

1. The climate-related problems of urban growth in the tropics.

Accelerated urban growth in developing countries (most of them in the tropics/subtropics) has been observed in recent decades. The uncontrolled flow of migrants to the cities has led to the proliferation of large metropolitan areas. By the year 2,000 the number of cities with more than one million inhabitants will increase threefold from the 52 cities that existed in 1982. Beside putting pressure on high priority services, such as sewage, water supply, and education, the mainly chaotic urbanization is leading to environmental degradation (e.g. air pollution, heat stress). Even though Africa is now the least urbanized region in the developing world, its rate of population growth is the highest, and at the end of the 1990's more than 340 million (42 % of the total population) will be living in cities (U.N. Centre for Human Settlements, Global Report on Human Settlements; New York, Oxford University Press, 1 987).

Despite the acclimatization to heat by the inhabitants of the tropics, increased morbidity and loss of productivity may result from the extra stress contributed by heat-island growth in large cities. Although tropical regions are projected to experience relatively small changes in temperature resulting from greenhouse gas warming, this increase in temperature, albeit small, will exacerbate the above mentioned health-related problems.

Although air conditioning is not yet generalized in the tropics, new buildings show a tendency to move away from traditional passive means of cooling and, as cities and their heat island grow, the demand for power to run air conditioning equipment will spiral. This implies for many developing countries, increasing expenditures on imported energy supplies for air conditioning. Further, this heat-island related additional power consumption would also contribute to the problems of carbon dioxide and pollutant release, and probably to the depletion of a non-renewable resource.

Even though tropical cities are considered generally less industrialized, many of them are plagued by high levels of air pollution mainly due to the inadequate siting of industry with respect to prevailing winds aggravated by local topography. Moreover, only exceptionally, tropical cities have the means to monitor air pollution, let alone enforce air quality standards so as to reduce emissions. To the mostly uncontrolled air pollution sources must be added the fact that many tropical inland cities experience weak ventilation, their atmospheres being prevailingly hot, thereby increasing their reactivity to pollutants. Such conditions are partly responsible for the observed increase in respiratory, cardiovascular, and cancerous diseases in large tropical cities.

2. The poor state of tropical urban climate knowledge.

Even though some progress has been accomplished in the last decade in the field of urban climatology, work in tropical areas still represents a small fraction of that published in urban climatology. Moreover, the nature of the work does not hold the promise of gaining rapid insight into the basic physics of the problem. The necessary descriptive base is largely unstructured and highly specific of the city involved. Most of the work is based upon data from standard stations, which are rarely ideal to monitor the urban system. There is little information concerning the state of the atmosphere above roof level, and there is almost no work into the underlying atmospheric processes.

The reason for this poor state of affairs can be traced to the relatively poor base of meteorological resources available to research workers. These include insufficient numbers of trained personnel, and a lack of research funding, equipment, computer facilities, and expertise. A contributing factor is perhaps the little demand for information for urban planning or environment management.

To address these problems, during the WMO Technical Conference on Urban Climate in 1984 in Mexico City, it was recommended that an international meteorological experiment be undertaken to better understand the urban tropical atmosphere. This project is now known by its acronym TRUCE (Tropical Urban Climate Experiment) project. The original project was presented in a paper by T. R. Oke, R. Taesler and L. Olsson at the WMO/CIB/IGU/IFHP Conference on Urban Climatology held in Kyoto in November 1989.

A recent development in the field of tropical urban climate has been the International Symposium on Urban Climate, Air Pollution and Planning in Large Tropical Cities that took place in the city of Guadalajara, Mexico in November 1990 under the auspices of the Mexican Meteorological Society (OMMAC) and the World Meteorological Organization. Papers on air pollution (24), urban climate (27) and urban planning (13) in tropical cities were contributed by mid-latitude (Canada, U.S.A., England, Israel) and indigenous (India, Malaysia, Argentina, Chile, China, Mexico, Kenya) participants.

During the last days of the conference a group of experts on urban climate were invited by the WMO Secretariat to discuss a WMO project on a Tropical Urban Climate Experiment (TRUCE). The 'core' group at the Guadalajara Meeting reviewed the draft plan of action for TRUCE prepared by the Commission for Climatology rapporteur on Urban and Building Climatology of WMO and made further suggestions. The draft plan was mainly based on the papers by T. R. Oke, R. Taesler and L. Olsson mentioned above.

3. The plan of action of the Tropical Urban Climate Experiment (TRUCE).

The project has been divided into three sections:

3.1 Goals
3.2 Education and training
3.3 Scientific tasks

3.1. The goals of TRUCE

1. Initiate, coordinate, and implement observational and theoretical research programmes. These should include studies on the ways in which various features of the physical structures of cities affect the urban climate and thermal stress of the inhabitants, the consumption of energy (cooling, etc.), and the dispersion of pollutants.
2. Improve the health, well-being, and productivity of the population by improving the urban and building climate.
3. Conduct experiments and develop models, so as to better understand the tropical urban climate and improve, through urban and building design, the urban environment.
4. Make available the results from activities related to TRUCE, with the aim of promoting the use of climate information for improving building and urban design.
5. Establish links between researchers, and create international collaboration and coordination of research in urban meteorology and other related fields.

3.2 Education and training

1. To developing countries steps (see below
   - A. Expert missions
   - B. Educational materials
   - C. Attachments to join projects

Steps:

1. Develop topics
   - a) Field studies
     - (on urban climate, air pollution) site selection, instrumentation, observation.
     - Data management/quality control, data achieving.
   - b) Building climatology and planning
     - design; passive cooling, ventilation, passive solar heating
2. *Prepare educational material*
   - Brochures; video/tapes; computer programmes, resources lists.
3. *Select experts*
   - Training seminars and mini-classes through WCP
   - Establishing pool of experts
4. *Identify recipient member countries*
   - Establish selection criteria

- WMO to request letter of intent
- •Final selection

5 *Coordination with steering committee*
- Set schedule for 3,4 above
- WMO to seek funding
- Identify joint projects (mid-latitude/indigenous groups, government to government, and between institutions, universities, etc.)

II. Developed countries
WMO to request Members to earmark scholarships for TRUCE-related projects.

3.3. Scientific tasks

		tasks (see below)
1.	Descriptive (long/short term)	b,d
2.	Process studies	c
3.	Model development for tropics	a,b,j,k,l
4.	Intensive studies	
5.	Synthesis and application	e,f,g,h,i,m

3.4 Scientific experiments/tasks

a) Boundary layer modelling b)Emission inventories for air pollution models c) Heat island structure/processes d) Effect of urban morphology on local urban climate patterns e) Building design and indoor ventilation f) Indoor air pollution g) Effects of green areas on urban climate h) Urban temperature and wind structure modelling in complex terrain i) Urban climate/health impact studies

4. *The Technical Conference on TRUCE.*

The TRUCE core group at the Guadalajara Meeting recommended that a conference be organized to be tentatively scheduled for the October-December 1992 period in a tropical city with the sponsorship of WMO/CIB/IFHP/IGU. The purposes of this conference would be to: a) assess the state of understanding of the atmospheric environments of tropical cities and our ability to use urban climate information to improve the living conditions of their inhabitants . b) present the plans for initial projects in the TRUCE programme involving both research and applications. c) refine existing, and create new projects for TRUCE, via extensive conference and workshop discussions. d) present the results of ongoing and planned work in urban and building climatology.

The field of urban climatology in the tropics is young and, as stated in the original paper by Oke and collaborators "the opportunity to investigate tropical urban atmospheres will open up a whole range of new possibilities, because tropical systems present a new set of boundary conditions and a forum in which to test the transferability of our much larger temperate latitude knowledge and experience".

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DEVELOPING WORLD WATER, edited by Water Engineering and Development Centre,: Hong Kong, Grosvenor Press International, 1988, 420 pp. Price: Not Available

In the last two decades, there has been a proliferation of literature on water resources development. This trend has been caused primarily by the realization that water resources, like any other resources, may be depleted through either over use or by pollution. In Africa, the challenge has been aggravated by the recurrent droughts that have put nearly one-quarter of the continent in jeopardy. However, the problems facing water resource managers in the More Developed Countries (MDCs) is basically of pollution and over use.

Developing World Water is an essential reading for the water industry worldwide. It has over seventy features and more than two hundred and fifty illustration that makes reading easy. The authors are drawn from a wide spectrum of professionals including engineers, natural scientists, sociologists and economists, amongst many others, and they have worked professionally in the Less Developed Countries (LDCs) for many years. Evidence shows also that the authors are fairly recognized in their area of specialization because they have served with the United Nations Agencies and other international organizations.

The book is divided into nine sections excluding a bibliography, list of contributors, conference proceedings and publishers and buyers guide. The first three sections present water resource development in Africa, Asia, Pacific, Latin America and Caribean. In these sections, emphases is placed on low level and appropriate technology, community participation, rehabilitation of old systems and problems associated with tropical hydrology. In accordance with the sentiments of World Health Organization and the first International Drinking Water Supply and Sanitation Decade water supply, sewerage treatment and sanitation are discussed together.

The fourth section deals with groundwater and other water resources. Although a disproportionate number of contributions in this section come from Nigeria, the section highlights recent developments in methodology and information acquisition in groundwater development. Research needs in groundwater resources apparently will continue to receive attention because most of the countries that are affected most by drought must rely on groundwater sources, on one hand, while the others in LDCs face the problem of groundwater degradation.

The fifth section of the book deals with water and wastewater treatment. The topics covered in this section are diverse including chlorination, desalinisation, and filtration techniques. While emphasis continue to be placed on the appropriateness of technology, the authors do not hesitate to demonstrate some latest findings of research in water quality.

The sixth section presents contributions on water for agriculture. Resolution of the Mar del Plata Plan of Action recognised the enormous deficit of food and agricultural production and outlined a specific "Action Programme on Water for Agriculture". The contributions cover popular albeit important topics on irrigation water assessment, appropriate technology and wastewater use of irrigation. Africa and Asia have the oldest traditions in irrigation and, therefore, one would have expected an evaluation of the impact of irrigation both to socio-economic development and also to environmental degradation.

The seventh section deals with water for power. There is one paper only presented in this section. There is vast hydropower resources in Africa nearly one-third of the world's power resources. The present installed capacity is only 5 percent of this total. Multipurpose hydroelectric power projects are being recommended in order to maximise water resource outputs. Besides the oil-producing LDCs, the area of hydropower needs to be a priority because power production is an important infrastructure needed for economic and social well-being.

The last two sections present contributions on water delivery systems and specialized services. It is generally one thing to develop water supply schemes and another to obtain full benefits from it due to problems associated with operation and maintenance. In many LDCs, water supply projects have little or non-sustainability built into them. Lack of sustainability has been attributed invariably to low community participation, under-costing of the projects, inappropriate technology and poor planning and project implementation procedures.

Developing World Water is one of well-focus, concentrated treatise on some of the problems of water resource development in LDCs. It is recommended for reading to every serious resource planner and especially to those in the field of water supply and sanitation.

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CLIMATOLOGY OF WEST AFRICA by D.F. Hayward and J.S. Oguntoyinbo
London: Hutchinson Books, 1987; 271 pp, Price £14.95

The book is divided in three major sections. The first section describes in detail the climates of West Africa while the second section explains these climates within the framework of global and local circulation patterns. The last section recognizes the importance of climate and goes on to show how it affects everyday life in the area. In all, there are 15 chapters. Each of the chapters has numerous illustrations in the form of figures and tables of oversimplify the otherwise complex concepts being discussed therein. Various references are also cited in every chapter. These are very important aspects of the book. It provides very useful data and bibliography for any reader who may be interested in tackling any climatological problem in the area.

The first chapter examines in detail three closely related climatic elements in the area, namely, radiation, sunshine and temperature. The chapter begins by giving the reader insights of what is known about these elements on a global scale and their distribution before focusing on West Africa. I find this approach to be proper in that it helps one appreciate the fact that in climatology, whatever that happens on a global scale (macro), has some bearing on a local scale (micro). The authors give very good illustrations of the diurnal and seasonal variations of these elements in the area.

In chapter 2, the authors illustrate how atmospheric pressure and wind patterns are closely related. With the aid of maps and wind roses, the authors show very clearly the diurnal and seasonal variations of these elements in the area. Most wind velocities discussed in this chapter are ..."recorded at, or estimated for a height above open, clear ground of about 9 meters" (p. 56). The authors conclude the chapter by briefly discussing upper tropospheric winds in the area although they concede that upper air movements in the area have not been undertaken regularly.

Chapter 3 discusses three climatic elements namely: evaporation, evapotranspiration and humidity in the area. The authors discuss each element by first defining it, then how it is measured and its duirnal and seasonal distribution in the area by use of figures and tables.

In chapter 4, cloud and visibility are discussed. I commend the authors for sparing a chapter to discuss these elements which more often than not are given inadequate treatment in Tropical Climatology books (e.g. Nieuwolt, 1977). The authors first discuss the types of clouds found over West Africa. This is followed by a discussion of the regional patterns of cloud distribution in the area. Visibility as the authors define is... "the maximum distance at which an object can be seen" (p. 78). The authors give a brief but useful description of visibility in the area for selected months using maps and tables. Such information is very useful particularly for the aviation industry.

Chapter 5 focuses on precipitation and water balance in the area. From a social and agricultural points of view, precipitation in the form of rainfall is by far the most important climatic factor in many of the tropical countries (Barring, 1988). The authors begin by giving examples of the different types of precipitation found in the area. More attention is paid to rainfall for the reason given above the authors illustrate the various characteristics of rainfall e.g. variability and intensity by use of isohytes, tables and graphs. The authors discuss the water balance by giving examples from selected stations. They conclude that water surplus increases southwards in the area. A serious shortcoming of this section on water-balance is the authors inability to adequately relate water balance to say agriculture. I would have expected the authors to consider such areas as water balance studies - their application to agriculture, the role of agricultural techniques in crop-water relations and rainfall regimes and crops in the area (C.F. Jackson, 1989). Such a coverage would have been adequate for this section.

Chapter 6 focuses on thunderstorms and line-squalls in the area. A detailed account of records, distribution and frequency of thunderstorms is given by the authors. These accounts are illustrated visually using maps and graphs. A brief section of the conditions in a storm is also given. Line squalls are disturbance lines (p. 109). This section on line squalls is given a similar treatment as thunderstorms.

In chapter 7, the authors try to explain the seasonal variations in the seasonal variations in the parameters discussed in chapters 1 through 6. The Inter-Tropical Discontinuity (ITD) is identified as a significant factor in explaining the pattern of weather characteristics in the area. The authors conclude the chapter by reclassifying and mapping new climatic regions of West Africa on the basis of length and dates of the rainy season. On the basis of these criteria, ten climatic regions emerge.

Chapter 8 through 10 deal mainly with the atmospheric circulations over West Africa with a view to explaining such anomolous local climatic phenomena such as line squalls, Togo gap and recent climatic fluctuations in the area. I feel that the authors should also have addressed the much publicised *El Nino/* South Oscillation (ENSO) phenomenon which scientists have sought to seek teleconnections with specific anomolous weather events in various parts of the world. Glantz (1987), for example, has examined the impacts of the 1982-83 ENSO advent in West Africa and found evidence of teleconnection.

In Chapters 11 through 14, the authors consider the relationship between climate, water resources, agriculture, forestry, health, industry and development in the area. The authors thoroughly elucidate these applied aspects of climatology by giving numerous examples from the area. Chapter 15 focuses on the human impact upon climate in the area. I submit that the authors did not give this chapter a thorough treatment. For example, man has had an impact on climate through land use patterns, i.e. urbanization (Adebayo, 1987). These are some aspects which the authors should have addressed in this chapter.

When revising this book, I urge the authors to give special treatment to drought in the area unlike the shallow discussion they have given it presently (p. 159). Other areas which also need consideration include desertification in the area from a climatological view point and some aspects of acid rain if any. The above lines of thought will no doubt make the book comprehensive in scope.

This book has a lot to recommend. It is written in a simple and clear language. The authors display an excellent use of visual aids which make reading quite interesting. The glossary at the end of the book enables the readers have quick access to definitions of terms used in the text when reading. The book is suitable for physical geography students at both under-graduate and post-graduate levels. The references therein are adequate and up to date; and as such the book is perhaps the most authoritative and up-to-date on climates of West Africa.

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Helen I. Safa, **TOWARDS A POLITICAL ECONOMY OF URBANIZATION IN THIRD WORLD COUNTRIES**
New Delhi: Oxford University Press, xVI + 315 pp. Soft Cover,Price Kshs. 60.00

The book edited by Safa introduces a new conceptual framework on addressing the issue of urban growth in the Third World countries and call it "a political economy or urbanization in third world countries".

The works in this book recognize first and foremost the historical process of urbanization in developing countries as radically different from those in advanced countries without any comparisons such as the development theory models, or W. W. Rostows (1960) stages of growth. Safa urges that even the ecological class structures of Third World cities are ecologically different from those of the western industrial ones. Unlike the development theories, safa does not attribute the problems of the Third World to its inability to conform to the western models, neither does her historical perspective fall prey to the dependency theories that solely blame the "metropole" economies for the failure of the development of under-development in "peripheral" economies.

While noting that the problems of hyper-urbanization in the Third World have to do with the late entry of the Third World in to the global capitalist economy, Safa in her introductory note, points out that the dependency theory focuses only on the external economic forces both at the national and international levels which shape the political economy of the developing nations. Safa moves further than this orientation when she tries to assess the impact of macro-political and economic forces on the micro-institutions such as the family and kinship, rural urban migration and small scale enterprises in the informal economy.

(1) The approach by Safa focuses on the dependent nature of capitalist development in the Third World, which places more emphasis on such factors as external forces in the study of cities.

(2) The importance of historical processes examining the changes which have occurred in the structure of cities as a result of the switch from pre-capitalist mode of production.

(3) The class structure of the cities particularly the way in which the urban and rural poor subsidize the informal sector of the economy by providing cheap goods and services and above all employment.

(4) The role of the state in shaping the process of urbanization by lending its support and thus strengthening the power of the elite and the formal modern sector in various ways.

The book can be divided into three broad themes. The first focuses on the informal economy as a means of survival in the urban sector. It is portrayed not only as a way of providing a brake on the expansion of the modern capitalist sector, but also provides employment to those not directly employed in the formal sector. By the nature of its capacity to absorb a huge labour force the informal sector sustain large numbers of the urban services as water, electricity schools and even health services. Castelles illustrates this using the squatter settlements of Latin America in Peru, Chile and Mexico. He portrays vivid cases of collective organization and action by the marginalized linking the urban crisis directly to the phenomenon of deprivation in the informal economy. He shows, for instance, how the evolution of the new urban movements in Mexico will be determined by the interaction between the interest of the squatters, the reformist policy of administration and experience of the new radical left trying to learn how to lead urban agitations. Singer, using a case of squatter settlements in portrays them as survival strategies for the urban poor in Sao Paulo shows how the poor are uniting in defence of their rights unlike earlier studies that dealt with the poor and portrayed them as passive recipients of aid. The two case studies of Sao Paulo and Mexico show that organized action among the poor is attaining growing political implications.

On the informal sector, a strategy geared toward maximization of earnings and minimization costs and level of consumption is portrayed. In this sector, as many members of a household as possible are engaged in income generating activities including women and children, as shown in the case of Calcutta. Barnejee is highly critical of those who seek a solution in the problem of urban unemployment in the informal sector not only because it is exploitive of the poor but because it lacks any inbuilt forces to improve this state of affairs. However, together with cases from Latin America by Arizpe, a show piece of how the tasks of the family members are divided is shown. They may include subsistence activities *in the home*, such as gardening and rearing small animals together with the formal and informal economy.

The book further shifts attention to the nature of articulation between the formal and informal economies. Contrary to earlier notions that regarded a separate and discreet nature of the formal and informal economies, this new perspective recognizes the two sectors as strongly interdependent. Tanga and Barnejee in their cases studies in India, Remy in her case of Zaire, Nigeria and Peattie's case of Colombia demonstrate the informal sector as dynamic and one that constantly reconstructs itself in response to changing conditions in the modern sector.

Interval differentiation in the Third World countries is understood from the level and nature of capitalist penetration. Lobban illustrates how the development of cotton plantation economy in the northern Sudan fed by a British colonial policy in the early twentieth century led to uneven development between the north and the south. This explains the current burgeoning grown population in Khartoum. This perception rates far better than the kind of explanation that the dual economy perspective would adopt in such instances. In Nigeria, Remy associates ethnic hostilities to differential access to education and better employment facilities. She illustrates the role of the state in continued domination of the formal over the informal sector where the former enjoys quota protection among others which the informal lacks.

Peattie raises the issue of government support for small firms in Colombia which constrasts with Remy's contribution. A comparison of Peattie and Remy's work shows that the degree of articulation between the formal and informal sectors increases with the level of capitalist development.

The importance of the household in the urban economy as a survival strategy is introduced by Tanga in her case study in India and shows how extended families can continue to act as a productive unit in the urban sector, an idea that for a long time was assumed as confined to the rural setting. In Lebanon, Joseph shows the family as a primary source of security. He also examines how capitalist penetration by foreign powers weaken the powers of the state in the Third World and makes it more difficult for the development of a viable nation and economy, because the foreign powers have so weakened that state that is, has failed to develop any strong intermediary institutions and the foreign power have therefore continued to function on the basis of personalistic patron client ties which tie members of the ruling elite to certain families, to whom they can offer patronage and other benefits in exchange for political control. The transition from a subsistence economy to an urban informal economy and further to increased articulation between the formal and informal sector especially in Latin America, and internal differentiation, is a glaring product inter-lia.

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AFRICAN CITIES IN CRISIS: MANAGING RAPID URBAN GROWTH

Richard E. Stren and Rodney R. White (eds) Boulder, Colorado: Westview Press, 1989, pp. xiii +335.

Since African urban centres are growing at unprecedented rate, under adverse economic conditions, national and local governments are faced with a very difficult situation - a crisis one could say - of managing this growth. This book is about the structure of local (urban) authorities and their efforts (where these exist) to provide services to their burgeoning populations, in a number of areas like housing, education, health, sanitation, transport, water, refuse disposal, energy and planning. There are case studies based on research findings drawn from seven countries and 14 urban areas i.e. Nigeria (Ibadan, Onisha and Kaduna), Cote d'Ivoire (Abidjan), Zaire (Kinshasa), Senegal (Dakar), Tanzania (Dar es Salaam, Morogoro, Moshi, Tanga, Tabora and Mbeya), Sudan (Greater Khartoum) and Kenya (Nairobi), Everywhere the story, with a few exceptions, is of abysmal failure; is of plans and targets, where they exist - falling short of expectations.

The choice of case studies appears to have been based on factors other than the true representation of Africa since countries covered are those poor ones in the middle belt. The Arab north is not covered - Sudan not being a true representative. The South is also not covered (Botswana is even missing on the map of Africa facing page 1). This is a bit sad since one of the causes of the crisis, if crisis we may call it, is adverse economic conditions. It would have been interesting to know what the situation was, in rich African countries like Botswana and Libya.

However, coverage of both Francophone and Anglophone countries is most welcome, and for an Anglophone reader, it was very instructive to learn of what is going on in Zaire, for instance. In this respect, White and Stren and their colleagues must be commended for translating three of the articles from French, although sometimes the translation is too literal and one doesn't quite get the meaning.

One general observation is that the case studies are not presented in comparable format, and this is not justified by the editors' contention that each country has its own agenda of urban issues (p.xii). Administrators and politicians, as well as academicians would have benefited more if the papers were presented within a comparable framework. As they are, the spectrum and depth of issues covered and even sometimes the terminology, differ very much . For example "waste disposal (or management)" is used to mean refuse disposal in one paper, both waste water and refuse disposal in another, and simply water and sanitation management in another. The illustrations, too differ. While some maps show the aerial accretion of the urban areas over a given period, others just show the position at a given point in time. Thus, while the information on the case studies is there, comparability is not there. This could be considered a major weakness, a weakness, which otherwise viewed, is strength, since each chapter is so different from the other.

In chapter 1, White gives a run down of the economic and environmental factors related to the urban crisis. Rapid urbanization is shown to cause environmental stress in an area, like sources of eater energy and food supply, and sites of dumping waste. It is, moreover, taking place in harsh economic circumstances characterized by high population growth rates, inclement weather, high price of petrol, a very strong USAS, a non-expanding world economy, adverse terms of international trade and a domestic pricing system favouring urban dwellers. All case studies have economies expanding at rates less than those of their population growth and since 1980, all have gone down the world table of GNP per capita.

In chapters two and three, Stren surveys the general growth and structure of local governments and the provision of services in Africa, highlighting the differences between Anglophone and Francophone countries. The former have a larger traditon of local governments which also provide services, but are now tending to centralization. The opposite is the case with the latter who, morever, have a tendency to sub-contract the provision of services.

In chapter 4, Onibokun presents the case of service supply in Nigeria, curiously missing out sanitation. He also does not talk of spontaneous areas and suggested that the outer areas in Nigeria urban centres are high-income areas *a la* Burgess's Concentric Zone Model[1]. This is all the more surprising considering that 75% of Ibadan's population lived in unplanned area in 1971[2]. The conclusion, that small growth centres can stem migration to the larger urban areas is contradicted by the conclusions of the book itself (p.307). Not all is gloom and doom in Nigeria though. Energy appliances acquired by about 50% of the respondents are electric fans, irons, and stoves, television, radios and kerosene stoves and all of these are not 'really a luxury' (p.97). 94% of the urbanites use electricity for lighting and only 29% and 4% use firewood and charcoal, respectively, for cooking (p.102).

In chapter 5, Attahi evaluates the effectiveness of the first five years of urban reforms undertaken since the late 1970s in Cote d'Ivoire and here we get some good news. The city (of Abidjan) is well provided with material resources" (p.130). "The Development of municipal revenues has began to take off" (p.136). "On the whole, political structures have worked reasonably well" (p.142). Democratic participation is still not realised, (p.145) but, "some mayors have demonstrated a great degree of imagination in managing to install facilities at relatively low costs (p.146). It is not crisis throughout after all!.

In chapter 6, Mbuyi discusses the problems of land management, infrastructure and food supply in Kinshasa. The picture is bleak. Food consumption is falling, there is stagnation of economic activity and employment, and private and public consctruction is minimal. The evolution and appearance of the urban centre owes much to the initiative and dynamics of its citizens. Traditional approaches to urban management have had little impact (p.149). What little land management there is, works in favour of speculators. Decentralization is yet to work. On the whole, the management of Kinshasa appears to need to be kickstarted to come to life.

In chapter 7, Ngom discusses the urban reforms in Senegal, but finds the system still in a confused state with lack of clear definitions of division of power and responsibility. Dakar has problems in most service spheres. Many services are subcontracted but high bills from these private companies are threatening the system. The paper discusses public toilets, which other papers have largely ignored, and which must be a big problem in many African urban centres. In Dar es Salaam at least, none of the public toilets is operative.

In chapter 8, Kulaba presents the case of Tanzania drawing from six urban areas, the largest total in all the papers. The concentration though is on Dar es Salaam. The picture of services is poor particularly in respect to sanitation, refuse collection, roads and planning. All the same, nobody is reported to be unemployed or to rely on rivers or wells for their water supply. The paper has valuable information on local authorities in Tanzania, but could have benefited from meticulous editing as there are subtle but annoying misconstructions and errors. For example: A census does not "estimate" (p.208). It is an official count. An "average" is not "about 2000 to 2150 plots" (p.226). It is either one figure, or between one figure and another. Bureaucracy is singular, much as it refers to a body of officials (p.221). There are also a few mathematical flaws. For example, 23,865 out of 100,000 is not 26.5% (p.226), nor is 8964 out of 19600, 43%. Again, the data given shows that Dar es Salaam is not "the most densely populated urban area in Tanzania" (p.206). Moshi is.

Some concepts in this paper are infuriating. How can an African call urban agriculture a 'health hazard"? (p.227). Surely Okpala's paper written in 1987 needed a wider readership[3]. Finally the solutions suggested to the problems, require more money, local and foreign, but no sources are proposed while the suggested rigorous enforcement of byelaws underplay the powerful local forces against such a course of action

In chapter 9, a team led by al Sammani discusses the management of Greater Khartoum in its unique three tie system: the neighbourhood councils, the town councils, and the city councils. Performance is (dimally) poor and self-help is a crucial element in local government. It is only in this paper that pit latrines are shown as a possible solution for sanitation in some areas. The team calls for predictive models to help planning, but their call for the removal of rural-urban imbalances as a way of reducing gravitation to Khartoum is far from convincing.

The last chapter, by Smith is about an informal mode of urban transportation in Nairobi - known as matatu, which is now legal, but which planners are yet to take into consideration in their schemes.

There is a "conclusion section" in which suggestions - not very strong one dare say - are given, calling for integration of urban management, for more effective decentralization, and for the collection of the necessary information on which management can be based. There is awareness that it may not always please the powers that be that information is collected and documented, as exemplified by the extreme case of Nigeria lacking census figures.

There is a lot of moaning in the book about failures but former Tanzanian President Nyerere's classification of problems into those within our powers to solve, and those without is of relevance here. The book should have identified and suggested solution to problems within the capabilities of the authorities to solve. Surely the squatters who defecate in the open in Khartoum (p.262) can dig pit latrines; and the noble Kinshasa residents who depend on water contaminated with faeces (p.159) can think of low cost water filtering methods. If there are no garbage lorries, there could be hand carts surely! If water-borne sanitation is impossible, pit latrines are possible. The labyrinthine bureaucracies, the pilferages, corruption and mismanagement are areas within "our" powers to solve. This local solution and self-help potential is given scant attention in the book, as is the employment and service provision potential of the "informal sector."

Lack of stronger conclusions and recommendations - "there is no formula, no simple cliché like "good government" (p.311) - is perhaps a result of the non-comparability of the case studies and the differing views expressed. Kulaba is wary of private buses (p.241). Lee Smith thinks these should be fully accepted and integrated. Onibokun, and Sammani et al. call for smaller growth centres to reduce migration to bigger urban areas, but the opposite is said in the conclusion: "the old belief that secondary growth centres could reduce the rate of rural to urban migration should be abandoned" (p.307); the Nairobi City Council was dissolved, *inter alia*, because councillors mismanaged the land allocation system (p.295) but in Cote d'Ivoire, mayors would like to be Chairmen of Land Allocation Committees (p.116), and so on.

Despite what has been said above, this is a very good book, the best book that has come out in recent times on African urbnanization and perhaps the only of its kind on the issues of management of services in Africa's cities. It is a must for all academicians, politicians, administrators, students and all those with an interest in African urbanization. The wealth of information in it is a treasure of its kind, and is likely to be useful for many years to come, and the fact that the systems are shown not to be measuring to the problems facing them should lead to the editors' wishes: Support for the improved management of African cities.

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3 The study of urbanization and planning, in relation to the quality of human life, deals with aspects of medicine agriculture, demography, transportation, political science, geography, history, sociology, economics, statistics, mathematics, urbanization, anthropology, archaelogy, education, law and environmental studies; and they must be brought to bear on the development of human life on rural as well as urban areas. AUQ welcomes manuscripts which focus on any of the problem areas just mentioned provided that the link between the subject treated and the central problem of the comparative urbanization and planning in Africa within the rest of the world is reasonably clear. In particular, we shall be happy to have manuscripts that are: (1) reports of empirical investigations; (2) studies of methodological problems; (3) studies of *real world situations* in Africa alone or compared to the rest of the world; (4) philosophical analyses of basic urbanization and planning theories; (5) prescriptions for policy research and practice; and, (6) reviews of current research, findings, information and interpretations of general interdisciplinary interest to African studies. In general, AUQ encourages and publishes quality papers reformulate traditional ideas within the context of *quantative and behavioral research.* AUQ IS A HEAVILY REFEREED JOURNAL.

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6 Four copies of manuscripts should be submitted, typed with lines double-spaced and with wide left hand margins.

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8 Appendices should follow immediately after the main text; any notes and references should be placed next. Acknowledgements should follow the notes, references, tables and charts.

9 Tables should be sequentially numbered in the order in which they are referred to in the text, and should be included in the text. Each table should have a brief descriptive title and source, both of which are written in lower case.

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