Advances in Science and Technology, Vol. 4, No. 2, September / October 2010, pp 91 - 97

Research Note

Day-Time Surface Air Temperature Variations at Locations In Owerri Capital City; Indications of Urban Heat Island Build-up?

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(Submitted: June 15, 2010; Accepted: September 10, 2010)

Abstract

We summarize the preliminary results of an on-going study of Urban Heat Island (UHI) build-up at Owerri capital city. Measurements of surface air temperatures were conducted during the day time (8a.m-6p.m) at 2-hour intervals for one week (from Monday 6th to Monday 13th of March 2006) at 7 locations within Owerri metropolis (Naze, Emmanuel College, St Paul's Catholic Church, AICE, Egbeada Housing Estate, Kedeni-Amakohia, and Imo State University Love Garden). The aim was to deduce the possible roles of urbanization on surface air temperatures within the metropolis and environs. The temperatures were highest at the city centre (St Paul area) and lowest at the semi-rural settlements of Naze and Egbeada. Locations with highly varying anthropogenic heat release such as Filling stations (for E-college and Kedeni) and Student's park (IMSU love garden) recorded large temperature jumps within a day compared to other locations. The day-time temperature averagely peaked at about 2pm at all stations even with the well known equinoxial solar declination maximum at noon suggesting that quick re-radiation of absorbed solar radiation from surfaces played significant roles in the observed day-time temperatures. It is expected that day-time power demand for air-conditioning would peak around this time in the town.These preliminary results generally reveal the influence of factors such as buildings, population, traffic, green area and rivers in temperature build-up in the city. Nighttime variations and attempts at parameter-based modeling shall be reported in subsequent papers. The UHI study is intended to assist town planners and atmospheric scientists who may wish to have information about temperatures in major cities in Nigeria and Africa.

Keywords: Urbanization, Urban Heat Island, Temperature, Anthropogenic, Owerri.

1.0 Introduction

Surface air temperature is a parameter that is very influential in defining changes in the global climate such as global warming, (IPCC, 2001). Global warming phenomenon is currently linked to increasing greenhouse gas concentrations and absorbing aerosols amongst other factors. The intensification of warming within urban environments generally referred to as the "Urban Heat Island (UHI)" phenomenon gives non realistic estimates of global warming scenarios. UHI arises from differences in heating and cooling patterns of urban and rural areas resulting in disparities in observed surface air temperatures.

UHI studies in different parts of the world indicate that very large cities may have average temperatures of several units of magnitude in excess over those of nearby rural settlements. (See for example, Quante, 2004). The identified causes of urban temperature elevations over those of rural areas are the types and density of urban cover and buildings as compared with those of rural areas and the higher population of the urban areas which accounts for anthropogenic heat releases, chemical and particulate emissions from traffic, factories, and household activities.

Specifically, the increased density and height of buildings in urban areas affect the aerodynamics, heat conduction and albedo with resultant increases in temperatures. Reduced air flow on another hand cause trapping of air which is consequently heated to increase surface temperature. Concrete and asphalt used for buildings and roads in urban areas

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store and release heat to the environment especially at night which also increases the temperature. The replacement of vegetation and open surfaces (which cools the environment through shading and enhanced evaporation) by roads, pavements, lawns and buildings also cause increases in urban temperatures.

The consequences of elevated urban temperatures are numerous. This includes increased energy demand for air conditioning and refrigeration, increased air pollution levels due to reduced ventilation, heat related illness such as meningitis and measles as well as reduction in general comfort. A comparative study of intensities of surface air temperatures in urban and rural areas gives a good indication of the build-up of the UHI. Although UHI is more pronounced during the night, its day-time intensity is equally considerable for very large cities.

This present study is undertaken to measure any disparities in surface temperatures at different locations within the vicinity of Owerri capital city during the day time and to gain insight into any possibly significant build-up of the urban heat island intensities in this previously moderately populated city that is now rapidly evolving into a large commercial city with high population densities at various points. The study will benefit town planners who may wish to map areas of abnormal temperature build-up due to over-crowding and atmospheric scientists who may wish to have information about temperatures in major cities in Nigeria and Africa. This study will be useful in planning energy consumption needs and traffic patterns in the town.

2.0 Theoretical Background

The urban heat island effect can be assessed from the energy exchange process, and the differential sensible heat associated with different surfaces. The relevant equation for quantifying the sensible heat of a surface is:

$$Q^* = Q_1(1-\alpha) + Q_L^{\downarrow} - Q_L^{\uparrow} \qquad ...1$$

where Q^* = Net radiation, Q_1 = Incoming solar radiation (direct + diffuse), $Q_L^{\downarrow}$ = Long wave counter radiation from atmosphere, $Q_L^{\uparrow}$ = Long wave terrestrial radiation (emitted from surface), and α = Albedo of the surface (see Thielen & Troude, 2000 and also Nicholson, 1992). The heat admitted into a body to change its temperature by an amount $\Delta\theta$ is known to depend on the heat capacity c of the body as follows

$$Q = c\Delta\theta \qquad ...2$$

The acquired heat is lost to the surroundings at a rate that is proportional to the excess temperature $(\theta-\theta_s)$ of the body above that of the surroundings according to the expression

$$-\frac{dQ}{dt} = -c(\theta-\theta_s)^{5/4} \qquad ...3$$

θ is the temperature of the body and θ_s that of the surroundings (see for instance Gibbs, 1996). Hence for environments composed mainly of materials of very large heat capacity such as concrete (3350 J/kg/K) which is the case with cities, the rate of temperature drop is slower especially at night. Since $Q^{\uparrow}$ increases for materials of large heat capacity it is high in urban areas in the night when trapped heat is re-radiated.

In the day-time the first term of equation 1 is moderated significantly by the albedo α , hence the day-time component of the urban heat effect is dominated by the albedo term ($Q_1(1-\alpha)$). Typical albedos of different building/roofing materials and land cover are shown in Table 1 (from Quante, 2004). These show that urban settlements which usually have more asphalt and concrete would generally have lower albedos (less reflection of radiation) than rural settlements which have more of green cover, with the consequence that more heat would be trapped within urban areas both during the day (albedo effect) and in the night (thermal absorption effect) resulting in higher temperatures- compared to the rural areas- all the time.

Table 1: Albedo of some materials

Material	Albedo Range
Grass	0.25-0.30
Asphalt	0.05-0.20
Concrete	0.10-0.35
Brick/Stone Walls	0.20-0.40
White Paint	0.50-0.90

(Source: Quante, 2004).

3.0 Measurement Procedure

In this study day-time (8am-6pm) measurements of surface air temperatures were simultaneously recorded at 2 hours intervals at the following locations in Owerri; Location A-Naze/FUTO junction along Aba-Owerri road, Location B - Emmanuel college gate along Douglas road; Location C-Saint Paul's Catholic church gate Douglas road; Location D-Alvan Ikoku College of Education (AICE) gate; Location E- Egbeada Housing Estate junction Amakohia-Orlu Road; Location F- Kedeni Filling Station Akwakuma and Location G-Imo State University Love Garden (see Appendix for a rough identification of these locations).

The measurements were made from Monday 6th to Monday 13th of March 2006.The March/April period was chosen for the measurements because it falls within the first yearly equinox when day-time UHI intensity is expected to maximize. This choice is justified by reference to Figure 1. The Figure shows the average monthly maximum temperatures for Owerri (Longitude;$7^{o}1^{I}\ 33^{II}$: latitude $52^{o}9^{I}33^{II}$) based on data from the International Water Management Institute (IWMI) Integrated Database Information System (IDIS) (http://dw.iwmi.org/IDIS_DP). In this Figure the mean deviation from the average of the entire data series is maximum during the April/March period.

The temperature readings were taken with the aid of mercury in glass thermometers placed at vertical height of 1.75 meters above the surface. This was to minimize vertical temperature influence of the ground surface as suggested by Avwiri and Ebeniro, (1995). With this type of set-up, the recorded temperatures are roughly the surface air temperatures.

The different locations at which measurements were taken have varying concentrations of buildings, human population, open areas and green cover, which are expected to influence the surface air temperature. Disparities in measured temperatures if any would therefore throw more light on what is thought to be the impacts of the above-mentioned features on temperature variations and from these the consequences of urbanization on local temperature build-up can be ascertained.

4.0 Results

Figures 2 (A-G) are column charts of the measured surface air temperature (^{o}C) for different days of measurements shown for the various stations. The times of the measurements are indicated in the legend. The day-time temperatures are obviously lower in the morning hours and peaking after noon (by 2pm) and slowly dropping towards evening. This figures show the role of the noon/afternoon minimum solar declination on measured temperature.

In Figure 3 the average temperature for the different periods of the day are plotted for the various locations. Temperatures are not highest at noon (12pm) when the sun is directly overhead but about two hours later (2pm) reflecting the time lag when the absorbed maximum solar radiation are re-emitted from surfaces as infra red radiation. This figure also shows that the patterns of temporal evolution of day-time temperature (inferred from the temperature gaps between successive measurements at a location) are different for the various locations. The transitions were smaller at Naze, St Paul, AICE and Egbeada (where the causative factors for the temperature variations were somewhat constant and more chaotic at E-college, Kedeni and IMSU where the presence of cars and people at filling stations (for E-college and Kedeni) and Students (for IMSU love garden) were highly variable thereby introducing sharp changes in anthropogenic heat build-ups.

On the average the most elevated temperatures were noticed for St Paul site which is at the heart of the urban. The lowest temperatures were recorded at Naze (a semi-rural location) and Egbeada (a new layout with considerable green area, little population density and presence of a stream). In Figure 4 the average temperature measurements for different times of the day and for all the stations are plotted. This figure makes it possible to compare the average daytime measurements for the different stations and for the different days (Figure 5). The maximum range in temperature disparities in 2006 is ~ 4^{o}C-10 ^{o}C . In Standard Deviation (SD) units disparities amounted to 1.07 ^{o}C over a one week period in 2006. From this figure there is no conclusive pattern of day-time temperature variability for different stations over a complete day within the capital city. It is however apparent that in the morning hours the difference in temperature values between semi-rural settlements such as Naze and Egbeada and the city centre such as St Paul is larger than in the afternoon. Hence the daytime maximum temperature (at 2pm) disparities are not as significant between many stations (see Figure 6) The implication is that in the afternoon many areas in the town could become

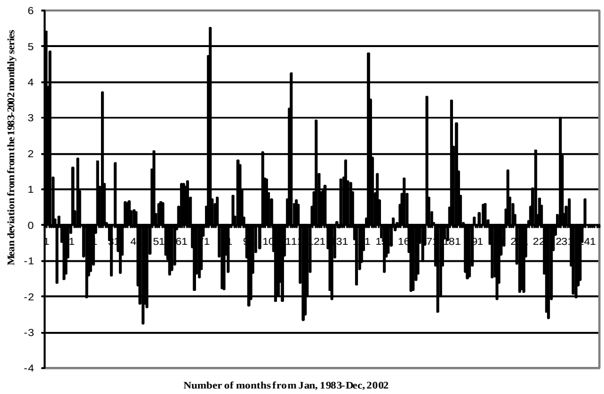

Figure 1: Plotted deviations of the average monthly maximum temperatures of Owerri from the 1983 to 2002 series mean value showing largest values around March (equinoxial period). The measurements were made during March to allow for the mapping of the most significant spatial disparities in temperatures.

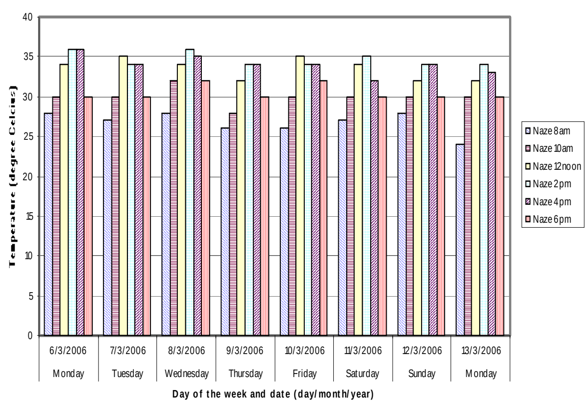

Figure 2A

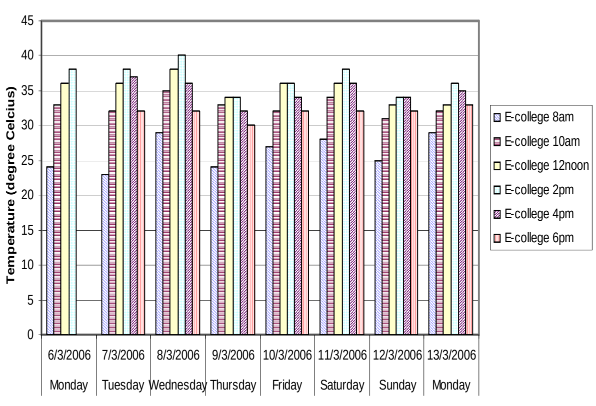

Figure 2B

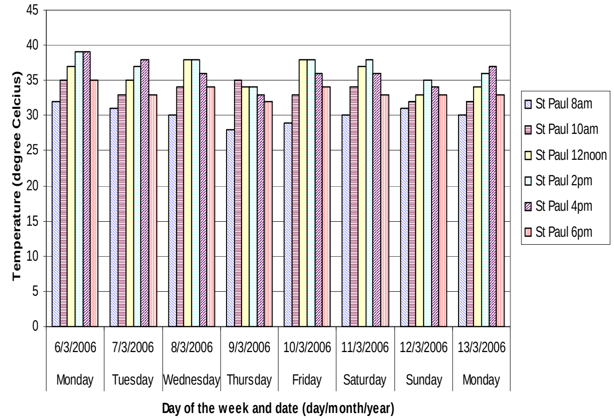

Figure 2C

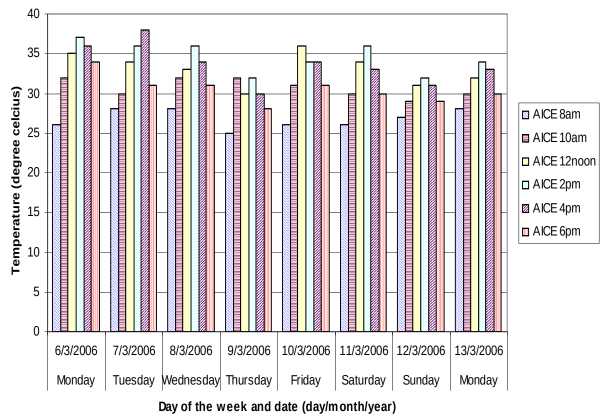

Figure 2D

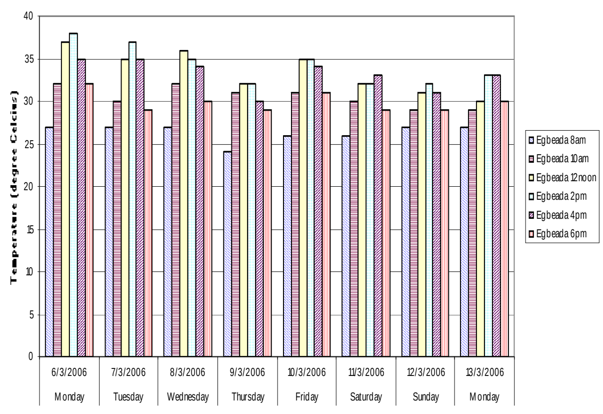

Figure 2E

simultaneously hot and hence the power holding company should expect day-time peak power demand for air-conditioning around this time.

5.0 Conclusion and Outlook

The conclusion from these preliminary results is that the rapid urbanization of the Owerri capital city may have caused temperature elevations in excess of 4-

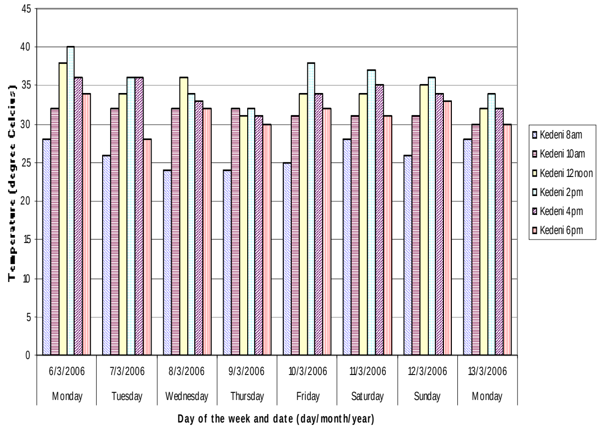

Figure 2F

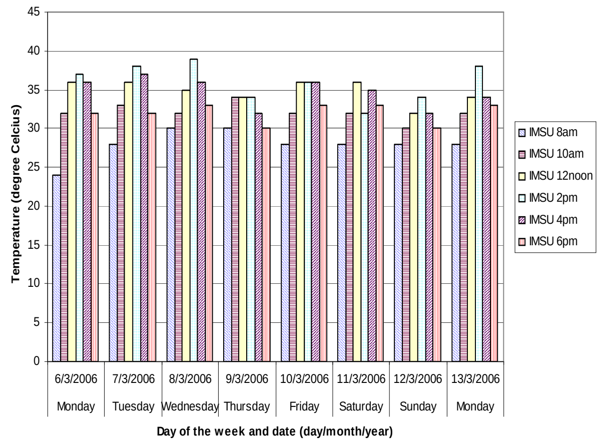

Figure 2G

Figure 2 (A-G): Daily day-time surface air temperatures over a one week cycle for stations A-G. Times of measurements are indicated in the legend.

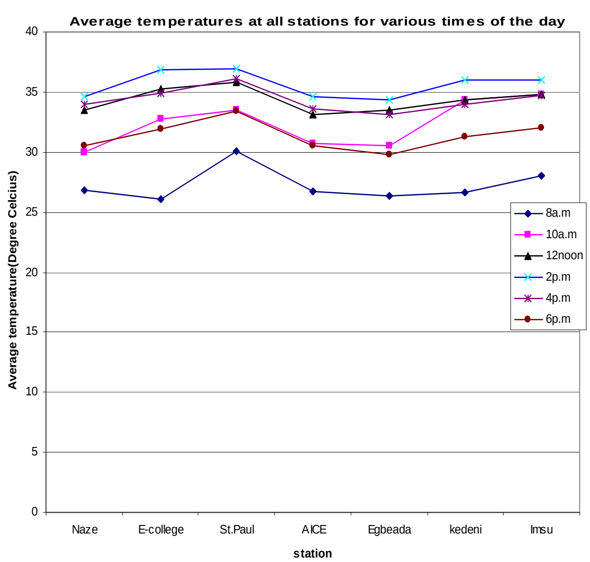

Figure 3: Average temperatures for all stations at different times of the day showing the 2pm maximum at all stations. Measurements made from 6th March, 2006- 13th March, 2006.

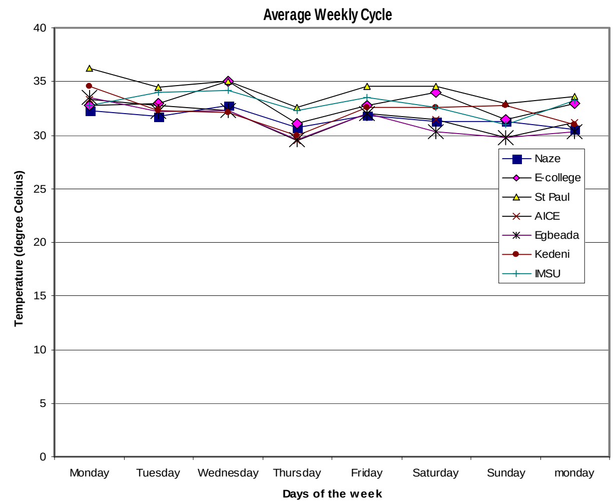

Figure 4: Average weekly cycle of temperatures plotted for all the stations for measurements made from 6th March, 2006- 13th March, 2006.

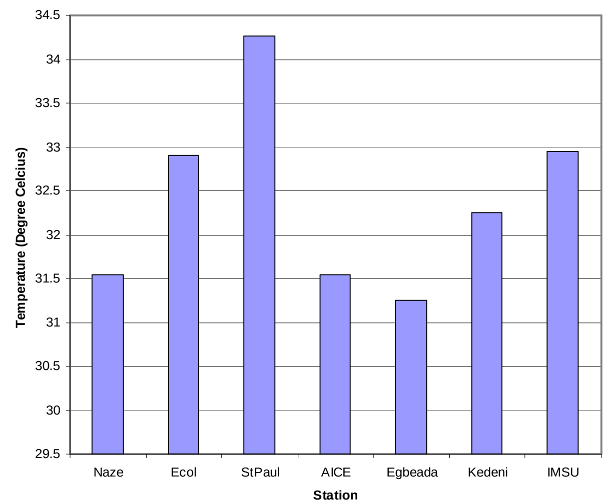

Figure 5: Average of all measured temperatures for all the stations.

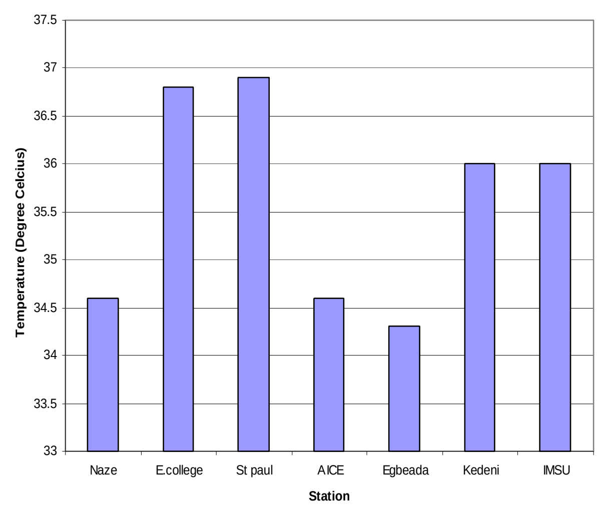

Figure 6: Average of all measured maximum temperatures for all the stations.

10 °C over the adjoining rural environment such as Naze. Within the city itself, temperatures are at variance reflecting the influence of varying concentration of people and traffic and changing patterns of airflow as were noted during the measurements. Efforts are being made to assess these individual contributions in future. The observed disparity in temperatures within the town is significant when one considers possible influence this uncertainty may have on baseline data used for meteorological forecast models. It is certainly obvious from these results that one cannot rely on single measurements at a location in Owerri for defining temperature of the town objectively. The average of readings from at least three locations will provide a more reliable result. Else the location of the measurement station could be quoted alongside the values. In the up-coming parts of the research report of this study, the use of different models that simulate effects of different parameters in the anthropogenic temperature variations will be tested for different locations in the city. In addition, the spatial structure of nighttime temperature variations will also be investigated.

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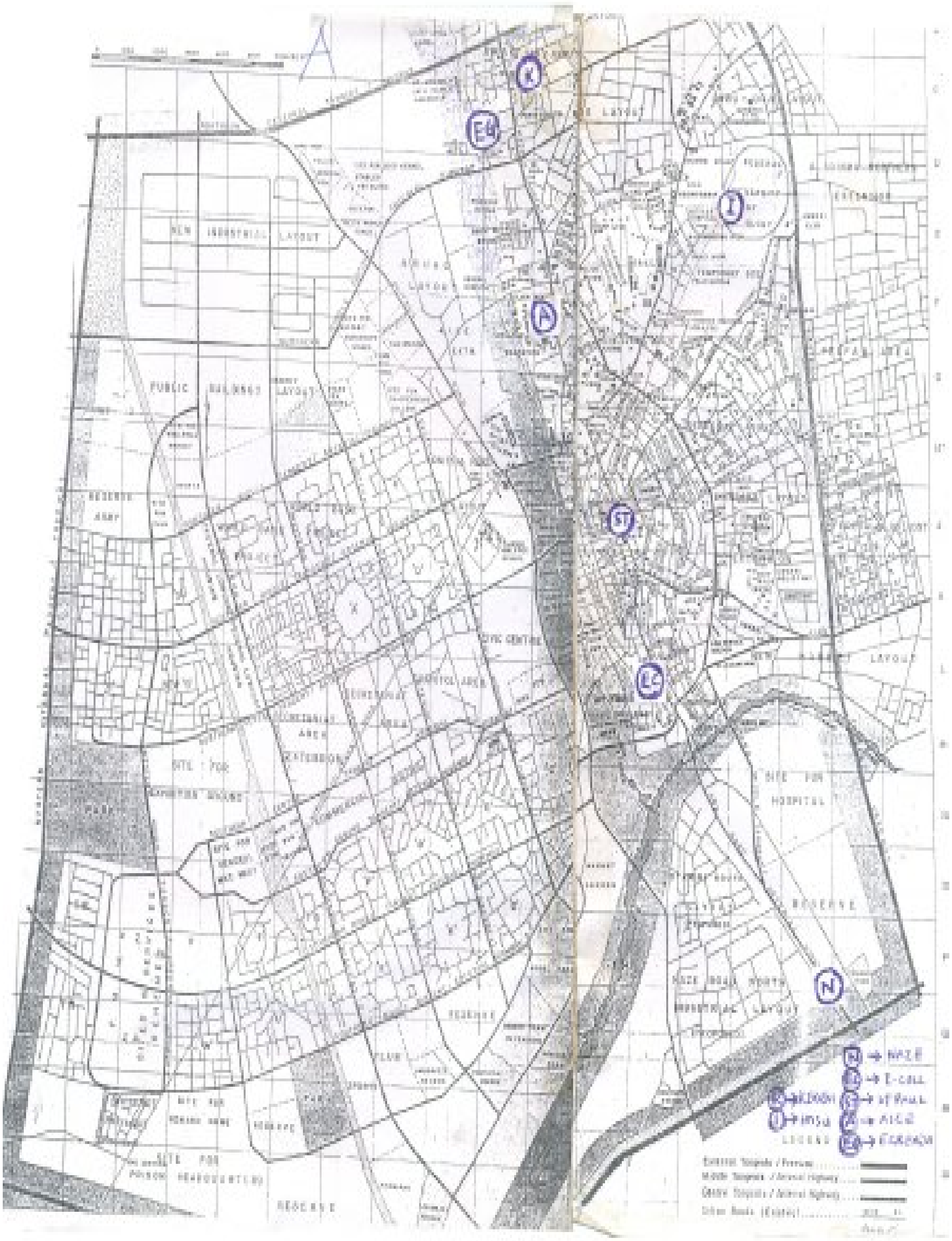
Acknowledgement

We acknowledge the contributions made by 2006/2007 session of 400 level students of Physics and 500 level students of Land Survey of Imo State University Owerri with regard to data acquisition for this work.

Appendix


NEW INDUSTRIAL LAYOUT
PUBLIC BUILDINGS LAYOUT
RESERVE ARMY
CIVIC CENTRE
SITE FOR HOSPITAL
RESERVE
PARK
SITE FOR PRISONS HEADQUARTERS
LEGEND