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An Aerial Photographic Method for Estimating Urban Population

The method is a relatively reliable way of obtaining urgently needed population data for planning and management of urban and rapidly urbanizing areas like Lagos, Nigeria.

Abstract: *This paper examines how remotely sensed data, especially aerial photographs, could be used for the estimation of urban population in Nigeria. A land-use method is employed. The basic notion of the method is that a particular residential class should, all things being equal, have a particular or 'characteristic' population density. Using Lagos, Nigeria, as a test site, the relationship between residential classes, based on photointerpretation, and residential groups, based on cluster analysis of sampled population data collected in the field, is examined. The analysis reveals that the assumption of a particular population density for a particular residential class is more plausible for the 'planned' residential areas than the 'unplanned' residential areas.*

A stepwise regression analysis further shows that density of buildings and average population per building account for the greatest variation in population distribution. Nearly all the residential classes are definable (i.e., separable) on the basis of building density. The estimated population figure arrived at is comparable to other estimates.

The result of the study justifies further research and practical efforts as it seems to be suitable as a relatively reliable way of obtaining urgently needed population data for the planning and management of urban and rapidly urbanizing areas like Lagos, Nigeria.

Introduction

In most countries, population data are obtained through decennial censuses. While such data might play significant roles in national and international programs, they are usually inadequate for the planning and management of rapidly urbanizing areas.

In recognition of the inadequacy of decennial censuses, and because of the need to meet the data requirement for rational urban planning and modeling, various methods have been developed for inter-censal population estimation. These include (1) housing unit method, (2) vital rates method, (3) component method, and (4) the Bogue-Ducan composite method. These methods are essentially based on past recorded information such as crude birth and death rates, migration records, number of school children, voting records, automobile registration records, building permits and demolition, and other house-hold statistics (Bogue, 1950; Starsinic and Zitter, 1968; Ericksen, 1973).

Unfortunately, these types of data, which are usually recorded and aggregated into well defined and properly mapped spatial units, are generally unavailable in most developing countries where the population growth rate is highest. Furthermore, with the exception of the housing unit method, these methods of making inter-censal population estimates are less suitable for small planning units (e.g., census tract, local government area, voting districts, etc.) as well as areas experiencing rapid population changes (Morrison, 1971).

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In Nigeria, there is a problem of generating adequate and reliable demographic data for planning and policy making purposes (Nigeria Third National Development Plan 1975-1980, pp. 291-294). The conventional methods of estimating the population listed above have not been employed satisfactorily in Nigeria.

In some parts of the world the valuable function of population data in urban planning and development has led to the development and testing of population estimation models based on remotely sensed data. As illustrated in Table 1, most of the attempts made at estimating population using remotely sensed data have been carried out in the United States. The results have revealed, in general, that remotely sensed data have the capability to provide timely, verifiable, and relatively accurate inter-censal population data, based on uniform criteria at local, metropolitan, and regional levels. However, it has been found also that each exercise of estimating population using remote sensing techniques tends to be valid only for the particular area under consideration. Consequently, there seems to be a need to formulate for each cultural area a suitable model based on relevant attributes of the area.

Objectives of this Paper

The primary objective of this paper, therefore, is to examine how aerial photography can be used systematically to estimate urban population in Nigeria. A thorough review of the various remote sensing methods has revealed that a model based on land use would be suitable for Nigeria (Adeniyi, 1976, 1978, 1980). Thus, the land-use method as advanced by Kraus *et al.* (1974) was adopted and examined for possible application. The basic notion of the land-use method is that a particular residential class should, all things being equal, have a particular or 'characteristic' population density. That means that the estimated population, EP, of a place at time period, t, becomes

$$EP = (A_1d_1)_{R_1} + (A_2d_2)_{R_2} + \ldots + (A_nd_n)_{R_n} \quad (\text{or } EP = \Sigma_{i=1}^{N} A_i d_i) \qquad (1)$$

where $A_1, A_2, \ldots, A_n$ are the measured areas of residential classes $R_1, R_2, \ldots, R_n$; and $d_1, d_2, \ldots, d_n$ are the characteristic population densities for the residential classes $R_1, R_2, \ldots, R_n$.

A test site selected for this study is Lagos, the Federal Capital of Nigeria. A set of black-and-white aerial photographs of Lagos, taken in 1974 at a scale of 1:20,000, was used.

Ideally, the evaluation of a model like the one proposed requires a base population data against which the result of the population estimation exercise would be assessed. In the case of Lagos (and Nigerian cities in general), such base data are not available. In the absence of such base data, the paper, therefore, concentrates on the operation of the model by examining the following questions: (1) Do residential areas located in different parts of a city but classified (on the basis of physical and spatial variables) into the same residential class have 'similar' characteristic population densities?

Table 1. Some Examples of the Use of Remotely Sensed Data for Population Estimation

Author/Year	Study Area	Types of Imagery and/or Scale
Green, 1956	Birmingham, U.S.A.	Black & White Photos 1:7,500
Porter, 1956	Liberia	Black & White Photographs
Hadfield, 1963	Chicago, U.S.A.	Black & White Photos 1:4,800
Binsell, 1967	Chicago, U.S.A.	Natural Color Continuous Strip 1:5,240
Sabol, 1968	U.S.A.	Radar
Holz *et al.*, 1969	40 Towns in Tennessee Valley	High Altitude Photography
Lindgreen, 1970	Boston, U.S.A.	CIR 1:20,000
Eyre *et al.*, 1970	Jamaica	Black & White Aerial Photos
Collins and El-Beik, 1971	Leeds, England	Black & White Photos 1:10,000
Hsu, 1971	Atlanta, U.S.A.	Black & White Photos 1:5,000
Anderson and Anderson, 1973	Eastern Kansas, U.S.A.	Aerial Photographs
Reining, 1973	Niger and Upper Volta	Landsat
Murai, 1974	Tokyo	Landsat
Kraus *et al.*, 1974	4 California Cities, U.S.A.	CIR 1:60,000
Horton, 1974	Washington, U.S.A.	1:50,000
Allan and Alemayehu, 1975	Wolaneo, Ethiopia	Aerial Photo
Thompson, 1975	Washington, U.S.A.	High Altitude
Henderson and Utano, 1975	Albany, N.Y., U.S.A.	Black & White Photographs 1:24,000
Dayal and KhairZada, 1976	Afghanistan	Aerial Photography
Henderson, 1979	U.S.A.	Aerial Photography 1:25,000
Lo 1979	Hong Kong	Aerial Photography
Lo and Chan, 1980	Sheuna Shui-Fan, Hong Kong	Aerial Photography
Clayton and Estes, 1980	Goleta Valley, St. Barbara, California, U.S.A.	CIR High Altitude 1:63,360.

(2) (a) What variables (if any) account for spatial variation in the characteristic population densities within each residential class? (b) Which of these variables are obtainable from aerial photographs? and (c) What percentage of the variation in (a) is accounted for by (b)?

Methodology

The following procedures were followed: (1) Identification and classification of residential areas by photointerpretation technique. (2) Collection of population data in the field from block samples selected randomly from each residential class. The population data so collected were analyzed and used in grouping the residential areas by cluster analysis, and the resulting groups were compared with the air-photo classification. (3) A stepwise regression analysis was also employed to evaluate the variables which account for variation in the characteristic population density. The variables which have the greatest explanatory values were later tested with a view to determining their ability to distinguish between the residential classes.

Identifying and classifying residential areas

Basically, according to Lo (1971) photointerpretation is a classificatory process aimed at assigning photo images into their proper groups so that an aggregate pattern can be brought out or their relationships revealed. Ordinarily, certain characteristics of objects, such as type and shape, size, site, and pattern; and photo qualities such as contrast, shadow, tone, texture, scale, and resolution are used to identify objects of interest.

In urban areas, the correct identification of a phenomenon does not depend only on these parameters; it also depends on the cultural attributes of the urban place and the background knowledge of the interpreter. In Nigeria, for instance, most families live in "rooming" type houses. Three to ten households may occupy a single storied building. In each household, it is common to find, in addition to the immediate family members, other 'extended' family members and/or house maids. Under this condition, it is difficult to classify a residential area directly by family size categories. For the same reason, individual dwelling units cannot easily be identified on aerial photographs.

The problem of classifying residential areas in Lagos (or in any urban area in Nigeria) is a very formidable one (see Lagos Metro Master Plan Project Report, 1977). Because of the apparent inapplicability of the established classification systems to urban areas in Nigeria, a new system had to be developed for this study.

The classification of residential areas was based on some socio-cultural variables and on physical and spatial variables associated with residential patterns in Lagos as seen on aerial photographs. The variables considered for the classification include dwelling types (e.g., Flat, Rooming, or both)*, building usage, building types by number of stories, density of buildings, and other environmental variables, such as plot size, landscaping, layout of buildings, and the presence of gardens and kiosks. Using these variables, the residential areas of Lagos were classified into nine classes (Figure 1). Table 2 shows the description of each residential class. The identification, classification, and mapping of the residential areas were based on stereo interpretation of the 82 (1:20,000 scale) aerial photographs of Lagos. The resultant residential land use of Lagos is shown in Figure 2.

Having identified and delineated the different residential classes, the next step was the evaluation of the population densities of each residential class. In order to do this, it was necessary to group the residential areas in terms of population variables. Because there were no population data for 1974, population data were collected in the field from samples selected from each residential class.

The selection of residential sample areas was based on stratified random sampling. The residential land-use classes provided a necessary stratification. Residential blocks were selected randomly from each residential class. In each block, data about the number of persons per family and number of families per different types of building were collected. Owing to limited financial resources, data were collected in 58 sample areas containing 3,479 buildings (Figure 2 and Table 3).

The sample areas covered 230 hectares, representing 3.14 percent of the total residential land in 1974. Out of the 3,479 buildings within the sampled areas, about 60 percent were single storied and nearly 33 percent were two storied buildings. By usage, over 70 percent were used wholly for dwellings, and by dwelling types, nearly 50 percent were rooming buildings. Also, about 62 percent of the people lived in single storied buildings, a percentage comparable to the proportion of such buildings. However, the relative proportion of people living in flat type buildings (25 percent) and rooming type buildings (73.4 percent) differs from the relative proportion of the number of such buildings (38.6 percent and 49 percent, respectively). Thus, while density of occupation does not differ significantly by number of stories, it does by dwelling types (see Adeniyi (1978) for full details).

However, a close examination of the sample data reveals that there are some intra- and inter-residential class similarities and differences. To

* 'Flat' residential building as used here refers to a building that is occupied by a single family or by many families with each family having a separate toilet, bathroom, kitchen, and/or doorway to the street. 'Rooming' residential building refers to buildings in which individual rooms are rented. Such buildings usually have common toilet, bathroom, kitchen, and doorway.

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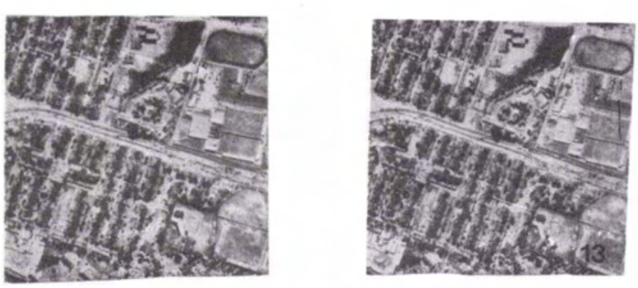

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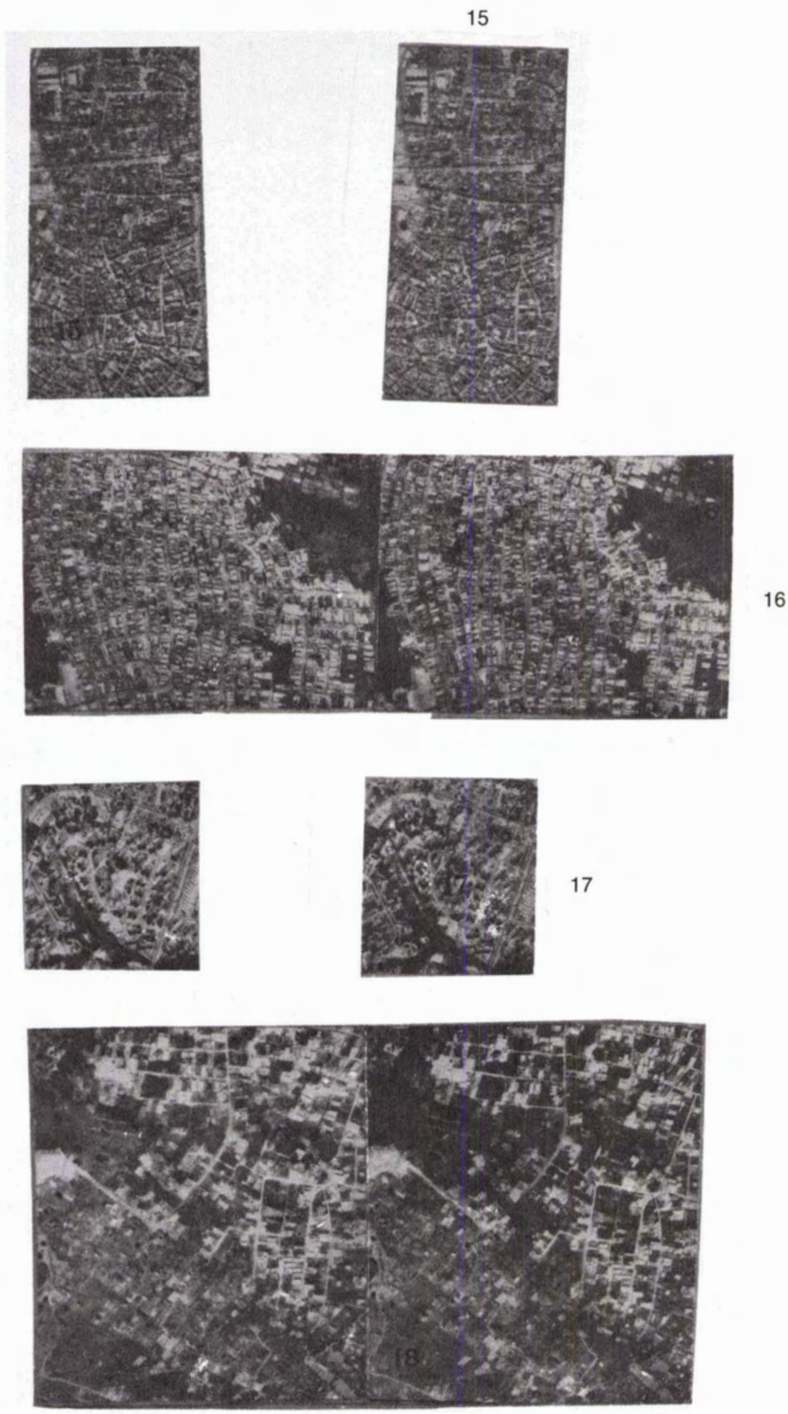

FIG. 1. Stereograms (approx. 1:20,000 scale) showing different residential types in Lagos. The definitions of these residential types (classes 10 to 18) are given in Table 2.

TABLE 2. RESIDENTIAL CLASSES AND SOME OF THEIR CHARACTERISTICS

CODE	Residential Land-Use Class Description	REMARK
10	One-two Storied (Flat) buildings with Vegetated Open Spaces. Average plot size (APS) 2000m²; Average building density (ABD) 5/ha.	Typically a 'colonial' and modern residential area with a good layout. Identification and delineation are easy.
11	Mixed (2-1) Storied (flat) buildings without Vegetated Open Spaces. APS 660m²; ABD 15/ha.	Modern, mostly two storied residential buildings. Areas privately developed have poor layout. Identification is moderately easy. Delineation is easier in the planned areas than in the unplanned areas, especially if adjacent to class 14.
12	Mixed (1-2) Storied (flat) buildings with Small Individual Open Spaces. APS 500m²; ABD 20/ha.	Free estate development with a good layout. Identification and delineation are easy but the latter requires careful interpretation if area is adjacent to class 11.
13	One Storied Row Buildings with Moderate Common Open Spaces. APS 830m²; ABD 12/ha.	Medium grade residential area built by the government with good layout for low income workers. Identification and delineation are easy.
14	Mixed (2-1-3) Storied, Traditional and Modern Buildings. APS 550m²; ABD 18/ha.	Privately developed residential areas with a mixture of different types of buildings. The layout is poor. Fairly easy to identify but difficulty to delineate if adjacent to classes 11 and 16.
15	Attached Single Storied Traditional Rooming Buildings. APS 280m²; ABD 35/ha.	This is the oldest area of the city. It is degenerating owing to over crowding, subdivision of buildings, and increasing commercialization. Density of structures makes identification and delineation easy.
16	Detached Single Storied Traditional Rooming Buildings. APS 400m²; ABD 25/ha.	Privately developed (mostly single storied) residential buildings. It is the most common residential type with poor layout. Fairly easy to identify but difficult to delineate if adjacent to classes 14, 15, and 18.
17	Apartment Buildings 4-Stories and above. APS 1660m²; ABD 6/ha.	Modern Multi-storied residential buildings. They are usually built by the government on planned parcel. Identification and delineation are easy.
18	New Developing Residential Areas (completed and uncompleted residential structures in close juxtaposition) APS 300m²–700m²; ABD (12–35)/ha.	It has the same characteristics as classes 16, 14, and 11 Identification is easy but delineation is difficult.

gain further insight into these similarities and differences, especially in terms of population densities, a cluster analysis was performed. The variables used are population density per hactare; average population per building; average population per one, two, and three storied buildings; average population per buildings used wholly and partly for dwelling; average population per 'flat' and 'rooming' type buildings; average number of families per building; and average number of persons per family. Ward's (1963) hierarchical cluster technique was employed*. The result of this analysis is shown by a dendogram (Figure 3) (see Kendig, 1976).

A DISCUSSION OF THE CLUSTER ANALYSIS RESULT

For easy interpretation and comparison, nine groups were decided upon (Figure 3). The coefficient of similarity of each group and the percentage of each residential sample falling into the original air photo classes are presented in Table 4. A zero similarity index means that the objects being grouped together are completely similar and, thus, the larger the index, the greater the disimilarity of the objects. The dendrogram (Figure 3) reveals two widely different divisions. The first division to the left, consisting of groups 1 (A and B), 2, and 3 contains all the sample areas in the residential land use classes 10, 11, 12, and 13. These classes constituted essentially the 'planned' residential areas. The division represents 'flat' type buildings with building density below 20 per hectare. On the other hand, the second division to the right consists essentially (with the exception of residential class 17) of 'unplanned' traditional rooming buildings. The coefficient of similarity between these two divisions is as large as 6,865.

This result, in comparison with the air-photo classification of residential areas reveals that (1) at least, judging by the sample data, residential classes 10, 12, and 13 are essentially homogeneous

* The program, called CLUSTAN from the Computer Centre, University of London, England was employed. The assistance of the statistical Consulting Office of the Department of Statistics, University of Waterloo, Waterloo, Ontario, Canada, is appreciated.

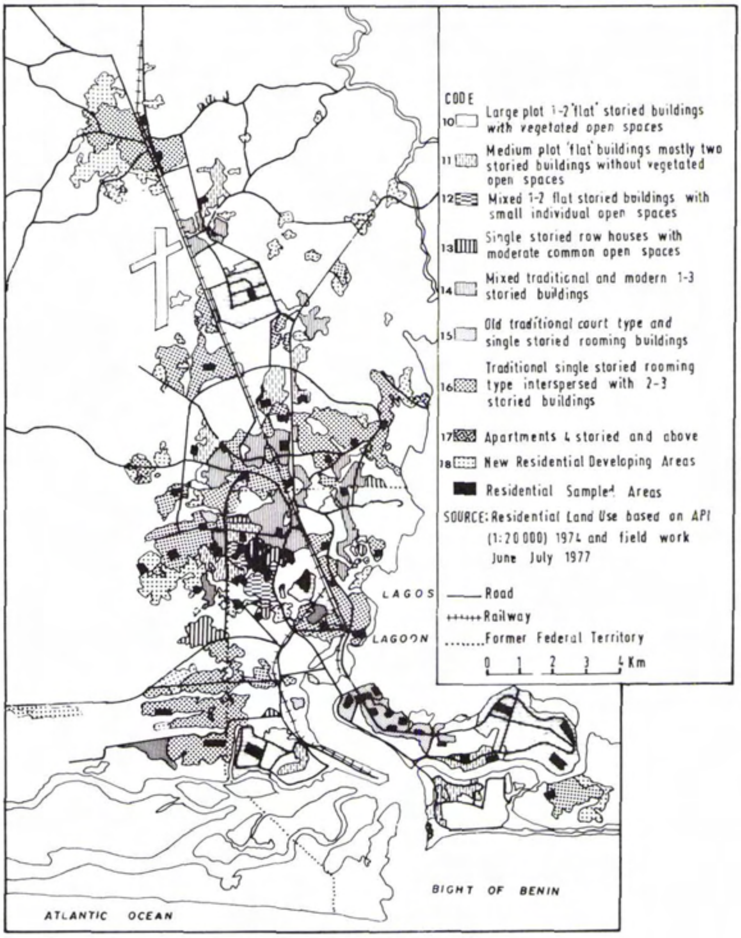

FIG. 2. Lagos, residential land use, 1974.

even though the latter two classes are subsets of two other cluster groups; and (2) samples from the other residential classes split into several cluster groups because some of the "residential buildings" are used unsystematically either entirely or partly for non-residential purposes. Other factors responsible for the split include combination of different dwelling types within similar residential

TABLE 3. SUMMARY DATA FOR THE SAMPLED RESIDENTIAL AREAS

Residential Code	No. of sampled Blocks	Total Area of samples (ha)	Total No. of Buildings	Total Population within sampled areas
10	7	84.2	471	2,267
11	9	38.2	593	7,059
12	2	9.6	198	1,798
13	2	8.2	99	2,775
14	5	16.6	302	10,076
15	10	16.3	515	10,770
16	20	50.2	1,178	26,943
17	1	1.3	8	8,888
18	2	5.9	115	1,565
TOTAL	58	230.5	3,479	64,135

SOURCE: Fieldwork June–July 1977

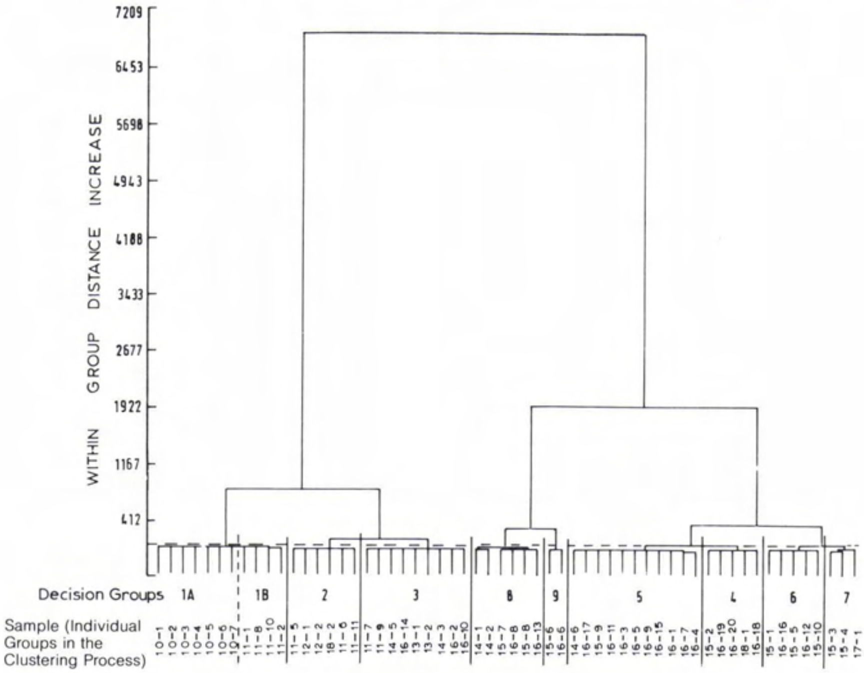

FIG. 3. Dendrogram of 58 sampled residential neighborhoods of Lagos, Nigeria (selected population characteristics).

buildings, the juxtaposition of different types of storied buildings, and the differing age and pattern of growth.

Finally, however, the result of the cluster analysis is indicative of the variation in population densities of the residential areas. With the possibility of 'measuring' and 'sampling' errors, especially with respect to location and coverage of the sample areas as well as the time gap between the year of photography (1974) and the field work (1977), the observed variations in the population characteristics of the residential classes may be different from those reflected by these results. Notwithstanding the individual groups, the analysis indicates that the bulk of the privately developed residential areas (residential classes 14, 15, 16, and part of 18), which constituted over 67 percent of the residential areas of Lagos in 1974, are less homogenous in terms of spatial and population characteristics than the 'planned' residential areas. By this analysis, it seems that the probability of the assumption that a particular residential

TABLE 4. CLUSTER ANALYSIS SUMMARY RESULT*

Groups	Coefficient of Similarities	Percent of number of samples in each residential class included in each group								
		10	11	12	13	14	15	16	17	18**
1	14.2	100	44.4	0	0	0	0	0	0	0
2	10.0	0	33.3	100	0	0	0	0	0	50
3	12.5	0	22.2	0	100	40	0	15	0	0
4	5.3	0	0	0	0	0	10	15	0	30
5	18.0	0	0	0	0	20	10	45	0	0
6	7.8	0	0	0	0	0	30	10	0	0
7	32.4	0	0	0	0	0	20	0	100	0
8	25.4	0	0	0	0	40	20	10	0	0
9	22.0	0	0	0	0	0	10	5	0	0

* See Figure 6 for the actual samples in each group.
** Codes for different residential classes.

class will have a particular population density is greater in the 'planned' areas than for the 'unplanned' areas.

IDENTIFYING THE VARIABLES ON WHICH RESIDENTIAL CLASSES ARE DEFINED

Recall that the residential classes were derived from the interpretation of aerial photographs while the groups resulting from cluster analysis were based on population data collected in the field. From the comparative analysis above, it becomes necessary to investigate further those variables on the basis of which the urban residential areas of the test site (Lagos) could be defined for the purpose of population estimation. Stepwise regression analysis and tests concerning means were employed for those purposes.

A stepwise regression analysis program called BMDP2R was employed using 19 variables (Table 5). Population density is regarded as the dependent variable. Table 6 shows the variable correlation matrix. Four variables which are not significantly correlated with population density are (1) density of two storied buildings, (2) density of buildings with open space for parking, (3) average population per 'flat' building, and (4) average population per family.

In order to understand the variables which best explained the variation in population for the study area and for different residential classes, stepwise regression analysis was applied to the following set of samples: (1) All the 58 sample areas, representing the study area; (2) 37 samples representing essentially the 'unplanned' residential classses 14, 15, 16, and 18; (3) 21 samples which represent all the samples in the 'planned' residential classes 10, 11, 12, 13, and 17; (4) all the 10 samples in residential class 15; (5) all the 20 samples in residential class 16; and (6) 11 samples, all seven from residential class 10 and four from residential class 11 (forming group 1 under cluster analysis result). The essence of carrying out stepwise regression analysis for the different group of samples as listed above is to understand whether the same (or different) set of variables have the same (or different) effect on the different sets of samples from different residential areas.

Table 7 shows the summary of the results. For the 58 sample areas, representing the study area, five of the variables explained 93.3 percent of the total variation in population. While the density of rooming type building accounted for 66.7 percent of the explained variation, average population per building accounted for 20.1 percent. This result indicates that an estimate of population for the total test site, based on the two variables above, will yield an accuracy of about 87 percent. This result may have been influenced by the disproportionate sizes of the different residential classes and the samples taken from each class.

However, rooming buildings *per se* may not be interpreted easily directly (in spite of their associated environmental variables) on aerial photographs. The correlation matrix (Table 6) shows that rooming buildings are highly correlated with (a) density of buildings ($r = 0.85$), (b) density of one storied building ($r = 0.88$), and (c) density of buildings with kiosks ($r = 0.85$). All these can be identified on aerial photographs. Therefore, instead of searching for rooming buildings, density of buildings (or any of the other two) can be used. Figure 4 shows the relationship between density of buildings and density of population.

By using 37 samples, four of the variables explained 94.9 percent. As in the first case, *density of buildings* and average population per building explained 84.4 percent. In this case, the variation in population density explained by the average population per building increased to 36.7 percent while the variation explained by building density decreased to 47.63. In the case of 21 samples, the result shows that four variables explained 98 percent of the variation in population density and that average population per building explained 97.2 percent. A detailed examination of the result reveals that the inclusion of sample 17-1 (apartment buildings) was responsible for the high explanatory value attached to population per building.

With the ten samples taken from residential class 15, *density of rooming dwelling* accounted

TABLE 5. VARIABLES FROM SAMPLED RESIDENTIAL AREAS OF LAGOS USED FOR STEPWISE REGRESSION ANALYSIS*

1. Population density/ha (PD)
2. Density of all buildings/ha (DB)
3. Density of one storey buildings/ha (DI)
4. Density of two storey buildings/ha (D2)
5. Density of buildings used wholly for dwelling (DW)
6. Density of buildings used partly for dwelling (DP)
7. Density of flat type buildings (DF)
8. Density of rooming type buildings (DR)
9. Density of buildings with associated kiosks (DBK)
10. Density of buildings with sufficient open space for parking (DBO)
11. Average population per building (APE)
12. Average population per one storey building (AP1)
13. Average population per two storey building (AP2)
14. Average population per buildings wholly used for dwelling (APW)
15. Average population per buildings partly used for dwelling (APP)
16. Average population per flat type buildings (APF)
17. Average population per rooming type buildings (APR)
18. Average number of families per building (AFB)
19. Average number of persons per family (APF)

* See Adeniyi (1978) for full data.

TABLE 6. VARIABLE CORRELATION MATRIX

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	DP	1																		
2	DB	0.77 a	1																	
3	D1	0.74 a	0.91 a	1																
4	D2	−0.14	−0.03	−0.39 a	1															
5	DW	0.61 a	0.74 a	0.74 a	−0.09	1														
6	DP	0.42 a	0.45 a	0.37 b	0.02	−0.30	1													
7	DF	−0.47 a	−0.22	−0.33 b	0.44 a	−0.08	−0.30 b	1												
8	DR	0.82 a	0.85 a	0.88 a	0.31 b	0.67 a	0.45 a	−0.62 a	1											
9	DBK	0.74 a	0.76 a	0.74 a	−0.20	0.49 a	0.54 a	−0.56 a	0.85 a	1										
10	DBO	−20	0.03	−0.07	0.29 c	−0.08	0.11	0.43 a	0.16	0.06	1									
11	APB	0.59 a	0.11	0.09	−0.14	0.06	0.11	−0.27 c	0.18	0.19	−0.20	1								
12	AP1	0.72 a	0.51 a	0.53 a	−0.21	0.37 b	0.31 b	−0.47 a	0.60 a	0.55 a	−0.28 c	0.36 b	1							
13	AP2	0.52 a	0.25 c	0.18	0.08	0.15	0.23 c	0.51 a	0.41 a	0.38 b	−0.21	0.31 b	0.51 a	1						
14	APW	0.61 a	0.15	0.13	0.16	0.05	0.18	−0.28 c	0.21	0.23 c	−0.18	0.99 a	0.37 b	0.31 b	1					
15	APP	0.50 a	0.23 c	0.13	0.20	−0.02	0.43 a	0.37 b	0.29 c	0.24 c	−0.26 c	0.34 b	0.57 a	0.56 a	0.31 b	1				
16	APF	0.10	−0.21	−0.21	−0.05	−0.18	−0.09	0.12	−0.24 c	−0.19	−0.06	0.72 a	−0.07	−0.08	0.72 a	0.00	1			
17	APR	0.66 a	0.41 a	0.31 b	0.09	0.21	0.34 b	−0.56 a	0.50 a	0.46 a	−0.31 b	0.40 a	0.71 a	0.70 a	0.39 a	0.77 a	−0.06	1		
18	AFB	−0.67 a	−0.21	−0.19	−0.19	0.15	0.18	−0.44 a	0.35 b	0.36 b	−0.29 b	0.94 a	0.45 a	0.42 a	0.93 a	0.38 b	0.54 a	0.53 a	1	
19	APF	−0.12	−0.10	−0.14	0.07	−0.07	−0.12	0.17	−0.18	−0.16	0.15	0.01	0.00	−0.05	0.01	−0.16	0.12	0.02	−0.04	1

Number of samples = 58, a = Significant at −0.001, b = significant at 0.01, c = significant at 0.05.

TABLE 7. SUMMARY OF STEPWISE REGRESSION ANALYSIS

	Variable Entered	R	R^2	Increase in R^2	F-value
I.	For all the 58 residential sample areas				
8.	*Density of Rooming Type Buildings*	0.8168**	0.6672	0.6672	112.27
11.	Average Population per Building	0.9317**	0.8681	0.2009	83.77
2.	Density of Buildings	0.9504**	0.9033	0.0352	19.69
12.	Average population per one storied building	0.9616**	0.9247	0.0214	15.05
13.	Average population per two storied buildings.	0.9657**	0.9236	0.0078	6.04
	TOTAL			0.9325	
II.	For 37 residential sample areas (all from residential classes 14, 15, 16, & 18)				
2.	Density of Buildings	0.6901**	0.4763	0.4763	31.83
11.	Average Population per Building	0.9185**	0.8436	0.3673	79.84
8.	Density of Rooming type Buildings	0.9704**	0.9417	0.0981	55.54
4.	Density of Two Storied Buildings	0.9740**	0.9487	0.0070	4.34
	TOTAL			0.9481	
III.	For 21 residential sample areas (all from residential classes 10, 11, 12, 13, & 17)				
11.	Average Population per Building	0.8922**	0.7961	0.7961	74.16
5.	Density of Buildings Used wholly for Dwelling.	0.9749**	0.9504	0.1543	55.94
12.	Average Population per one Storied Building.	0.9883**	0.9768	0.0264	19.35
13.	Average Population per Two Storied Buildings.	0.9909*	0.9819	0.0052	4.57
	TOTAL			0.9820	
IV.	For 10 sample areas (Residential Class 15)				
8.	Density of Rooming Buildings	0.7918**	0.6269	0.6269	13.44
17.	Average Population per Rooming Building	0.9921**	0.9843	0.3574	159.13
10.	Density of Buildings with Open Space	0.9969*	0.9938	0.0095	9.27
	TOTAL			0.9938	
V.	For all the 20 sample areas (Residential Class 16)				
8.	Density of Rooming Buildings	0.8598**	0.7393	0.7393	45.38
11.	Average Population per Building	0.9830**	0.9663	0.2270	101.01
7.	Density of Flat Buildings	0.9933**	0.9866	0.0203	21.18
	TOTAL			0.9866	
VI.	For 11 sample areas (All samples in residential class 10 plus 4 samples in residential class 11).				
5.	Density of Buildings used wholly for dwelling.	0.9669**	0.9348	0.9348	129.12
11.	Average Population per Building.	0.0050**	0.9919	0.0571	56.31
19.	Average population per family	0.9983**	0.9965	0.0046	9.365
17.	Average population per rooming building	0.9994**	0.9989	0.0023	12.3632
	TOTAL			0.9988	

** Significant at 0.01 level.
* Significant at 0.05 level.

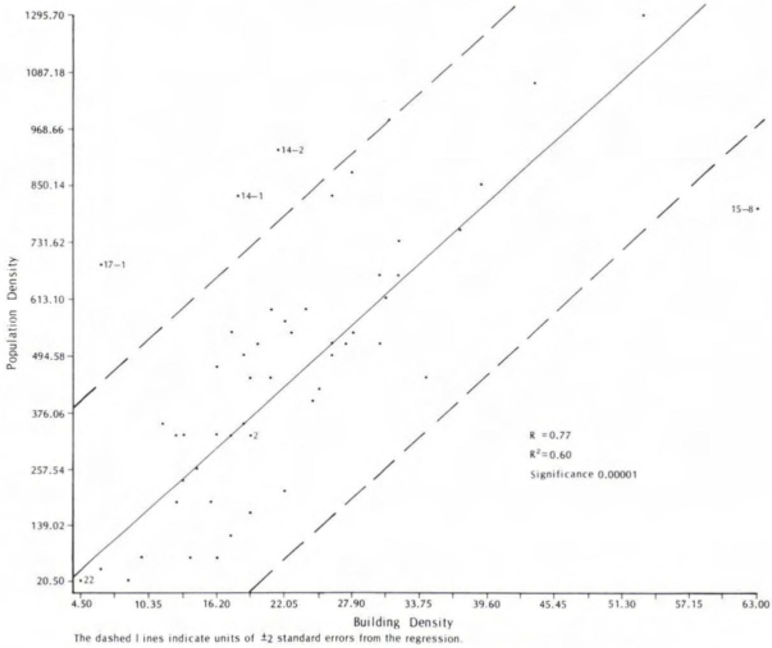

FIG. 4. Scattergram with regression line.

for 62.7 percent, and average population per building accounted for 35.7 percent of the variation in population density. In this case, over 80 percent of the buildings are single storied and over 70 percent are rooming dwellings. Also, the density of rooming buildings is significantly correlated with the density of single storied buildings ($r = 0.81$). In residential class 16, *density of rooming buildings* accounted for 73.9 percent while population per building accounted for 22.7 percent. In this case, over 90 percent of the buildings are used as rooming dwellings. This residential class represented about 42 percent of the total residential area of Lagos in 1974.

With respect to residential class 10 and part of residential class 11, *density of buildings used wholly for dwelling* accounted for 93.5 percent while average population per family accounted for only 5.7 percent. The density of buildings used wholly for dwelling is highly correlated with the density of buildings ($r = 0.95$).

The foregoing analysis indicates that density of 'buildings' and average population per building accounted for the greatest variation in population density of Lagos. The results reveal further the manner in which density of buildings reflects the urban population density of Lagos. In the 'planned' residential areas, the variation in population density that is explained by the density of buildings is over 80 percent. This value decreases to below 60 percent in parts of the 'unplanned' high density residential areas. Conversely, the percentage of the variation in population density explained by average population per building increases from low density residential areas to high density residential areas. The proportion of variation in population density explained by building density in such high density residential areas (e.g., apartment areas) is lower than the proportion explained by the average population per building (note samples 17-1, 14-1, 14-2, and 15-8 in Figure 4). From such areas, extra field data collection (or supplementary information from other sources) is necessary. In this respect, the proportion of samples selected from the high density residential areas, especially residential classes 14, 16, and 17, do not appear to be representative of the population density pattern. For future research, more samples should be selected in such residential areas and in the new developing areas.

In order to investigate how significantly defined the residential classes are, a test concerning the means of the density of buildings and the average population per building together with the average number of family per building, average number of persons per family, and the density of population was performed. The means of these variables were tested among pairs of residential classes. For instance, the mean of building densities of residential sample areas taken from residential class 10 was tested against similar means form different residential classes 11, 14, 15, and 16 (i.e., ten pairs—classes 10/11, 10/14, 10/15, 10/16, 11/14, 11/15, 11/16, 14/15, 14/16, and 15/16; see Table 8 and Figure 5). The essence of carrying out these tests is to verify whether each major residential

TABLE 8. MEAN ($\bar{x}$) AND STANDARD DEVIATION (SD)* OF SOME RESIDENTIAL VARIABLES**

Residential Classes***	Variables	Average person/ Family	Average Family/ Building	Average population/ Building	Density of Buildings/ha.	Density of population/ha.
10 (7 sample areas)	$\bar{x}$	3.9	1.4	5.0	5.8	27.0
	S.D	0.6	0.2	0.9	1.4	2.8
11 (9 sample areas)	$\bar{x}$	4.9	2.8	13.4	15.6	176.0
	S.D	0.9	1.6	7.1	3.4	107.1
14 (5 sample areas)	$\bar{x}$	4.7	7.5	35.0	18.1	580.0
	S.D	0.5	2.8	14.1	2.3	314.1
15 (10 sample areas)	$\bar{x}$	4.8	5.6	26.0	34.6	702.0
	S.D	0.7	1.4	4.4	12.4	189.4
16 (20 sample areas)	$\bar{x}$	4.0	6.3	24.5	24.5	557.0
	S.D	0.5	1.4	5.6	8.9	223.5

* Bessel's correction has been applied to all the SDs because of the small size of the samples.
** The data contained in this table were manipulated (as indicated in the text) for the construction of Figure 5.
*** See Table 2 for the definition of residential classes.

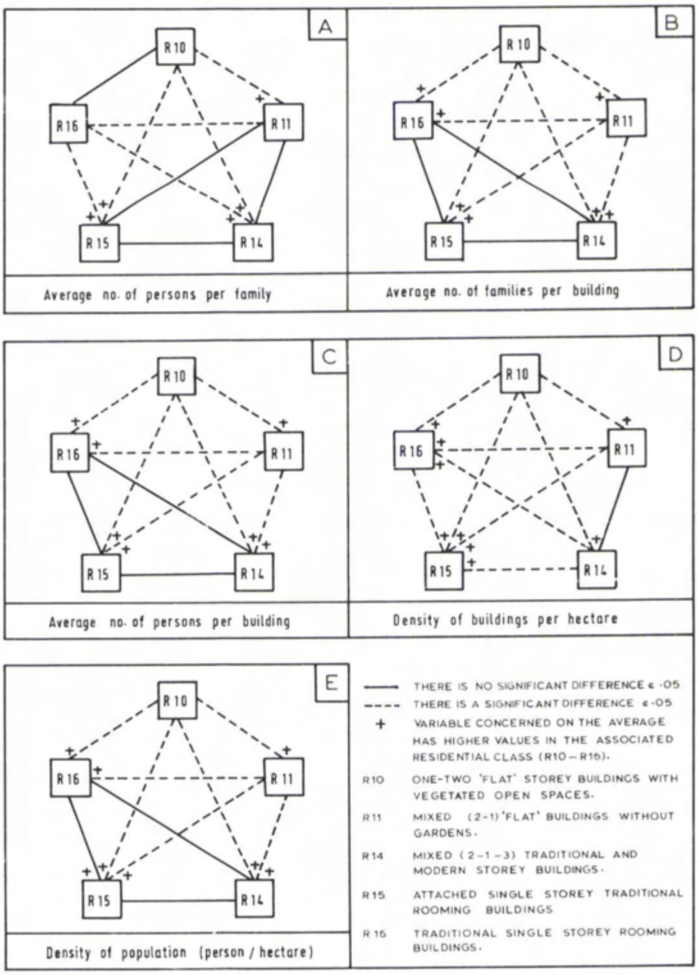

FIG. 5. Relationship and separability of residential classes.

class is significantly different from any or all the others on the basis of identified variables. The tests were conducted on five of the residential classes (classes 10, 11, 14, 15, and 16) having a minimum of five sample areas. These residential classes accounted for 83 percent of the total residential area of Lagos in 1974.

The result of the tests as shown diagramatically in Figure 5 (A-E) corroborates the results of cluster and stepwise regression analyses. The result reveals essentially that while most residential classes are better defined in terms of density of buildings (Figure 5d), the unplanned residential classes are not significantly different from one another in terms of the average number of people and family per building (Figure 5, B & C). This situation is reflected in high variations in the population densities of the unplanned residential classes (Table 8).

Overall Assessment of the Model

A more rigorous assessment of the model is constrained by a lack of temporally and spatially compatible population data. Such data could have been used to determine the accuracy of the model. In spite of this constraint, the model as stated in Equation 1 is applied to the study area and the result as shown in Table 9 is compared with the population projection made by Einsele and Karpe (1975) for metro-Lagos. Their population projection was prepared on the basis of minimum, medium, and maximum concept and for the period 1963 (the year of the last officially acceptable census in Nigeria) to year 2000. For the year 1974, their minimum, medium, and maximum projections are 1.61, 2.57, and 2.82 millions, respectively. In their report, Einsele and Karpe (1975, p. 15) noted that "There are very few reasons to believe that the minimum projections seems likely to match with the actual and foreseeable developments. . . . Even the medium projection was regarded . . . as being the lower limit of a possible population growth." Thus, the estimated 2.85 million population arrived at in this study can be adjudged to be reasonable. The accuracy of the estimates for each residential class as shown in Table 9 is difficult to assess. However, the results of the preceding analyses have shown that the 'unplanned' residential areas exhibit greater variation in terms of dwelling and population characteristics.

Table 9. Estimate of Population for Lagos, Nigeria, 1974

Residential Classes	Area (ha) of Residential Classes*	Estimated Characteristic Population Density/ha.	Estimated Population
10	1,274	27	35,398
11	685	180	123,300
12	100	187	18,700
13	102	340	35,680
14	780	593	462,540
15	203	681	138,243
16	3,145	545	1,717,170
17	46	683	31,418
18	1,007	291	293,037
TOTAL	7,342		2,853,486

* See Adeniyi (1980) for the method used for the area calculation of each residential class.

Conclusion

This paper focused on how aerial photographs could be used for the purposes of estimating urban population in Nigeria. The estimating method was based on a land-use model. Using Lagos, Nigeria, as a test site, the relationship between residential classes based on photointerpretation, and residential groups based on cluster analysis of sampled population data collected in the field, were examined. The analysis revealed that the assumption of a particular population density for a particular residential class did not hold equally for all the residential classes. Essentially, the result indicates that a fairly accurate estimate of population of the "planned" residential area of Lagos can be made on medium scale photographs (for area and building density calculation) with "minimum" field work (for the determination of the average population per building). On the other hand, large scale aerial photographs with a large number of samples, based on random selection of residential buildings, will be required in the "unplanned" residential areas in order to obtain a fairly accurate population estimate.

A test concerning the variables which account for variation in population density showed that density of buildings and average population per building contributed to the population density pattern. Density of buildings, which is obtainable from aerial photographs, accounted for between 60 and 80 percent of the variation in residential population density pattern. It was further found that most of the residential classes could be distinguished from each other on the basis of building density. There is, however, a need to further test this approach by increasing the number of samples in the unplanned areas and in other urban centers for the purpose of calibration.

Nevertheless, the results of this study lend support to the potential of aerial photography in classifying urban residential areas into similar classes and in estimating urban population. In addition, the approach will be of tremenduous assistance to urban planners, social service agencies, and urban researchers in Nigeria as well as in other developing countries.

According to Rhodes (1968), "data collection and preparatory costs for urban modeling will continue to rank as a very high proportion of total study costs;" therefore, it seems justified that a search for comparatively easy, fast, and economical methods should be pursued. In this context, the approach examined in this paper seems to be suitable as a relatively reliable source for obtaining urgently needed population data for urban planning and management.

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