AN AERIAL FRAME TECHNIQUE FOR POPULATION ESTIMATION: PROBLEMS, ACCURACY AND POTENTIALS

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Abstract

A net residential land use concept of population estimation from aerial photographs was applied in estimating the population of two major and two medium-sized urban centres in Nigeria. A variety of aerial photographs (scale 1:6000 and 1:10,000) were utilized. A regression analysis of land use and population variables was made and the exponential coefficients of a population estimation model were established. The results provided some insights about the spatial patterns of population distribution in the neighbourhoods of rapidly urbanising cities in Nigeria. The application problems, accuracies and potentials of the aerial frame technique of population estimation are discussed.

Key words: aerial photographs, population, estimation, problems, accuracy, potentials, urban centre, net residential, landuse.

INTRODUCTION

Among the outstanding features of urbanization trends all over the world are the spectacular increases in urban population. In spite of the uncertain accuracy of the resultant data, the use of aerospace imagery for urban population estimation is still desirable for a variety of purposes. In the developed countries, the use of aerial photography for population estimation is largely exploratory with focus on speed, accuracy and completeness of the approach vis-a-vis the decennial census method. In the developing countries population census data are not regularly available and aerial photography may be the only means of providing up-to-date population statistics for a specific region (Lo, 1986).

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Population estimates made from non-conventional sources such as aerial photographs are useful for the generation of inter-censal data for planning. It is particularly useful in a situation where census data are not available. These reasons underscore why this research was undertaken to complement that of Adeniyi (1983) and Olurunfemi (1982) who have stressed the need to generate population data from aerial photographs for rapidly growing urban areas in Nigeria and other developing countries because of the existing lack of census data or other reliable estimates.

Problems of population data in Nigeria:

Several colonial and post-colonial problems have militated against accurate and reliable population censuses in Nigeria. The colonial census of 1952 for example had several logistics problems, hence counting spanned three years from 1950-1952. Lagos area was counted in 1950. In the North, counting took place from May-July in 1952, while that of the West lasted from December, 1952 to January, 1953, and the East was counted from May-August 1953.

Post-colonial census problems were characterized by inadequate preparations and over-politicization. The problems were manifested in the inflation and manipulation of census figures. Others included sectional interests which resulted in official dishonesty and serious ethnic controversies over published results. Consequently, the census result of 1962 was cancelled and a fresh one was conducted in 1963. Although remarkable improvements in logistics, cartographic and computer applications were made during the 1973 census, the re-occurrence of old irregularities lead to its cancellation. Planning policies had to be based on even the hitherto controversial 1963 census data for almost three decades.

A recent census was conducted in Nigeria in 1991 (after 28 years) but Government authorities have not as at June 1996, released the figures of localities, towns and urban centres, perhaps because of controversial and political reasons. Only regional population figures of States and Local Government areas have been published. Similar problems also occur in other developing countries.

Given this situation, it is desirable to evolve a non-conventional source of population estimates such as an *aerial frame technique* which could be used to provide population estimates for localities and urban areas and perhaps could be useful in checking the reliability of controversial census figures. These are the main objectives of this research, including that of devising an improved *aerial frame technique* of population estimation. In Nigeria for example, the urban population has been increasing so rapidly and has been so mobile that major shifts in population growth have continued to create intractable problems for urban planning and city management. The *aerial frame technique* of population estimation could therefore serve as a valuable supplement to the conventional census in Nigeria and other Third World countries, particularly for purposes of data updating in rapidly growing cities.

AERIAL FRAME TECHNIQUES

Population estimation from aerial photographs is usually based on either Dwelling Count or the Land use Area methods. The dwelling count method involves the counting of dwelling units on the aerial photographs, followed by a determination of the average number of people (occupancy rate) in each type of dwelling. The product of the dwelling units and the corresponding occupancy rate yields the population estimate.

The land use area method on the other hand requires a determination of the area under residential use from the aerial photographs followed by an estimate of the number of persons per unit area (population density). The problem with the land use area method relates to the accurate definition of residential limits, particularly in the urban fringe, while some of the major problems in the dwelling count method are the high degree of variability in the accuracy errors caused by the enumeration of multi-unit structures, and the tedious and time-consuming nature of the method, especially when applied over a large area (Lo, 1986).

The dwelling count method has however received greater emphasis in the last four decades. This is exemplified by the works of Green (1957) for the City of Birmingham, Alabama; Collins and El-Beik (1971) for the City of Leeds in England; Hsu (1971) for the City of Atlanta; Dayal and Kharizada (1976) for the census exercise in Afghanistan; Clayton and Estes (1980) for the Goleta Valley of Santa Barbara Standard Metropolitan Statistical Area; Lo and Chan (1980) for the New Territories of Honk Kong; Polle (1980, 1984) for the cities of Enschede, Netherlands, Colombo in Srilanka, and Teheran in Iran; Watkins and Morrow-Jones (1985) for the city of Boulder, Colorado; and Lo (1986) for the city of Athens, Georgia.

Because of the contiguous and heterogenous nature of dwelling structures in developing countries, the application of the dwelling count method has been less suitable (Adeniyi, 1983, Olorunfemi, 1982). In order to improve the definition of the residential area involved in the Land use Area method, an alternative model, **- NET RESIDENTIAL AREA** method - was explored in this paper to estimate the population of four urban centres in Nigeria (Fig. 1). Two of them, Benin City and Warri, are representative of major urban centres while the other two, Ekpoma and Uromi, are of medium-sized urban centres.

METHODOLOGY

A variety of rather 'old' (but these are the only ones available) black and white aerial photographs was employed in this investigation. The photographs were obtained from the Federal Department of Surveys, Lagos, Nigeria, at the following nominal scales and dates:

Warri	1:10,000	1977
Benin	1: 6,000	1979
Ekpoma	1:10,000	1982
Uromi	1:10,000	1982

Altogether, 400 photographs covered Benin City, 60 covered Warri, 25 covered Ekpoma and 30 photographs covered Uromi. The photographs were of good quality and the scales permitted detailed identification of subcategories of land use types. Before beginning the population estimation, a photomosaic of each urban centre was prepared. The land use and land cover characteristics in each urban centre was interpreted and delineated on a clear acetate film superimposed on each photomosaic with a china-graph pencil. Adeniyi (1980) urban land use classification scheme as modified by Ikhuoria (1983) was adopted for mapping (Table 1). The classification scheme and the interpretation exercise, permitted the photo interpreter to distinguish the different residential building types in order to delineate them into the sub-class categories. Neighbourhood administrative boundaries (Quarters) were also delineated on the photo mosaics to serve as the frame or unit of data aggregation.

The residential structures were classified into four types: (1) Low density (2) Medium density (3) High density and (4) developing areas. The low residential density class, typically represented the Government Reservation Areas (GRA) which contained relatively large wooded lots. The GRA's were created with colonial government edits and the areas were developed into high grade low density (4-10 houses per ha) residential quarters. Today, the areas are occupied by wealthy and public service personnel. The structures reflect colonial and contemporary architectural designs. The medium residential density class consists of medium plots of detached or row houses with small individual or common open spaces. The

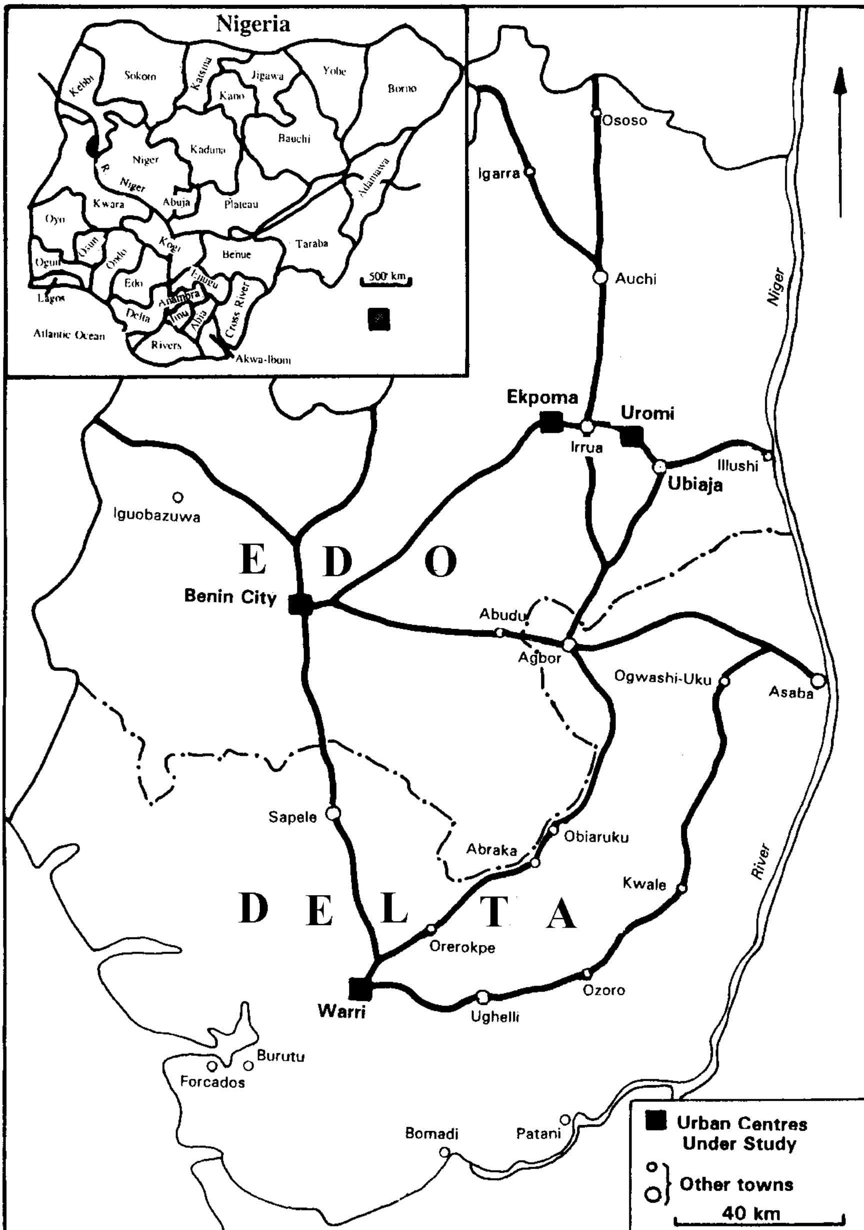


Figure 1 Areas of Study

residential class is a manifestation of Government assistance in providing accommodation for public servants and has fostered polynucleation of residential areas based on social status in the urban milieu.

The high residential density class comprised of two major residential sub-classes in both inhabitants and dwelling structures. The first is residential class 14, which is made up of the indigenous population. The area is characterized by dense (20 to 24 houses per ha) of the "court" or "rooming" type. They are regularly arranged but monotonously rectangular housing units in Benin City. In Warri, class 14 is an admixture of the "court", "rooming" and "shanty" structures. The traditional "court" type buildings are rectangular compound structures with open spaces in the centre, usually occupied by an indigenous family and his dependants. While the "rooming" building has shared kitchen, toilet and bathroom facilities. The second class is residential class 15 structures which occupy lots of about $460m^2$ and are about 20 to 22 houses per ha. These are generally either "rooming" or "flat" type residential structures that are occupied by other ethnic migrants who have settled in the city. The flats are bungalows or 1-2 storey buildings that are partitioned into separate self-contained household units.

The developing residential area consisted of completed and uncompleted structures in close juxtaposition. The developing area was about 2-5 houses per ha and occupied a significant proportion of each urban centre, and it illustrates the tremendous expansion of urban areas taking place in Nigeria, the traumatic impacts of urbanism and attendant socio-economic problems.

In population estimation, the residential categories were not only identified but the Net residential area (built-up plot area) was determined. The following formula was applied:

$$P = \sum_{i=1}^{n} (R_i \ D_i) \text{........} \textit{equation 1}$$

Where P = the estimated population

R_i - R_n are the areas devoted to net residential land use types 1 to n in each neighbhourhood.

D_i-D_n are the corresponding population densities associated with the net residential land use types 1 to n in each neighbourhood.

The net residential land use concept was defined to entail the following:

1. a built-up plot or lot or contiguous lots and excluding such spaces as the plot frontage, vegetated open spaces around the plot, the space occupied by streets and roads;

Table 1: Urban Land Use Classification Scheme

Category	Map designation	Description
1. RESIDENTIAL		
Low density	10	Large plot, 1 and 2 storey (flat) buildings with or without vegetated open spaces.
	11	Apartment buildings (3 storey & above).
Medium density	12	Medium plot, mixed 1 & 2 storey flat buildings with small individual or common open spaces.
	13	Single storey row houses with moderate single or common open spaces.
High density	14	Mixed, traditional court-type building & traditional rooming buildings interspersed with modern 1 to 3 storey buildings.
	15	Mixed traditional rooming buildings and modern 1 to 3 storey (flat) buildings.
Developing	16	New developing residential areas with completed and uncompleted residential structures in close juxtaposition & interspersed with undeveloped plots (usually 15.25 x 30.5m).

Source: Ikhuoria (1983).

2. Built-up residential areas excluding vacant areas, recreational spaces, hotels and public facilities;
3. “Normalised” developing residential land use areas.

Developing residential land use areas are often characterized by completed and uncompleted structures. During the photo-interpretation, the ground layout and unroofed structures of the uncompleted buildings were easy to recognize. Also field investigation revealed that most of those completed were yet to be inhabited. Thus it was necessary to use a correction factor to “normalize” the residential land use data of developing areas. The correction factor was determined by assessing the proportional area of completed and inhabited dwellings in the developing areas. This ranged between 42-71 percent. The plot size, built-up space etc., were taken into account. This can be expressed by the formula:

Table 2: Determination of Correction Factor for a developing residential area

Sample Area	Completed Buildings	Uncompleted Buildings	Total Buildings
1. Area bounded by Oviasogie St., Otete St, Okhoro, Uwelu and Uwasota St.; and area between Uwagboe St., Osakpomwan, Iyahen Igbinosa and Osaretin Asemota St.	60	104	164
2. Area bounded by Technical Sch. Rd., Universal, Medical Store Uyigue and Federal Roads.	95	131	226
3. Area bounded by Oba Erediauwa St., Awhan Dumez, Maria Gorretti and Upper Sakpoba Road.	120	143	263
Total	275	378	653

Proportion of completed buildings (correction factor) = 0.42.

$$R = \sum_{i=1}^{n-1} r_i + (AC) \ldots equation\ 2.$$

where:

R = Net residential area of a neighbourhood

r_i-r_{n-1} = Net residential area of residential classes

1 to (n-1) in a neighbourhood (i.e. class 10 to 15)

A = area of the developing residential land use class in the neighbourhood

C = Correction factor.

In this paper, the frontage space and the space occupied by roads and streets were not determined because of the scale of the photographs. Table 2 shows how the correction factor for a developing residential area in Benin was determined. A sample survey of the houses in the developing residential area was undertaken by photo-counting and field inspection. A total of 653 houses (completed and uncompleted) were counted. Of this only 275 were completed. Thus a proportion of 42 per cent or correction factor of (C=0.42) was the net residential area. Similarly, the correction factor for developing residential areas in Warri was determined to be 0.68 while that of Ekpoma and Uromi were 0.71 and 0.65 respectively.

Using equation 2 and the correction factors, the neighbourhood net residential area of each urban centre was determined. The net residential area of each neighbourhood (quarter) was the sum of the net residential area of each residential class (i.e. excluding vacant, open spaces and recreational areas) and the sum of the product of the correction factor and the area of developing residential zones (Table 3).

The next stage was to determine the population density of each neighbourhood. Since there was no official census records, a field sample survey was undertaken. The parameters of the population density are the area under residential use and the household size. The following procedure was used to find these parameters. After the photo-interpretation, non-homogenous residential areas in a residential class (plot sizes) were randomly selected in each neighbourhood quarter. The houses in the area were then counted and their land area was accordingly calculated (Table 4). The corresponding number of persons in the houses was determined from a questionnaire record. Using such data, the population density of the neighbourhood of Ikpokpan Quarter in Benin City for example, was determined to be 30.34 (Table 4). Similarly, other neighbourhood population densities in each urban centre were determined. Finally, equation 1 was used to estimate the population of each neighbourhood in each urban centre.

POPULATION ESTIMATION MODEL

According to Boyce (1963) and Tobler (1969), it was concluded that on the basis of empirical and theoretical deductions, the built-up area of a settlement should be proportional to the population raised to some exponent. Conversely this implied that the population of a city would be proportional to the net residential area and the population density raised to some exponents.

The formula may be expressed as:

$$P = R^{e^x} + D^{e^y} \text{..............} \textit{equation 3}$$

where:

R = the net residential area of the city

D = population density

e = exponential function

x and y = exponential co-efficients.

Table 3: Determination of Net Residential Area (hectares) in Benin City.

Quarter	Residential Areas (ha)			Net Residential Area (ha) = (a + c)
	Class 1 - 15 (a)	Class 16 (b)	Class 16 x 0.42 (c)	
1. Ibiwe	5.96	-	-	5.96
2. Ezoti	11.06	-	-	11.06
3. Ugbague	4.59	-	-	4.59
4. Ugboka	35.87	-	-	35.87
5. Iguisi	28.71	-	-	28.71
6. Ewuiso	11.81	-	-	11.81
7. Okaiavbiogbe	14.94	-	-	14.94
8. Okaieben	12.53	-	-	12.53
9. Eguadase	10.85	-	-	10.85
10. Igbesanwan	45.95	-	-	45.95
11. Evbohonvien	21.89	-	-	21.89
12. Ogiamon	43.89	-	-	43.89
13. Ihinmwirin	7.94	-	-	7.94
14. Uhumwunidumwum	144.41	-	-	144.41
15. Eyanugie	8.71	-	-	8.71
16. Okedo	40.64	-	-	40.64
17. Ewuakpon	96.73	20.25	8.51	105.24
18. New Benin	64.37	59.06	24.81	89.18
19. Urubi	77.72	-	-	77.72
20. Uselu	177.17	518.42	217.74	394.91
21. Oliha	150.88	45.56	19.14	170.02
22. Uzebu	274.49	60.21	25.29	299.78
23. Adesogbe	54.50	-	-	54.50
24. Iyekogba	45.77	44.42	18.66	64.43
25. Ogida	42.66	172.82	72.58	115.24
26. Ikpokpan	130.48	87.99	36.96	167.44
27. Evboriaria	55.69	-	-	55.69
28. Etete	25.93	20.81	8.74	34.67
29. Ugbeku	147.17	6.98	2.93	150.10
30. Aduwawa	9.02	26.46	11.11	20.13
31. G.R.A.	199.85	3.08	1.29	201.14
32. Oregbeni	1.22	64.57	27.12	28.34
33. Hausa	13.48	-	-	13.48
34. Yoruba	16.63	-	-	16.63
35. Ogbelaka	60.75	-	-	60.75
36. Ugbowo	34.04	85.89	36.07	70.11
37. Ivbioto	10.18	408.11	171.41	189.59
Total	2146.48	1624.63	682.36	2828.84

It follows that the population of an urban centre could be readily estimated with the above model, particularly when city sizes can be confirmed from satellite data. In light of this, multiple regression analysis of the land use and population variables generated for the urban centres under study was made in order to obtain the exponential co-efficients (Table 5). The result of the standardized regression coefficients are shown in table 6, and the model can be expressed linearly as:

$$P = 287R + 34D - 8541 \text{................ equation 4.}$$

or exponentially as:

$$P = R^{e^{5.66}} + D^{e^{3.51}} - C^{e^{9.05}} \text{.....eqation 5}$$

where:

P = estimated population

R = net residential area

D = population density

C = constant.

RESULTS AND DISCUSSIONS

The results of the population estimates obtained by the Net Residential Area (equation 1) P = S(Ri Di) are shown in tables 7 - 10. The results show that the estimated population of Benin City and Warri were 801,691 and 186,151; while that of Ekpoma and Uromi were 77,100 and 56,628 people respectively. The detailed neighbourhood population estimates, population densities and household occupancy rates of each urban centre were also made as shown in tables 7-10. And, the spatial variation of population distribution in Benin City is shown in figure 2.

On the other hand, when we apply the new Net Residential land use model (equation 5) to estimate the population of the urban centres the following population figures were obtained: Benin City, 813,993; Warri 151,979; Ekpoma, 72,269; and Uromi, 81,731. The overall average variation of these estimates from those obtained with equation 1 was 14% (Table 11).

Problems and Accuracy

The operational efficiency of the aerial frame technique of population estimation was rather difficult to access. There were several difficulties associated with the effort to compare the estimated population figures with other sources of population data. Firstly, there was the fact that official figures were projections based on the contraversial 1963 census data which according to Udo (1995) was an over count. Secondly, the official frame of population aggregation were inconsistent

Table 4: Determination of Population Density

	Plot Size (metres)	Residential Class	No. of Houses Sampled	Area in hectares	No. of Occupants	Population density
a.	$900m^2$	10	5	0.46	11	5.06
b.	$1,800m^2$	10	11	2.02	82	40.59
c.	$7,200m^2$	10	3	2.20	29	13.18
	Total		19	4.68	142	30.34

Table 5: Regression Analysis

Variable	Multiple R^2	Multiple R^2 Change	Beta Coefficients	Significance
No. of Dwellings	0.005	0.006	0.275	1.04
Dwelling Space	0.666	0.060	0.414	19.51
Occupancy Rate	0.074	0.004	0.297	0.71
Population Density	0.114	0.040	0.154	2.88
Net Residential area	0.935	0.821	0.960	376.58

Table 6: Standardized Regression Coefficients

Multiple R	0.83
R Square	0.69
Adjusted R square	0.66
Population Density	33.69
Net Residential Area	287.20
Constant	-8541.40
F. Significance	19.14

Table 7: Benin City - Neighbourhood Population

Neighbourhood (Quarter)	Occupancy rate	Population Density	Net Residential Area	Estimated Population
1. Ibiwe	20.1	410.1	5.96	2444
2. Ezoti	15.0	300.0	11.06	3318
3. Ugbague	17.6	361.5	4.59	1659
4. Ugboka	19.6	424.5	35.87	1522
5. Iguisi	28.9	365.5	28.71	1049
6. Ewuiso	19.4	392.8	11.81	4639
7. Okaiavbiogbe	26.8	439.3	14.94	6563
8. Okaieben	18.1	374.7	12.53	4695
9. Eguadase	25.9	333.6	10.85	3620
10. Igbesanwan	19.8	431.9	45.95	19845
11. Evbohonvien	19.2	417.4	21.89	9136
12. Ogiamon	21.4	263.0	43.89	11543
13. Ihinmwirin	26.7	298.2	7.94	2368
14. Uhumwunidumwum	23.9	459.0	144.41	66284
15. Eyanugie	24.9	293.2	8.71	2553
16. Okedo	22.1	184.0	40.64	7478
17. Ewuakpon	24.1	282.1	105.24	29688
18. New Benin	23.8	343.4	89.18	30624
19. Urubi	23.9	324.6	77.72	25228
20. Uselu	18.9	238.8	394.91	94305
21. Oliha	17.1	352.3	170.02	59898
22. Uzebu	22.3	429.5	299.78	128756
23. Adesogbe	14.9	165.9	54.50	9042
24. Iyekogba	9.7	70.1	64.43	4517
25. Ogida	23.3	461.4	115.24	53172
26. Ikpokpan	7.5	30.3	167.44	5073
27. Evboriaria	32.1	344.0	55.69	19157
28. Etete	11.8	94.3	34.67	3269
29. Ugbeku	21.0	396.7	150.10	59545
30. Aduwawa	29.6	286.7	20.13	5771
31. G.R.A.	6.4	20.9	201.14	4203
32. Oregbeni	12.3	218.9	28.34	6203
33. Hausa	29.3	322.2	13.48	4343
34. Yoruba	22.2	376.8	16.63	6266
35. Ogbelaka	20.1	363.8	60.75	22100
36. Ugbowo	11.7	124.5	70.11	8728
37. Ivbioto	11.9	263.4	189.59	49938
	Ave = 19.3	Ave = 304.3	2829	801691

Table 8: Warri - Neighbourhood Population

Neighbourhood (Quarter)	Occupancy rate	Population Density	Net Residential Area	Estimated Population
1. Odion	24.2	493.2	17.48	8621
2. Essi	23.9	275.1	13.84	3807
3. Pessu	17.0	459.5	29.58	13592
4. Igbudu	15.6	282.7	28.01	7918
5. Agbassa	26.3	478.1	19.68	9409
6. Nelse-Obahor	18.6	406.2	20.20	8205
7. Alderstown	13.8	404.4	10.88	4400
8. Agaga	22.0	400.0	22.71	9084
9. Midwest College	13.5	270.7	12.56	3400
10. Bendel Estate	12.9	292.4	39.85	11652
11. Effurun West	24.9	256.6	73.36	18824
12. Effurun East	22.4	158.4	65.97	10450
13. Enerhen	20.7	217.4	36.69	7976
14. Market	20.1	358.3	2.88	1032
15. S.S.Q.	14.0	134.6	11.88	1599
16. N.P.A.	12.9	201.0	-	-
17. Okere	19.9	601.5	24.23	14574
18. Ajamogha	18.1	564.0	21.28	12002
19. Ogunnu	17.2	352.6	-	-
20. Okumagba	25.7	592.2	66.88	39606
Total	Ave = 19.2	Ave = 360	517.96	186151

Note: N.P.A. (Nigerian Ports Authority) is an industrial neighbourhood. Although it contains residential areas the land use classification was `industrial'. Ogunnu was a rural settlement that was now gubbled by urban sprawl. Their population and those in institutional areas were not estimated.

Table 9: Ekpoma - Neighbourhood Population

Neighbourhood (Quarter)	Occupancy Rate	Population Density	Net Residential Area	Estimated Population
1. Eguare	18.8	326.9	120.49	39388
2. Emaudo	16.3	382.6	25.22	9649
3. Ihonmudumu	18.3	299.4	38.85	11631
4. Ukpenu	17.0	247.3	31.88	7884
5. Ujoelen	15.4	301.5	28.35	8548
Total	Ave = 17.2	Ave = 311.5	244.79	77100

as they varied from Clans in 1952, Wards in 1963, to Local Government Areas in 1987. In some cases, Wards were used synonymously with Quarters, in others they were different neighbourhood units. Thirdly, other sources of estimates such as Sada (1976), and Doxiadis (1976) were not aggregated into any neighbourhood frame. Fourthly, the aerial photographs were too old. Although the photographs were flown between 1977 and 1982, the photo-interpretation and field survey was conducted between 1986 and 1987.

It is obvious that there would have been some additional buildings between the dates of photography and the date of the field survey. Furthermore, there would have been some possible increase or decrease in household sizes (occupancy rates) during the period. Nevertheless, it was assumed that the dynamism of residential land use change (except for developing areas) should be minimal. Therefore, 1987, the year when the household size (occupancy rate) and population density were determined was used as the base year for comparing the aerial frame population estimates with the projected population data.

The 1963 census population of Benin, Warri, Ekpoma and Uromi were 100,694, 55,256, 13,015 and 17,174 respectively. Since the 1973 census result was cancelled, information on the population of these towns were based on projected estimates or published scholarly research. Thus in 1972, Doxiadis estimated the population of Benin to be 20,100 while Sada estimated it to be 314,219 in 1976, with an 8.6 growth rate in 1984. Warri was estimated to have a population of 151,000 in 1975 and 228,000 in 1982 with a 10.6 growth rate. The 1975 population of Ekpoma and Uromi were estimated to be 35,000 each (Doxiadis, 1972, 1976, 1977; Sada, 1976, 1984). Prior to 1976 when Ekpoma and Uromi were recognised as urban centres, the rural growth rate of 2.5 was used to project their populations.

If we apply the census urban growth rate of 5.5 and Sada's estimate of 8.6 and 10.6 growth rates for the respective urban centres, then the 1987 projected population estimates would be as shown in Table 12. Thus according to projected figures based on 1963 official census data, Benin City had a population of 376,940 while Warri, Ekpoma and Uromi had a population of 206,846, 32,854 and 43,527 each in 1987. These figures should be unrealistic because of the appreciable increase in urban population since 1963, due to natural increase, and rural-urban migration as reported by Sada (1984). The projected estimates based on Doxiadis' (a consultant firm on development and planning) figures for Benin City was 730,190; Warri 292,154; Ekpoma, and Uromi 67,718. While the projected estimates based on Sada's 1976 comprehensive household survey are 809,236 for Benin and 387,356 for Warri.

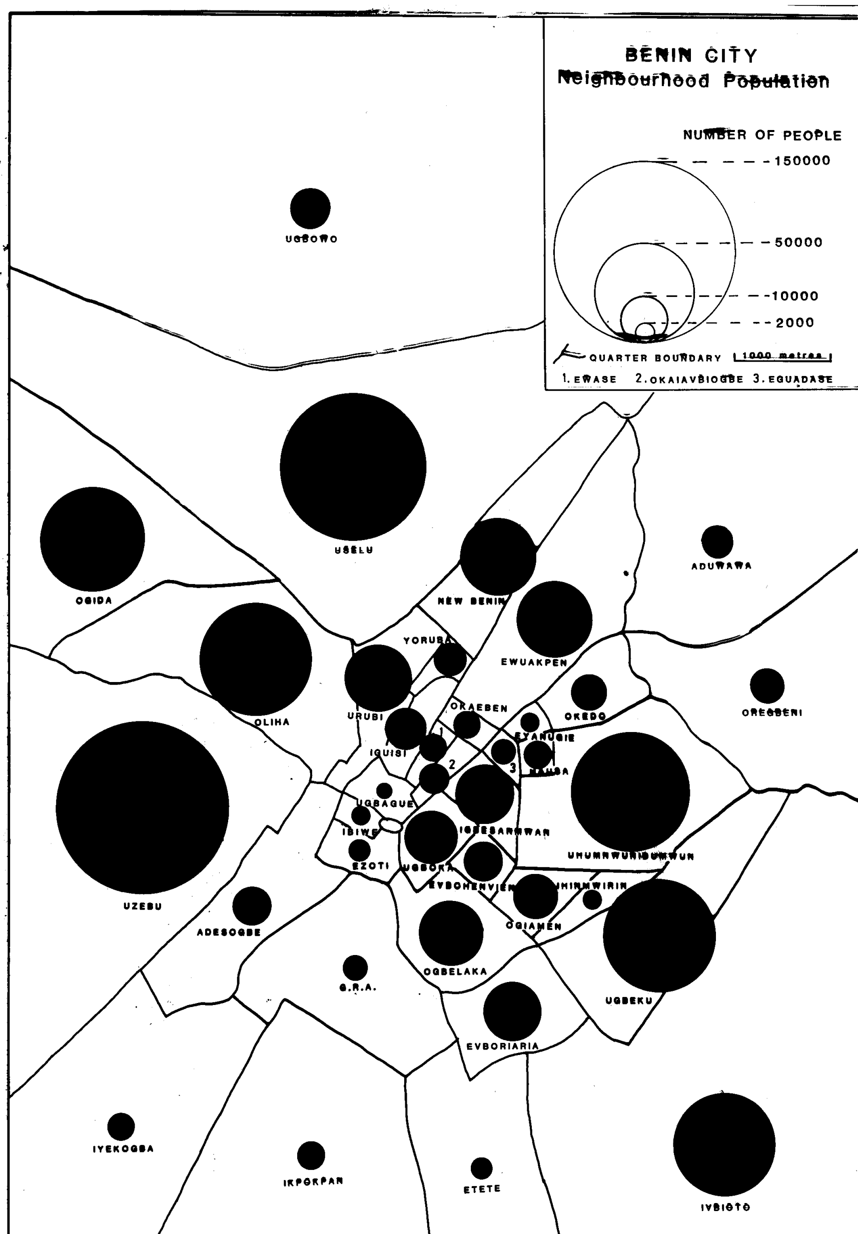
Comparatively however, the results of the population estimates made from the aerial photographs compared relatively well with projections based on Doxiadis and Sada's data. In Benin, the estimate varied by 8.9% with projected Doxiadis'

Table 10: Uromi - Neighbourhood Population

Neighbourhood (Quarter)	Occupancy Rate	Population Density	Net Residential Area	Estimated Population
1. Eguare	17.5	213.2	151.67	32336
2. Egbele	13.9	225.9	29.59	6684
3. Ewoyi	12.6	160.9	109.44	17608
Total	Ave = 14.7	Ave = 200	290.79	56628

Table 11: Estimated Population Figures with the new model.

City	Area	Net Residential	Population Density	Estimated Population using $P = \Sigma(R_i D_i)$	Estimated Population using $P = R^{e^x} + D^{e^y} - C$
1 Benin City	6241	2829	304	801,691	813,993
2. Warri	1311	517	360	186,151	151,979
3. Ekpoma	432	245	312	77,100	72,269
4. Uromi	498	291	200	56,628	81,731
5. Lagos	11597	5798	388	1.7 million	1.67 million


BENIN CITY
Neighbourhood Population
NUMBER OF PEOPLE
150000
50000
10000
2000
QUARTER BOUNDARY
1000 metres
1. EWASE 2. OKAIAVBIOGBE 3. EGUADASE
UGBOWO
USELU
OGIDA
ADUWAWA
NEW BENIN
YORUBA
EWUAKPEN
OLIHA
URUBI
OKAEBEN
OKEDO
IGUISI
EYANUGIE
UGBAGUE
IBIWE
EZOTI
UZEBU
ADESOGBE
OGIAMEN
OGBELAKA
G.R.A.
UGBEKU
EVBORIARIA
IYEKOGBA
IKPOKPAN
ETETE
IVBIOTO

estimate, and 0.9% with projected Sada's estimate. In Ekpoma and Uromi, the variation was 12.1% and 19.5% with Doxiadis estimates respectively. The high proportion of variation in Warri, 56.9% and 108.1% with Doxiadis and Sada's estimates are quite significant. The reasons are obvious. According to Sada (1984), Warri's unprecedented growth was due to petroleum, steel and associated industries, hence its estimated 10.6% growth rate in 1984. But although the household size and population density survey was conducted in 1986-1987, the aerial photographs only covered the 1977 territorial extent of Warri. Areas of expansion were thus not adequately covered in this estimate.

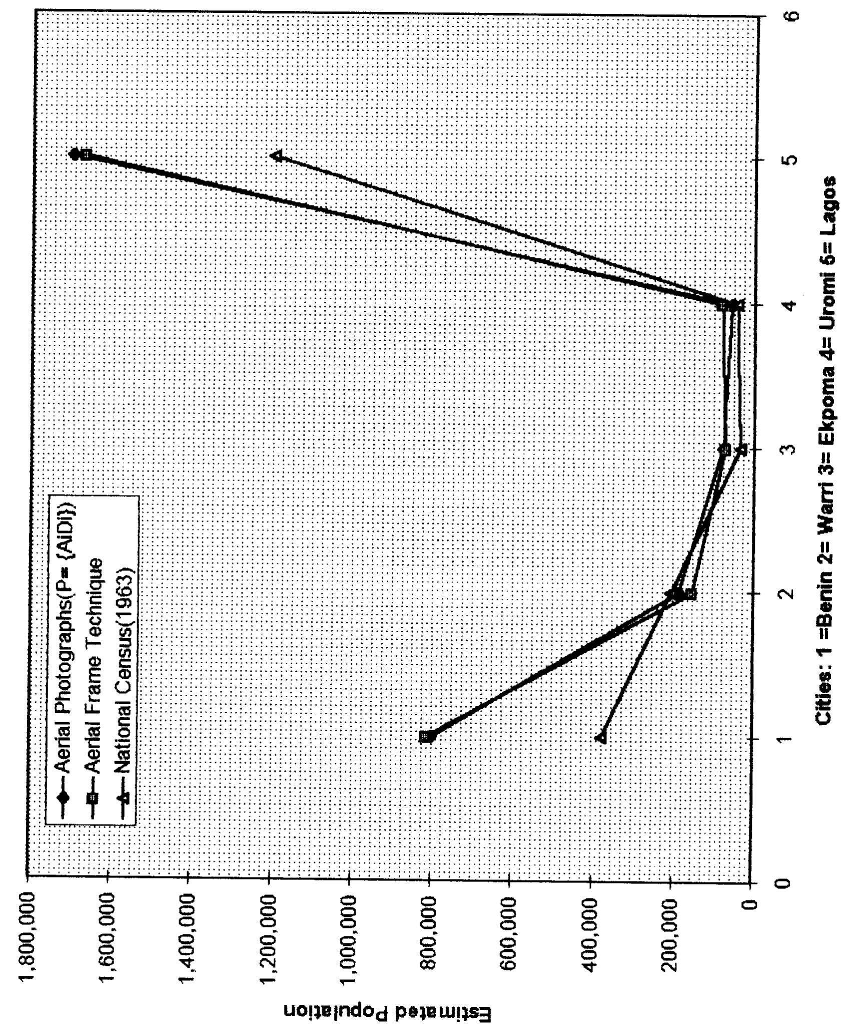
The result of the new aerial frame model also compared fairly well with the conventional Land Use Area method. The population estimates made with the two methods varied by 1.5% in Benin, 18.3% in Warri, 6.2% in Ekpoma, 44.3% in Uromi and 1.7% in Lagos. With the exception of Uromi, it appeared reasonable that the new model could serve as a quick method of deriving urgently needed urban population estimates. A graphic illustration of the reliability performance of the aerial frame technique is shown in figure 3.

There were also a number of other problems. For example the population of some industrial and institutional areas such as university campuses, secondary school premises and industrial estates were not estimated. These premises have residential houses which a number of families occupy but because in the land use classification the entire premises were categorised and classified under the primary function, that is, as institutional or industrial land use, the population of such areas were not incorporated or accounted for in the land use model of population estimation. Thus, the population of Warri, or Ugbowo quarter in Benin City are rather lower than they may actually be because they contain many institutions. Similarly, the population of the Nigerian Ports Authority (NPA) which is wholly an industrial area in Warri with several official residential quarters was not estimated. This may account for the high variability of the Warri estimates when compared with the projected figures. Further studies in the development of land use classification schemes and the predictive efficiency of the population estimation model that will incorporate solutions to these problems are therefore necessary. Thus, in spite of the comparative accuracy of the result, there is need to further explore the aerial frame technique of population estimation by extending research to other cities in Nigeria and other countries.

Potential Values:

One of the most pernicious consequences of the past censuses in Nigeria has been the manner in which the integrity of the published results have been criticised with claims and counter-claims of over-inflation of figures in particular

Figure 3: Comparative Accuracy of Population Estimation



areas. The case study examples in this paper have made it increasingly clear that the solution lies in supplementing the traditional population census with a modern technological and scientific scheme such as the aerial frame technique, or remote sensing approach.

Past experiences have shown that there are population pressure points and associated political "hot spots" in the West, East and Northern parts of Nigeria. The adoption of the aerial frame approach will tremendously ease the political tension associated with census taking in these areas. Population estimates made from aerial photographs or aerospace data before and after the census enumeration in these areas will help to validate the "real" census results.

Thus, a well articulated government policy and programme for remote sensing application will ensure provision of consistent and comprehensive information supply for multipurpose use in population estimation, urban and regional planning, topographical mapping, agricultural, forestry and environmental applications.

CONCLUSION

By and large, the results of the aerial frame technique of urban population estimation enabled us to gain some insights into the spatial pattern of neighbourhood population distribution as well as population density variations in rapidly urbanising major and medium-sized urban centres in Nigeria. Although the results of the aerial frame technique compared fairly well with other estimates, further research is necessary in order to refine the accuracy of the method. Its potentials lie in the usefulness for generating urgently needed population data. If the photography is current, the technique could be used to supplement census exercises in developing countries.

REFERENCES

1. ADENIYI, P.O. (1980): "Land use change analysis using sequential aerial photography and computer techniques: *Photogrammetric Engineering and Remote Sensing*, Vol. 46, No. 11, pp. 1447-1464.

2. ADENIYI, P.O. (1983): "An Aerial Photographic Method for estimating urban population", *Photogrammetric Engineering and Remote Sensing*, Vol. 49, No. 4, pp. 545-560.

3. BOYCE, R. (1963): "Changing pattern of urban land consumption", *Professional Geographer*, Vol. 15, pp. 19-24.

4. CLAYTON, C. and ESTES, J.E. (1980): "Image analysis as a check on census enumeration accuracy", *Photogrammetric Engineering and Remote Sensing*, Vol. 46, No. 3, pp. 756-764.

5. COLLINS, W.G. and EL-BEIK, A.H.A. (1971): "Population Census with the aid of aerial photographs: an experiment in the City of Leeds" *Photogrammetric Record*, Vol. 7, No. 37, pp. 16-26.

6. DAYAL, H.H. and KHARIZADA, B.A. (1976): "The first national demographic survey of Afghanistan: the role played by air photos and photo-counting techniques", *ITC Journal*, No. 1, pp. 84-87.

7. DOXIADIS ASSOCIATES (1972): *Nigeria development problems and future needs of major urban centres*: Benin City. A Planning report prepared for the Federal Government of Nigeria.

8. DOXIADIS ASSOCIATES (1976): *Bendel State Regional Development Plan*, Vol. 2, No. 2, Bendel Development and Planning Authority, Benin City, Nigeria.

9. DOXIADIS ASSOCIATES (1977): *Bendel State Regional Development Plan*: Existing Conditions and Problems, Bendel Development and Planning Authority, Benin City, Nigeria.

10. ENSELE, D. and KARPE, H.J. (1975): *Metropolitan Lagos Water Supply Demand Analysis* G.W.K. Consulting Engineers, Dortmund.

11. GREEN, N.E. (1956): "Aerial Photographic analysis of residential neighbourhoods: an evaluation of data accuracy", *Social Forces*, Vol. 35, pp. 142-147.

12. HSU, S.Y. (1971): "Population estimation", *Environmental Engineering*, Vol. 37, pp. 449-454.

13. IKHUORIA, Isi A. (1983): "Urban land use in inventory and mapping from semi-controlled photo-mosaics" *ITC Journal*, No. 4, pp. 341-347.

14. LO, C.P. and CHAN, H.P. (1980): "Rural population estimation from aerial photographs", *Photogrammetric Engineering and Remote Sensing*, Vol. 46, pp. 337-345.

15. LO, C.P. (1986): "Accuracy of Population Estimation from medium-scale aerial photography" *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 12, pp. 1859-1869.

16. OLORUNFEMI, J.F. (1982): "Application of aerial photography to population estimation in Nigeria", *Geojournal*, Vol. 6, No. 3, pp. 225-230.

17. POLLE, U.F.L. (1980): “The Size of net residential areas on aerial photographs” *ITC Journal* No. 3, pp. 544-562.

18. POLLE, V.F.L. (1984): “Population estimation from aerial photos for non-homogenous urban residential areas”, *ITC Journal* No. 2, pp. 116-122.

19. SADA, P.O. (1976): “Population structures and household characteristics in Benin City”, *Research Bulletin* No. 1, University of Benin, Benin City, Nigeria.

20. SADA, P.O. (1984): “Migrants in Nigerian Cities, with special reference to Warri, Benin and Auchi”, in Sada, P.O. and Osirike, A.B. (eds.) *Case Studies in Migration and Urbanisation in Nigeria*, Department of Geography and Regional Planning, University of Benin, Benin City, pp. 1-15.

21. TOBLER, W.R. (1969): “Satellite confirmation of settlement size coefficients”, *Area*, Vol. 1, No. 3, pp. 31-34.

22. UDO, R.K. (1995): “*The 1991 Population Census of Nigeria: a Comparative Study*” Fellowship Lecture delivere at the Annual Conference of the Nigerian Geographical Association, Benin City 28-31 May.

23. WATKINS, J.F. and MARROW JONES, H.A. (1985): “Small area population estimates using aerial photography”, *Photogrammetric Engineering and Remote Sensing*, Vol. 51, No. 12, pp. 1933-1935.