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Rural Population Estimation from Aerial Photographs

The house count method, applied to the New Territories of Hong Kong, was subject to overestimation due to vacant buildings and underestimation due to multistoried buildings mixed with rural dwellings.

Introduction

Research on the use of aerial photographs for population estimation has tended to focus on the Western urban environment where the variety of built-forms is most diverse. Usually, medium-and large-scale aerial photographs were used, which included 1:5,000 (Hsu, 1971), 1:10,000 (Collins and El-Beik, 1971), and 1:40,000 (Kraus *et al.*, 1974). In general, these studies reported an error of 3 percent, 2 percent, and 4.5 percent underestimation, respectively, in the population figures obtained. The close correlation between the photographic scale and the degree of accuracy, as well as the predominance of underestimation, are noteworthy.

The application of the methods of population estimation from aerial photographs to the rural environment has largely been neglected. It would be useful to know of the applicability of the methods to the rural areas of countries which are economically less advanced and culturally different from those of the West. Indeed, in many developing countries, the population is still predominantly rural. An accurate knowledge of the rural population size is therefore equally important. So far, only one application of the technique to the demographic survey of the rural population at the national level in a developing country has been reported by Dayal and Khairzada (1976) for Afghanistan where aerial photographs at the scale of 1:5,000, specially flown for this purpose, were used. Unfortunately, no accuracy figure was given for the resultant population estimates although it appeared from the report that the method worked well.

Abstract: *The house count method of population estimation is applied to a rural area of immigrant vegetable farmers in the New Territories of Hong Kong, using 1:25,000 scale aerial photographs and a Bausch and Lomb Zoom Stereoscope. A typology of rural dwellings is developed and the associated residential densities are determined from sample surveys. The close association between the rural dwelling types and their spatial patterns is employed to facilitate house counting. The result shows that reasonably accurate population estimates of the rural area at the Tertiary Planning Unit level (TPU) can be obtained although problems concerning overestimation caused by the occurrence of vacant dwellings, underestimation caused by the multistoried buildings mixed with rural dwellings, and the discrepancies given rise by the residential densities determined need to be resolved. It is concluded that the technique developed can be usefully employed by town planners in collecting accurate and up-to-date population data of the rural environment between two census dates.*

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It is hoped that the present application of the method to the rural New Territories of Hong Kong can throw light on the problems of rural population estimation from aerial photographs under different cultural and economic conditions.

The Study Area

The New Territories occupy an area of 916 km^2 or 87 percent of the total land area of Hong Kong (Figure 1). Within this area, most of the agricultural activities are found. Although in absolute terms only 93 km^2 or 8.8 percent of the total land area of Hong Kong was under cultivation in 1978, the extremely intensive use of the arable land makes possible a supply of 43 percent of the vegetables consumed, about 65 percent of the total live chicken requirements, and about 17 percent of all pigs slaughtered (Hong Kong Government, 1978).

The study area where rural population estimation is to be carried out occupies the Northeast Plain where the Ng Tung River runs across and embraces the market towns of Sheung Shui and Fan Ling (Figure 2). This area is very well served by a railway and other good surfaced roads, and is an important vegetable producing area associated with the immigrant farmers from Mainland China since 1949. Because of the good accessibility, there tends to be a greater concentration of rural-farm and non-farm population. This is a typical area of the New Territories where rural and urban characteristics mix together.

The aerial photographs employed for this study were taken by the Flying Unit of the Crown Lands and Survey Office, Public Works Department with a Wild RC-10 camera (focal length 152.53 mm) from an altitude of 3,810 m on 24 December 1975, giving a nominal scale of 1:25,000. This scale is too small for distinct identification of individual dwellings with a standard mirror stereoscope. A Bausch and Lomb Zoom Stereoscope Model 95, which is capable of magnifying the stereomodel ten times, had to be used. It is hoped that population estimation for this area can be obtained at the Tertiary Planning Unit (TPU) level—the smallest areal unit employed by the Town Planning Office for Hong Kong in planning. Because a by-census based on a 10 percent sample of the entire population of Hong Kong was conducted on 2 August 1976 by the Census and Statistics Department, data were available for comparison with the results of population estimation from aerial photographs. Despite the nearly eight-month discrepancy between census date and photography, the population change in the area under study was considered not drastic enough to nullify the comparison.

The Method Employed

The methods of population estimation employed at this microscopic level of application are usually (1) the area-density method and (2) the house count-household size method. By the first method, the residential land-use types in an area first have to

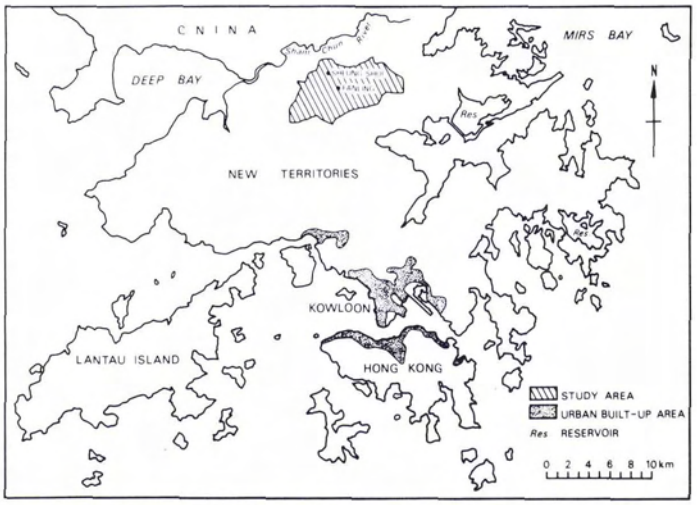

FIG. 1. Hong Kong and its New Territories: the location of the study area.

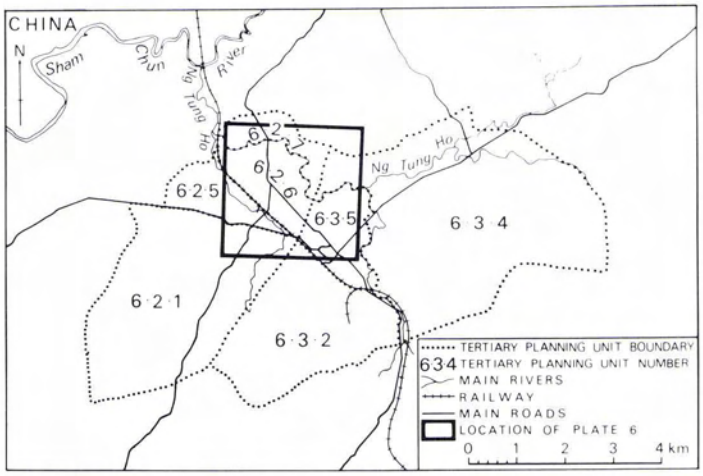

FIG. 2. The Sheung Shui-Fan Ling study area showing communication lines and TPU Boundaries.

be identified and their areal extent measured directly from the aerial photographs. Then, the characteristic population density associated with each residential land-use type is determined, either from the latest census (if one is available) or from field surveys. The following relationship is employed to determine the population size, P:

$$P = \sum_{i=1}^{n} (A_i D_i) \qquad (1)$$

where $A_1 \ldots A_n$ are the areas devoted to residential land use types of 1 to n, and $D_1 \ldots D_n$ are the corresponding population densities associated with residential land use types 1 to n. A typical example is the work by Kraus *et al.* (1974) in their application to four California cities.

The second method involves identification of dwelling types in the area. The number of dwelling units in each type is then counted from the aerial photographs. The residential density in the form of the number of persons per household is then obtained for each dwelling type from sample surveys or more usually from census statistics. The population estimate, P, is computed from the following relationship:

$$P = \sum_{i=1}^{n} (H_i D_i) \qquad (2)$$

where $H_1 \ldots H_n$ are the numbers of dwelling units in dwelling types 1 to n, and $D_1 \ldots D_n$ are the corresponding household size for dwelling types 1 to n. An example of such an application is found in Hsu's work (1971) in an area near Atlanta, Georgia.

In comparing the advantages and disadvantages of these two methods, it becomes clear that the house count-household size method is more suitable for application in rural population estimation. The measurement of area directly from aerial photographs required in the first method can be inaccurate, especially if large-scale aerial photographs are used for an area with a great difference in relief. Relief displacement and tilt have combined to give errors in the measurement, especially around the edges of the photographs. Also, in the rural environment housing density is generally not as high as that found in the urban environment, and multistoried buildings are relatively rare. Thus, more accurate counting of the rural dwellings can be carried out.

The present application to the Sheung Shui–Fan Ling area makes use of the house count method. The study area was first examined under the Bausch and Lomb Zoom Stereoscope in order to provide a preliminary classification of the rural dwellings into specific types. This was then field checked. Altogether, four types of rural dwellings were identified: (1) traditional village houses (Figure 3), (2) temporary shacks or huts (Figure 4), (3) new village houses (pitched roof type) (Figures 5a and 5b), and (4) new village houses (flat-roof type) (Figure 6). The characteristics of these rural dwellings as interpreted from the aerial photographs are summarized in Table 1, which can be treated as a key for photo-interpretation. Because of the common

FIG. 3. Traditional Chinese village houses with double sloping roofs and eaves.

FIG. 5a. Two-storied new village houses with double-sloping roofs and low parapets.

practice of raising pigs by farmers in the area, pig sties are found along with other residential structures. One has to exercise particular care in distinguishing them (Figure 7).

From aerial photographs and field work, one observed that rural dwellings of the same type tend to occur in clusters and that three distinctive patterns are identifiable: (1) the regular and compact pattern of the traditional village houses (marked as A in Figure 8), (2) the irregular but dense cluster of the temporary shacks (marked as B in Figure 8), and (3) the isolated pattern of the new village houses (marked as C in Figure 8). However, they are also found mixed in some areas because of the rather haphazard development styles which reflect the economic status of the rural population at different times.

The residential density in each rural dwelling type was determined in the field. About 1 percent of the rural dwellings in each class was visited and the number of residents counted by the method of quota sampling in the study area. It should be noted that, unlike the Western cultural area, a rural dwelling could contain more than one household. The household concept, therefore, was not used. Instead, the number of persons actually living in the rural dwelling was determined. The result of the survey revealed that on the average the new village type houses (both categories) had the highest residential density with 4.4 persons per dwelling unit as compared with only 3.1 for the traditional village house and 3.3 for the temporary shacks or huts.

The procedure of rural population estimation in this case involves the following steps:

(1) The aerial photographs are examined and the Tertiary Planning Unit (TPU) boundaries are marked with a chinagraph pencil on the prints.

(2) With reference to Table 1, the rural dwelling types are identified and their areal extent marked on the prints with a chinagraph pencil of a different color.

(3) Counting of the individual rural dwellings is carried out in each cluster determined in (2) above under 10× magnification of the Zoom Stereoscope with the aid of a fine pin. A hole is lightly pricked on each dwelling unit so counted, thus giving a distinguishing mark to avoid duplicated counting.

(4) Estimation of the number of stories of the buildings is occasionally required when

FIG. 4. Temporary shacks made of metal plates.

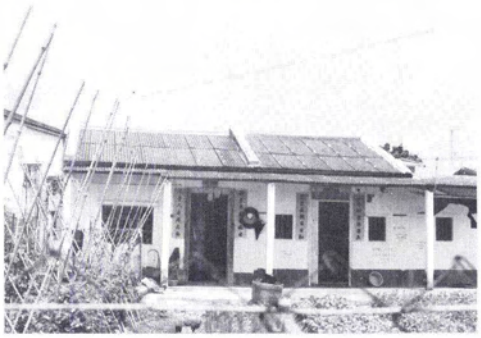

FIG. 5b. One-storied new village houses with double-sloping roofs and asbestos roofing.

FIG. 6. A two-storied new village house with flat roof.

the market town is mixed with the rural dwellings.

(5) The result of the count is separately recorded according to type by TPU's. The appropriate residential density is used according to Equation 2 to obtain an estimate of population.

ACCURACY OF POPULATION ESTIMATION

The results for seven TPU's of the study area are shown in Table 2. They are compared with the 1976 By-Census figures of the corresponding TPU's. The error analysis (Table 2) reveals that the accuracy of the population estimates obtained by the method described above varies from one TPU to another. It is particularly noteworthy that TPU 627, which is the smallest unit of all, shows an extremely high overestimation of the population. After a field check, it was found that many of the rural dwellings counted were either vacant or were no longer used for residential purpose. It is extremely difficult to detect this type of functional change from the aerial photographs based on the structure alone. It also implies that the residential densities obtained from the sample survey are perhaps not typical in this relatively new agricultural area.

On the other hand, a large underestimation of population occurs in TPU 626, TPU 634, and TPU 635. The cause for the underestimation in TPU 626 and TPU 635 is the inclusion of the market towns of Sheung Shui and Fan Ling, respectively, in the units. These market towns feature multistoried buildings similar to those found in the urban environment. An underestimation of the number of stories in a building is an easily committed error as in the case of the urban environment. Hence, as the size of the market town increases, the degree of underestimation also increases because it occupies a greater area of the TPU. As for TPU 634, the underestimation most probably reflects the inapplicability of the residential densities determined from a small sample survey. This is clearly brought out when an independent set of population estimates for each TPU is also computed using residential densities determined from the 1971 census data. The underestimation for TPU 634 has been greatly improved (Table 2).

On the whole, under normally rural conditions, the method reported in this paper gives a mean accuracy of about 6.3 percent in either overestimation or underestimation of the population with a standard deviation of ±9 percent. If the other approach is used, that is, residential densities determined from the previous census data, the accuracy is about the same (6.2 percent) but its standard deviation is greatly improved (±4 percent). This suggests that the use of residential densities determined from a previous census conducted five years ago can yield more precise population estimates than the use of residential densities determined from a small sample survey. Alternatively, sample surveys for individual TPU's rather than the study area as a whole should be carried out to determine residential densities if more accurate population estimates are to be obtained.

When the population for each TPU is added up (Table 2), the tendency towards underestimation is clearly shown in both approaches, with the census-derived residential densities yielding a better accuracy (−6 percent). It is noteworthy that, when a large area is under study, the overestimation and underestimation tend to cancel out. The accuracy of house count is even better (−1.1 percent) (Table 2). This suggests further that the error in population estimation is the result of some discrepancies in the residential densities from the actual situation in some TPU's, and is not so much the result of miscount.

CONCLUSIONS

The method of photographic rural population estimation described in this paper yields reasonably accurate results at a small areal unit level such as the TPU used in this study, and when a larger areal unit level is used, under and over-estimates tend to cancel each other out, and even more accurate results are achieved. The method is convenient to use because of the close association between rural dwelling types and clustering patterns. The most tedious stage of the task is the counting of the number of dwelling units. But with the 10× magnification of the

TABLE 1. TYPES OF RURAL BUILDINGS AND THEIR PHOTOGRAPHIC CHARACTERISTICS IN SHEUNG SHUI–FAN LING AREA

Rural Building Type	Building Material	Roof Form	Roofing Material	Photo Tone	Size (m^2)	Shape	Geometrical Character	No. of Stories	Height (m)	Example
1. Traditional village houses	stone or brick	double-sloping occasionally with eaves	tile	dark	25-35	rectangular or square	symmetrical	one with a cockloft	4-5	Ground: Figure 3
2. Temporary shacks or huts	timber or metal plate	double sloping	metal plate	light	20-30	rectangular	symmetrical	one	2.5-3.5	Ground: Figure 4
3. New village houses (Type A)	concrete or brick	double sloping occasionally with parapet or eaves	asbestos	light to dark	50-65	rectangular	symmetrical	one or two	3-8	Ground: Figures 5a & 5b
4. New village houses (Type B)	concrete or brick	flat-topped with parapet	brick or concrete	light	50-65	rectangular	symmetrical	one or two	3-8	Ground: Figure 6
5. Pig sties	metal plate	single or double-sloping	metal plate	light	35-45	rectangular (elongated)	symmetrical	one	4-5	Ground: Figure 7

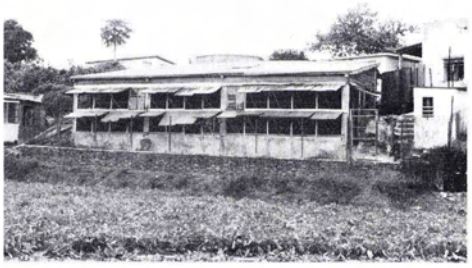

FIG. 7. A pig sty.

Zoom Stereoscope, the task of identifying the rural dwelling types and counting has been greatly facilitated.

Some problems have emerged in this study. The most important one is that, in a rural area with a predominance of vacant or abandoned dwellings (which may suggest out-migration), population estimation from aerial photographs will break down unless an intensive survey can be carried out in the field. Such changes are so irregular and haphazard that they cannot be compensated for statistically. Another problem concerns the mixing up of market towns with rural dwellings, which tends to cause underestimation of the population. Therefore, market towns should better be separated from the dispersed or clustered dwellings of the rural area in population estimation from the aerial photographs. Field surveys are required to establish more accurately a typology of multistoried buildings and the associated residential densities.

The original photographic scale of 1:25,000 would be too small by itself to per-

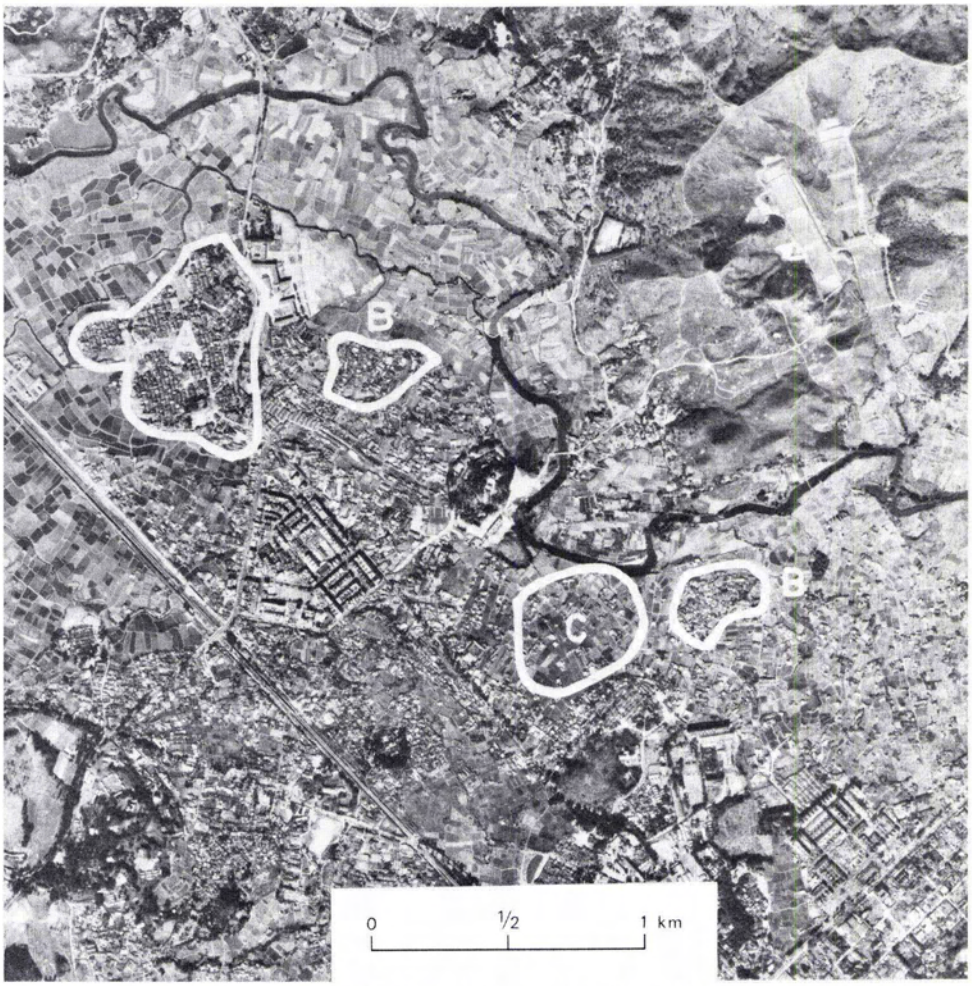

FIG. 8. An enlarged portion of the aerial photographs showing three distinct types of rural settlement patterns: (A) regular and compact, (B) irregular and dense, and (C) isolated.

TABLE 2. ACCURACY OF PHOTOGRAPHICALLY DERIVED POPULATION ESTIMATES AS COMPARED WITH CENSUS RESULTS BY TERTIARY PLANNING UNIT IN SHEUNG SHUI–FAN LING AREA

TPU	Area (Km^2)	No. of Living Quarters 1976 By-Census	No. of Dwellings from photo count	Accuracy %	Actual Population 1976 By-Census	Photo-Estimated Population using surveyed residential densities	Accuracy %	Photo-Est. Population using 1971 Census derived residential densities	Accuracy %
621	10.6	3,150	3,792	+20.4	14,560	15,015	+3.1	14,334	−1.6
525	1.9	830	1,006	+21.2	3,630	3,696	+1.8	4,004	+10.3
626*	2.5	5,050	4,586	−9.2	22,970	19,214	−16.4	19,582	−14.7
627	1.4	180	399	+121.7	690	1,542	+123.5	1,704	+14.7
632	7.1	1,290	1,356	+5.1	5,700	5,721	+0.4	5,885	+3.2
634	1.6	3,830	3,458	−15.1	16,500	13,229	−19.8	14,541	−9.7
635+	2.5	3,720	3,452	−7.2	16,510	14,681	−11.1	15,672	−5.1
Whole Study Area	27.6	18,050	17,844	−1.1	80,560	72,196	−10.4	75,722	−6.0

* Includes the market town of Shek Wu Hui (Sheung Shui)
+ Includes the market town of Luen Wo Hui (Fan Ling)

mit accurate identification and counting of the rural dwellings if the 10× magnification of the Zoom Stereoscope had not been used. As it is, the small photographic scale cuts down the number of stereomodels required to cover the study area, thus facilitating the delimitation of areal units and counting of rural dwellings. It is perhaps necessary to explore the use of color-infrared photography as a means to improve on the accuracy of identification of dwellings in a rural context and to assess its cost-effectiveness, especially if it is to be applied in a developing area where population data are always in great demand for use in planning.

To conclude, the successful application of the method of population estimation from aerial photographs to the rural environment depends on an understanding of the cultural and socio-economic characteristics of the population under study. The technique is best employed to estimate population between two censuses rather than to dispense with census-taking entirely. It can also be easily combined with statistical sampling to enhance the accuracy of the results. It is a useful technique which deserves more widespread application by practicing town planners in collecting up-to-date population and housing data of the rural environment.

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