Are rapid population estimates accurate? A field trial of two different assessment methods

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Emergencies resulting in large-scale displacement often lead to populations resettling in areas where basic health services and sanitation are unavailable. To plan relief-related activities quickly, rapid population size estimates are needed. The currently recommended Quadrat method estimates total population by extrapolating the average population size living in square blocks of known area to the total site surface. An alternative approach, the T-Square, provides a population estimate based on analysis of the spatial distribution of housing units taken throughout a site. We field tested both methods and validated the results against a census in Esturro Bairro, Beira, Mozambique. Compared to the census (population: 9,479), the T-Square yielded a better population estimate (9,523) than the Quadrat method (7,681; 95% confidence interval: 6,160–9,201), but was more difficult for field survey teams to implement. Although applicable only to similar sites, several general conclusions can be drawn for emergency planning.

Keywords: area sampling, emergency, internally displaced persons, Quadrat method, rapid population estimation, refugees, T-Square method

Introduction

Emergencies may result in the large-scale displacement of populations, which resettle in areas where basic health services and sanitation are not available. During the acute phase of an emergency, a rapid estimate of the size of the displaced population provides essential information with which to plan relief activities. A complete population census or other registration initiative may not be finished until the situation has stabilised, often several weeks later. Rapid population size assessments are carried out in refugee camps, sites of internally displaced persons (IDPs) and more general settings where populations are gathered, and for more stable populations living in slum-like conditions where population enumerations may not exist (Brown, Moren and Paquet, 1999).

The currently recommended approach is based on the estimation of population density from a sample of square blocks of known area (Quadrat method). An alternative approach estimates population density based on the distance between a sample of random points to the closest household and its closest neighbour (T-Square method). Recent research suggests that distance methods, such as the T-Square, may yield comparable population size estimates in less time (Brown et al., 2001; Espié, 2000; Kaiser et al., 2003; National Research Council, 1988).

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Although of clear importance for an efficient and effective response during an emergency, little research has been done on the validity of these methods for the estimation of population size in displaced human populations. The aim of this study was to test and validate the results of these two methods and to recommend under which conditions each should be used to yield reliable population estimates. Our specific objectives were to:

- validate the Quadrat method;
- test the T-Square method at the field level;
- compare the results obtained using both approaches (population estimates, timeliness and logistical feasibility);
- determine whether the methods could be simplified and still provide reliable results; and
- make general recommendations on their use in emergency environments.

Methods

Study site

This research was conducted within a portion of Esturro Bairro, a neighbourhood of the city of Beira, Mozambique. The study area, measuring approximately 500 metres by 350 metres (0.18 square kilometres), was selected because of the availability of a population census conducted in September 2003. The census included the name, age and sex of residents, as well as the longitude and latitude—global positioning system (GPS)—location coordinates of households. Households were defined as persons who sleep regularly in the shelter. An occupant was defined as a person sleeping regularly in the household. The study population was 9,479 persons. The average household size was 5.2 persons, with a total of 1,828 housing units. Figure 1 shows the GPS position of each household in the study area.

Population estimation methods

We field tested two population estimation methods: the Quadrat and the T-Square. Detailed information on the calculation of confidence intervals and the underlying statistical theory has been published previously (Diggle, Besag and Gleaves, 1976; Diggle, 1977; Ludwig and Reynolds, 1988).

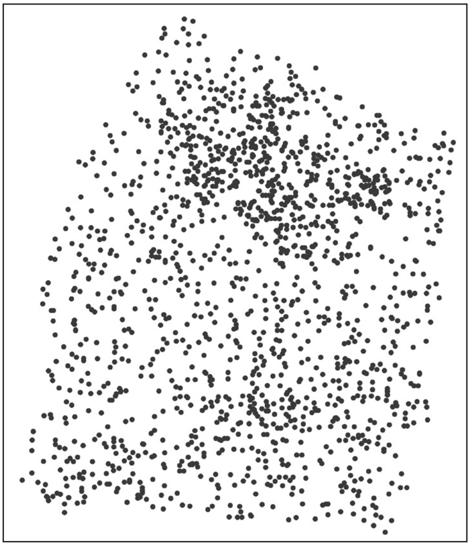


Figure 1 Location of each household in the study area

Note: locations identified through the census.

The first step in estimating the population size is to obtain a map of the site. In this study, a previously available map of the census site was used to define the study area boundaries. GPS boundaries of the site were entered into a computer application to generate an electronic map of the study area.[2]

Quadrat method

The Quadrat method is the currently recommended approach for estimating population size. Based on previous experience and empirical research (Brown et al., 2001; Espié, 2000), we selected 30 blocks of 625 square metres (25 x 25 metres) systematically distributed throughout the study site. We chose to take a systematic sample in order to address any underlying heterogeneity in the population distribution within the study site. Although a simple random sample of quadrats could be employed, a systematic sample guarantees an even spatial sample, which is especially important in sites with heterogeneous spatial distributions (for example, different density zones). Another benefit of utilising a systematic sample is that it is easier and faster for field survey teams to implement than simple random sampling.

To define the quadrats, 30 systematically distributed GPS points were selected. This was accomplished using mapping software, which automatically generated the points (although they may also be selected by hand on a gridded paper map). A buffer zone was used to prevent quadrats or parts of quadrats from falling outside the boundary of the study site. Each point is considered to be the lower left corner of the quadrat, with the left side of every quadrat oriented to the north.

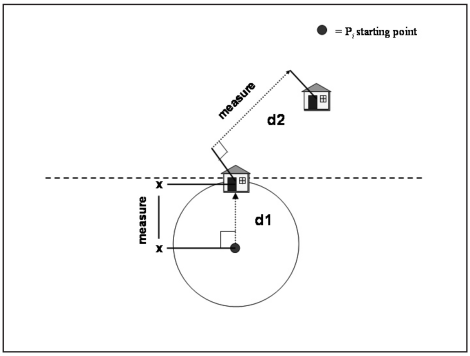
After the 30 points were identified, survey teams located each of the 30 points using the hand-held GPS 12XL. Quadrat boundaries were marked off using a rope. When the boundary of a quadrat fell within the confines of a household the field survey team included the household in the sample if more than 50 per cent of it lay within the square. After demarcation of the quadrat boundary, the total number of occupants and the total number of households were noted.

Using population data from all 30 quadrats, the average population per quadrat was calculated. The total site population was obtained by extrapolating the average population per quadrat to the total site surface. That is, (average population of quadrats) ÷ (size of quadrat) × (site area) = site population estimate. Confidence intervals around the population estimate were then obtained.

T-Square

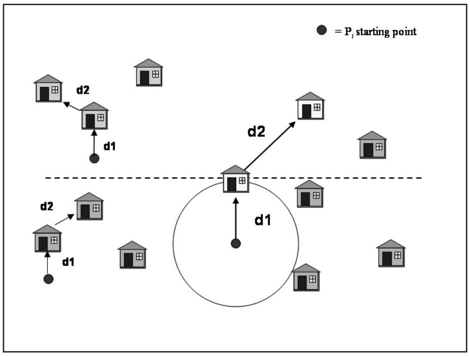
The T-Square method uses information on the spacing and population of shelters to produce an estimate of population size. We defined 60 systematically distributed GPS points using computer software (Brown et al., 2001; Espié, 2000). From each point (P_i), the distance (d1) to the nearest household (HH1) is measured (see Figure 2). The distance is measured from the GPS point to the centre of the household (using a tape measure, decametre, or footsteps) by projection, as shown in Figure 3. The number of persons living in HH1 is also obtained. Next, the distance (d2) between HH1 and the nearest household (HH2) situated in the 'half-plane' excluding P_i, or on the other side of the 'T', is measured (see Figure 2). The number of people in that household is then collected. This

Figure 2 Measurement of distances between households for the T-Square method



Note: To ensure precise measurements, it is necessary to take into account shelter dimensions at ground level without going inside the household. To avoid this difficulty (measuring the internal dimensions of households), field survey teams project distances, and using trigonometry they are able to take measurements of d1 and d2.

Figure 3 Overview of household selection for the T-Square method



Note: The distance d1 between the starting point P_i and the nearest shelter (HH1), and d2 between HH1 and next closest shelter (HH2), are shown in Figure 3. Shelters that lie in the same 'half-plane' as HH1, below the dashed line or within the 'T', are excluded when selecting HH2. The distances d1 and d2 are used to characterise the spatial pattern of households within the site and subsequently the site population.

process is repeated for all 60 GPS points where the distances d1 and d2 were collected, along with household size, for a total of 120 households (60 HH1 and 60 HH2).

To estimate the total site population, one of two formulae for calculating the average HH area are used depending on the results of statistical tests characterising the underlying distribution of shelters. The details of these statistical tests are presented in Appendix 1 and are integrated into computer software for employment in the field. For the T-Square, the average ratio of distances d1 and d2 represents an index of spatial pattern (ISP) of the population (see Appendix 1 for details on statistical tests). Its value is equal to 0.5 for random patterns, significantly less than 0.5 for uniform patterns and significantly more than 0.5 for clumped patterns (Ludwig and Reynolds, 1988). To test the significance of the ISP, the index is standardised and its significance level is obtained from a probability table for the standard Normal distribution.

While ISP tests are carried out for household local spatial distribution, an additional statistical test is conducted for global spatial distribution (see Appendix 1 for details on the second test) (Espié, 2000; Diggle, Besag and Gleaves, 1976; Diggle, 1977). The second test allows for the calculation of confidence intervals of density when households are globally distributed in a random–homogenous manner. Otherwise, only the point estimate of household density is appropriate (Diggle, 1983). The total site population using the T-Square method is calculated as the (site area ÷ average HH area) × (average HH population).

Data collection

A rapid estimate of population size is required within one to two days for emergency planning (Brown et al., 2001). As we tested the two methods in a non-emergency setting, data collection was carried out over a longer period and included two days of training of field survey teams, to familiarise them with the methods. Data collection was conducted by six persons (two teams) over the course of nine days, with individuals working for approximately six hours per day.

Field survey teams used the same definition of household and occupant as the census. The number of occupants was defined by interviewing the household head. If no individual was present at the time of data collection, a community leader or neighbour was asked to state the number of persons sharing the household.

Data analysis

Comparison with census population

To verify data quality, and ensure there were no gross differences between the census and field data, we compared age distribution estimated by the Quadrat and T-Square using a Chi-square test. A p-value of less than or equal to 0.05 was considered significant. The criterion for a satisfactory population estimate corresponds to the acceptable margin of error used by field actors engaged in logistical planning during acute emergencies. A population estimate was considered satisfactory if it fell within plus or minus five per cent of the census (point estimate and 95 per cent confidence intervals are reported).

Sensitivity analysis

Since the Quadrat and T-Square methods could be implemented only once, we used simulation and the map of GPS household locations to address further the objectives of this research. Our aim here was to determine whether the methods could be simplified without losing reliability or precision in our estimates. Calculations were performed in Microsoft Excel 2003.

Quadrat method

To study the effect of the number of sampled quadrats on the resulting population estimate, we calculated household density using between one and 30 quadrats of 625 square metres. Utilising the same quadrat locations as the field study, we created 30 simulated quadrats including all households located within their borders as well as on the perimeter (that is, we included all 'edge households'). All combinations of square numbers were repeated 10 times and the median result presented. Quadrats were selected randomly with equal probability and replacement.

Next, we simulated 30 new quadrats using a 'flip-a-coin' rule to determine whether households on the edge were included. Edge households were included based on the selection of a random number. We then created another set of quadrats using an 'always exclude' rule for households located on the edge of quadrats.

We also explored the possibility of using the average number of households per quadrat, instead of the population counts, to estimate the site population. Households, instead of the number of individuals, are actually a more relevant unit of analysis and may lead to more reliable population estimates. To calculate the site population we used (average number of HH x average population per HH) ÷ (quadrat area) × (site area) to estimate the site population. We performed this analysis using the observed quadrat data.

T-Square method

Past research suggests that 50 randomly selected points (P_i) are sufficient to provide a population estimate (Brown et al., 2001; Espié, 2000). To explore this assumption, we calculated population estimates for the T-Square method based on fewer points. Beginning with the complete set of 60 points, we randomly removed one point and estimated the site population using only 59. We performed this same analysis until we were left with 25 randomly selected GPS points.

Results

The study was conducted in August 2004, approximately one year after the census. Although inmigration and outmigration occurred during this period, the total population remained relatively stable according to available information. Data collection for the Quadrat method was completed in three days. The teams averaged approximately one hour per square. The time taken to complete each square ranged from 82 minutes on the first day of data collection to 36 minutes on the last day. The T-Square method was completed over four days. The average time per point was 31 minutes. On the first day of data collection each point took 83 minutes, decreasing to 11 minutes on the final day.

Figure 4a The location of the 30 quadrats (625 square metres) selected

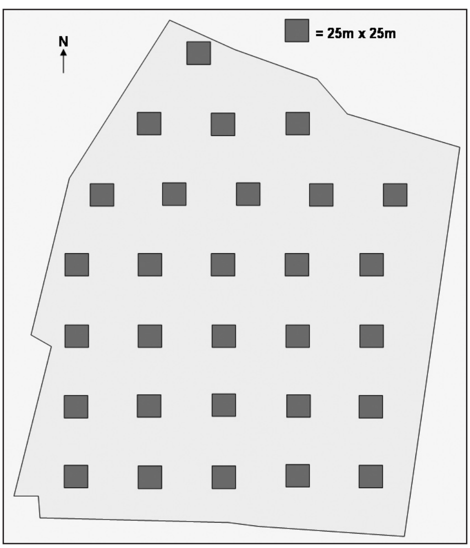


Figure 4b The 60 initial starting points selected for the T-Square method

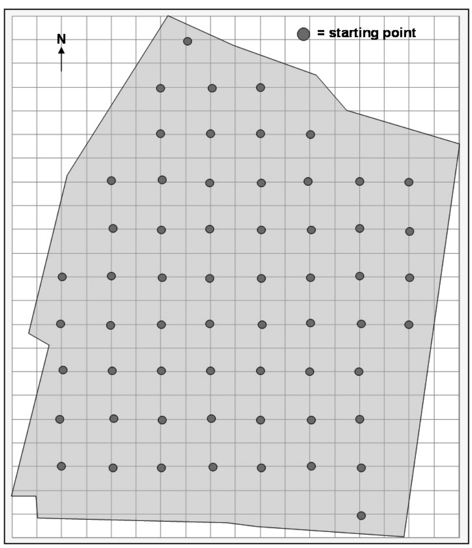
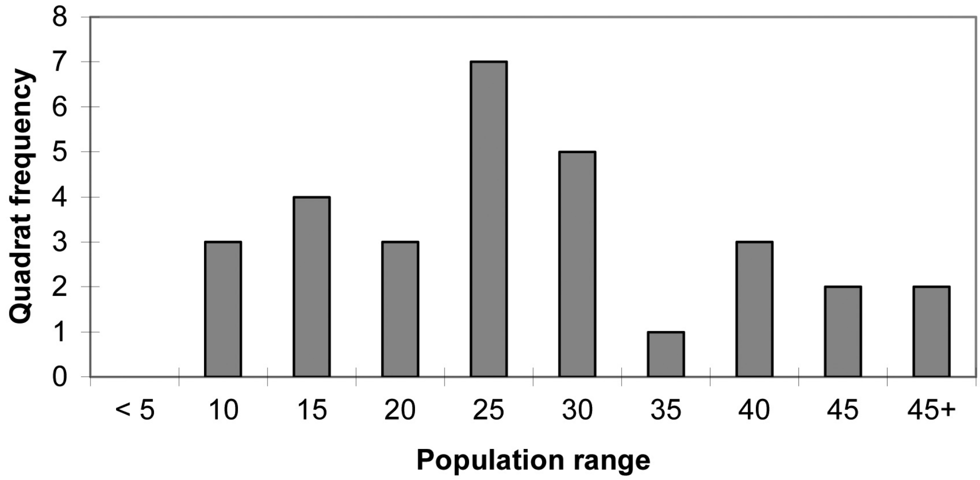


Figure 5 Histogram of population counts in observed quadrats



Comparison with census

The age distribution was not statistically different from the census for both the Quadrat method (p=0.089) and the T-Square (p=0.21).

Figure 4 shows the location of the 30 quadrats and 60 initial starting points selected for the T-Square.

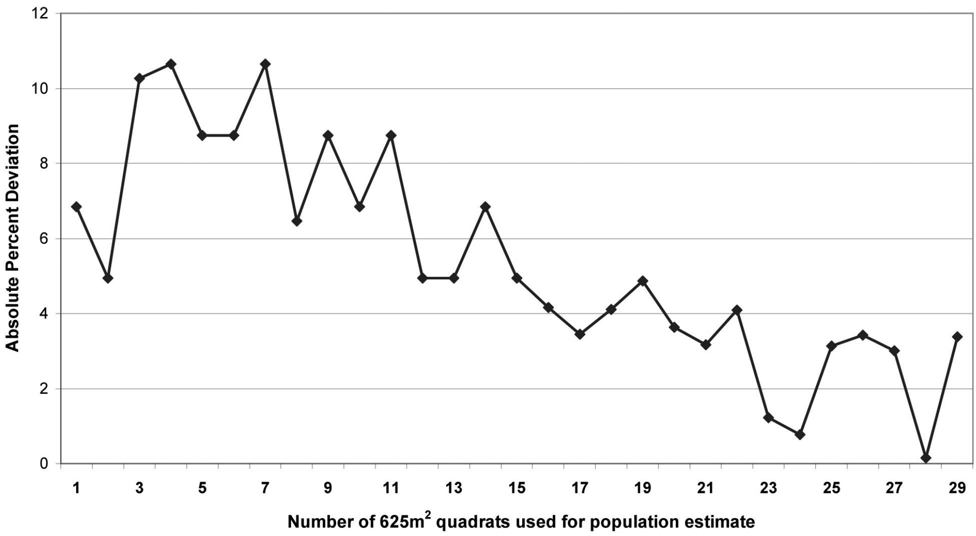
Using all 30 observed quadrats, the mean population per quadrat was 26.3 persons (range: 7–68). The resulting population estimate is 7,681 (6,160, 9,203), underestimating the census population by 19 per cent. The Quadrat method yielded an estimate of 1,548 households, thereby underestimating the census estimate of 1,828. The average number of persons per household for the Quadrat method (4.9) approximates the census count of 5.1 persons per household. The population counts for the 30 quadrats of 625 square metres ranged considerably (see Figure 5). The number of households per quadrat varied less with a mean of 5.9 (range: 3–10).

The population estimate for the T-Square was 9,523 persons, extremely close to the census population of 9,479. The T-Square method produced an estimate of 1,685 households with an average of 5.3 persons per household compared to the census enumeration of 1,828 households with an average population of 5.1 persons. Since the results of heterogeneity tests confirmed that households were not distributed in a random–homogeneous fashion, it was not possible to calculate confidence intervals around the population estimate.

Sensitivity analysis

Using the 30 simulated quadrats yielded an average of 6.5 households per quadrat and a population estimate of 9,872 (8,173, 11,512). Population estimates remained within plus or minus five per cent of the census estimate using at least 15 quadrats over 10 simulations. There was little gain in stability above 25 quadrats (Figure 6).

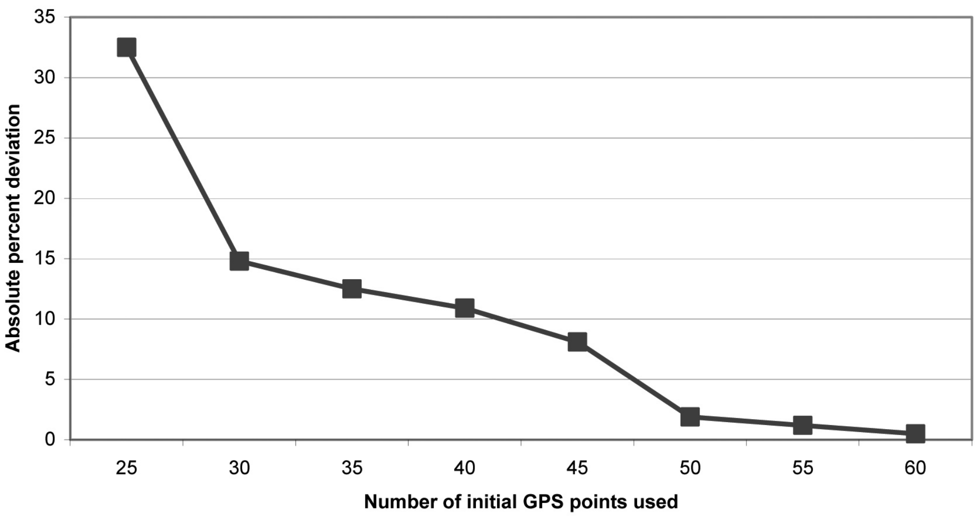
Figure 6 Absolute per cent deviation between the census population and estimate using 30 simulated 625 square metre quadrats (including edge households) and varying the number of quadrats



Note: The value shown is the median over 10 simulations.

When this same analysis was repeated with the random inclusion of edge households, the population estimate was 8,392 (6,916, 9,868). Excluding edge households entirely resulted in a population estimate of 7,827 (7,045, 8,609). The estimate of population size based on the number of households per quadrat was closer to the census estimate. An average of 5.9 households per quadrat yielded a population estimate of 9,065 (7,519, 10,647).

Figure 7 Absolute per cent deviation between estimated population (census estimate) and population estimated using up to 60 initial GPS points for the T-Square



Note: Values shown are the median over 10 simulations of the T-Square using the observed distances between households.

We analysed the error in the population estimate using less than 60 samples for the T-Square. When using more than 40 points, the margin of error falls below 10 per cent, but it increases significantly when using less (Figure 7).

Conclusions and recommendations

The results of this research are the product of the first field validation of two rapid population assessment methods. Field implementation of the T-Square yielded a better population estimate than the Quadrat method. Both adequately reproduced the age distribution of the census. While not the purpose of this study, these results suggest that the two approaches could be used to estimate age distribution of the population as well. The results of the simulation analysis suggest that both methods generate reasonable population estimates employing fewer quadrats, or GPS starting points in the case of the T-Square, than previously recommended to field actors.

There are important issues concerning implementation and data analysis that require discussion. Field survey teams encountered difficulties in enumerating household population. They collected information on both the total number of persons present at the time of data collection and the resident population (household). This difference was recorded during implementation of the T-Square, which, if present population (rather than household population) is used, overestimates the site population by 26 per cent. The use of a community leader to provide information on empty households, or households where the head of the household is absent, is a potential weakness in non-stable populations. During the initial phase of an acute emergency, reliable informants may be difficult to find. An alternative would be to include a 'replacement' household from outside of the sampled quadrat. An additional problem, although not one faced in this study, may occur when household size is linked to the provision of food or non-food items, thereby offering an incentive to overestimate the population.

The data collection teams encountered fewer methodological problems when applying the Quadrat method, yet there were several important difficulties. Of key concern is the range of population counts within quadrats, highlighting two important implications for future implementation of the method. First, as shown in Figure 5, the histogram of quadrat counts has two rough peaks, suggesting the presence of both dense and sparsely populated areas. The distribution of households within quadrats was more regular. Second, the method relies on the average population of individuals per quadrat to estimate population size and is highly sensitive to relatively small changes in quadrat population. Using the average number of households, instead of individuals, provided a population estimate closer to the census. In the field, the problem of 'edge effects' may have led to a lower population estimate than we would have expected because excluding a household from a quadrat (based on whether 50 per cent fell within the confines of the square) was determined by the field survey team. This is also evidenced by the results of the sensitivity analysis that included 'edge households'. When included, the population estimate is clearly within acceptable bounds for planning and comes very close to the census estimate.

While conducting the T-Square, survey teams encountered difficulties in measuring distances between households. Because of solid housing structures (as opposed to tents or plastic sheeting), there were problems locating the initial GPS (P_i) when it fell inside of a household, and making projections from there. Survey teams also faced difficulties when calculating distances between households due to challenging environmental conditions. This may be alleviated by using trigonometry instead of physical measurement, but it was not performed here. The primary limitation of the T-Square was connected to its lack of 'intuitive appeal' to the survey teams. Survey teams took great care in measuring the distances between households, often repeating the same measurement several times. This resulted in an accurate population estimate, but timing is prohibitive during an emergency. The T-Square method is highly sensitive to distance measurements between households and may not be appropriate where this is challenging due to time or environmental constraints.

Furthermore, although simple simulations were used to gain insight into the number of squares necessary for the Quadrat method, and initial points needed for the T-Square, they can only be viewed as showing general trends. Implementation depends on site geography, population density and survey teams' familiarity with the methodology, among other factors. We explored the influence of different parameters with *a priori* knowledge of the GPS location of residents.

This study provides valuable information for the rapid assessment of populations in refugee camps, IDP sites, and in more general settings where population enumerations may not exist. Several lessons can be learned for future implementation of the two methods. Although the T-Square provided an excellent population estimate, it was complicated to conduct and for survey teams to understand quickly. The Quadrat method is simple to perform and is flexible enough to be employed under a variety of field conditions. In an emergency, one square (625 square metres) is expected to be completed in approximately 15–30 minutes depending on population density. Survey teams significantly reduced the time needed to measure each square by the end of the data collection exercise, highlighting the importance of training before implementation during an emergency.

Recent implementation of the Quadrat method using 15 quadrats (625 square metres) yielded an acceptable estimate of population (data not shown),[3] which is further confirmed by the results of the sensitivity analysis. The size of squares measured was appropriate for this analysis (625 square metres), but as a general rule, the number of squares and the choice of square size depend on the underlying population distribution. Since settlements are often densely distributed, especially during the acute phase of an emergency, a sufficiently homogeneous population distribution for implementation of the Quadrat method is likely. We recommend using the number of households, rather than individual population count, for quadrats to estimate population size. Instead of relying on a judgment of whether 50 per cent of a household falls within the confines of a 625 square metre quadrat, 'edge' households, where the south and east limits of the shelter fall within the square, should be included, or another clear decision rule should be employed. In addition, the boundaries of the site should be confined to habitable space.

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Endnotes

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[2] For further details on initially mapping a site and other specifics of implementation see Brown et al., 2001.

[3] Personal communication with Vincent Brown, Director, Epicentre, December 2005.

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Appendix 1 Estimating site population using the T-Square

After distances d1 and d2 have been obtained for *m* initial starting points, two statistical tests are used to decide between two formulae for calculating average household area.

Step 1: evaluate Test 1 and Test 2 for statistical significance.

Test 1

$$t_n = \frac{\sum_{i=1}^{m} \frac{d1_i^2}{(d1_i^2 + \frac{1}{2} d2_i^2)}}{m}$$

$$z = \frac{\left(t_n - \frac{1}{2}\right)}{\sqrt{\left(1/12m\right)}} \sim \mathbf{N}(0, 1)$$

Test 2

$$C = \frac{48m}{13m+1}[mLog\ [\sum_{i=1}^{m} (d1_i^2 + \frac{1}{2} d2_i^2)] - \sum_{i=1}^{m} \log(d1_i^2 + \frac{1}{2} d2_i^2)]$$

$$C \sim \chi^2 (m\text{-}1)$$

Step 2: calculate the average household area using Formula 1 if both Test 1 and Test 2 are not statistically significant ($p>0.05$) or Formula 2 otherwise. Confidence intervals around the average household area are possible, only when Formula 1 is used.

Formula 1

$$\gamma = \pi\left(\sum_{1}^{m} d1_i^2 + \frac{1}{2}\sum_{1}^{m} d2_i^2\right) \Big/ 2m$$

$$SD(\gamma) = \frac{\gamma}{\sqrt{2m}},\ \text{95\% confidence interval: } \gamma \pm [1.96 \times SD(\gamma_r)]$$

Formula 2

$$\gamma = \frac{\pi}{m}\sqrt{(\sum_{1}^{m} d1_i^2 \frac{1}{2} \sum_{1}^{m} d2_i^2)}$$

Step 3: calculate the average household population

Step 4: the site population can then be estimated by (site area $\div \gamma$) $\times$ (average household population)