

## Research Article

# Use of Remote Sensing for Population Number Determination

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**Abstract.** Ideally, in a country the population censuses are held regularly (five or ten-year intervals), population surveys, called “control surveys” are then conducted during the intercensal period. The latter, as well as the registers of civil status (information on the movements of the population), help determining a representative sample, called “scale model of the population.” Random, stratified and weighted, it has the advantage of providing a good statistical database for any generalizations about the target population with relatively little risk of error. Our study area, Bukavu city, doesn’t comply with the classical scheme of data collection for two main reasons: - there are more than twenty years that real demographic censuses have been carried out in the province, the records of the ‘civil status is poorly maintained and often incomplete—if any!—Especially during this post-conflict period. A study was conducted in Bukavu City to determine the number of people living in this city. Two GeoEye satellite images of 50 cm resolution captured in July 2012 were used. A net of 200 × 200 meters was created with ArcGIS to divide the satellite images into regular cells. In total 2772 cells were created to cover the two satellite images but only 2353 cells were considered for classification. Three classes were identified in the satellite images according to houses density: High density, medium density and low density zones. Three samples were selected and for each different density type, a point map was created covering each house of the selected sample zones received a point. Using the three different density patterns, 95 highly populated zones were identified, 307 medium density zones and 800 low density zones having each respectively a total of 30’400, 46’050, and 40’000 houses. The population of the city was obtained by taking the number of houses times an average of 8, 7 and 6 habitants per house respectively in high, medium and low density zones. A total of 805550 habitants was obtained for Bukavu city which is almost the same number of people estimated (830’000) by the Inspection Provinciale de la Santé which is the health office in charge of vaccination campaign in South-Kivu Province. This method can be used whenever there is a need to quickly estimate the number of the population in a region where there is no census data.

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## 1. Introduction

The traditional approach to estimate population is generally based on a census, which is labour-intensive, time-consuming and costly. Since the 1970s, remote sensing estimation of residential population has been applied more often, as space borne satellite data have become available (see [5–7, 11, 13, 14, 16, 20, 30, 31]). In [17] the author summarizes four categories of population estimation approaches using remotely sensed data. These methods are based on (1) counts of individual dwelling units using high spatial resolution data such as aerial photographs (see [18]), (2) measurements of urbanized land areas (see [20, 31]), (3) estimates derived from land use classification (see [11, 14]), and (4) automatic image analysis based on spectral features (see [6, 7]).

One of the first applications of remote sensing in population estimation can be traced to the 1950s, using air photos in manual counts of dwelling units. A first approach to estimate population from remotely sensed images is called the direct approach. The houses are manually identified and counted.

This number of dwelling units is multiplied by the mean density of inhabitants per dwelling to obtain an estimation of the population in the area. While estimated population information is relatively accurate, such a house-counting approach is time consuming and labour intensive, making it difficult to apply to large urban areas. Moreover, in some cities, particularly in developing countries and especially in slums, it's hard to identify the houses (see [9, 15, 21, 27, 32]).

Population data is very important to stipulate for decision-making for governments. Census is carried out every decade. Though the precision is very high, the cycle is long and the cost is high. So every kind of population estimation method with low cost and short cycle is worthy studied.

Accurate estimates of small-area population are essential for supporting a wide variety of planning processes. The size and distribution of the population are often key determinants for resource allocation for state and local governments (see [29]). Population estimates are critical in decisions about when and where to build public facilities such as schools, libraries, sewage treatment plants, hospitals and transportation infrastructure. Population estimates are also often used by private sectors for customer-profile analysis, market-area delineation and site-location identification (see [24, 26]). In addition, population information is an important input in many urban and regional models, such as land-use and transportation-interaction models, urban-sprawl analysis, environment equity studies and policy-impact analysis (see [28]). Clearly, accurate and timely population estimates are of great importance (see [29]). Accurate population data, however, is only available for every decade through the national census survey. It is obvious that this frequency does not meet the needs for rapid growth areas where noteworthy local intercensal population changes occur. Thus, appropriate estimation methods for such geographical areas are extremely necessary.

This is fundamental for Bukavu city, because, there are more than twenty years that real demographic censuses have been carried out, the records of the 'civil status is poorly maintained and often incomplete and in addition, this part of the D.R. Congo has emerged from conflict and has experienced a long period of major political and economic instability.



## 2. Methodology

The study area selected for this research is located between 2° 33' 42" and 2° 28'S and 28° 47' 28" and 28° 53' 34", Bukavu city. Bukavu, the capital city of South-Kivu Province, eastern DRC, has a total area of about 80 km<sup>2</sup> of land and approximately 50 km<sup>2</sup> of water.

Like most D.R. Congo cities, Bukavu has been experiencing a real expansion through encroachment on agricultural land and other non-urban land as population increases. Thus, a timely estimation of the population distribution is valuable for urban land use planning.

Two GeoEye satellite images of 50 cm of resolution acquired in July 2012, were used in this study. These images were rectified to a common Universal Transverse Mercator (UTM) coordinate system based on 1 : 24000 scale topographic maps. A nearest-neighbour resampling algorithm was used during image rectification and a root mean square error (RMSE) of less than 0.5 pixels was obtained (see [20]).

Both images were reprojected to the Universal Transverse Mercator (UTM) projection (datum WGS84).

The easiest dasymetric mapping approach with remote sensing-derived land use data used, is a binary division approach in which land use is classified to "populated" and "unpopulated" and populations are simply redistributed to those populated areas; some example studies included [4, 8, 12]. Furthermore, a more specific dasymetric mapping approach would classify a number of land use classes and redistributed populations to these classes; some example studies include [3, 11, 25, 37].

In this study, the approach consisted of subdividing the city into homogeneous areas: this is called the zonal approach. For each type of homogeneous areas a mean density was estimated (field survey). Then, the global population was estimated by extrapolating the sampled areas estimations (surface type multiplied by density) (see [1, 10, 33, 35, 36]).

Because residential land is the only relevant class in this study, the LULC map was recorded as a binary image to develop an image of residential areas.

A "fishnet" of 200 × 200 meters was created with ArcGIS to divide the satellite images into grids (see Figure 1: Satellite Imagery with 200 × 200 m grid overlay—detail of the City of Bukavu).

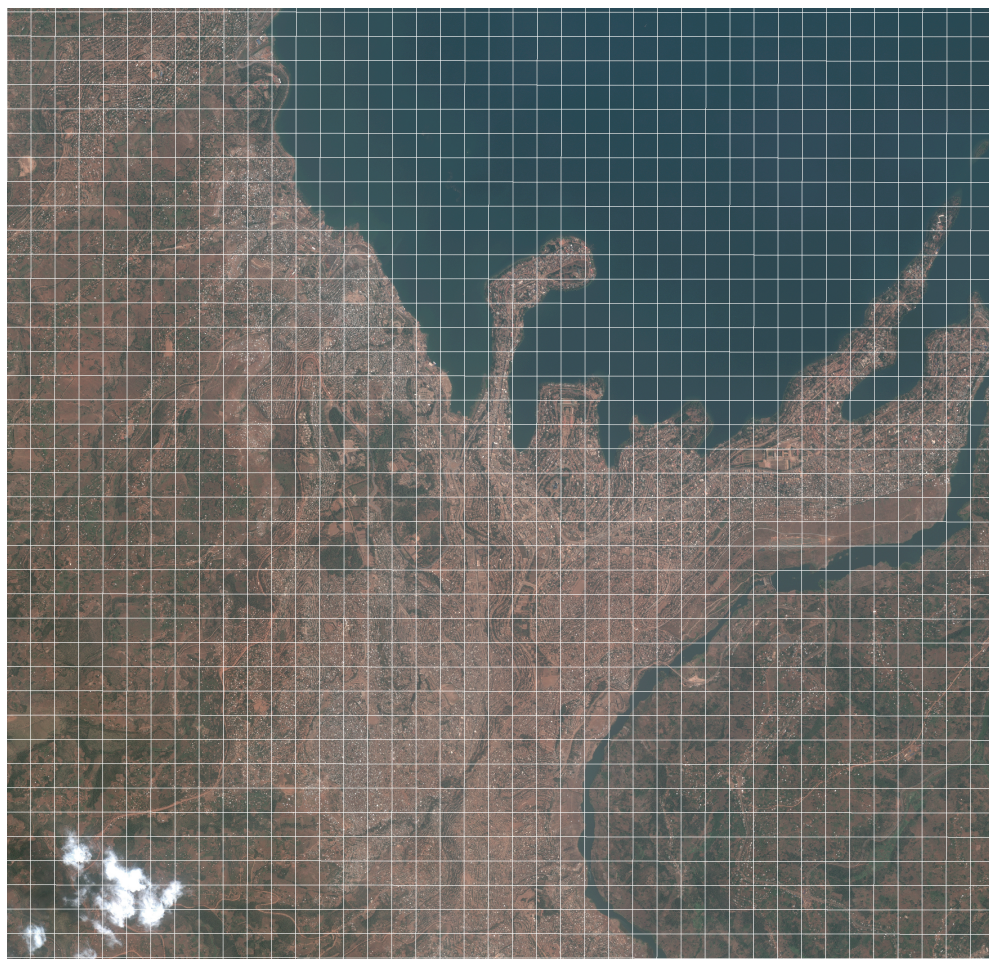
Three different density classes were identified from the satellite image according to houses density: High density, medium density and low density zones (see Figures 2, 3, 4). The samples were applied to all residential areas of Bukavu.

The total population of an area was estimated by multiplying the total number of dwelling units with the number of persons normally living in a dwelling unit. Dwelling units were categorized and a different persons-per-dwelling unit ratio to each category was applied. This ratio has been derived from field visit made the 8<sup>th</sup> and 9<sup>th</sup> July 2013; with the assumption that a single household occupies one dwelling unit. The total number of dwelling units in an area was estimated from remote sensing images.

The formula for inhabitant unit is

$$P = N_1 F_1 + N_2 F_2 + \dots + N_n F_n$$

$P$  is the total population,  $N$  the average population of every family,  $F$  the count of family and  $1 \dots n$  inhabitation type



**Figure 1:** Detail of Satellite Image of the City of Bukavu with a 200 x 200m fishnet.

The population of the city was obtained by taking the number of zones times an average of 8, 7 and 6 habitants per house respectively in high, medium and low density zones.

### 3. Results and Discussion

For the all Bukavu city a total of 2353 counts were recorded as shown in Table 1 below. But, for population estimate only populated areas were considered. This was found to be 1202 counts.

During the study, pupils and students were in holydays and thus the number of inhabitants in schools was taken as zero.

The most populated area in Bukavu, is the Medium Density Residential area which accounts for almost half of the total population living in Bukavu city.

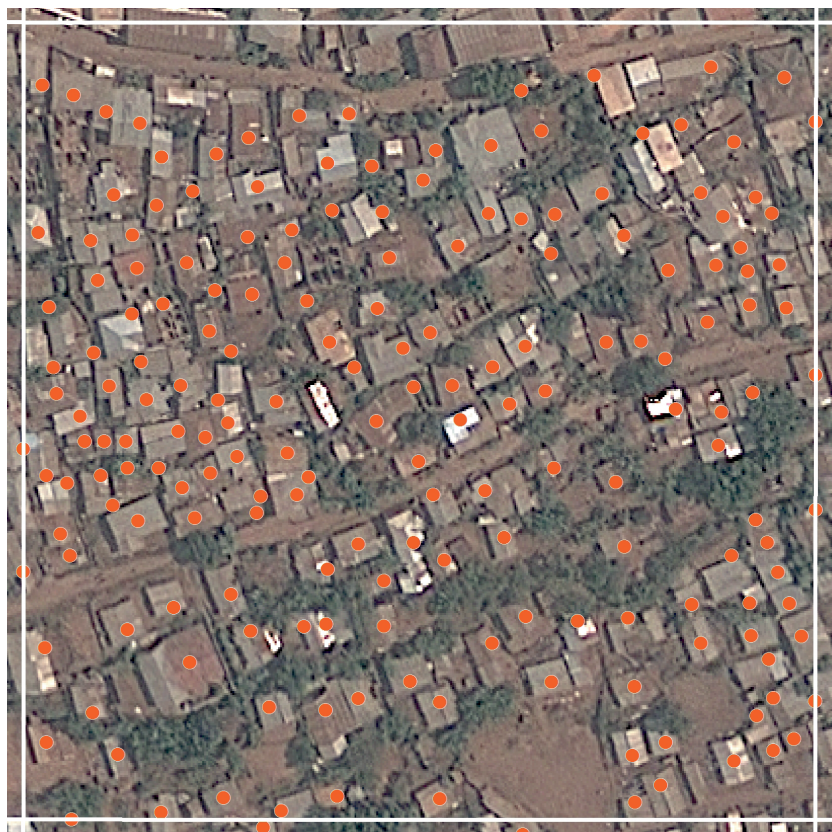
A total of 805550 habitants was obtained for Bukavu City which is almost the same number of people estimated (830'000) by the Inspection Provinciale de la Santé, the health office in charge of vaccination campaign in South-Kivu province.

Half of the city is covered by open water and unpopulated area. This is due to the topography of the area, constituted by steep hills and terrain in which any construction cannot be made.





**Figure 2:** Low building density.



**Figure 3:** Medium building density.



**Figure 4:** High building density.

**Table 1:** Estimated population for Bukavu city.

Type	Count in 200 X 200 m <sup>2</sup>	Sum Houses	Estimated Population
High Density Residential	95	30400	243200
Medium Density Residential	307	46050	322350
Low Density Residential	800	40000	240000
Industrial Area	15		
Lake Kivu	510		
No Satellite Data	30		
Open Space	593		
School	3		
Sum		116450	805550

All studies inferring population from remotely sensed data have reported a consistent finding, i.e., that small-area population estimation is often not as accurate as large-area estimation. It may be explained that overestimation and underestimation are cancelled out for large-area population estimation and thus the overall accuracy is high (see [18]).



## 4. Conclusion

It is clear from the review that remote sensing provides valuable resources for useful ancillary information.

Past studies of population estimation mainly relied on images of relatively coarse spatial resolution. With the availability of high-spatial-resolution commercial images, such as Geoeye, QuickBird and IKONOS, as well as the advancement of image processing techniques, improvement in population estimation accuracies is expected.

Remote sensing-based population estimation is still a challenging task, especially for residential regions with extremely high population densities.

One important source of errors for population estimation is from high-rise apartment buildings.

The optical sensor data such as Geoeye and TM/ETM+ can only provide land surface information and cannot provide height and intra-building information. The incorporation of building height information in population estimation models may improve model performance. Light Detection And Ranging (LiDAR) data, for example, have been shown to be capable of extracting building height information (see [2, 23]), and may provide new insight for population estimation through integration of LiDAR-derived information.

Of all the population estimation methods, the dasymetric method is commonly regarded as a more accurate approach, provided that the used ancillary information gives a truthful description of where people actually live. Furthermore, the dasymetric method is not only more accurate, but also relatively stable. It is robust to the variation of population density associated with a certain type of land use, as well as the anomaly of highly urbanized but sparsely inhabited areas (see [4]). The reason is because the volume-preserving property preserves the population of the source unit in the transformation to raster representation, and thus all associated errors are inherently limited to variation within each individual source unit. The dasymetric method used with remote sensing is also robust to imagery classification error. In [4] the authors reported that errors of up to 40% in the classified TM image still yield better estimates of the interpolated populations than other regression or surface methods they tested. The reason for the relative robustness of the dasymetric method under classification error is due to the aggregated error within zones.

## Competing Interests

The authors declare that they have no competing interests.

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## References

- [1] P. O. Adeniyi, "An aerial photographic method for estimating urban population," *Photogrammetric Engineering & Remote Sensing*, vol. 49, no. 4, pp. 545–560, 1983.
- [2] M. J. Barnsley, A. M. Steel, and S. L. Barr, "Determining urban land use through an analysis of the spatial composition of buildings identified in LIDAR and multispectral image data," *Remotely Sensed Cities*, Taylor & Francis, London, 2003.
- [3] C. L. Eicher and C. A. Brewer, "Dasymetric mapping and areal interpolation: Implementation and evaluation," *Cartography and Geographic Information Science*, vol. 28, no. 2, pp. 125–138, 2001.
- [4] P. F. Fisher and M. Langford, "Modeling sensitivity to accuracy in classified imagery: A study of areal interpolation by dasymetric mapping," *Professional Geographer*, vol. 48, no. 3, pp. 299–309, 1996.
- [5] J. T. Harvey, "Estimating census district populations from satellite imagery: Some approaches and limitations," *International Journal of Remote Sensing*, vol. 23, no. 10, pp. 2071–2095, 2002.
- [6] J. T. Harvey, "Population estimation models based on individual TM pixels," *Photogrammetric Engineering and Remote Sensing*, vol. 68, no. 11, pp. 1181–1192, 2002.
- [7] J. T. Harvey, "Population estimation at the pixel level: developing the expectation maximization technique," *Remotely Sensed Cities*, Taylor Francis, London, 2003.
- [8] J. B. Holt, C. P. Lo, and T. W. Hodler, "Dasymetric estimation of population density and areal interpolation of census data," *Cartography and Geographic Information Science*, vol. 31, no. 2, pp. 103–121, 2004.
- [9] S. Y. Hsu, "Population estimation," *Photogrammetric Engineering*, vol. 37, no. 5, pp. 449–454, 1971.
- [10] S. P. Kraus, L. W. Senger, and J. M. Ryerson, "Estimating population from photographically determined residential land use types," *Remote Sensing of Environment*, vol. 3, no. 1, pp. 35–42, 1974.
- [11] M. Langford, D. J. Maguire, and D. J. Unwin, "The areal interpolation problem: estimating population using remote sensing in a GIS framework," *Handling Geographical Information: Methodology and Potential Applications*, Wiley, New York, NY, 1991.
- [12] M. Langford and D. J. Unwin, "Generating and mapping population density surfaces within a geographical information system," *Cartographic Journal*, vol. 31, no. 1, pp. 21–26, 1994.
- [13] G. Li and Q. Weng, "Using Landsat ETM+ imagery to measure population density in Indianapolis, Indiana, USA," *Photogrammetric Engineering and Remote Sensing*, vol. 71, no. 8, pp. 947–958, 2005.
- [14] C. P. Lo, "Zone-Based Estimation of Population and Housing Units from Satellite-Generated Land Use/Land Cover Maps," *Remotely Sensed Cities*, Taylor & Francis, London, UK/New York, NY, 2003.
- [15] C. P. Lo and H. F. Chan, "Rural population estimation from aerial photographs," *Photogrammetric Engineering and Remote Sensing*, vol. 46, no. 3, pp. 337–345, 1980.
- [16] C. P. Lo, "Accuracy of population estimation from medium-scale aerial photography," *Photogrammetric Engineering & Remote Sensing*, vol. 52, no. 12, pp. 1859–1869, 1986.
- [17] C. P. Lo, Ed., *Applied Remote Sensing*, Longman, London, UK, 1986.
- [18] C. P. Lo, "Automated population and dwelling unit estimation from high-resolution satellite images: A GIS approach," *International Journal of Remote Sensing*, vol. 16, no. 1, pp. 17–34, 1995.
- [19] C.-P. Lo, "Population estimation using geographically weighted regression," *GIScience and Remote Sensing*, vol. 45, no. 2, pp. 131–148, 2008.
- [20] C. P. Lo, "Urban indicators of China from radiance-calibrated digital DMSP-OLS nighttime images," *Annals of the Association of American Geographers*, vol. 92, no. 2, pp. 225–240, 2002.
- [21] C. P. Lo and R. Welch, "Chinese Urban Population Estimates," *Annals of the Association of American Geographers*, vol. 67, no. 2, pp. 246–253, 1977.
- [22] X. Liu and K. C. Clarke, "Estimation of Residential Population Using High Resolution Satellite Imagery," Istanbul Technical University, Istanbul, Turkey.
- [23] H.-G. Maas and G. Vosselman, "Two algorithms for extracting building models from raw laser altimetry data," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 54, no. 2-3, pp. 153–163, 1999.
- [24] D. Martin and H. C. W. L. Williams, "Market-area analysis and accessibility to primary health-care centres," *Environment & Planning A*, vol. 24, no. 7, pp. 1009–1019, 1992.
- [25] J. Mennis, "Generating surface models of population using dasymetric mapping," *Professional Geographer*, vol. 55, no. 1, pp. 31–42, 2003.
- [26] D. A. Plane and P. A. Rogerson, Eds., *The Geographical Analysis of Population with Applications to Business and Planning*, John Wiley, New York, NY, 1994.
- [27] P. W. Porter, *Population Distribution and Land Use in Liberia [Ph.D. thesis]*, London School of Economics and Political Science, London, UK, 1956, 213 p.
- [28] P. Rees, P. Norman, and D. Brown, "A framework for progressively improving small area population estimates," *Journal of the Royal Statistical Society. Series A. Statistics in Society*, vol. 167, no. 1, pp. 5–36, 2004.



- [29] S. K. Smith, J. Nogle, and S. Cody, "A regression approach to estimating the average number of persons per household," *Demography*, vol. 39, no. 4, pp. 697–712, 2002.
- [30] P. Sutton, D. Roberts, C. Elvidge, and K. Baugh, "Census from Heaven: An estimate of the global human population using night-time satellite imagery," *International Journal of Remote Sensing*, vol. 22, no. 16, pp. 3061–3076, 2001.
- [31] P. Sutton, D. Roberts, C. Elvidge, and H. Meij, "A comparison of nighttime satellite imagery and population density for the continental United States," *Photogrammetric Engineering and Remote Sensing*, vol. 63, no. 11, pp. 1303–1313, 1997.
- [32] J. F. Watkins and H. A. Morrow-Jones, "Small area population estimates using aerial photography," *Photogrammetric Engineering and Remote Sensing*, vol. 51, no. 12, pp. 1933–1936, 1985.
- [33] C. Weber, "Per-zone Classification of Urban Land Use Cover for Urban Population Estimation," *Environmental Remote Sensing from Regional to Global Scales (1985)*, Watkins, Chichester, UK: New York, NY, 1994.
- [34] C. Wu and A. T. Murray, "Population estimation using landsat enhanced thematic mapper imagery," *Geographical Analysis*, vol. 39, no. 1, pp. 26–43, 2007.
- [35] S.-S. Wu, X. Qiu, and L. Wang, "Population estimation methods in GIS and remote sensing: A review," *GIScience and Remote Sensing*, vol. 42, no. 1, pp. 80–96, 2005.
- [36] S.-S. Wu, L. Wang, and X. Qiu, "Incorporating GIS building data and census housing statistics for sub-block-level population estimation," *Professional Geographer*, vol. 60, no. 1, pp. 121–135, 2008.
- [37] Y. Yuan, R. M. Smith, and W. F. Limp, "Remodeling census population with spatial information from Landsat TM imagery," *Computers, Environment and Urban Systems*, vol. 21, no. 3-4, pp. 245–258, 1997.