



Use of satellite imagery as a tool for producing socio-demographic data in urban areas

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Abstract

The geographic information sector has been booming since the early 1980s. With the arrival of very high resolution satellite images (resolution of less than 5 m), the supply of image data has multiplied. Satellite imagery now offers possibilities for developing new methodological processes for analysing spatial facts. This article therefore proposes to draw up an assessment, based on documentary sources, of the processes available via imagery and which contribute to the production of socio-demographic data in urban environments. The article draws on a synthesis of explanations of the contribution made by imaging tools to overcome the difficulties associated with conventional methods of observing the dynamics of urban populations. The summary reveals the limitations of conventional methods of counting the population and the morphology of living environment structures in urban centres. Finally, this contribution shows that the information obtained by analysing satellite images makes it possible to model the socio-economic, demographic and spatial realities of cities more accurately.

Keywords: Enumeration, living environment, satellite images, geographical information

Introduction

The speed of urbanisation, the characteristics and lifestyles of populations, and the lack of traditional knowledge such as maps, cadastral planning or administrative registers make it difficult to observe urban populations in different parts of the world, particularly in developing countries. The traditional instruments of socio-demographic observation - exhaustive censuses and probability sample surveys - have shown their limitations in practice (Dureau and Barbary, 1990, p.63) ^[11]. Furthermore, the implementation of these techniques has revealed its limitations and does not always take into account the real needs of research or urban management policies in terms of monitoring and spatialised observation of populations. What's more, the cost of collecting census data and the length of time it takes to process it mean that it has to be collected every ten years or so. This is not enough to monitor the fast-growing urban population. The lack of a complete and up-to-date sampling frame often compromises the performance and reliability of sample surveys. This is why, in 1985, a multi-disciplinary team at ORSTOM developed a method for collecting demographic data in urban areas that incorporates the information on urban morphology provided by high-resolution satellites. Geographic Information Systems (GIS) make it possible to increase the effectiveness of information rendering (Assako, 1995-b p.110) ^[11] and the preventive scope of planning documents. Urban growth in recent years has resulted in the sprawl of urban areas. This urban sprawl poses management problems due to the premature obsolescence of information and budgetary restrictions, which considerably weaken the capacity of cities to keep up to date with information relating to their territory and population (Codja, 2013). The quality and relevance of the system for reading the city and its spatial and social dynamics largely depend on the quality of decisions (Dureau and Weber, 1995, p.11) ^[12]. It is in this context that we felt it necessary to attempt to make a contribution to the observation of urban populations, by developing a new approach to the collection of demographic data adapted to

the specific characteristics of cities in developing countries. For this purpose, spatial remote sensing, which provides continuous and relatively accurate observation of land use, is a particularly interesting source of data. Recent advances in the collection, management and analysis of information on the dynamics of the urban environment provide an interesting opportunity to renew systems for reading the city while substantially reducing the associated costs. Since the 1950s, Dureau and Barbary (1987, p.23) ^[7] have supported the idea that exhaustive information on urban morphology can be used to rapidly collect data on urban populations by sampling. However, the unavailability of complete and up-to-date sampling frames in many cities in developing countries is a key factor in the selection of the sample to be surveyed, which is a sine qua non for any statistically representative sample to be drawn. Updating an outdated cartographic database is often problematic in a constantly changing urban fabric. Furthermore, conventional sampling plans generally prohibit any spatialisation of the results, since they almost never include a spatial stratification of the city surveyed. Yet this is an essential element of knowledge for both city managers and researchers. From this perspective, remote sensing and geographic information systems can play an essential role (Dureau and Weber, 1995, p.98) ^[12]. Satellite images can be used to produce data quickly and to study urban structures (Dureau, 1990, p.24) ^[11]. In fast-growing cities, traditional techniques for producing base maps are too cumbersome to ensure that reference cartographic documents are kept up to date. The use of satellite images (Figure 1) can make it possible to identify fundamental urban objects such as roads and blocks, and thus rapidly produce base maps that are currently lacking. We can also take advantage of the exhaustive and finely localised information on land use provided by satellite images to rapidly produce demographic or socio-economic information by means of surveys. Satellite imagery can also be used not to produce, but to improve existing socio-economic information, and to distribute demographic or socio-economic data from census

or administrative sources, initially based on coarse and insignificant geographical breakdowns.

Today, the ongoing use of Geographic Information Systems (GIS) in the field of spatial planning and urban development requires regularly updated data on urban and peri-urban areas, with a determinism of time linked to its development. These data are generally obtained by collecting them in the field, and are often costly in terms of time and resources for the end users (Tellez and Servigne, 1998) ^[23]. Hence the frequent use of multisource data. With the exception of regulatory procedures and general studies, the use of data from several sources is essential for research (Metl, 1999) ^[19]. The search for the most appropriate geographical, urban, demographic and socio-economic information is now part of the agenda of all those involved in planning.

As cities grow, so does the amount of information describing the urban area and those who live there: the location of activities, means of transport, facilities, green spaces, land and property management, etc. All of this information carries a location attribute in one way or another, whether it is accessible in the form of a precise reference or in the form of aggregated data available according to predefined breakdowns. All of this information carries a location attribute in one way or another, whether it is accessible in the form of a precise location or in the form

of an aggregation available according to predefined breakdowns. Visualising them in the form of plans or maps remains one of the simplest and most relevant ways of understanding them (Steinberg, 2003). It is in this context that this study, based on a review of the literature, demonstrates the use of satellite imagery as a palliative tool to overcome the shortcomings of conventional systems for studying urban population dynamics. This use of satellite images (fig.1) is made through Geographic Information Systems (GIS), a powerful tool for territorial analysis. GIS is proving to be an essential tool for managers of data located in geographical space; urban agencies fulfil the main tasks of a GIS, namely information, production and decision-making, on the one hand, and producing cartographic documents, on the other. The lack of reflection on the use of imagery in our space was the main reason for this contribution on the contribution of satellite imagery to the production of socio-economic and demographic data in urban areas.

The use of these new spatial analysis tools in the present study is intended to produce documents that can be used to support the project of counting and guiding urban development. It is a scientific contribution that updates the thinking already done on the deficit that spatial data can fill in the control of territorial governance.



Source: SA Splanet image, January 2021.

Fig 1: Illustration of a high-resolution satellite image of 2 plateaux in the commune of Cocody, Abidjan

1. Difficulties in producing demographic information in fast-growing cities in developing countries

Traditionally, demographers have relied mainly on two techniques to collect data on populations. These are the exhaustive census and the sample survey. The current design of the census requires substantial technical, financial and human resources, limits the cycle to less than 10 years and results in a substantial reduction in the information

collected during each data collection operation. What's more, the cumbersome nature of the data and the time required to process it mean that the results are often out of date as soon as they are published for cities whose growth rates can exceed 10% per year.

In addition, the lack of basic mapping in certain towns, mainly in recently expanded areas, and the problems of monitoring the large number of interviewers required for

this type of operation have a significant impact on the quality of the results. Finally, the scale of the resources required for a census means that the data collected exhaustively is under-utilised. This is why, in order to reduce the amount of information collected, the questionnaires, or some of the variables in the questionnaire, are often only used on a sample basis. At the end of this process, only the overall results for the city as a whole are published. However, the sample survey (partial exploitation of the information collected) calls into question the main quality of censuses, exhaustiveness, which theoretically makes it possible to obtain results for any type of geographical breakdown.

Based on observation of a fraction of the population making up the sample, sample surveys are an alternative to reducing the financial and human resources mobilised for the census. They make it possible to ensure the quality of the data collected, with fewer and better supervised interviewers, who gather richer information than that permitted in the census. Conventional sampling plans generally prohibit any spatialisation of the results. The use of surveys does not guarantee knowledge of the differences in population density, demographic or socio-economic composition of the city. Knowledge of these elements is essential for both city managers and researchers. However, many cities in developing countries lack a complete and up-to-date survey database. This information is almost never available in Third World cities, where cartographic documents are rare or old. And even when they do exist, access to them is an obstacle course. Updating the obsolete cartographic database through new field surveys is often problematic in an urban fabric that is undergoing rapid change. And when it is carried out, it falls far short of the expectations of applicants, leading to significant biases.

In the cities of developing countries, the lack of basic cartographic information and urbanisation patterns combine to make conventional demographic data collection techniques ineffective. Such an environment is not conducive to the production of data through spatialised monitoring of urban populations. What alternative is there to ensure easy observation of the urban population in our cities?

2. Estimating the urban population on the basis of urban morphology

Maintaining the logic of improvement at all costs by carrying out complete censuses brings few advantages, as these will always take too long to implement and operate. For this reason, only the advent of a system based on survey technology can meet the conditions of flexibility and speed required in cities with rapid population growth. But for this to happen easily, better knowledge of the intra-urban space through satellite imagery can be a fundamental element in improving sample survey techniques. To achieve this, we will need a good cartographic knowledge of the environment, made up of precisely identified blocks, and a good perception of urban morphology. Knowledge of these two elements will make it possible to stratify the city successfully, thus improving the accuracy of the survey, and to obtain results based on a meaningful spatial breakdown of the city under study. This is an opportunity for African countries that do not have aerial coverage but are looking for recent, up-to-date demographic data.

For several decades, researchers studying the urban environment have been interested in the relationship between the morphological characteristics of residences and the demographic and socio-economic characteristics of their inhabitants. The work of American researchers such as Kenzie (1934) and Park (1937) was echoed in France, where studies on the same theme began to develop in the 1950s (Chombart de Lauwe, 1952). The relationships between urban morphology and the characteristics of the urban population established by these studies led to the development of methods for estimating the population based on the information on land use provided by aerial photographs. As early as 1956, Green used low-altitude aerial photographs (scale 1/7500) to estimate the population of the city by dwelling, provided by the latest census. This *detailed* method, which is based on *counting dwellings*, has been used by many authors, and has been the subject of a few applications in developing countries, the first of which was in Liberia (Porter, 1956). An experiment carried out in the USA by Watkins (1985, p.1933)^[25] shows the degree of accuracy of the method. Watkins' conclusion is the same as that which led to the development of another type of population estimate based on aerial photographs: improving accuracy means taking into account differences within the city.

The basic idea behind this second group of methods is that there is a relationship between the morphological characteristics of the urban environment and the demographic and socio-economic characteristics of the inhabitants. The principle is to exploit the exhaustive information provided by aerial coverage. The various studies that have applied this method have shown that this spatial survey technique makes it possible to reduce the sample size and spatialise the results. Many consultancies apply this technique, which has been developed to obtain demographic information on towns for which they have to draw up development plans, or to programme facilities. For example, a study by IAURIF successfully tested this method for estimating the socio-economic characteristics of the inhabitants of various districts of Niamey and Bouaké.

The integration of satellite data into a GIS gives it an operational character that enhances this long-standing technical approach (Delavaud, 1996, p.12)^[5]. Today, the development of public policies requires precise knowledge of the size and characteristics of the population. To meet this need, it is the responsibility of national statistical institutes to carry out enumeration operations. In this respect, national censuses are the cornerstone of data collection on the number of inhabitants in a country.

At national level, population is the denominator of many development indicators and their trends (Carr-Hill, 2014, p.99). Estimating this denominator reliably is an important and recurring need in all areas (spatial planning, education, democratic representation, social protection, health, etc.), including at different geographical scales (United Nations, 2017)^[20]. While traditionally, the publication of headcounts follows administrative units such as the region or the departement, this format imposes a spatial discontinuity that can prove arbitrary and does not make it possible to respond to the segmentation of the territory according to other criteria such as employment (employment area) or health (health districts). However, geographical data can also be used to estimate population numbers and can therefore be considered as 'predictors' of population numbers. In this

context, gridding a very high spatial resolution satellite image makes it possible to define a uniform grid for the entire territory, creating a common matrix for counted and uncounted areas.

Spatial data in the context of the population census is mainly seen as an operational tool to facilitate field logistics and ensure complete coverage of the census map. It can also be considered as a vector of demographic information through thematic maps, in which geographical divisions are assigned a colour according to their population size (Martin, 2011) ^[18].

However, because of the complexity of the survey and the risks of omissions that it can generate, it is customary, after the survey phase, to take a representative sample of the enumeration areas by stratum and to send out a simplified version of the questionnaire. The aim of this operation is to measure the omission rate and the quality of the information collected, a procedure known as the post-census survey (PCS). Furthermore, even when the quality of the EPC is deemed acceptable, the adjustment is made uniformly across the layers, masking deficiencies depending on the quality of the work of certain groups and the associated practical difficulties. Lastly, entire sections of the territory are sometimes inaccessible to census teams, either for physical or security reasons (Buettner and Garland, 2008) ^[2], making it necessary to estimate the population using another method, in this case high-resolution satellite images. The new generations of RGPH (General Census of Population and Housing), which are characterised by the use of satellite imagery, a digital geographic information system and the switch to tablet-based questionnaires, have drastically improved census mapping, remote monitoring of data collection and hence data quality (Eyinga Dimi, RGPH, 2019) ^[15].

3. Imaging as an alternative for data collection in insecure areas

Satellite images make it possible to study and understand the composition of the territories that are most hostile to human presence or even to the practice of socio-economic activities. Insecurity, which prevents complete census coverage, is also at the root of vast internal population movements that are difficult to quantify and map (Carr-Hill, 2014, p.139). The series of censuses taking place against a backdrop of rising insecurity is jeopardising the full implementation of traditional censuses in some regions of the world, particularly in sub-Saharan Africa (Jhamba *et al.*, 2020, p.44) ^[22]. Cameroon, which has been experiencing assaults by the Islamist sect Boko Haram since 2015, but also secessionist pressures in its English-speaking part, has not been able to carry out its censal mapping in full (Ebolé Bola, 2019) ^[13]. It is in this context that the UNFPA promotes and encourages the use of statistical methods for estimating the population (United Nations Population Fund, 2020, p.5) ^[24]. The Bayesian estimation framework makes it possible to integrate different sources of population data while quantifying uncertainty (Leasure *et al.*, 2020, p. 24176) ^[16]. It should be pointed out that this method has its limitations. It cannot be used to reconstruct a range of information, only population numbers. The many other characteristics of the population, such as its composition by sex and age, socio-economic level, habitat conditions and migratory movements, are currently less easily derived from remote sensing data.

Current techniques for high-resolution mapping of social indicators, such as access to drinking water (Local Burden of Disease WaSH Collaborators, 2020, p.1164) ^[17], use geostatistical modelling, which requires samples to be mapped across the territory. By using a hierarchical model incorporating different geographical levels to model the spatial distribution of the population, this method enables extrapolation to areas not covered. However, it is based on the assumption of similarity in building occupancy between accessible and inaccessible areas. Once the type of building and the administrative structure have been mastered, the similarity is adjusted locally by geographical variables.

4. Very high resolution images: new expectations and new uses.

At present, the proliferation of very high resolution commercial optical sensors (THR resolution of 5m or less) should be a major asset for remote sensing in urban environments. At the same time, producers of geographic information have developed an entirely digital system of aerial photographs with metric to sub-metric resolution. As a result, the highly heterogeneous nature of towns and cities, whatever the type or phase of urbanisation, can only benefit from finer spatial resolutions that provide a new vision and enable urban objects to be located, identified and quantified. The convergence of these two technological developments is leading to an abundance of digital data that can be used directly to create or update large-scale geographic databases adapted to urban environments. This is creating new expectations and defining new uses. Potential users are looking for the geographic information best suited to their objectives, depending on the tasks or applications to be carried out, from among the multitude of products and data available, whether raw or with added value. The enthusiasm for modern spatial representation techniques reflects a new approach to territorial management issues, based on the preponderance of satellite imagery. This development is bringing about a considerable transformation in the chain of production, distribution and use of information. It is leading to new requirements that are changing user expectations.

What's more, the use of these new techniques is changing the nature of the relationships between players, and ultimately changing the issues fundamentally. With very high-resolution satellite images, the potential for satisfying the need to describe and analyse urban areas is high and appreciated by all. Analysis of environmental dynamics is inseparable from observation of urban growth. The impact of urban growth on the environment (vegetation, soil, hydrography) is a major concern for decision-makers. Satellite imagery can be used to assess some of these aspects: degradation of the natural environment, deforestation, wetlands or very steep slopes (Delavaud, 1996, p. 8) ^[5].

5. The benefits of using satellite images

In Côte d'Ivoire, the strategy of setting up a coherent information structure is at the heart of the daily concerns of the players, managers and users of the urban environment. Effective urban intervention requires the acquisition of multi-source, multi-scale data that is regularly updated in line with changes in the environment. This requirement is a consequence of the growing demand for localised information at various scales. From a technological point of view, the satellite images provided by satellites make it

possible to meet this requirement. They can now be used by anyone to measure their position accurately, radically changing the way in which information is gathered. In addition, the actual and announced launches of high spatial resolution earth observation satellites (Ikonos, Quickbird, Spot5, Orbview, Eros, etc) have opened the way to the automated production of digital urban information. These images are no longer used solely to delimit the urban area, but also to analyse the internal components of the urban space (housing, socio-economic activity, etc.). We are therefore witnessing an evolution in the scale of application of urban remote sensing, where the object studied is the urban fabric, the district, or even the urban element (building, road).

Technically, the rise of computing, the development of software specialising in the manipulation of geographic information (storage, management, analysis) such as GIS and the development of online technologies have changed the practices and challenges of geographic information, providing direct and interactive access to a wide range of data.

In addition, the creation of a thematic base map covering the whole of the city finally offers a global vision of the urban fabric covering huge areas, which is effectively impossible with traditional data, even when it exists. It will make it easier to compare over time when an image from a different date becomes available. Its purpose is to assist urban planning (Delavaud, 2000, p.10) ^[6]. Used essentially as a tool for global knowledge of the city at a specific date, remote sensing compensates the geographer for the lack of traditional information in the form of maps and aerial photographs, which are often partial, out of date and from different dates, and which have to be assembled into an incomplete jigsaw puzzle.

Conclusion

This article is a contribution to updating the literature on the use of satellite imagery in the observation of urban dynamics and demographic and socio-economic surveys. The hybrid census, which combines field enumeration and the use of high-resolution satellite images, represents an undeniable technological advance in a context of security challenges, where geographical data, particularly from satellite imagery, can supplement the population data from an incomplete demographic census. However, even though the objectives of a demographic census go beyond simply counting the population, estimating other demographic trends such as sex and age composition, socio-economic level or migration using spatial models remains a challenge. The use of imagery makes it possible to rapidly implement a sample survey in a city with no conventional sampling frame. The speed with which the results can be obtained and the way in which they can be broken down into different parts of the city are features of the method that should appeal to the various players involved in urban management. Drawing a socio-demographic survey sample from a satellite image also makes it easier to highlight differences within a city and to analyse the dynamics of urban sub-populations, an approach to urbanisation that is often highlighted in research on cities in developing countries. What's more, it can be used to reduce the number of samples to be surveyed, thanks to its greater precision, at the same overall cost, and to provide more in-depth observation than traditional survey methods. In addition, the

increasing number of applications in urban contexts that differ both physically and socio-economically will necessarily contribute to a refinement of the satellite image areal survey method presented in this article.

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