Application of Remote Sensing to Urban Population Estimation: a case study of Marrakech, Morocco

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ABSTRACT

Population information is an important component of city planning. In most developing countries, where urban areas are experiencing rapid population growth, this aspect is even more important, but it cannot be assessed efficiently using traditional methods. The advent of satellite remote sensing, complemented by aerial photographs and sampled field surveys, has now made it possible to obtain timely estimates of population for such areas. This paper reports on an application to the city of Marrakech (Morocco) using SPOT XS+P data. An estimation of the population was made using a segmentation in areas of homogenous urban typology. Advantages and limitations of the proposed methods are compared.

INTRODUCTION

The population of the world currently shows an incredible growth: it is currently estimated at 5.5 billion, and by year 2050, it is projected to reach 10 billion. Moreover, the part of the population living in urban areas also will increase, especially for cities larger than one million people. The localization of the population of the world also changes: in Africa, the population was multiplied by 5 from the beginning of the last century until now, and this is expected to increase to 30 by the next century. Most of the population growth is located in the less-developed countries, especially in urban areas. In a recent report, the World Bank stated that “Urban growth in developing countries is obviously one of the most explosive problem for the beginning of the next century” If we want to be able to manage such a problem, good diagnostic tools will be required. Current methods used to gather information on cities are usually too expensive, too slow and too complex to be operationally used for third-world’s fast-growing cities.

Remote sensing has, perhaps, a role to play in order to provide this diagnosis. From other application domains, it has been proved that remote sensing data are (relatively) inexpensive, can be quickly processed and are usually accurate enough (various authors in ISPRS, 1992). Could it be the same for applications dealing with urban management? More specifically, we want to test the possibilities of using remote sensing as an alternate source for population information. Both technical and economics aspects have to be analysed to assess the effectiveness of this approach.

1 STATE OF THE ART

1.1 General urban monitoring

The use of aerial photographs for urban monitoring is nearly as old as photography (pictures of suburban areas near Paris from a balloon by ‘Nadar’ in 1859). Since, aerial photography proved an unrivalled source for urban monitoring, especially with tools provided by photogrammetry. The use of satellite remote sensing data for urban monitoring is also associated with the beginnings of satellite remote sensing (shoots of large cities of Texas taken during Gemini 5 mission, in 1969). One of the most frequent aim of urban studies is to provide a land-use map, acting as a synthesis of the recent and actual situation. This information is usually required before any urban management operation. Remote sensing, in its widest acceptation (i.e., including aerial photography) has always provided such information, using visual interpretation, and more recently, digital processing. The accuracy of such monitoring obviously depends on how detailed the data are (scale and/or resolution), of the complexity of the city, and of operator’s skills.

1.2 Population estimation

From the information on land-use, it is possible to derive many indicators and models such as the percentage of vegetation per district, the length of road network, land-
scape complexity... It is also possible to derive information about the population of the city, as was done by Green (1956) by counting the dwelling units on aerial photographs of Birmingham, USA. Since then, many studies have been carried out in cities of developing countries (for a detailed review of past studies and existing methods, see Adeniyi, 1983).

1.2.1 Population estimation using aerial photography

Large scale aerial photographs (ab. 1:10 000) were always very widely used in cities of developed countries for several objectives:
- preparation of demographic surveys (definition of census tracts for exhaustive surveying, stratification for sampling schemes)
- direct estimation of population

For the latter, the general methodology can be summarised as follows:
- delimitation of homogenous housing areas: from aerial photos
- analysis of urban typology (size of buildings, number of storeys, width of local roads, size of gardens, etc.): from large-scale photographs and/or field checking
- estimation of vacancy rate and household size: from field survey

This technique was proved to be efficient, but it was less used in developing countries, for obvious reasons of cost and know-how.

1.2.2 Population estimation using remote sensing

The aims of using satellite remote sensing data for gathering demographic information are slightly different. The resolution and related scales of earlier MSS (80 m / 1:250000) only allow a global approach of the city (estimation of the total number of inhabitants). Existing archived data (20 years) are nevertheless invaluable for studying the evolution of cities and their impact on surrounding region (Soyer & Wilmet, 1986). Modelisation of the hierarchical network of cities was also of interest (Lo & Welch, 1977). The advantages of low cost and potential repetitiveness of satellite data also suggest using those data for inter-census estimations, based on the assumption (widely verified) that the relation between measured population densities and morphological aspect is stable in time. Consequently, the spatial extension of a district with known population density corresponds to a population rise.

The resolution of the satellites of second generation allows more detailed scales (TM and SPOT XS: 1:100 000 to 1:50000, SPOT XS+P: 1:50 000 to 1:25 000). The interest for urban population monitoring logically focuses on more precise analysis, at the district level or even at the city-block level. The transfer of some methods defined for aerial photographs to remote sensing data has been tested by various authors (e.g., Lo et al., 1977, Mahavir et al., 1991); they can be classified according to the method used:
- count of dwelling units (only usable in a few cases of regular cadastral scheme and large buildings)
- measured land-use area (estimation of population density for each identified land use type)
- stratification for sampling field survey

Most often it is possible to build a demographic estimation only from the two first tasks. Nevertheless, the field survey is useful to give more accurate estimations and/or provide more complex demographic indicators (age structure, household income, etc.).

![Fig. 1 - General location of the test-site.](image)

2 TEST SITES

Our research is intended at develop operational methods usable for demographic estimations of fast-growing cities in less-developed countries. In order to define and test those methods, we choose to work on Marrakech, Morocco.

Located in the fertile Haouz plain, at 30 Km from the Atlas piedmont (Fig. 1), the original site of Marrakech was first explained by its role of communication node. Beside this site of contact between natural regions (fertile north and arid south), it represents the first important city for migrants coming from the south.
This city has now ca. 1 million inhabitants, (3rd city of Morocco) and presents a recent and very fast evolution, related to both natural demographic increase and migrations from rural areas, severely affected by recent drought years. The population increase corresponds to both a spatial spreading (new settlements) and to density rise of some districts. This city presents a very wide variety of urbanistic and architectural typologies, including traditional adobe construction. Nevertheless, the general urban planning is spatially well supervised. Last, we expected to be able to use existing demographic data in order to check the validity of our estimation, but this expectation falls short.

In a later phase, we are going to transpose those methods to a ‘real scale’ problem, in Ouagadougou (Burkina-Faso). This city is just under 1 000 000 inhabitants, but here the informal settlements are the majority (> 65%). The population increase is very problematic, and traditional census methods are obviously inadequate (cost, speed, etc.).

3 GENERAL FLOWCHART OF THE METHOD USED

The suggested processing of remotely sensed data can be summarised as follow, from the raw data (level 0) to the application (level 4). Some topics of this general flowchart will not be covered here, but have been used in other applications.

3.1 Processing of Raw Data

The techniques used to produce usable colour composites from original satellite data are not specifically related to the aims of our research. They involve:
- Noise removal (a.o. the vertical stripping, frequent on XS & P data)
- XS & Pan merging (through IHS transform of “true colours” composite)
- Standard radiometric enhancements (histogram stretching)
- Local contrast enhancement (for visual interpretations only)
- Geometric corrections

Special care was nevertheless given to this task, because later treatments use visual products in an intensive way. It is also worth noticing that high quality hard-copies of colour composites made from recent satellite data are a worthwhile support for many urban management tasks without any sophisticated hardware or software. The latter aspect being especially interesting for less-developed countries.

3.2 From image to land-use map

3.2.1 Land-Cover classification

The information provided by observation satellites are related to physical properties of observed objects. More specifically, the registered signal gives an indication about the quantities of reflected energy, in a specified spectral range. Thus this information could at best only distinguish objects presenting differentiated cover materials, view from the satellite’s orbit. Two types of spectral confusion can occur: the same building material (asphalt, for instance) used on the roof of a multiple-storey building cannot be distinguished from the one covering a new parking place. On the other hand, two different materials can have near similar spectral properties (at least with the satellite’s sensibility); in our application, it was very difficult to distinguish between water and shadowed concrete surfaces or between bare soils and rammed earth buildings. We have tested several methods for supervised classification, but none of them really solve this intrinsic problem. The categories resulting from a classification based on spectral properties are thus often badly defined and/or related to useless properties. This is especially cumbersome for applications dealing with urban land-uses that are less linked to physical properties than, for instance, crop types in large homogenous fields or for some categories of soils. In urban applications, land-cover classification will usually not completely satisfy the re-
requirements of the users. This information will nevertheless be useful for further treatment, but cannot be considered as a final result.

In Marrakech, we were able to identify 15 land-cover classes (see table 1, in § 4.2).

<table>
<thead>
<tr>
<th>1. Water, shadow</th>
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</thead>
<tbody>
<tr>
<td>2. Vegetation</td>
</tr>
<tr>
<td>3. Irrigated vegetation</td>
</tr>
<tr>
<td>4. Crops (various types)</td>
</tr>
<tr>
<td>5. Uncovered soils (dark)</td>
</tr>
<tr>
<td>6. Uncovered soils (clear)</td>
</tr>
<tr>
<td>7. Very reflect. soils / pebbles</td>
</tr>
<tr>
<td>8. Concrete</td>
</tr>
<tr>
<td>9. Asphalt, ballast</td>
</tr>
<tr>
<td>10. Trees</td>
</tr>
<tr>
<td>11. Waste lands</td>
</tr>
<tr>
<td>12. High density housing</td>
</tr>
<tr>
<td>13. Med. density housing / squat</td>
</tr>
<tr>
<td>14. Mixed housing &amp; gardens</td>
</tr>
<tr>
<td>15. Gardens</td>
</tr>
<tr>
<td>16. Undefined</td>
</tr>
</tbody>
</table>

3.2.2 Visual Interpretation of RS data: segmentation in homogenous housing areas

An attentive look at the images suggests that some information more useful for planners can be extracted. General principles of photo-interpretation are well known. Their transfer in (partially) automated procedures is not an easy task. In urban areas, visual interpretation is based, as usual, on colour, but special emphasis is made on textural and structural information. It is worth noting here that the notion of texture used for this visual interpretation is very different from the textural parameters extracted by digital processing in a moving window. Results based on visual interpretation of urban textures cannot currently be reached by any available automatic process, as far as we are informed.

Subsequently, we decided to use methods based on visual interpretation. Nevertheless, we made this interpretation on an image processing system rather than on hard-copies. This allows us to use the large number of functions of image processing software. The use of dynamic control of contrast/brightness and zooming capabilities were especially appreciated. The storage of the results of the interpretation as vectors and polygons was also of great interest. Finally, all digitised polygons are merged and transformed into one single raster file, registered to the original data. For this task, we use the ERDAS 7.5 system. We especially appreciate the possibility to use this software on a portable PC during field works. This allows us to improve and/or modify some interpretations according to ground-truth checking.

For our application on Marrakech, we focused the visual interpretation on classes for which the spectral classification was less efficient. The large institutional/service buildings were spotted, and in most cases, their actual function was determined from external sources (city maps, telephone directory, field survey). Large unbuilt areas with dedicated function were also delineated (cemeteries, military zones, golf courses, etc.). The most important part of the interpretation focused on the segmentation of urban areas into Homogenous Housing Areas (HHAs). The delineation of the boundaries and a coarse determination of the affectation of the homogenous areas was done on the SPOT XS+P composite, while precisions about their content are obtained from large scale aerial oblique photographs and/or field surveys. Delimitations of the limits of alluvial plains were also added in order to correct easily confusions of land-cover classification occurring between water and urban shadows.

Each area is associated with a concise description of urban typology (building’s type and size, number of storeys, estimated age, etc.) and estimated population density obtained from aerial photographs and/or field survey.

The categories used for this interpretation are determined according to the characteristics of the city (see table 2 for a list of the classes used in Marrakech).

### Table 2: Urban categories obtained from visual interpretation (the numbers correspond to the color key of figure 4-C where only residential classes are colored).

<table>
<thead>
<tr>
<th>1-3</th>
<th>Modern housing (3 densities)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-7</td>
<td>Tradit. Housing. in “Medina”, (4 densities)</td>
</tr>
<tr>
<td>8-12</td>
<td>Unplanned settlement (4 densities)</td>
</tr>
<tr>
<td>13</td>
<td>Main road</td>
</tr>
<tr>
<td>14</td>
<td>Main railroad</td>
</tr>
<tr>
<td>15</td>
<td>Alluvial plain</td>
</tr>
<tr>
<td>16</td>
<td>Industry (and related outbuildings)</td>
</tr>
<tr>
<td>17</td>
<td>School</td>
</tr>
<tr>
<td>18</td>
<td>Hospital</td>
</tr>
<tr>
<td>19</td>
<td>Other services</td>
</tr>
<tr>
<td>20</td>
<td>Hotel</td>
</tr>
<tr>
<td>21</td>
<td>Park of hotel</td>
</tr>
<tr>
<td>22</td>
<td>Cemetery</td>
</tr>
<tr>
<td>23</td>
<td>Military zone</td>
</tr>
</tbody>
</table>
3.2.3 From Land-Cover to Land-Use

For many users (operators of urban management), the information provided by the land cover map was considered of poor significance, while the fine details were usually appreciated. On the other hand, the segmentation in homogenous areas was based on the information aimed, but the precision of the limits was not adequate.

By merging both documents (land-cover map and homogenous housing areas), it was possible to benefit of most of mentioned advantages. The resulting classes are judged compatible with the requirements of an urban land-cover map.

This task is made using logical rules between the two raster layers in order to recode the large number of theoretically available combinations (16 land cover classes x 22 categories provided by visual interpretation) in a few meaningful ones. For example, a pixel of “woody vegetation” (land cover) in residential area will be classified in a “tree-garden” land use class. A pixel with “high reflect. mineral” land cover will be classified in the “urban building works” land use category if located in residential area, but in the “saline soils / pebbles” category if located in an unbuild area. This was also achieved with the GIS modules of ERDAS.

Table 3 shows the land-use categories adopted for Marrakech, but many other options are also possible (merging all housing densities in one class, merging all planned housing schemes into one class, etc.).

It is worth noticing that many awkward confusions of classification can be corrected using this approach (like pixels of crops in the high density housing area, pixels of housing observed along field boundaries...).

3.3 From land use map to application

Land-Use maps providing faithful and updated information are obviously one of the most useful document for urban management. It is thereafter required by the law of most countries before some planning operation.

At level 3 of the flowchart of figure 1, we considered land-use maps as the raw material for many GIS applications such as specific thematic maps, urban structure models, etc.

Repeated satellite coverage with related land use maps can easily and efficiently provide an estimate of changes with their location. Existing SPOT archives (5 years) are already sufficient for applications in fast-growing cities.

Among others derived applications, land use maps can be used for demographic estimation. As mentioned earlier, this aspect will be developed specifically.

3.4 Demographic estimations

3.4.1 Principle

The method assumes the two following hypothesis:
- Urban areas with similar typologies have similar population densities.
- Areas of homogenous typology can be identified from remote sensing data.

3.4.2 Estimation of densities

All the areas having similar typology are merged into the same subset, or stratum. For each stratum, an estimation...
of the mean population density has to be made. Normally, this is done using a two-steps approach: we first determine the number of dwelling units per hectare (using aerial photographs in a sampling approach). Then the number of persons per dwelling unit is estimated during a specific field survey. The variance of both parameters is also estimated, for each stratum.

3.4.3 Spatial analysis

The information provided by the estimation of densities is spatially generalised according to the segmentation in homogenous housing areas. On the other hand, the land-use document provides a (spatially) precise representation of the build-up areas. By cross-comparison of both documents, it is possible to calibrate the land-use map in terms of population, but also to dis-aggregate the population density map according to the actual distribution of housing. This is done using the method of "spatial dis-aggregation" explained by figure 3. The resulting document provides information about the expected "number of inhabitants per pixel" that can be used in many applications.

3.5 Accuracy

The evaluation of the accuracy of demographic estimations is obviously of first importance. Unfortunately, this evaluation is not easy: the global accuracy involves errors of classification, generalisation errors related to the photo-interpretation, the errors of estimation of the number of dwelling units, of the vacancy rates and of household size. We plan to modelize the effect of those errors on the global results, using a synthetic data set. This model can then be used in order to assess the global effect of specific error decreases.

One other approach will be to consider the specific errors as a whole, and to give an estimate of expected error from a set of control areas.

4 RESULTS and DISCUSSION

4.1 Data used

We have used two SPOT scenes of Marrakech, both acquired simultaneously in XS and P:
- September 16, 1987 (SPOT-1)
- September 21, 1991 (SPOT-2)

The first scene, already existing in the SPOT archive, was used for methodological tuning. The second one was especially programmed according to a field survey planned in October 1991. They were treated as mentioned in § 3.1. Data acquired by SPOT-2 are perceptibly better than previous ones, but neither scene was perfect.

We extract an area of 1536x1536 pixels covering the whole urban area. Figure 4 presents main results obtained on a sub-area of 400x400 pixels (4x4 km) covering the districts of Daoudiai and Assif and the northern part of the Médina.

4.2 XS+P Colour composites

Colour composites made from XS+P data were produced in both digital and hard-copy versions. All digital processings were made using an ERDAS 7.5 / PC system. High quality hard-copies of colour composites (at scales of 1:40000) were also used during field works. Figure 4-A shows the improved resolution provided by P+XS data.

4.3 Land-Cover spectral classification

The supervised classification of the data allows us to identify 15 classes of land cover. As mentioned earlier, most of these classes present poor significance for operational planning. Moreover, provided by a classification at the pixel level, it has a “pointillistic” aspect, not really suitable with cartographic practice. The land cover map have to be considered as an intermediate step towards more operational documents. The classes are given by table 1, and results are shown by figure 4-B.
4.4 Visual interpretation

The segmentation of urban areas in homogenous housing areas uses the following key (Table 2 and fig. 4-C). The delineation of those affection was easily done on XS+P composite, using digital processing system. This task is quite tedious, but it gives the operator the opportunity to scrutinise all the districts of the city. The interpretation of the content of those areas uses often external information. In Marrakech, we used outdated aerial photographs and existing city maps (not very accurate), but mainly the knowledge of local collaborators.

The aspect of resulting document is totally different from land-cover map. Here we have a clean segmentation, more compatible with users needs.

4.5 Land-use map

The land-use map is provided by a cross-overlay between the land-cover document (16 classes) and the homogenous housing areas (22 categories), both in raster mode. The resulting 352 classes are recoded using logical interpretation rules. Various recode schemes are possible. We have used the following key (table 3).

The resulting land-use map benefits of the advantages of its components: high spatial precision given by per-pixel land-cover map, and high significance obtained by visual segmentation. This document was very appreciated by most potential users. On this document, the land-cover classes were smoothed by median filtering (compare the NE corner on maps 4-B and A-D. Otherwise, classes 1-8 are directly provided by the land-cover document. Other land-use classes are obtained by cross-comparison between land-cover map and the photo-interpreted map, but classes 29-32 are obtained by interactive digitizing, and are not compared to land-cover information.

4.6 Demographic estimations

4.6.1 Restricted access to the information

In the proposed methodology, we base the estimation of population densities on dwelling units counts made on large scale sampled photographs and household size obtained by field inquiry. Until this stage, all previous operations can be done discreetly, without official co-operation: data acquisition, processing and interpretation only require a few field surveys for initiating the classification and for checking its accuracy, with no more difficulties than usual common-sense security rules adapted to the realities of poor slums. But the organisation of an aerial survey, even with an ordinary small aircraft is much more complicated, especially in some developing countries. In those countries, mapping and remote sensing are mainly considered as military or related to intelligence operations and therefore are strictly controlled. More specifically, objective demographic estimations of the population of Marrakech and its recent evolution were perceived as too sensitive by Moroccan authorities, for complex reasons of international and internal politics. Despite the interventions of Moroccan scientists and city planners interested by our project, we never get the official authorisations for an aerial survey and for field inquiries. Moreover, despite the international open access to SPOT data, the use of satellite images is prohibited in Morocco (the acquisition and use of topographic maps, or the use of GPS are also restricted). Consequently, this study has to be completed with restricted means.

4.6.2 Alternate approach

We were able to consult an existing aerial coverage of 1987 (1:7 500), which was very useful for the calibration of HHAs. During an aerial survey on the outskirts of Marrakech, small-format oblique views of the city were shoot through the window of the airplane. While these photographs cannot replace vertical view (especially for measurement of surfaces), they are useful to have an estimate of the typology, and are efficient to assess the filling rate of new housing estates.

We didn’t neither get the authorisations required to make efficient demographic inquiries in Marrakech. It was nevertheless possible to obtain valuable information about the housing typology of HHAs and their general socio-economic level. Also, a rough estimate of the average number of people per building was obtained through the assistance of local city planners.

Each of the 225 HHAs identified in Marrakech was estimated by those means. We use the notion of “net residential densities”, which computes the average number of inhabitant per hectare, including “associated” outbuildings, gardens and local service roads. Large equipment buildings, public green spaces and main roads are not included in this estimate. The densities range from 50 Inhabit./Ha. in luxurious district of “Gardiennage” to up to 1 500 Inhabit./Ha. in populous districts of the Médina (“Mellah”). Those values are mean raw densities per HHA. Locally, much higher densities are observed, with one (large) family per room, and shed squats on the roof, rising the (local) densities to near 10 000 Inhabit./Ha. !
Fig. 4 - Some results obtained on a 4x4 km area of Marrakech (Daaouadi - Assif - Médina) - see text for comment.
4.7 Spatial distribution of the population

The map of HHAs, calibrated in densities from our estimations gives a good idea of the distribution of the population. Nevertheless, we have proceeded to a finer analysis through the cross-overlay of this document and the per-pixel land-use map. The resulting raster map attributes an estimated population to each pixel classified in one housing class of the land-use map (fig. 4-E). This document can serve in many applications. For instance, we use it to demonstrate the possibility to estimate the total number of inhabitants living on the area related to one sewage collector. This kind of application seems very promising for various actual cases of urban management. They give rise to great interest from public works administrations.

4.8 Accuracy

We were not able to estimate the level of accuracy of our estimation in Marrakech, because of the lack of authorisations for inquiries mentioned earlier. We have only compared our estimations for well-known districts to reliable information sources and this comparison is encouraging.

5 DISCUSSION

5.1 Data

We used SPOT XS+P data. Recent scenes are not always available, but the satellite can be programmed to provide wanted data. The application of Marrakech has taken advantage of an appreciated performance of SPOT-Image: we get the data 3 weeks after their acquisition, allowing us to work on field with one-month old images!

Some “cosmetic” processing are always required on the data we use, but the resulting image quality worth the time spent. The resolution of XS+P data allows a good delineation of almost any housing areas. The precise identification of the typology is still critical, while possible (individual houses are not distinguishable).

5.2 Methods

5.2.1 Classification

Supervised classification based on spectral properties gives good results for non-urban land-cover but have poor efficiency in urban areas.

The use of topological information is not currently efficient through standard digital processing. A good operational segmentation in homogenous housing areas can be provided by visual interpretation, especially in its computer-assisted form.

5.2.2 Demographic estimation

It is possible to estimate roughly the population densities only from satellite images, but external sources of information are highly recommended. The general strategy is to:

- measure the surface of homogenous housing areas from SPOT data,

- estimate the density of dwelling units from aerial photographs gathered according to a sampling scheme based on the segmentation of SPOT data,

- calibrate it by the number of inhabitant by household obtained by stratified sampling.

It was not possible to achieve the precise calibration in Marrakech, but a more recent application in Ouagadougou demonstrates the effectiveness of the methodology.

5.2.3 Cartographic presentation

Besides usual documents provided by remote sensing processing, we propose a raster map of the distribution of estimated population, using both the demographic estimation and the land-use map. This document gives rise to various applications. Figure 4-F illustrates one possible graphical representation of the distribution of population, on a per pixel basis. Values indicates the number of inhabitant per pixel (one pixel is 1/100 Ha.)

On figure 4-F, we tested a spatial modelling of the distribution of population using the principle of population’s potential: each pixel is influenced by the population of all pixels, but their influence is inversely proportionnal to their distance to the pixel considered. This model is useful to highlight the internal hierarchical organisation of the districts. The values of the contour lines are only relative.

5.2.4 Stratified sampling

One of the most promising results was found in the potential to optimise demographic sampling. The use of sampling surveys spatially stratified on basis of the actual housing typology can greatly improve the accuracy of the
results, or can reduce the costs, for a fixed level of accuracy.

5.3 Results

The results obtained during this phase of methodological tuning have not yet been used in an actual urban management operation in Marrakech, but they are now on the good way. On the other hand, they induce a Belgian management operator to introduce this methodology in an important urban management contract, on another urban area of Morocco, planned for 1993.

6 FUTURE DEVELOPMENTS

The following of this research is now dedicated to Ouagadougou (Burkina Faso), where the same methodology has been used with great success. We still hope to get the authorisations to go further in the analysis of Marrakech. To be completed, this study needs a more precise calibration of population densities (by field survey) and an assessment of the general accuracy.

6.1 Use of sampled aerial photographs

A more consistent use of large-scale, vertical photographs should precise the urban typology and the determination of buildings sizes. Information about the socio-economic level and related population densities can also be gathered. This gives a simple and inexpensive complement to the information provided by satellite data (i.e., delimitation of homogenous housing areas). This was done recently on Ouagadougou, but results are not already available.

6.2 Stratified demographic sampling

One of the most interesting use of remote sensing data for demographic estimations is stratified sampling: the study area is divided in 'strata', (homogenous areas). The criterion of homogeneity has obviously to be strongly correlated to the measured parameter. This stratification allows to split the whole area, with its variance, into subsets having smaller variance. Smaller variances means better accuracy, for a given number of points, or can be used to reduce the number of sampled points, for a given accuracy (optimal allocation). Specifically, much effort can be done on districts having a (pre-estimated) larger variance. This method has already been applied and tested by a team of french ORSTOM on Quito, Equator (Dureau et al., 1989), with very encouraging results (30 to 40 % increase of accuracy). We plan to apply this method, with some adaptations (using a housing typology determined by aerial sampling and field survey rather than a spectral / textural criterion for the segmentation, etc.). We expect this approach will reduce the demographic survey costs, allowing realistic monitoring of the urban growth.

ACKNOWLEDGEMENTS

This research is part of the “Belgian Scientific Research Programme on Remote Sensing by Satellite - phase two” (Services of the Prime Minister - Science Policy Office). The scientific responsibility is assumed by the author. Many thanks to anonymous reviewer for its highly valuable constructive comments.

REFERENCES


