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GIS Based Census Mapping Approaches: Brazilian experience*

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GIS Based Census Mapping Approaches: Brazilian experience

ABSTRACT

The Brazilian Institute of Geography and Statistics – IBGE is at present involved in conducting the 2007 Censuses, an operation comprehending the Agricultural Census, the Population Counting and the Address File, surveys simultaneously and integratedly applied in 2007. This paper presents the activities developed by the Institute since 2003, preparing the Census Mapping for this operation. The Census Mapping is subdivided into a rural and an urban component, both of them digital, corresponding to a hybrid solution of raster data (topographic and cadastral maps) and vectorial data (municipal boundaries, enumeration areas delineation, information derived from GPS surveys, etc.), the latter structured on Geographic Information Systems – GIS environment. This paper also includes the technological improvements achieved, the difficulties faced and the lessons learned towards the 2010 Demographic Census.

INTRODUCTION

The Brazilian Institute of Geography and Statistics – IBGE - is the Federal Government institution responsible for producing, analyzing and disseminating statistical information (demographic, economic and social), as well as geodetic, cartographic, geographic information and that related to natural resources and to the environment. Within these activities, it periodically conducts the Demographic and Agricultural Censuses, as well as Population Counting abiding by international recommendations. The combination in its structure of both the statistics and the geosciences areas allows IBGE to optimize resources and to maximize the quality of the contributions of each Institute area in the conduction of the Census activity, constituting an excellent example of an institutional integrating project.

The Institute is now carrying out the 2007 Censuses, an operation comprehending the Agricultural Census, the Population Counting and the Address File, surveys simultaneously and integratedly applied in 2007. This paper presents the activities developed by IBGE since 2003 in the preparation for the Census Mapping for this operation, including the technological improvements achieved, the difficulties faced and the lessons learned towards the 2010 Demographic Census.

THE 2007 CENSUSES

The Agricultural Census is surveying information in about 56 million Agricultural establishments, in all the 5,564 Brazilian municipalities. This survey results will show the changes that occurred in the sector since the latest Census, conducted in 1996, and provide updated information on economic, social and environmental aspects of the agricultural activity. The Population Counting is being conducted in 5,435 municipalities, corresponding to those with up to 170 thousand inhabitants and additional 21 above this range[1], encompassing about 29 million residences, where about 110 million people live. The survey will provide updated data to mainly drive the distribution of the Municipalities Participation Fund - FPM, which is the financial resource that the Federal Government transfers to the municipalities in order to be invested in improving their inhabitants' lives [IBGE, 2007a].

The 2007 Censuses represent one more opportunity for IBGE to innovate in its work projects. Thus, the 2007 census operation brings about two important novelties that will allow more agility in conducting surveys and in disseminating results, with greater accuracy, better managerial control and a more thorough territory detailing. The first novelty is the National Address File for Statistical Purposes - CNEFE, prepared from records of units surveyed in 2000. This file aims to improve the survey, treatment and dissemination of statistical information. At the end of the 2007 Censuses, the CNEFE will cover addresses of the residential and non-residential units of the Country, including those in the rural areas. In the rural area, the geographical coordinates necessary to geocoding rural properties will also be collected, as well as health and education establishments. Another great novelty provided by the 2007 Censuses is the replacement of the traditional questionnaire on paper by a handheld

[1] Located in states in which only one or two municipalities exceed this population estimation

computer or Personal Digital Assistant - PDA (Figure 1). This digital equipment is already used in other IBGE surveys; however this is the first time the institution is using this resource in a Census operation. The PDA is being intensively employed in data collection, providing a number of advantages, as the following:

Figure 1: PDA used in the 2007 Censuses (source: IBGE, 2006)

- Immediate quality control at the moment of data typing, allowing the correction of the information during the interview;
- Filling of all compulsory items, avoiding the lack of answers due to census interviewer forgetfulness or error;
- Control of data filling by automatic leaps in the form, dispensing with the exhibition of items for which there may be no information, which optimizes the census interviewer's and interviewee's time;
- Real time tracking of the data collection pace in all municipalities, providing better work management, mainly in cases for which the adoption of corrective measures during data collection is necessary - for example, when a flaw is detected in the territory coverage which may be excessive or too low in the number of units surveyed. This tracking is made possible by the data transmission directly from the PDAs to the central system during the collection period; and
- Dispensing with the transportation of great volumes of paper questionnaires and their handling in the data collection centers, providing gains in information accuracy and processing agility.

Besides all these advantages, the PDAs will greatly facilitate the location of the units to be surveyed, since they are equipped with a GPS (Global Positioning System) receiver. This will allow geocoding of the collection units and of the health and education establishments located in the rural areas, as well as tracking of the geographical coverage practically in real time, better controlling the working area of each of the 68 thousand Census interviewers.

It is also worth stressing that the use of the PDA equipment contributes to the digital inclusion both of IBGE and of the Country, since about 80 thousand pieces of equipment are being used both by IBGE employees distributed in more than 530 agencies, and by temporarily hired Census interviewers. The PDA use training activities, in the presential and distance modalities, also contributed to disseminating this technology. Moreover, the interview conducted with the PDA will allow many citizens to make their first contact with this type of equipment, a relevant fact considering that only 13.7% of the permanent private residences in the Country were equipped with a microcomputer linked to the Internet in 2005 [IBGE, 2007b].

2007 CENSUSES PLANNING: CENSUS MAPPING PREPARATION

The 2007 Censuses collection operation comprehends 162,770 enumeration areas, out of 249,068 ones that compose the Census Mapping. It is formed by a set of maps and databases that allow guiding the division of the territory into small areas, called enumeration areas. Its preparation takes into account, besides the organization of the Censuses data collection operation, the necessity of fulfilling the demands of the municipal governments and of the private sector for more detailed information that supports decision-making for both public and private investment.

The criteria adopted for defining the size of the enumeration areas are the following: about 300 residences in urban areas, and up to 150 residences and 500-km^2 area in rural zones. At times the municipal boundaries

alterations make it necessary to exceptionally define smaller enumeration areas than those aiming to maintain the comparability with previous Censuses results.

IBGE prioritized the Census Mapping update and digitalization in all 5,564 municipalities for the Agricultural Census and in 5,435 municipalities for the Population Counting. The Census Mapping revision work included the update of the so-called special areas (Indian areas, subnormal agglomerations, rural settlements for landless workers, environmental protection areas, etc.), of the municipalities maps, of localities and of enumeration areas, of the road and hydrographic systems, of the toponyms and of the geographical boundaries of each enumeration area, and of their inner components (such as streets, blocks, etc.).

IBGE started the elaboration of the Census maps in digital form during the preparatory actions for the 2000 Census, providing continuity to these efforts for the 2007 Censuses. In the National Cartographic System structure, IBGE is responsible for producing the systematic terrestrial mapping of the Country in 1:25,000 scales or smaller, a task shared with the Army Geographical Service Directorate [CONCAR, 2007a]. This fact implies that IBGE is the producer of the topographic maps used as basic input for generating rural maps composing the Census Mapping. However, as to the urban mapping in cadastral scales – 1:2,000 to 1:10,000, its production is not conducted by the Institute, but by public state and municipal institutions and by the private sector.

Due to the characteristics of the inputs used, the Census Mapping production differs in relation to the rural and urban segments.

Rural Census Mapping Production

The rural segment is supported by the systematic topographic maps available at IBGE and at the Army Geographical Service Directorate. The municipal maps are then elaborated, where the physical natural and artificial elements of the municipality are represented, such as rivers, roads, localities, municipal boundaries, which are associated to databases of toponyms, localities, rural properties, special areas, and others. From these maps, statistical municipal maps are produced, with the addition of the enumeration areas delineation, which is associated to the enumeration areas description database.

The production of these maps is conducted from the use of the Municipal Maps Semi-Automatic Elaboration System - SisCart, especially developed for IBGE, in Visual Basic 6.0, having MicroStation/MGE, from Bentley/Intergraph, as graphic platform and Access97, from Microsoft, as alphanumerical platform. The SisCart significantly facilitated the construction of the municipal map, made in a decentralized way, contemplating, among other tasks, the homogenization of projection and scale, the geocoding of the topographic sheets composing the municipal map, the validation and geometric treatment of features when joining sheets, the cropping of sheets following the municipalities perimeter, besides the framework and footnote data composition [Barbuda, 2004].

For the Rural Census Mapping of the 2007 Censuses, the production process used in the 2000 Census was continued, through a great municipal maps updating effort. In the 2000 Census planning, the maps update using field campaigns was prioritized for municipalities with more than 25,000 inhabitants. Thus, for the 2007 Censuses, the need for a comprehensive map update was identified, not only by using field campaigns, but also by carrying out office activities using several information sources (for example, data obtained in the 2000 Census collection operation).

Rural Census Mapping Update

This stage aimed to update the Rural Census Mapping by means of GPS field campaigns and by office activities, using properly registered inputs for the composition and maintenance of the database and metadata composing the Digital Municipal Maps.

The cartographic update was operationalized by acquisition and insertion, using the SisCart, of cartographic information derived from:

- GPS field surveys conducted in 2,016 municipalities;
- office surveys by consulting field notes from previous Censuses, IBGE internal surveys and rural enumeration areas descriptions, in all 5,564 Brazilian municipalities;
- utilization of DGN format files produced by sectorial institutions (for example, National Institute of Colonization and Land Reform - INCRA, Brazilian Institute of the Environment and of Renewable Natural

Resources - IBAMA, National Foundation of the Indians - FUNAI, etc.), having a data quality compatible with the accuracy of the Municipal Mapping.

The information surveyed (coordinates of punctual and linear elements and those corresponding to the complementary office information) were incorporated into the Digital Municipal Map with differentiated representation associated to information accuracy. The digital map produced has a hybrid format, corresponding to a raster basis on which vectorial information is placed, structured on a Geographic Information Systems – GIS environment, corresponding to the rural enumeration areas delineation and those deriving from the updating stage. Figure 2 shows an example of a rural enumeration area map, whose area is represented in grey, with field update data in magenta and office update data in green.

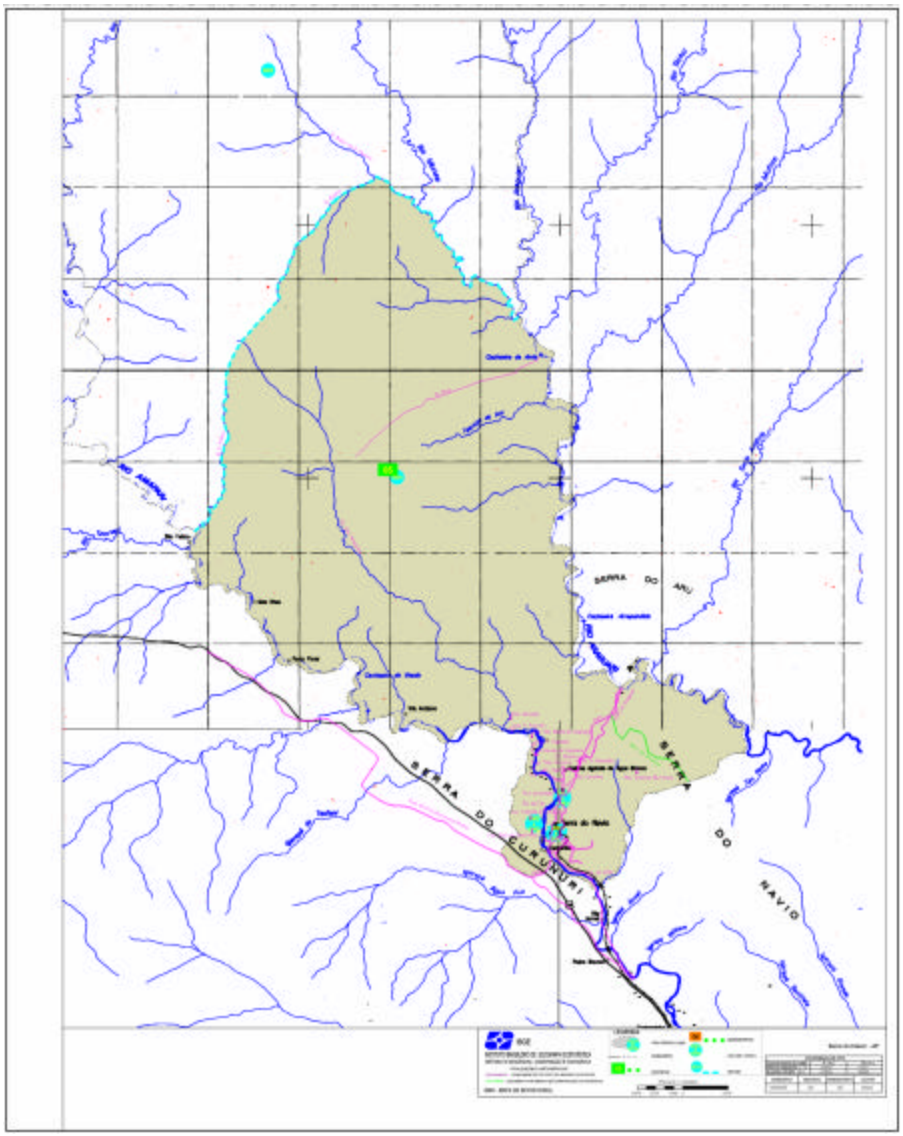

Figure 2: Rural Enumeration Area Map, with field update data in magenta and office update data in green

Urban Census Mapping Production

The urban segment is supported on cadastral mapping, in 1:2,000 to 1:10,000 scales, produced by public institutions (Municipal Governments and others), by water, sewage, power, telecommunications utilities and other producers of maps in cadastral scale. From these maps, which present varied geometry, updating degree and computational platforms, maps of the Brazilian cities, towns, and villages are elaborated. The Statistical Localities Maps – MLE contain the basic urban features, roads (street arrangements), hydrography, buildings and

intra-urban divisions, such as: sub-districts, neighborhoods, subnormal agglomerations, etc., on which the Census enumeration areas are represented.

The MLEs production is conducted from a system called Urban Enumeration Areas Map – MSU (Figure 3), based on the MicroStation platform, enriched with a series of resources that facilitate specific tasks, such as edition, quality control and query. Thus, the preparation of the Urban Census Mapping presupposes the conversion of maps from different computer environments into MicroStation, from different coordinates systems into UTM (Universal Transverse Mercator) Projection System and into SAD 69 (South American Datum of 1969) [Fortes, 1995] and an update process analogous to that of the rural segment, with field and office activities.

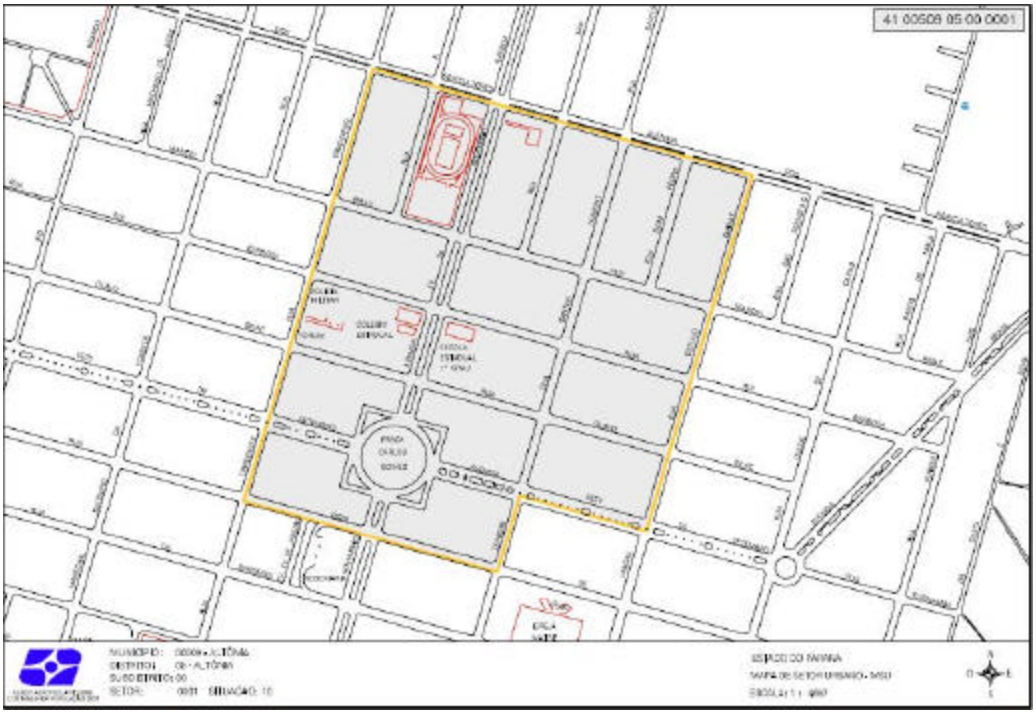

Figure 3: Example of Urban Enumeration Area Map

Urban Census Mapping Update

As from the mid of the XXth Century, the urbanization process was accelerated in Brazil. In the 1940s, two metropolis counted on over a million inhabitants (Rio de Janeiro, with 1,781,567, and São Paulo, with 1,318,539), whereas in 2000, this raised to 13 cities. This process was characterized by a large growth in the number and in the total population of average and large cities, as can be seen in Table 1.

New technologies, such as the use of GPS equipment and orbital images, the establishment of partnerships between municipal governments and local institutions, and the field reconnaissance work, in which the precise survey of updated geographic names is included, conducted by IBGE field teams, are indispensable factors for tracking this phenomenon. This is a process comprehending investigation, selection, registering stages and incorporation of corrections and updates to the graphic (Statistical Localities Maps) and alphanumerical (Enumeration areas descriptions) databases. The mostly used processes are:

- field surveys, specially using GPS;
- office surveys through researching different collections, composed by maps, digital and/or conventional registers, referring to the urbanization densification related, for example, to the emergence of new streets, new buildings, etc.;
- research, analysis and representation of alterations in the intra-urban division and fragmentation of the urban space.

Table 1: Number of Municipalities per size class and Urban Population in the 1970-2000 period

(source: IBGE, Demographic Censuses of 1970, 1980, 1991 and 2000)

Municipalities classes	1970		1980		1991		2000	
	nr.	urb. pop.	nr.	urb. pop.	nr.	urb. pop.	nr.	urb. pop.
0 - 1,999	1,587	1,768,253	1,059	1,299,122	786	1,031,722	1,090	1,341,917
2,000 - 9,999	1,711	7,669,676	1,930	9,193,424	2,299	11,287,971	2,663	13,019,743
10,000 - 19,999	327	4,586,082	475	6,682,199	651	9,151,278	826	11,593,095
20,000 - 49,999	202	6,273,933	297	9,167,740	438	13,806,828	517	15,852,640
50,000 - 99,999	58	4,063,060	125	8,443,777	160	11,356,763	208	14,588,240
100,000 - 499,999	55	10,207,560	88	17,630,670	133	27,113,710	173	36,023,741
500,000 - 999,999	6	4,125,152	7	4,455,126	13	8,816,033	17	11,944,408
1,000,000 -3,999,999	3	3,279,319	8	10,136,410	9	13,533,023	11	17,919,084
over 4,000,000	2	10,124,236	2	13,427,941	2	14,893,662	2	15,671,091
TOTAL	3,951	52,097,271	3,991	80,436,409	4,491	110,990,990	5,507	137,953,959

For the results dissemination stage, the boundaries concerning the Brazilian political-administrative division and the Census enumeration areas delineation are treated in GIS (Arcview/AtlasGis) environment and made available in geographic and UTM coordinates in Shape vectorial format [ESRI, 1998]. Thus, although the Urban Census Mapping has its construction in a CAD environment, the polygons of the legal and institutional territorial structures are converted into GIS platform, making viable analyses associating territory to statistical data.

NEW PRODUCTS OF CENSUS MAPPING FOR THE COLLECTION AND FOR TRACKING OF THE 2007 CENSUSES

The technological innovations introduced in the 2007 Censuses, especially the use of PDA/GPS, justified the generation of new Census Mapping products aiming to maximize the benefits brought about by these innovations. These new types of product were:

- Maps of 70,085 rural enumeration areas and 92,685 urban enumeration areas in PDF format;
- Description of rural and urban enumeration areas in PDF format;
- Maps of rural enumeration areas in JPG format;
- Municipal/enumeration areas digital boundaries in Shape vectorial format, encompassing urban perimeters and the isolated urban areas [2] in all 27 Federation Units, with about 77,000 polygons.

The first three product types were installed on the PDA of each interviewer responsible for the enumeration area of the Agricultural Census and of the Population Counting, to help them to locate themselves during the collection (Figure 4), while the fourth one aims to allow tracking of the collection operation, in practically real time, from the IBGE headquarters in Rio de Janeiro for collection management purposes. The visualization of the coordinates collected with the PDA/GPS, by the about 68,000 Census interviewers spread all over the Country, allows the visual tracking of the collection, as the example in Figure 5. Figure 6 shows the digital municipal boundaries of the Country.

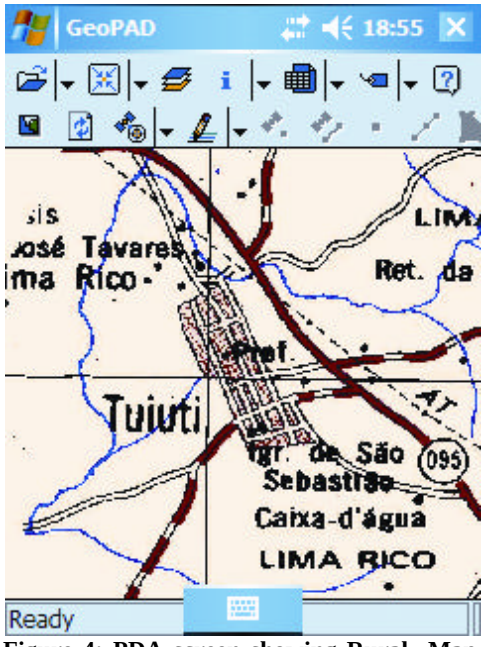

Figure 4: PDA screen showing Rural Map for Census interviewer location (source: IBGE, 2006)

[2] Areas with urban characteristics, distant 1 km or more from effectively urbanized areas of a city or town

Geodesy and the 2007 Censuses: the SIRGAS2000 System

A highly relevant detail in the generation of these products was the one concerning the geodetic reference system adopted in the digital maps. This system constitutes the first layer of geocoded information, over which all the other layers are positioned. Therefore it was fundamental for all coordinates involved in the 2007 Censuses project to be referenced to a single accurate and consistent national geodetic system. For this, SAD 69, a system adopted in Brazil as of 1979, was kept in use for the printed maps, since all the Census maps were already referred to that system. However, since February 25, 2005, Brazil officially adopted a new reference system for coordinates, the Geocentric Reference System for the Americas (SIRGAS2000), continental, geocentric, modern and totally compatible with the GPS system [SIRGAS, 2007]. With this, all the digital files of the Census Mapping downloaded to the PDA were previously converted into SIRGAS2000, so that the coordinates supplied by the GPS could be directly visualized on the Census maps with no need for additional transformation.

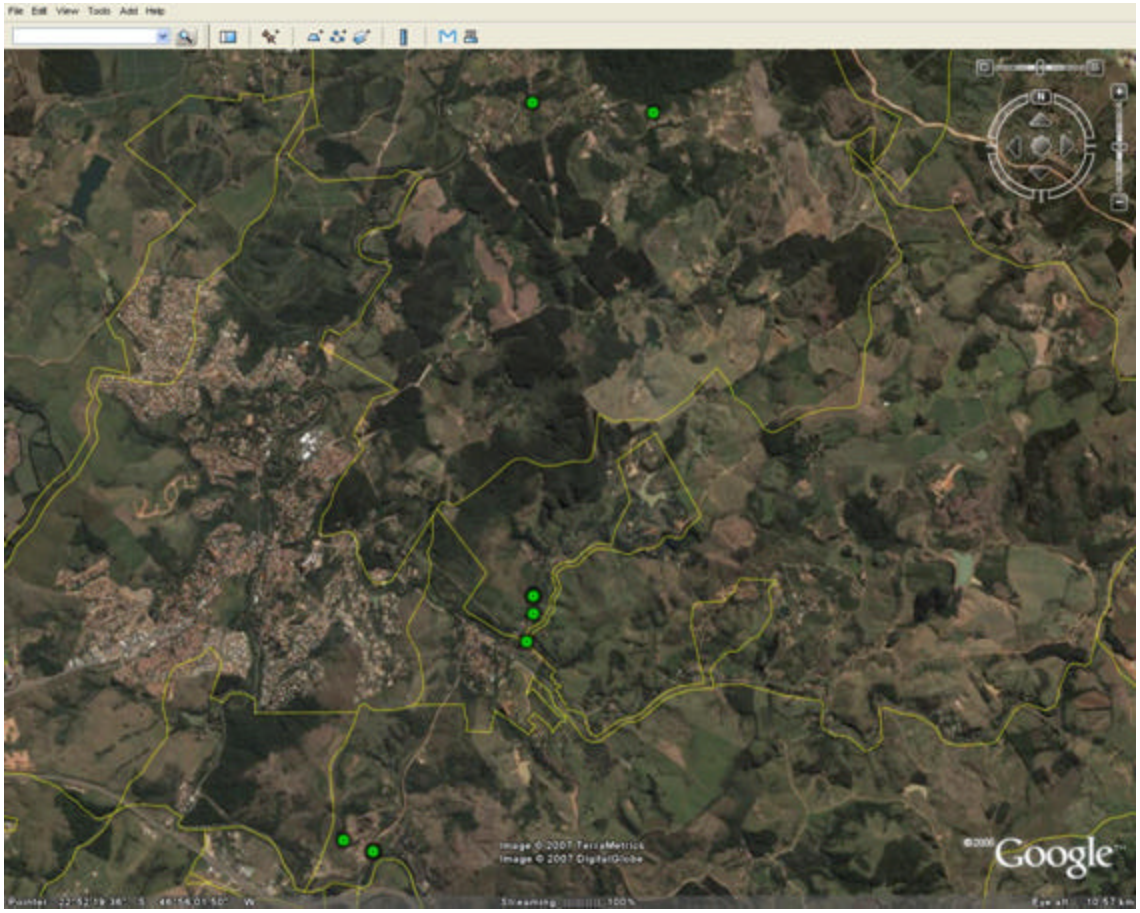

Figure 5: Visual tracking of the collection. In this example, the agricultural establishments visited by the Census interviewer are represented by green circles on a Google image, with the enumeration areas in yellow

MUNICIPAL CENSUS COMMISSIONS

Before starting the statistical data collection stage on the Brazilian population and agriculture in the 2007 Censuses, IBGE established a Municipal Census Commission – CCM in each municipality in the Country, aiming to integrate the efforts of different segments in society to ensure the quality of the Census operation.

Each CCM is composed of at least five members, among which representatives from IBGE, from the executive, legislative and legal powers of the municipality, and from local civil organizations that may somehow cooperate.

The Census map of each Brazilian municipality was built to represent the boundaries and the geographic characteristics of each 2007 Censuses enumeration area. The first CCM activity consisted in assessing the consistency of the information contained in the Census Mapping, when the local participants could provide valuable contributions for improving these maps.

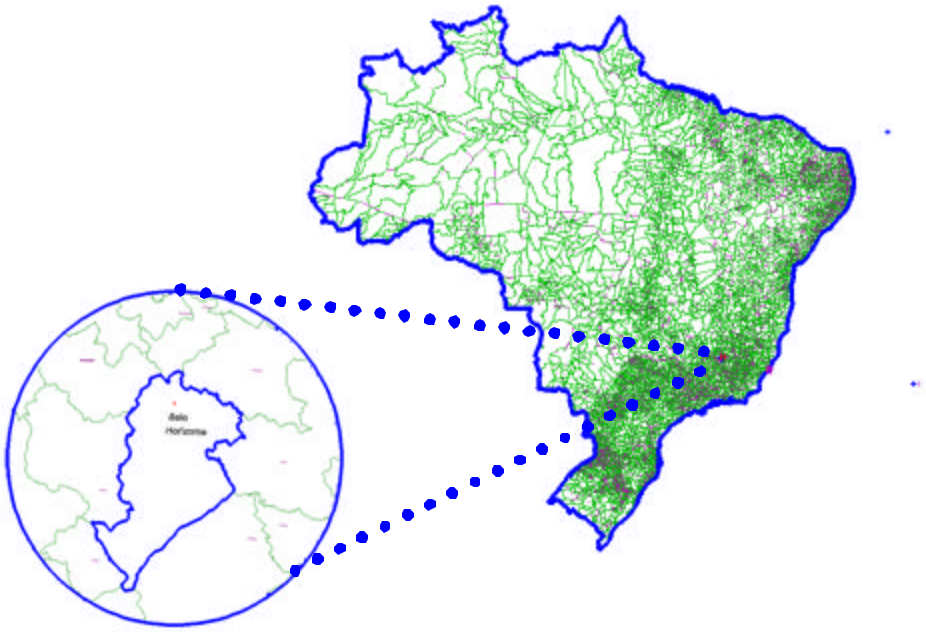

Figure 6: Brazilian digital municipal boundaries, detaching the Belo Horizonte municipality

DIFFICULTIES, LESSONS LEARNED AND ACTIONS FOR THE 2010 CENSUS

For the 2010 Census, the intention is to keep improving the Census Mapping, by the use of updated and comprehensive cartographic information. As an example, it may be mentioned that the data collected in the 2007 Censuses (coordinates of rural properties, of health and education establishments, and of identifiable points in urban enumeration areas) will contribute to improve the Rural and Urban Census Mapping. For this new coming effort, it is fundamental to observe the difficulties faced and the lessons learned aiming to direct actions for the 2010 Census.

For the first time, the Municipal Census Commissions formed by representatives of each municipality, were installed early enough for Census Mapping assessment purposes. This measure showed to be extremely important to increase the quality of the Census maps and databases used in the 2007 Census. This is an experience that will certainly be repeated for the 2010 Census.

Among the existing difficulties, the platform for producing the municipal maps needs to be mentioned. In spite of having facilitated the production, the SisCart currently faces updating problems, since it was developed on an old version of MicroStation (v.95), for which there is no longer maintenance. Furthermore, it does not allow processing of new cartographic inputs, such as orthophotocharts, satellite images, among others, fundamental in the refining process of the cartographic maps composing the Census Mapping. IBGE is now reassessing the system, considering new options, looking forward to the preparation of the Census Mapping for the 2010 Census.

At present, mapping in cadastral scale does not fulfill cartographic standards and specifications, which causes difficulties for integrating the Rural and the Urban Census Mapping, because of indefinitions in the cadastral maps related to the adopted geodetic reference system and cartographic projection, combined with problems in the maps geometry. Due to this problem, in the pre-collection operation of the 2007 Censuses, the coordinates of four identifiable points in each urban Census map is being collected by GPS, in order to support the evaluation and correction of the corresponding cadastral map by translation, rotation and scale adjustments. Moreover, the National Cartographic Commission [CONCAR, 2007b], collegiate unit of the Ministry of Planning, Budget and Management which assists the Minister in terms of the National Cartographic System supervision and

coordinates the conduction of the National Cartographic Policy, established a Specialized Committee to elaborate standards and specifications for the cadastral mapping, which must be followed by the various producers in the Country, so that the urban maps that come to feed the Census Mapping for the 2010 Census satisfy quality and standardization requirements.

Still within CONCAR, a vectorial geospatial data infra-structure standard for the Digital National Map Database [CONCAR, 2007c] was elaborated, which shall be adopted for storing the vectorial data of the 2010 Census Mapping.

The systematic topographic mapping of the Country, on which the production of the municipal and rural enumeration areas mapping is based, shows to be mostly outdated by more than 20 years. Despite the efforts made in the field and office updating activities within the preparation of the Census Mapping, the search for viable alternatives for dynamizing the Brazilian cartography is deemed necessary. In this sense, new remote sensing inputs show to be promising for this purpose, among which optical and radar images generated by the ALOS (Advanced Land Observing Satellite) Japanese satellite [Gelli et al., 2006] can be mentioned as well as the orthophotocharts generated by IBGE from recent aerophotogrametric flights. In the first case, Resolution VIII of the 8th United Nations Regional Cartographic Conference for the Americas recommended the adoption of satellite data dissemination policies at reduced cost, as the ones practiced by the ALOS mission [UNSD, 2005]. With this regard, IBGE established a partnership with the University of Alaska, ALOS data distribution node for the Americas, in October, 2006, in order to be responsible for the distribution to non-commercial users in Brazil and in the rest of South America. This condition will allow IBGE low-cost access to the satellite images, whose resolution may vary from 100 to only 2.5 meters. These images shall be used for a broad update of the national cartography, which will significantly contribute to improving the Census Mapping quality for the 2010 Census.

Among the many challenges to be overcome towards the effective establishment of an Address File to support the 2010 Census operation, the following should be mentioned:

- the need of updating urban addresses associated to the 129 municipalities where the Population Counting collection has not been carried out in 2007;
- the establishment of procedures that allow permanent compatibility of addresses with the ever changing territorial division of the Country;
- the need of binding the Address File to the cartographic maps. In the case of the rural segment, the 2007 Censuses are obtaining coordinates of residences and Agricultural establishments, which makes viable the representation of these elements in the Census maps. In the case of the urban segment, there is the possibility of associating the urban address geocode (formed by joining the following codes: Federation Unit (State), municipality, district, sub-district, enumeration area, block and face) to the coordinates of each block face to be obtained in the office;
- the intensive use of orbital images as indicators of updating level, especially in rural areas.

It is worth pointing out the studies already started at the Institute covering alternative Census modalities, also known as continuous Censuses. Even though permanent updating of the Census Mapping is sought in the present model, procedures assessment for elaborating the Census Mapping is included in these studies, in order to satisfy the specific requirements of these new Census modalities. These studies presuppose the perspective of adopting the new modalities after the conduction of the 2010 Census.

CONCLUSIONS

The Census Mapping elaborated for the 2007 Censuses, in their rural and urban components, is the result of a great effort for updating and improving the maps elaborated by IBGE to conduct the 2000 Census, with the generation of new digital products aimed at maximizing the benefits brought about by the technological innovations introduced in the collection, especially the use of PDA/GPS. The experience acquired will be used in the project for preparing the Census Mapping for the 2010 Census, as well as in the specification of the corresponding stage of the continuous Censuses modality, taking into account the technological developments besides the new remote sensing inputs available.

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