BRAZILIAN EXPERIENCE IN USE OF GEORREFERENCING AND REMOTE SENSING IN CENSUS

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1- INTRODUCTION

This paper presents the brazilian experience in use of Georreferencing and Remote Sensing in the recent 2007 Census, a cooperative operation with the goal to update population estimates and information about economic activities of agriculture performed in the country by individual producers and agricultural companies. The combination of the surveys was made easier by the use of hand-held computers, Personal Digital Assistants or PDA's – equipped with GPS in field operations and by the use of CNEFE - the National Address List for Statistical Purposes, the basis for the field operation which was aimed at updating the address registers of each residential and non-residential unit in the country, including those in rural areas collecting geographic coordinates. The list represents an effective element in the conduction of IBGE continuous surveys, and society benefits from a more accurate register which allows the combination of statistical data from several different sources.

2- STATISTICS AS A SDI LAYER

IBGE – *Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics) has a special characteristic as it includes in the same institution the missions of a National Statistical Office and of a National Geographical Office. It is a Federal Government institution in Brazil responsible for producing, analyzing and disseminating statistical information (demographic, economic and social), as well as geodetic, cartographic, geographic, natural resources and environmental information. This configuration gives to the institution an extraordinary comparative advantage in the production of environmental information, considering the possibility of intensively using geospatial tools in the production, analysis and dissemination of environmental statistics.

Georreferenced Statistical data may be seen as geospatial data up to the consideration of the producer. GIS adds value to the various stages of the statistical processes by optimizing data collection, enhancing the accuracy and timeliness of statistical data, enabling spatial analysis and modeling, as well as facilitating data dissemination.

The three main operational phases of any National Statistics Office (NSO) can be supported by GIS: integrating field data collection; processing of statistical data, disseminating data and supporting statistical surveys using maps that can be made available through the web for wide public access (Figure 1).

The function of data integration offered by GIS, allowing the combination of information from different sources and application areas, has led to a wider use of statistical information. This has increased the pressure over statistical offices to produce high quality spatially-referenced information for small geographic units. The types of application for these data are almost unlimited.

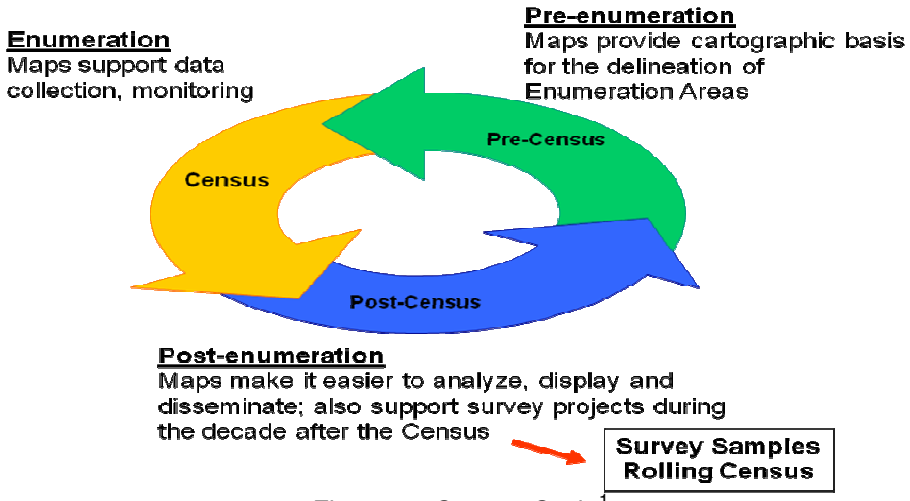

Figure 1 - Census Cycle[1]

2 – 2007 CENSUSES: AN INTEGRATED CENSUS OPERATION

The objective of this cooperative operation was to update population estimates and information about economic activities of agriculture performed in the country by individual producers and agricultural companies. The combination of surveys was made easier by the use of hand-held computers, Personal Digital Assistants or PDA's – equipped with GPS in field operations and by the use of CNEFE.

Figure 2 below shows an image of the model used by IBGE.

Figure 2: PDA used in Censuses 2007

[1] United Nations Statistics Division, 2007. *Digital Census Mapping Process: conceptual framework and different approaches,* United Nations Expert Group Meeting on Contemporary Practices in Census Mapping and Use of Geographical Information Systems 29 May - 1 June 2007 United Nations, New York

Censuses are data collecting operations of the most importance for the creation of public policies and for the decision-making process concerning private and governmental investments. In terms of the Census of Agriculture, statistics help make a comprehensive portrait of agricultural activity at the same time it reveals important aspects of Brazilian rural life. The Population Count provides updated population figures of the municipalities covered and more accurate estimated for the other municipalities. The Count highlights the demographic changes which have occurred in the country since the last Demographic Census, which was conducted in 2000.

The National Address List for Statistical Purposes – CNEFE was one of the innovations brought by the 2007 Censuses. A previous list elaborated using registers of units surveyed in 2000 was the basis for the field operation which was aimed at updating the address registers of each residential and non-residential unit in the country, including those in rural areas. From these areas were collected geographic coordinates of agricultural establishments and also of health, teaching, religious establishments and of households.

In the realm of the 2007 Censuses, the address list helps increase the speed of data collection, guides the census taker in the field work, besides offering new tools for collection and control. Indeed, the list represents an effective element in the conduction of IBGE continuous surveys, and society benefits from a more accurate register which allows the combination of statistical data from several different sources, such as health and education, for example, and of information grouped into different enumeration areas and produced by IBGE.

2.1 - COVERAGE OF THE 2007 CENSUSES

The decision of conducting the Census of Agriculture and the Population Count as an integrated operation was the only way possible to have both surveys, considering the limited financial resources directed to these activities. Having them done separately would have been about 40% more expensive, possibly resulting in expenditure beyond the amount budgeted by the government at the occasion.

In order to better understand the coverage of the Population Count, it is necessary to take into consideration that Brazil has 5,564 municipalities[2] and that the population limit of 170 thousand inhabitants was based on municipal estimates for 2005. These 5,435 municipalities represented, in 2005, approximately 110 million persons, that is, about 60% of the estimated population in the country and about 28 million households, reaching 57% of the total number of households in Brazil.

The Census of Agriculture was planned with the objective of investigating about 5.7 million agricultural establishments in all the Brazilian municipalities.

The Brazilian agricultural scenario has gone through several changes in the last ten years. The agricultural sector has become more modern, has increased its activities and contributed to the generation of significant results in the trade balance. These changes have raised several important issues; however, it is important to point out that the transformations which have occurred in the country's agricultural activity can only be

[2] In fact, there are 5,562 municipalities. The two other ones refer to the district of Fernando de Noronha, which belongs to the state of Pernambuco, and to Brasília, the Federal District. Both are considered units for the planning of survey activities at municipal level.

understood if based on a complete and updated portrait of this new reality, which the census activity can provide.

2.2 - NATIONAL ADDRESS LIST FOR STATISTICAL PURPOSES – CNEFE

The 2007 Censuses, similarly to previous ones, represent an opportunity for the renewal of IBGE projects. One of the main innovations introduced by the census operation is the National Address List for Statistical Purposes – CNEFE, which had been previously created based on registers of units surveyed in the 2000 Census and was updated due to the field work in the 2007 Censuses.

One of the objectives of the address list is to improve the survey, the treatment and the dissemination of statistical information. In a national statistics bureau such as IBGE, addresses are frequently used in the regular conduction of surveys. Either in the data collection period, during which the interviews are done, or monitoring period of this task, or even during the sending and control of receipt of postal questionnaires, the address has an essential role, although not very evident several times.

This way, the creation of CNEFE is extremely important not only to the institution but also to society. For IBGE, this initiative helps increase the efficiency of the planning and supervision stage of data collection in the 2007 Censuses. In a near future, this will allow IBGE to conduct postal household surveys. Society as a whole will benefit from a more precise register for geocoding, that is, the identification of the enumeration area in which an address provided by the user is located; this combination – address $\rightarrow$ enumeration area will allow the connection of information from several sources, such as health and education, for example, to information produced by IBGE at enumeration areas level[3].

2.3 - TERRITORIAL BASE PREPARATION

The data collection operation of Censuses 2007 encompassed 162,770 enumeration areas, from a total of 249,068 which form the Territorial Base. This base is formed by a group of data and registers which guide the division of the territory and its preparation takes into consideration, besides the operation of census data collection, the necessity to fulfill the demand of municipal governments and of the private sector for further information which may influence the decision-making process of public and private investments

IBGE started the elaboration of Territorial Base maps in digital media during the preparatory step for the 2000 Census, as a continuation of this work for the 2007 Censuses. According to the structure of the National Cartographic System, IBGE is in charge of the production of systematic land mapping of the country in the scales 1:25:000 or lower, a task which is divided with the Army Directorate of Geographic Service [CONCAR, 2007a]. This means that IBGE is the producer of topographic mapping used as basic input for the generation of rural maps which form the Territorial Base. However, as for urban mapping in cadastral scales – 1:2,000 to 1:10,0000, the production of these inputs is not done by the institute, but by public state and municipal institutions and by private companies.

[3] An enumeration area is a cadastral control unit formed by a continuous area; it is located in a single urban or region, with the size and number of households or of agricultural establishments, whose perimeter encompasses the territory limits legally defined and established by IBGE for statistical purposes.

The production processes of the Territorial Base of rural and urban areas differ a lot due to the characteristics of the inputs used.

For rural areas, the process is supported by the systematic topographic mapping available in IBGE and in the Army Directorate of Geographic Service. The municipal maps elaborated represent natural, physical and artificial elements of municipalities, such as rivers, roads, localities and municipal limits, combined with toponyms, localities, rural properties, specific areas, and others. These maps are the bases for the creation of municipal statistical maps, with the addition of the boundaries of enumeration areas, which is associated to files with their descriptions.

The activity of cartographic update in the planning of the Territorial Base analyzed the need of improvement of information about the 5,564 Brazilian municipalities, with the selection of those which lacked a small or big amount of information since the end of the 2000 Census. The complementary approach uniting office and field information generated updated municipal maps. This analysis indicated the municipalities whose territory had faced changes, in political, administrative or physical respects or even for the improvement of the quality of the cartographic base. The quantity and quality of information presented led to the division of municipalities into two major groups:

- municipalities of which data would be updated in the field (which needed more precise information about positioning of elements, about the beginning of new population groups and about the existence of major constructions with change of the locality headquarters); and
- municipalities of which data would be updated only with office information, considering the slight changes to be effected in the municipal map.

Based on documents generated by many IBGE surveys, and on others coming from state sector institutions, important information was incorporated to municipal maps in the office. Field update was done in order to obtain confirmation and better accuracy of physical data of the land, with the use of GPS technology. The inputs used were properly registered to form and maintain databases and metadata bases which constitute the Digital Municipal Maps.

The information obtained (coordinates of point and line elements and those corresponding to complementary office information) were included in the Digital Municipal Map with representation associated to the precision of information. The digital which results from this work has a hybrid shape, corresponding to a raster base over which are placed vector information, structured in a Geographic Information System – SIG environment related to the rural enumeration area and the updating elements. Figure 3 shows an example of a rural enumeration area in gray, with field updates in magenta color and office updates in green.

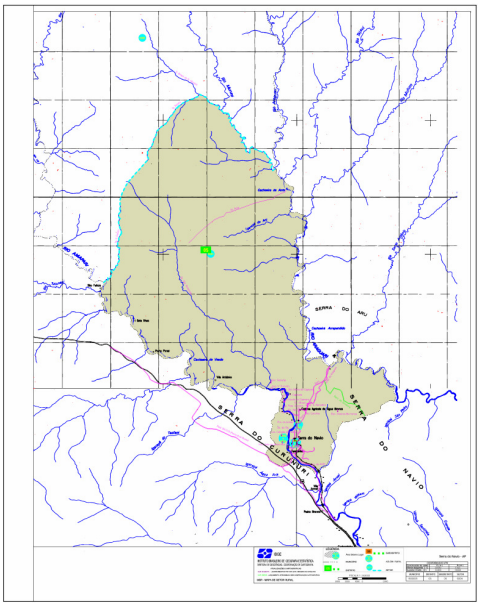

Figure 3: Example of Map from a Rural Enumeration area
Note: field updates are in color magenta red and office ones are in green.

Urban localities are based on cadastral mapping, in scales from 1: 2,000 to 1:10,000, produced by public organizations (Municipal Governments and others), concessionaries of water, sewer, electricity and telecommunications services, and other producers of mapping in cadastral scale. These maps, which present varied geometry, updating level and computer platforms, contribute to the elaboration of maps of Brazilian cities, towns, villages and communities. Locality Statistical Maps– MLE present basic urban features, streets, hydrography, buildings and intra-urban divisions, such as: sub-districts, boroughs, low income settlements, etc, about which enumeration areas are represented.

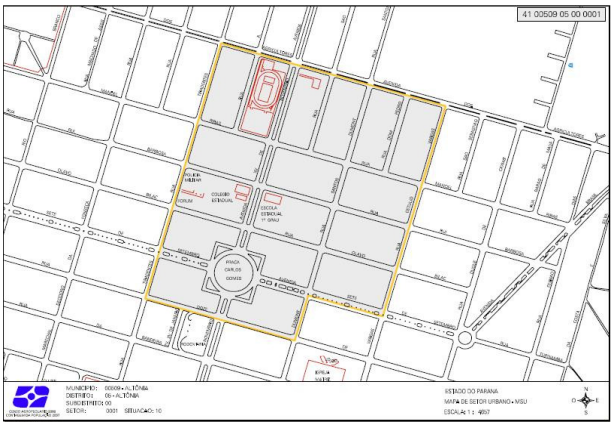

Figure 4: Example of a Map from an Urban Enumeration area

New technologies, such as the use of GPS equipment and of orbital images, the establishment of partnerships with municipal governments and local institutions, and the

work of field recognition which involves the research of updated geographic names and is conducted by IBGE collecting unit, are essential factors for the monitoring of this process. It is the update of the Urban Territorial Base which encompasses steps of investigation, selection, register and incorporation of the graphic and alphanumerical assortment of correction and updates: (Locality Statistical Map) and (Enumeration area Registers), respectively. The most often applied processes are:

- field surveys, especially with the use of GPS:
- office surveys of several groups, formed by maps, digital and/or conventional cadastres, relative to the increase of urbanization density related, for example, to the presence of new locality addresses, new constructions, etc.
- survey, analysis and representation of changes in intra-urban division and fragmentation of the urban space.

The technological innovations introduced in the 2007 Censuses, especially the use of handheld computers equipped with GPS, justified, according to IBGE, the generation of new Territory Base products:

1. maps of 70,095 rural enumeration areas and 92,685 urban enumeration areas in PDF format;
2. a description of rural and urban enumeration areas in PDF format;
3. rural enumeration area maps in JPG format;
4. 70,085 images taken from Google Earth and georeferenced;
5. municipal /enumeration area in vector shape, encompassing the urban perimeters and isolated urban areas[4] of all the 27 Federative Units, with approximately 77,000 polygons.

The first two products initially planned for PDA were shown printed in paper, considering that the two following products (items 3 and 4) used the potentialities of the PDA to help guide census takers during data collection in the enumeration area under their responsibility (Figure 5).

[4] Areas with urban characteristics, at least 1 km away from effectively urban areas in cities or villages

Figure 5: Satellite image on PDA screen

On the other hand, the fifth product, the municipal and the ennumerations areas boundaries, allows the management of the collecting operation, almost at real time, from the headquarters of IBGE, in Rio de Janeiro. Figure 6 shows the visualization of coordinates collected with PDA/GPS by the census takers working all over the country, allowing the collection visual monitoring.

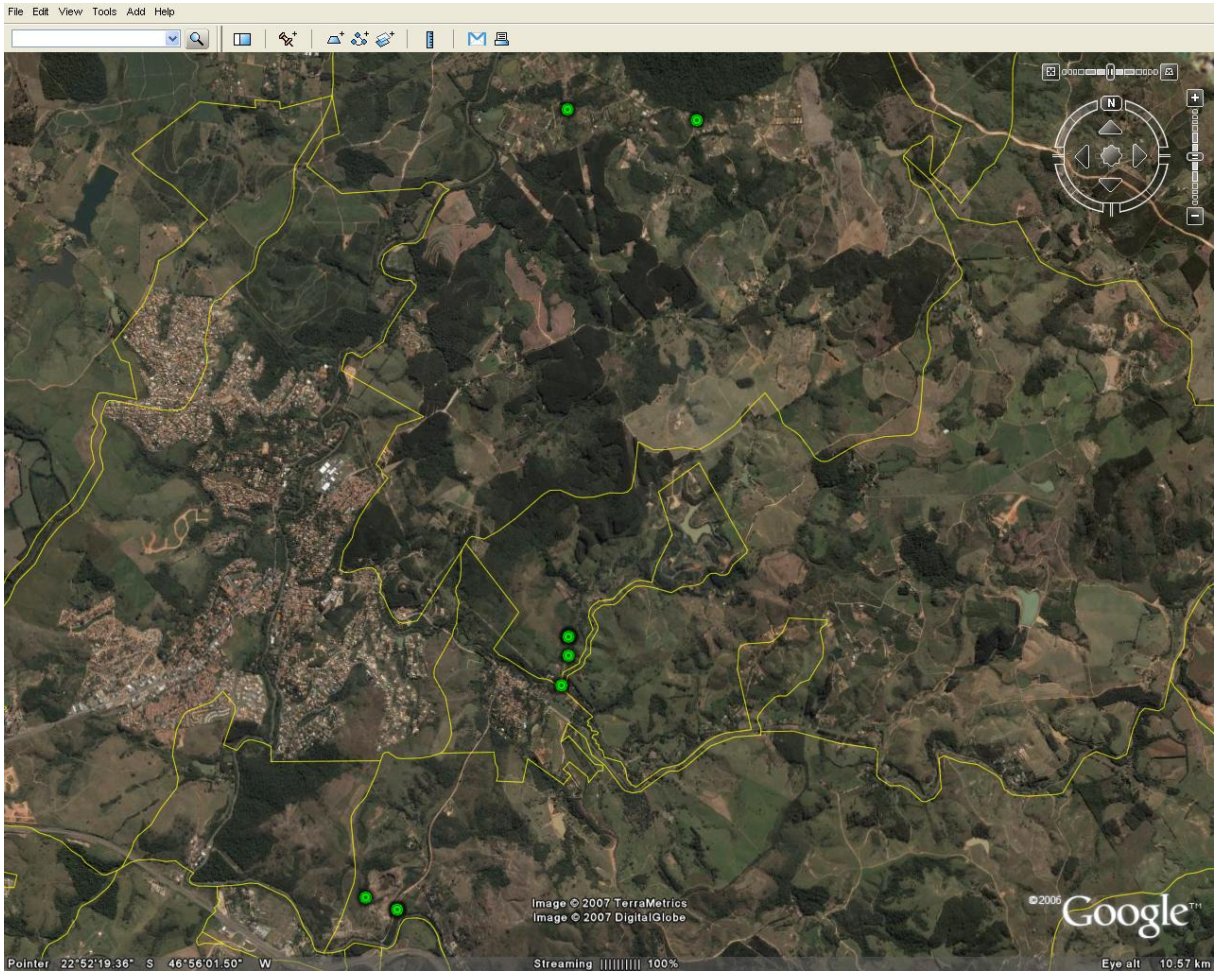

Figure 6- Example of collection visual monitoring

Note: In this example, agricultural establishments visited by the census taker are represented by green circles over a Google image, with the enumeration area shown in yellow.

A detail of the almost importance in the generation of the products mentioned is related to the geodetic system of reference adopted in digital mapping. This system constitutes the first layer of georeferenced information in relation to which all the others are positioned. This way, it was essential that all the coordinates involved in the 2007 Censuses project be referenced in relation to a single national, precise and consistent geodetic system. In this respect, for printed maps, the work was continued using SAD 69, a system adopted in Brazil in 1979, once all the Territory Base maps were already based on this system. However, since February 25, 2005, Brazil has had a new official system of coordinates, the Geocentric Reference System for the Americas (SIRGAS2000), a continental, geocentric and modern system which is totally compatible with GPS [SIRGAS, 2007]. This way all the digital files in the Territorial Base charged in the PDA were converted to SIRGAS2000, so that the coordinates provided by GPS could be visualized directly over the maps of the enumeration area without any additional changes. Figure 7 represents the digital municipal boundaries of the country

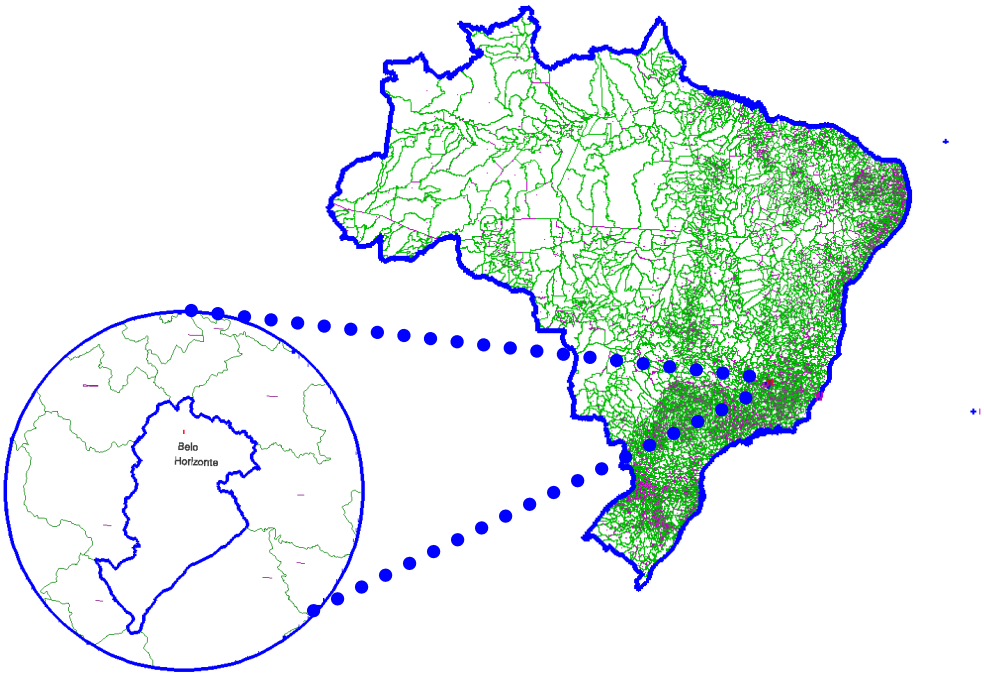

Figure 7: Brazilian Municipal Boundaries, with a highlight in the municipality of Belo Horizonte

2.4 – GPS GEOREFERENCING IN DATA COLLECTION

The use of GPS equipment and PDA's represented, undoubtedly, one of the most important innovations in the 2007 Censuses. By allowing the access to quality coordinates adequate to a wide range of uses, the introduction of GPS created the necessary conditions for the development of a big number of innovative applications. As a result of impressive technological development, this equipment can, in a short period of time and at low cost, provide an operator who has little technical knowledge with precise coordinates, in a type of operation which used to involve complex calculations and procedures.

Four major processes have been developed for the use of GPS, as shown below:

- access to coordinates of spots in the urban enumeration area perimeter during the pre-collection operation;
- access to coordinates of the units visited during data collection in rural enumeration areas;
- use of coordinates obtained during data collection in distance-supervision procedures
- use in the field of the coordinates obtained for positioning and guidance of the census taker

The collection of coordinates was a priority of the rural area in each existing unit, limited to the urban area, instead of the obtaining of coordinates of spots in the perimeter of the enumeration areas. The choice was not to collect household coordinates in urban areas, due to constraints in the use of GPS technology, especially in terms of what concerns interruption of the signs sent by satellites.

During collection itself, coordinate from all the households and establishments in rural areas were obtained. Considering construction differences of a list of addresses in rural areas, similar to that of urban areas, these coordinates functioned as an alternative address, making it easier to return to the unit georeferenced and registered. It also made it possible to visualize the progress of collection, in the map of each enumeration area.

Although coordinates are easily obtained, some specific situations may turn this process difficult or even impossible. Units located in deep valleys, or in areas with dense vegetation may turn the identification of coordinates impossible. In order to inform the census taker about the possible loss of quality of the coordinate obtained, the system displayed a quality indicator which prompted the census taker into looking for a better position. In case the difficulty remained, the census taker should register this problem through an option available in the system. Considering agricultural establishments, the coordinate was supposed to be collected, preferably, in the place itself, or at the entrance of it.

The use of GPS also made it possible to monitor the evolution of collection by means of the visualization of coordinates obtained, superposed on orbital images, especially in more remote rural areas. The comparison of the coordinates obtained with signs of residential or agricultural occupation detected in the image (Figure 8) represented a real effective and low-cost supervision mechanism in rural areas. Comparison also made it possible to observe, in the office and after collection, inaccuracies due to enumeration area invasion and their correct spatial distribution.

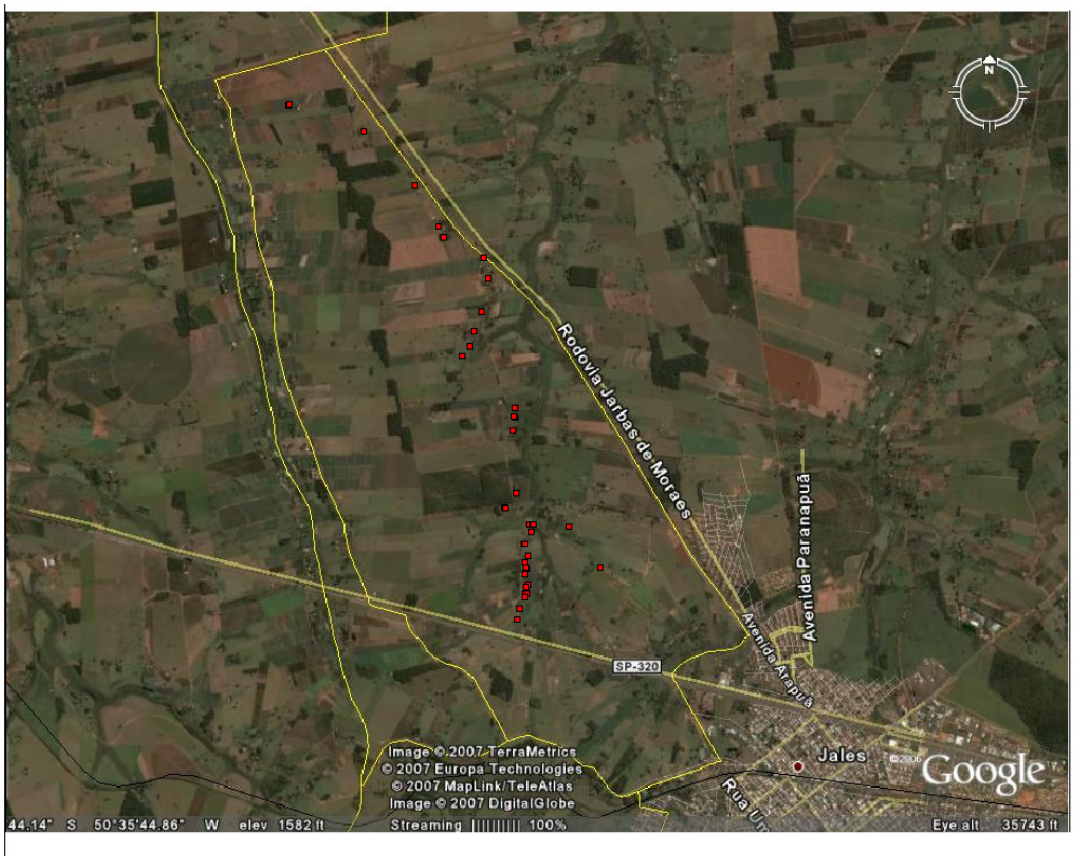

Figure 8 – Example of material available for supervision

Note: The red spots represent geographic coordinates obtained from units (households, agricultural establishments, teaching establishments, etc), found during the movement along the enumeration area, whose area is represented in yellow. The areas located in the east part of the enumeration area, with intense agricultural activity, had no coordinates obtained, a fact which can indicate the census taker's omission of registers of establishments installed there and which should have been visited, registered in the PDA and of which information should have been collected in the 2007 census questionnaires. This simple visualization can indicate the need of supervision in the referred enumeration area for correction of the information collected and inclusion of items omitted.

The availability of a GPS receiver in the PDA helped IBGE develop a software to better guide the movement of the census taker in some rural areas, especially in the north and central west areas.

In order to give support to the 2007 Census operations, IBGE used the geoprocessing software Geopad and customized it to fulfill the demands of field work. The software was then called IBGE Mobile Gis, and it allowed the census taker to identify their position in the rural area, their working enumeration area and the distance covered in the field.

Being installed in the PDA's, the software included spatial information, such as maps in shapefile format and orbital images in JPG format, georeferenced in a simple and dynamic way. It worked through basic commands such as move, zoom in and zoom out, in the location of the enumeration area, in the identification of its boundaries the access ways and significant elements in the territory.

3 – ACTIONS FOR THE BRAZILIAN STATISTICAL AND GEOGRAPHIC SYSTEMS STARTED TO CENSUS 2010

IBGE, as the Brazilian statistics and mapping agency, has already been preparing the 2010 Demographic Census operation. The census maps, which will be used to plan and direct its operations, are being prepared with intensive use of satellite images, what is composing a catalog of satellite imagery with resolution between 2.5 and 100 m of Brazil, as IBGE is the exclusive distributor of ALOS satellite images for non-commercial users in the country.

In order to prepare the fundamental layers for National Spatial Data Infrastructure - NSDI, IBGE is updating and converting to NCD/MND the integrated digital 1:1,000,000 and 1:250,000 scales geospatial data for the entire country. Further update and convertion to NCD/MND of the larger scale maps (1:100,000, 1:50,000, 1:25,000) will be considered, when appropriate.

3.1 – INTEGRATION OF CARTOGRAPHIC INFORMATION WITH THE ADDRESS LIST

With the implementation of the National Address List for Statistical Purposes - CNEFE, in coming operations, census takers will receive the data about the enumeration area in which they are working in two different ways: through the traditional map, with the identification of its limits and its internal organization and through a previous list of all the addresses included in it. Locations represented in the map will be found in the list and those included in the list will be identified in the map.

. One of the keys to attaining this level of integration will be the use of a common technological platform: the Geographic Information System – GIS. While allowing the storage and the combined processing of graphic and alphanumeric information, the structure of GIS will lead to the expected integration.

For 2010 a further step is being taken, based on linking address records to block faces of the digital census maps – figure 9. This will improve data collection, allowing the 2010 census interviewers to tap on each block face on the PDA screen to have access to addresses and corresponding questionnaires of that specific block face. In addition, this will increase data dissemination possibilities based on the association of census data to different portions of the territory.

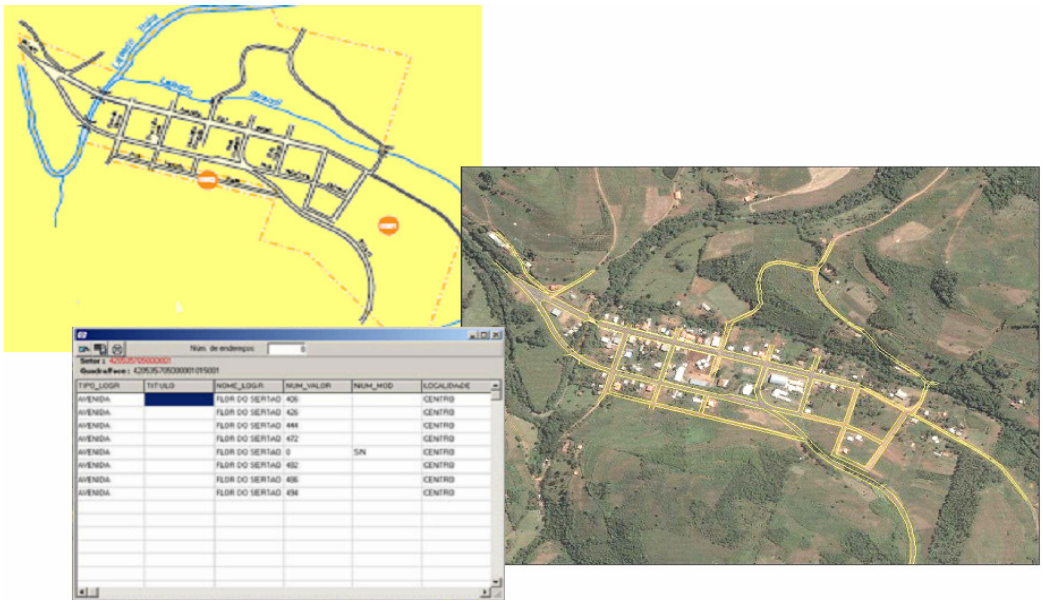

Figure 9 - Linking of block faces to the National Addresses File using Geobase, software developed by IBGE

3.2 - INTEGRATION OF THE URBAN AND RURAL TERRITORIAL BASES

Currently, cadastral mapping does not follow cartographic norms and specifications, creating obstacles to the integration of the Urban and Rural Territorial Bases. This occurs due to lack of definition of the register maps regarding the geodetic reference system and the adopted cartographic projection, and also due to problems with the geometry of bases. Due to this fact, with the intensive use of different satellite images, ortophotos we are building a georreferenced address file and produce georreferenced statistical data for the maps to Census 2010, as showed in Figure 10.

Figure 10 - Integrated 2010 urban and rural census maps

3.3 – ADDRESS LIST IN HOUSEHOLD SURVEYS SYSTEMS

The continuous updating of the address lists of the selected enumeration areas in the samples of inter-censuses household surveys is a fundamental activity for their success. Therefore, a significant number of technicians and financial resources are directed all the years to listing activities.

However, since there was not an integrated project, such as the CNEFE, each household survey conducted its own updating operation with isolated procedures and its own methodology. With the implementation of the CNEFE, it will be possible to concentrate, in only one area, the diverse activities of address updating in order to generate gains in productivity and scale.

This form of work will guarantee, in first place, the total coverage of the enumeration areas of interest of the surveys besides functioning in areas which can become outdated more easily. This way, each survey will receive from the CNEFE the addresses of interest, conduct its collection and report back to the list eventual changes identified in field work. The activities of address updating will therefore be planned, budgeted and performed in a unified way and will be developed according to a timetable compatible with the household surveys.

The continuous updating of the CNEFE is one of the elements that will facilitate the implementation of a new modality of execution of demographic censuses, as is being studied in IBGE, in the project named Alternative Modalities Studies for Demographic Censuses, which considers the collection distributed by the territory in a defined period of time, instead of the traditional operation. It will also be useful for a new Integrated System of Household Sample Surveys, currently being planned in IBGE.

3.4 – REGISTER OF AGRICULTURAL ESTABLISHMENTS AND PRODUCERS FOR AN AGRICULTURAL SAMPLE SURVEY SYSTEM

The 2006 Census of Agriculture gives society a wide set of information for the constitution of systems of reference and of statistical infra-structure which will be necessary for the implementation of sample surveys of agricultural establishments. It will also provide the construction of complete and updated registers, by list and by area.

After the collecting stage, the combination of information of the CNEFE and the 2006 Census of Agriculture allows the construction and implementation of the Register of Agriculture Producers and Establishments, fundamental for the structuring of sample surveys which have as the survey unit the agricultural establishment.

The Register of Agriculture Producers and Establishments derived from the 2006 Census of Agriculture will be the first computerized list register unifying the agriculture producers of the country. With this register, it will be possible to identify and distinguish all the agriculture producers and establishments, as showed in figure 11, facilitating the contact with the persons in charge of the producing units considering the statistical investigation. Besides this, these registers will provide sufficient data for the definition of samples which will be able to be used in future surveys about the enumeration area.

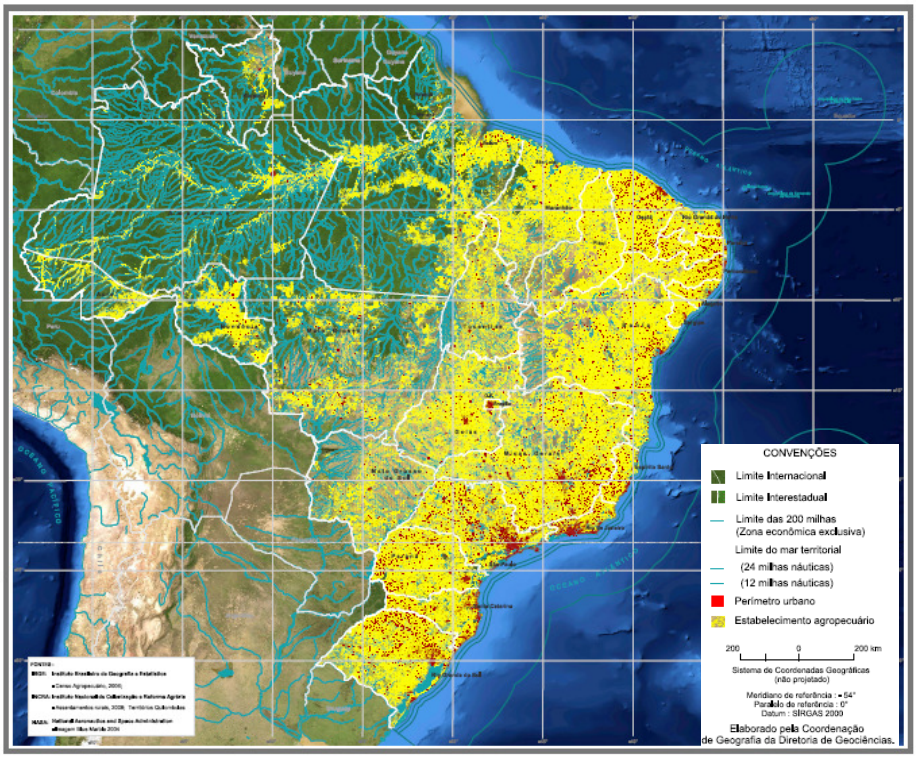

Figure 11 – More than 5 millions of agriculture producers and establishments georreferenced in the country, as the yellow points in the image.

From collected register information stands out the coordinate of location of the agricultural establishments, which is an additional element for the orientation of access to field work. It may be used in the selection of sample units in eventual survey schemes covering area segments smaller than the enumeration area.

The enormous utility and importance of the register for statistical use are already known. However, a permanently updated register is a basic condition for the good quality of statistical information. Without correct maintenance and updating, a register will not show the reality, nor will it fulfill the necessities it was created for. Hence, the register updating is a task as important as the implementation; it requires the organization of register maintenance services and the determination of new tasks in the scope of the national statistics system.

The ideal register updating is the one obtained in a sweeping operation, that is, it occurs when all the agricultural establishments are visited, which is only possible when a census is conducted. As a consequence, the register updating shall use other methods to guarantee a complete and updated register. This way, the use of external sources, such as institutions and entities which produce register information about agricultural establishments and producers, will become a fundamental and feasible alternative. In this sense, the task of register updating will involve different institutions working in the coordination and sharing of updating efforts.

The set of registered enumeration areas forms a register of enumeration areas which, through an exhaustive and mutually excluding way, covers all the universe of identifiable events in the territory. Therefore, it is admitted that the group of enumeration areas with agricultural activity, together with aggregated information about the agricultural structure obtained in the Census, constitutes an adequate register available for the selection of area samples to be used in the research of agriculture in the inter-census period.

In this sense, through the 2007 Censuses, a Register of Enumeration areas with Agricultural Information was also obtained and structured with the incorporation of adjustments of the descriptions and delimitations of the enumeration areas of the 2007 Censuses.

The statistical infrastructure represented by these registers opens several possibilities for the Brazilian agricultural and statistical surveys. Currently, continuous statistics about agricultural surveys are based on indirect investigation of subjective nature carried out by specialists and, in a general way, do not involve the collection of individual data. The conditions established through the results of the census operation allow the implementation of a national system of agricultural surveys, based on probabilistic samples of establishments, and may include surveys by list samples as well as surveys by area samples.

The configuration of this system will serve a program of regular surveys and also provide support for the execution of special surveys. The development of a system of continuous agricultural surveys by probabilistic sample for the country, which can guarantee more exactness, reliability and control of statistical precision is imperative, having been expected for many decades. It is also important that the statistical infrastructure associated to the system be able to face challenges - new demands, eventualities and changes - when the options of public policies depend on fast and precise answers to result in government actions.

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