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THE CENTER PIVOT IRRIGATION IN MINAS GERAIS STATE, BRAZIL, UNDER THE OPTICS OF GOOGLE EARTH

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1 ABSTRACT

The Southeast region has the highest water demand and the largest irrigated area in Brazil, with an emphasis on the central pivots in the state of Minas Gerais. However, the reliability of this information is poor, which limits its use to such management. As an alternative to obtain more consistent data, especially regarding central pivots, there is the use of remote sensing with satellite images to the mapping of irrigated areas in spatial and temporal scales, with some technical and financial difficulties as barriers. Google Earth solves part of these barriers, but the temporal discontinuity is a point to be evaluated. In this context, the present work aimed to use Google Earth to visually identify areas irrigated by center pivot in Minas Gerais, from an overflight in the state at an altitude of the viewpoint of 4,000 meters, characterize and register them, which resulted in 4,607 areas totaling 295,059.76 ha, with the municipality of Paracatu presenting the largest number with 598 areas, and Unaí, the greatest extent, with 42,846.04 ha. Data available in the year of 2010 indicated 4,432 areas occupying 303,368 ha with 570 areas in Paracatu and 44,258 ha in Unaí, confirming the functionality of the method.

Keywords: GIS (SIG), water resources, remote sensing**.**

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A IRRIGAÇÃO POR PIVÔ CENTRAL NO ESTADO DE MINAS GERAIS, BRASIL, SOB A ÓPTICA DO GOOGLE EARTH

2 RESUMO

A região Sudeste tem a maior demanda de água no Brasil e a maior extensão irrigada, com destaque para os pivôs centrais no estado de Minas Gerais, contudo, a confiabilidade destas informações é precária e limitam seu uso para a referida gestão. Como opção à obtenção de dados mais consistentes, principalmente quanto aos pivôs centrais, tem-se a utilização do sensoriamento remoto com imagens de satélites para o mapeamento em escalas espacial e temporal, tendo como entraves algumas dificuldades técnicas e financeiras. O Google Earth soluciona parte destes entraves, tendo na descontinuidade temporal um dos pontos a ser avaliado. Neste contexto, o presente trabalho teve como objetivo utilizar o Google Earth para identificar visualmente áreas irrigadas por pivô central em Minas Gerais, a partir de um sobrevoo no estado a uma altitude do ponto de visão de 4000 metros, caracterizá-las e cadastrá-las, o que resultou em 4607 áreas que totalizaram 295059,76 ha, com o município de Paracatu apresentando o maior número, com 598 áreas, e Unaí a maior extensão, com

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42846,04 ha. Dados disponíveis do ano de 2010 indicam 4432 áreas ocupando 303368 ha, com 570 áreas em Paracatu e 44258 ha em Unaí, ratificando a funcionalidade do método.

Palavras-chave: SIG, recursos hídricos, sensoriamento remoto.

3 INTRODUCTION

The National Water Resources Plan considers that 69% of the water consumed in Brazil is used in irrigated agriculture, with an average efficiency of 64%, i.e. 36% of the water for irrigation in the country is lost in conduction and distribution in the hydraulic infrastructures, causing a great waste of water use in agriculture (BRASIL, 2008). It also considers that even with new technologies, modern equipment and skilled technicians, Brazil has moved slowly on irrigation management and water conservation issues.

Paulino et al. (2011) said that the knowledge of irrigated areas and their geographical distribution in Brazil are of fundamental importance for the planning of water resources management in the country. They show the Southeast with the largest irrigated area in Brazil, with center pivot representing 24% of the total (395,590 ha). In Minas Gerais, sprinkler is predominant, with center pivots occupying 31.7% of total irrigated area (166,504 ha).

Sano et al. (2005) aimed to strengthen the idea that the knowledge of water resources demand should be frequently updated. This need has the remote sensing and the geographic information systems as tools for monitoring water use activities. This consideration made by Ferreira et al. (2011) supported the work in which CBERS-2B images, dated from 2008 to 2010, were used to map areas irrigated by center pivot in Minas Gerais, obtaining 3,781 areas totaling 254,875 ha. Similar studies using LANDSAT 5 and LANDSAT 7 satellite images are observed in Bauder et al. (2004), Schmidt et al. (2004) and Sano et al. (2005). Both satellites have spatial resolution which prevented the visual identification of center pivots.

Alternatively there is Google Earth imagery with high spatial resolution, referring to some places of the globe. By working on this basis, Equipo Urbano (2007) claimed that this software has become a technical tool of great importance for study and geographic research, whereas Simon and Trentin (2009) consider that the Google Earth images are suitable as a source for the representation of land use.

Guimarães and Landau (2011) identified areas irrigated by center pivot in Minas Gerais in LANDSAT 5 images of 2010, overlapping the images on Google Earth, where the collections of sample points and area delimitation were made. As a result, the authors obtained 4,432 areas totaling 303,368 ha with an average of 68 ha, relatively larger than those obtained by Ferreira et al. (2011).

A review of methods and results of existing studies that applied remote sensing in irrigated agriculture, performed by Ozdogan et al. (2010), enabled the authors to state that data of satellites provide enormous benefits to the problems of irrigated areas mapping in various temporal and spatial scales, emphasizing that the analyst must be aware of the limitations and advantages involved.

The text above shows the importance of center pivot irrigation in the demand for water resources and the need to have updated information regarding its use, having Google Earth as a GIS base and a source of satellite images of high resolution with potential to identify, characterize and register areas irrigated by center pivot. The aim of this work was to apply this capability in the state of Minas Gerais, comparing some of the results with available data in the literature, seeking to validate the procedure.

4 MATERIAL AND METHODS

The methodology proposed in this paper for the identification, characterization and registration of irrigated areas by center pivot using Google Earth and taking the state of Minas Gerais as object of study, consisted on a sequence of steps detailed below.

The first step was to acquire a georeferenced map of the municipal boundaries of Minas Gerais, available at IBGE (Brazilian Institute of Geography and Statistics) website (MALHA…, 2015). This map in SHP format was converted to KML format and imported into Google Earth.

After having the municipal boundaries superimposed on the satellite images on Google Earth environment, the next step was to perform an overflight in tracks over the entire subject of study at an altitude from the fixed viewpoint equal to 4,000 meters. The fixed value assured tracks of constant width, difficulting the occurrence of regions that were not visualized between adjacent tracks, while the chosen altitude ensured a spatial resolution that allowed to distinguish areas with the possibility of being or having been irrigated with pivot center equipment, generally characterized by circular or semicircular shape. At this viewpoint, on a video screen of 15 inches with 1,366 x 768 pixels, the image scale is approximately 1:15,000.

Having one of these areas been detected, the same was observed at a lower altitude seeking to visually confirm the existence of center pivot. In situations where this visualization was not possible, visual details to confirm its use were sought through marks left on the ground by the passage of the towers. In the case of irrigated areas by towable pivots, they are generally characterized by two or more surrounding areas of equal radii with features that confirm the use of the equipment or the visual identification of the structure of the pivot point for coupling the equipment.

In all cases of visual confirmation of the equipment or area with the characteristic shape, a marker was inserted at the center point and it received a serial number, allowing quickly visual access of the area that it represents, storing geographical coordinates of the area and allowing the record of all the details regarding the area and the equipment.

The details were stored in Google Earth with the following symbols and meaning: DT - date of the satellite image, in the month/day/year format; EL – ground elevation or altitude, in meters; ST - sectorization of area, in quarter of circle (1/4, 2/4, 3/4, 4/4); RC - radius of circular area, in meters; US - land use (T=temporary, P=perennial, N=bare soil or fallow); PV - visible pivot (S=yes, N=no); CP - length of visible pivot, in meters; MR - sign of the wheel tracks (S=yes, N=no); NT - number of towers or signs of the wheel tracks; PP - basis of anchoring of the visible pivot point (S=yes, N=no); MS - assembly scheme pivot (F=fixed, R=towable); CA - source of water capture (S=surface, I=indeterminate/well); LA - city of area location.

After completion of the overflight and identification of all areas, the data saved in a KML file was opened in Excel, keeping the column "description" of the worksheet and deleting the others. Each cell in the column contains the details of an area, arranged in a single line of text, and the Excel text functions were used to individualize each detail and tabulates them.

The tabulated data were organized to obtain numbers that could characterize the use of center pivots in Minas Gerais, as total amount of areas identified in the state and in each municipality, extension of each area obtained from the radius of the circular area (RC) and its sectorization (ST) and the totals in the state and municipality, the largest and the smallest area, as well as details about equipment characteristics and land use under the pivots.

Data available regarding the number of installed equipment, presented by Guimarães and Landau (2011), were used for assessing the functionality and effectiveness of the proposed method.

5 RESULTS AND DISCUSSION

During the Minas Gerais overflight it was found, in the mosaic of images from Google Earth, areas with coverage of old pictures and possibly not representing the current situation, as well as regions with relatively recent coverage and updated in relation to the use and occupation of the land. The areas were identified in images dating from the year 2000 until the year 2013, representing a discontinuity of up to 14 years. This discontinuity can cause an error in the analysis proposed in this work. However, it is not possible to say whether the numbers obtained are underestimated or overestimated. It was noted that in some situations, existing areas in older images no longer exist in newer images, indicating conversion to non-irrigated crops. Opposed to this, there was a remarkable growth in sales of new equipment over the years, and some of which may not have been identified by the images.

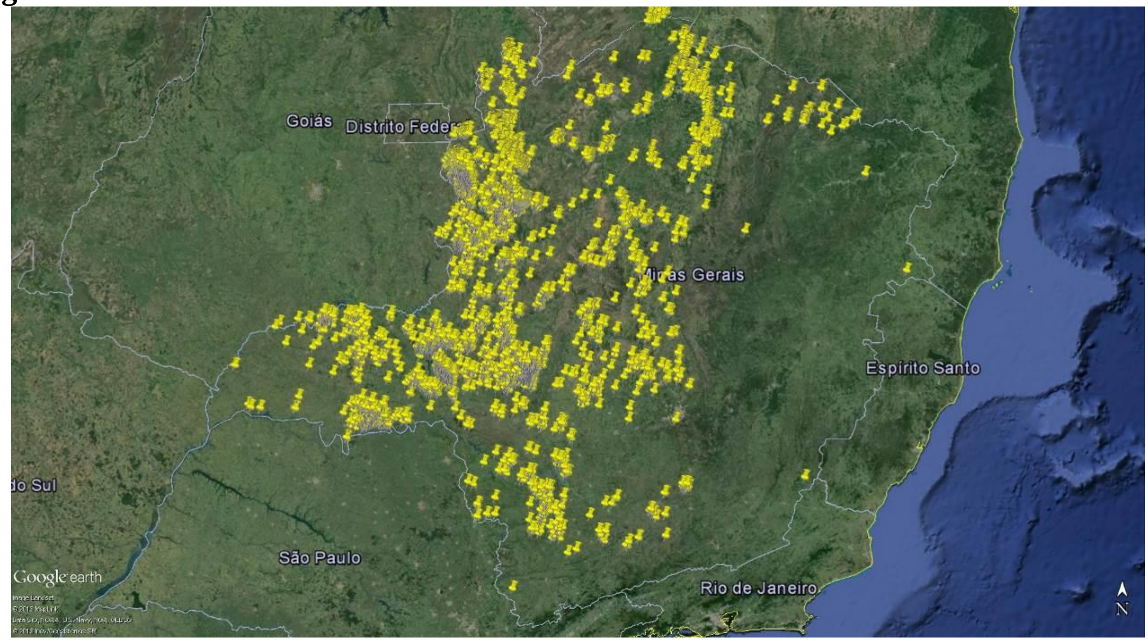
It was also observed the covering with images from the SPOT satellite, but spatial resolution does not allow the identification of the center pivot, although the largest area is represented by images with proper resolution for such identification.

It was noted that, in some situations, visual confirmations were impossible, usually due to the resolution or sharpness of the satellite imagery in a particular region. It was also verified the existence of circular cultivated areas where no longer center pivot irrigation is used, but which sought to keep the consolidated road at its perimeter.

In other situations, the occurrence of exposed soil, with recent preparation at the time of the image that was not restricted to the irrigated circle and without road delimiting the area of the center pivot, hampered the identification of the equipment. A similar fact occurred in cultivated areas not restricted to the extent of the center pivot, but conducted without irrigation.

Situations where the marker was inserted totaled 4,607 areas that have been or are irrigated by center pivots (Figure 1), distributed in 220 municipalities and higher concentrations in Paracatu (598 areas), Unaí (472 areas) and Rio Paranaíba (237 areas).

Figure 1. Distribution of the identified areas in Minas Gerais state.



The extent analysis results were larger in the municipalities of Unaí (42,846.04 ha), Paracatu (40,151.15 ha) and Rio Paranaíba (12,825.90 ha), resulting in the total of 295,059.76 ha. Table 1 presents the list of 10 municipalities with the largest amounts of identified areas and 10 municipalities with the highest total extent of areas.

Table 1. List of 10 municipalities with the highest amounts of identified areas and 10 municipalities with the highest total extents of areas.

municipality	amount of areas	municipality	total extent of areas (ha)
Paracatu	598	Unaí	42,846.04
Unaí	472	Paracatu	40,151.15
Rio Paranaíba	237	Rio Paranaíba	12,825.90
Guarda-Mor	119	Santa Juliana	6,202.49
Ibiá	109	Perdizes	6,100.11
Perdizes	102	Guarda-Mor	5,898.49
Santa Juliana	96	Buritis	5,345.21
Conceição das Alagoas	94	Conceição das Alagoas	5,335.05
Patos de Minas	82	São Romão	5,178.47
Campos Altos	76	Romaria	5,081.20

The largest identified area, in the municipality of Brasilândia de Minas has 330.06 ha, equipped with a center pivot of 958 m in length, distributed over 17 towers, while the lowest is 0.95 ha, located in the municipality of Unaí. 50% of areas have extent up to 57.28 ha, with the overall average equal to 64.05 ha, considering all the identified areas.

Data obtained by Guimarães and Landau (2011), referring to the year 2010, totalized 4,432 areas and an extent of 303,368 ha, with an average of 68 ha. They present the municipality of Paracatu with the largest number of areas (570) followed by Unaí (471) and

Rio Paranaíba (227). By analyzing the extents, Unaí appears with 44,258 ha, followed by Paracatu (40,179 ha) and Rio Paranaíba (12,676 ha).

These data show consistency with those obtained in the present work. However, there are some considerations to be made regarding the methodology used in the work discussed above, which at first moment was based on images of low spatial resolution. Under these conditions, the identification of small areas and areas without a well-defined contour, as explained earlier in this text, becomes technically difficult, excluding them of statistics. This situation may explain the higher number of identified areas in this study (4,607 areas) compared to the analyzed (4,432 areas), as occurring in the totals by municipality.

Another consideration concerns the extent. The work analyzed tried to trace the outline of the identified area of the Google Earth environment and this tracing got its extent in hectares, being a procedure relatively difficult to perform due to the tooling available in the software, usually resulting in a contour that goes beyond the correct limit, indicating a larger extent. In the present study, the radius was measured from the pivot point to the edge of the identified area, and using the information of sectorization, the extent in hectares was calculated. In this case, such situation may explain the lowest extent obtained in the present work (295,059.76 ha) compared to the analyzed (303,368 ha).

It is noted that, in such considerations, it is believed that inclusion and exclusion of areas occurred, but not registered in images, was not substantial enough to interfere with the values obtained in function of existing temporal discontinuity between the studies analyzed.

In the analysis of the collected details, it was found that more than half of the identified areas were visualized in images obtained from 2010, while 16.30% were on SPOT images, but acquisition date was not consulted. Table 2 shows the distribution of the identified areas regarding the year of the latest images, also indicating the participation of SPOT images in total.

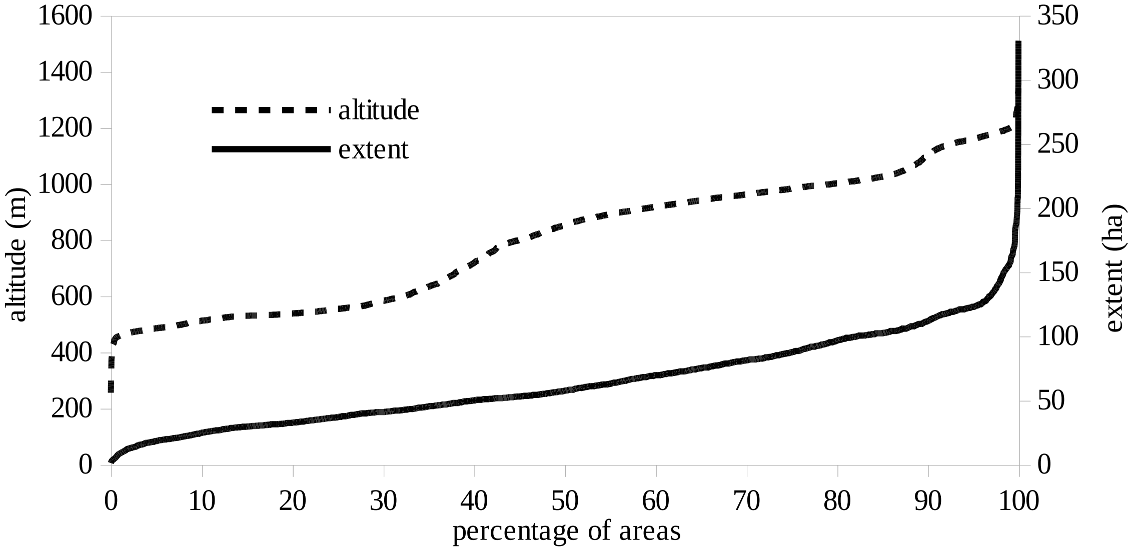
Table 2. Distribution of the identified areas in relation to the year of image acquisition.

year	amount	representativeness		year	amount	representativeness	
		of the year	accumulated			of the year	accumulated
2000	27	0.59%	0.59%	2008	168	3.65%	26.31%
2001	7	0.15%	0.74%	2009	207	4.49%	30.80%
2002	72	1.56%	2.30%	2010	892	19.36%	50.16%
2003	505	10.96%	13.26%	2011	858	18.62%	68.79%
2004	21	0.46%	13.72%	2012	385	8.36%	77.14%
2005	130	2.82%	16.54%	2013	302	6.56%	83.70%
2006	221	4.80%	21.34%	SPOT	751	16.30%	100.00%
2007	61	1.32%	22.66%	Total	4,607		

In the analysis of ground elevation where the area is located, values from 255 m in altitude up to 1,339 m were observed, with an overall mean of 800 m, and 50% of the identified areas are located at altitudes up to 852 m.

Figure 2 shows the percentage distribution of the areas with respect to their altitudes (left vertical axis) and in relation to their extents (right vertical axis). The verticality of the curve related to the extents clearly shows the predominance of areas up to 150 ha.

Figure 2. Percentage distribution of areas with respect to their altitudes and extents.

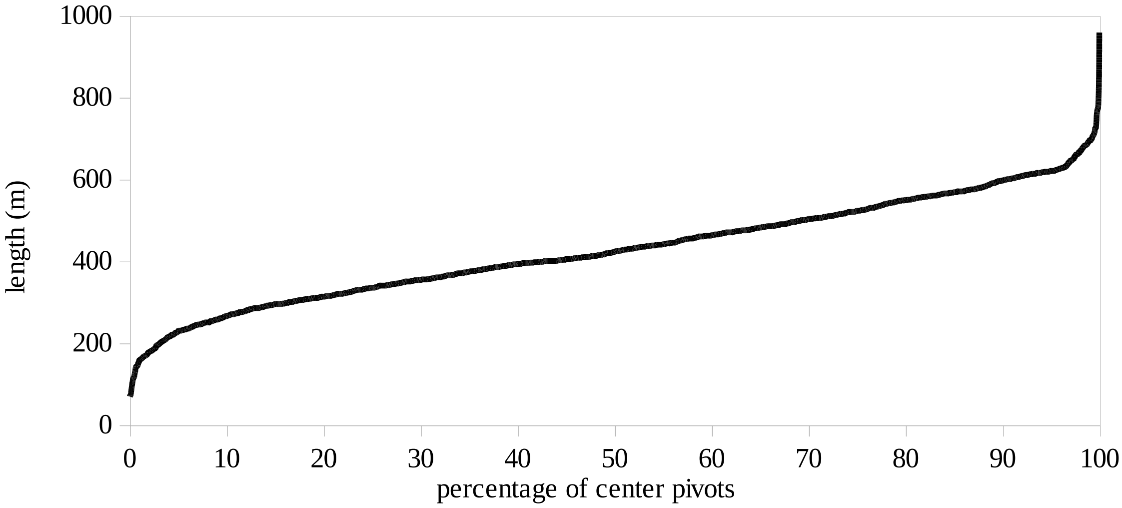


With respect to sectorization, 97.33% of the identified areas are shown as full circles (4/4) while 3/4 and 2/4 sectorization represent 1.15% and 1.52%, respectively, with 1/4 not identified. The sectorization, together with the circular area radius, was used to calculate the extent of each identified areas.

The land use, in the vast majority of the identified areas, refers to temporary crops (83.63%). Areas with bare soil or fallow represent 9.46%, while areas under permanent crops account for 6.06%. Other conditions, with areas presenting two or more conditions of land use, represent 0.85% of the identified areas.

Regarding the characteristics of the equipment, it is observed that in 64.27% of areas the existence of the center pivot was visually identified and in 2,570 areas it was possible to measure its length. The shortest equipment has 69 m and the longest has 958 m, with an average length of 427 m, with 50% of the center pivots having up to 422 m. Figure 3 shows the percentage distribution of center pivots in relation to length, where it is observed the predominance of equipment with 200 m to 700 m.

Figure 3. Percentage distribution of center pivots with respect to their lengths.



As for signals of the wheel tracks, in 60.73% of areas the visualization was possible, and in 2,946 areas, the total number of towers or wheel tracks signals could be quantified. Pivots were identified with 1 to 17 towers, and equipment with 6 to 9 towers was the most frequent, accounting for 53.67% of 2946 areas. Table 3 shows the distribution of center pivot equipment regarding its tower number.

Table 3. Distribution of center pivots with respect to their number of towers.

number of towers	amount	representativeness	
		of number	accumulated
1	4	0.14%	0.14%
2	18	0.61%	0.75%
3	52	1.77%	2.51%
4	132	4.48%	6.99%
5	240	8.15%	15.14%
6	402	13.65%	28.78%
7	413	14.02%	42.80%
8	413	14.02%	56.82%
9	353	11.98%	68.81%
10	293	9.95%	78.75%
11	266	9.03%	87.78%
12	177	6.01%	93.79%
13	97	3.29%	97.08%
14	47	1.60%	98.68%
15	23	0.78%	99.46%
16	12	0.41%	99.86%
17	4	0.14%	100.00%

By knowing the length of the pivots and the number of towers, it was possible to calculate the average length of their spans. This combination was possible in 2,455 equipment, obtaining the smallest span with 30 m and the largest with 63 m and an average of 50 m. In pivots with fewer towers, spans tended to be longer and close to 52 m, while pivots with more towers have shorter spans (around 43 m).

In 99.09% of the areas identified, it was possible to confirm the existence, or something that might imply the existence of the pivot point. Regarding the mounting scheme, in 99.24% of the areas there is evidence of fixed equipment assembly, while only in 0.76% of the areas, the visual analysis gives evidence of the towable pivot fitting scheme.

In all identified areas, it was found superficial water sources in their vicinity, suggesting surface uptake.

6 CONCLUSIONS

The use of the Google Earth software for identification, characterization and registration of areas irrigated by center pivot is technically feasible.

The discontinuity of the mosaic images of Google Earth is the main factor adversely affecting the effectiveness of the proposed methodology, followed by existence of regions with coverage of SPOT images.

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