UPGRADE OF WATER RESOURCES MAPS FROM MATO GROSSO DO SUL STATE USING GEOTECHNOLOGIES

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Abstract

The objective of this work is to present the methods used and results obtained in the activities of upgrading water resources maps from Mato Grosso do Sul State. The geographic boundaries of the hydrographic sub-basins or Planning and Management Units (UPG) were upgraded using an algorithm based on D8 (Deterministic Eight-neighbor Method) applied to the Digital Elevation Model (DEM) of the State. The digital hydrographic network was corrected and upgraded from medium resolution satellite images CCD/CBERS-2B, at 1:100,000 scale. The results obtained with these activities constitute a significant improvement on the information of water resources available for the State, although some inconsistencies occurred in the Pantanal flatlands, where minimal or nil height changes jeopardized the analysis of water features, as well as the performance of the algorithm to delimit hydrographic basins. The resulting vector dataset of these upgrading activities is available at SISLA (Interactive System for Environmental Licensing Support), a web tool managed by Mato Grosso do Sul State for the evaluation of environmental licensing processes, which will contribute to improve the management of water resources from this State.

Key-words: Geo-processing. Remote sensing. Hydrographic basins, Drainage network. Mapping.

Resumo

Atualização dos mapas de recursos hídricos do estado do Mato Grosso do Sul por meio do uso de geotecnologias

Este artigo tem por objetivo apresentar os métodos e resultados alcançados nas atividades de atualização dos mapas de recursos hídricos do estado do Mato Grosso do Sul. Os limites geográficos das sub-bacias hidrográficas, ou Unidades de Planejamento e Gerenciamento (UPG), foram atualizados com o auxílio de um algoritmo baseado no método D8 (*Deterministic Eight-neighbor Method*), o qual foi aplicado ao modelo digital de elevação do estado. Já a malha digital hidrográfica foi corrigida e atualizada a partir da interpretação de imagens de média resolução espacial CCD/CBERS-2B, na escala 1:100.000. Os resultados alcançados nessas atividades representam uma significativa melhora nas informações de recursos hídricos que o estado tem à sua disposição, embora algumas inconsistências tenham ocorrido nas áreas planas do Pantanal, onde a pequena ou nula variação altimétrica prejudicou o entendimento das feições hídricas, bem como o desempenho do algoritmo para delimitação de bacias hidrográficas. O conjunto de dados vetoriais resultante dessas atividades de atualização será disponibilizado pelo Sistema Interativo de Suporte ao Licenciamento Ambiental (SISLA), uma ferramenta Web gerida pelo estado do Mato Grosso do Sul nos processos de avaliação de licenças ambientais, podendo contribuir no gerenciamento mais detalhado dos recursos hídricos daquele estado.

Palavras-chave: Geoprocessamento. Sensoriamento remoto. Bacias hidrográficas. Rede de drenagem. Mapeamento.

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INTRODUCTION

The periodic upgrade of maps considering environmental changes is an essential process to maintain the different existing geographic databases available, so that they don't become obsolete and lose its utility. Methods for the production and cartographic upgrade of maps have evolved gradually with the development of new technological processes, such as the digital mapping, the use of GIS (Geographic Information Systems) and remote sensing images with different details and periodicity.

In this frame, Project GeoMS (Geo-referenced Information System to support decision making – case study: Mato Grosso do Sul State) (SILVA et al., 2011b), a cooperation between the Brazilian Agricultural Research Corporation (Embrapa) and the Environmental Institute of Mato Grosso do Sul State (IMASUL), generated and upgraded a set of digital maps with natural resources from Mato Grosso do Sul State, besides developing a geo-referenced information system for decision-taking, aiming to support the State Government to improve its efficiency to implement environmentally sustainable projects (SPERANZA et al., 2011). So, the Interactive System for Environmental Licensing Support (SISLA) is a web tool containing a set of maps from the State, allowing each user to start a request procedure for an environmental license in Mato Grosso do Sul State.

One of the activities of Project GeoMS was the upgrade of water resource maps from Mato Grosso do Sul State, including drainage networks and geographical boundaries of their 15 hydrographic sub-basins, which were defined as Planning and Management Units (UPG) by the State Plan of Water Resources (PERH/MS) (SEMA/IMASUL, 2010).

The hydrographic basins are an integrated and independent bio-physical and socio-economic system, whose borders are established topographically by a line connecting those points of highest altitude defining the watersheds between a basin and its adjacencies (ROCHA et al., 2000). The official boundaries of sub-basins from Mato Grosso do Sul State were defined in the 1990s, using analogical methods, based on maps and topographic charts at 1:100,000 scale, presenting insufficient detail for regional planning. However, alternative methods for the automatic delineation of hydrographic basins based on algorithms applied to Digital Elevation Models (DEM) were proposed and tested (JENSON; DOMINGUE, 1988; TRIBE, 1992; MARTZ et al., 1992; LIANG; MACKAY, 1999; RENNÓ et al.,2008). With the advent of SRTM (Shuttle Radar Topography Mission) data (RABUS et al., 2003), a new global altimetry base became available with a spatial resolution of nearly 90 m, promoting the use of automatic techniques. The availability of DEMs and the improvement of the spatial resolution from SRTM data, as well as other models from other sources, contributed for the development and use of techniques for the automatic delimitation of hydrographic basins.

The digital drainage network of Mato Grosso do Sul State was produced by digitalization of topographic maps from the Brazilian Army Geographic Service (DSG), generated during the 1960s and 1970s from aero-photogrammetric surveys and stereoscopy techniques. The analogical mapping method carried out by DSG was expensive and subject to cartographic errors which, added to errors of map digitalization, and to its time-consuming production, require an upgrade of the database. A low cost alternative for cartographic upgrading was the adoption of recent satellite data with medium spatial resolution, such as data from CCD/CBERS-2B (High Resolution Imaging Camera/China-Brazil Earth Resources Satellite) as a terrestrial cartographic reference for the adjustments and upgrading of the drainage network, as long as they are subjected to a rigorous geometric correction process.

In this context, the objective of this paper is to disclose methodologies used and results obtained during the procedures for cartographic upgrading of the borders from hydrographic sub-basins of Mato Grosso do Sul State, with automatic methods based on a DEM, as well as the results of the digital drainage network updating, gathered from the comparison of official data and medium spatial resolution images.

MATERIAL AND METHOD

Area under study

The relief of Mato Grosso do Sul State is relatively flat with predominantly moderate altitudes, including the Pantanal Complex in the extreme West, the plains in the Northeast and plateaus with scarps at Serra da Bodoquena in the centre of the State. Its drainage systems from the 15 sub-basins contribute to the basins of Paraná River (to the East) and to Paraguai River (to the West) and there is a large watershed in the centre of the State. Figure 1 illustrates the DEM from the State, the delimitation of hydrographic sub-basins or Planning and Management Units.

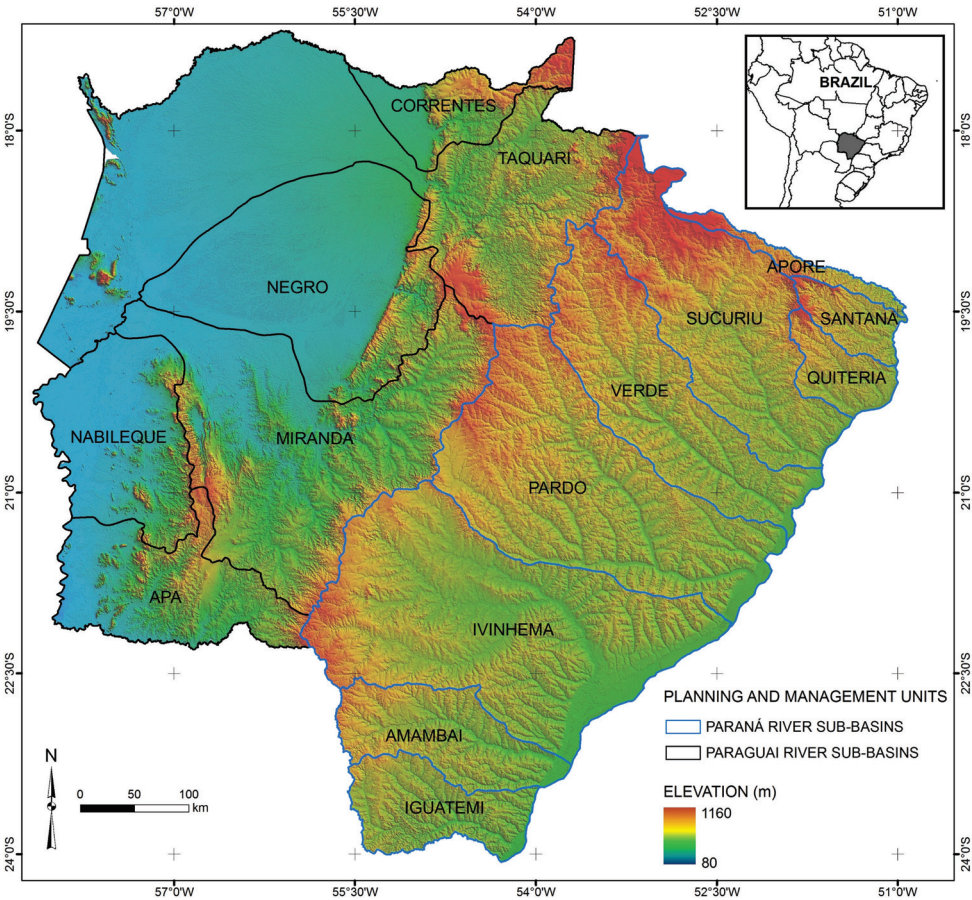

Figure 1 – Area under study: Mato Grosso do Sul State, its altimetry and hydrographic sub-basins

Upgrade of geographic boundaries from hydrographic sub-basins

This procedure was conducted using the automated method applied to the DEM mentioned. This altimetry model used was obtained from the Brazilian Geomorphometric Database, a repository derived from TOPODATA Project, carried out by the National Institute for Space Research (INPE) with support from Embrapa Agricultural Informatics (TOPODATA, 2010). TOPODATA Project delivers the DEM and its basic local derivations for the entire Brazilian territory from reprocessed SRTM data, refined from the original spatial resolution of three arc seconds (90m) to one arc second (30m) using kriging techniques (VALERIANO et al., 2009).

The computer program used for this activity was Idrisi Taiga, module Watershed, based on the method proposed by Jenson & Domingue (1988) where a water flow is simulated over the topographic surface. This concept applies the D8 method (Deterministic Eight-Neighbor Method) to determine the flow direction of each cell, where the local elevation is compared to neighboring elevations. The Watershed module performs a sequence of procedures, starting with the DEM correction to fill out depressions or cells surrounded by elevations of higher altitudes, named "sinks", which represent inconsistencies of the topographic model and cause critical problems in hydrologic applications, because they interrupt the continuous flow in the entire DEM area. Afterwards, a calculation of the water flow direction is performed, which defines the hydrologic relations within the hydrographic basins, determined in accordance with the steepest slopes in a 3x3 cell window, in order to identify the direction of the highest steepness of a pixel, related to its 8 neighboring pixels. The result of this procedure is an image where the value of each pixel represents the direction of water flow. From the grid of flow direction, a grid of flow accumulation is calculated, where each pixel receives a value corresponding to the number of pixels contributing to the water flow coming to it. This is done from the summation of the cells area, towards the flow. This parameter indicates the degree of flow confluence and it represents the hydrographic net existing in the DEM.

Due to limitations of the computer program used, the delimitation of the sub-basins was conducted in regional sections, because the DEM containing the entire extension from the State has a very large data volume, not supported by the software. Finally, from the accumulated water flow the micro-basins were extracted, whose water catchment area was kept within a previously defined level by the user. In order to perform a more detailed delimitation, a minimum area of 100 km2 was used, for the posterior visual interpretation of sets of micro-basins, which were transformed in vectors and loaded in the ArcMap program. During this visual process, as auxiliary data, medium spatial resolution images from CCD/CBERS-2 and the hydrographic digital grid from the State at 1:350,000 (ANA, 2008) and 1:100,000 scales were used. Furthermore, an interpretation of the results for the definition of the new hydrographic sub-basins within the UPGs was done, considering, however, a direct derivation in the rivers Paraná or Paraguai and visible at 1:100,000 scale.

Upgrade of the digital hydrographic net

The adjustment of the digital hydrographic network from Mato Grosso do Sul State was made manually, from visual interpretations at scale 1:100,000 by a team of trainees of Project GeoMS, using as a spatial reference, a mosaic of CCD/CBERS-2B images from 2007, with spatial resolution of 20 m, covering the entire State. Several vector editions were made on ArcMap software, in order to adequate linear vectors to the visible features on satellite images. The CCD/CBERS-2B images, obtained from INPE, were defined as the cartographic base from GeoMS Project. This dataset underwent a judicious geometric correction: GPS points collected during field survey and Landsat images from GeoCover Program were considered as spatial reference. After their enhancement, the images were prepared as

mosaics and cut, adopting the cartographic net at 1:250,000 (totaling 34 charts for the entire State).

The digital mesh of the drainage network from the State was disclosed by the Agency for Agrarian Development and Rural Extension (AGRAER) in vector files at UTM projection, in 161 charts at 1:100,000 scale. Most files were received in vector format and classified as perennial or temporary rivers and others did not have any classification. Besides the cartographic adjustment of the digital hydrographic network, new drainages visible on CBERS images but not present on the original topographic maps were added to the dataset. Furthermore, the nomenclature of rivers and brooks (not available in the original vector files) was added as well as corrections related to the classification of the drainage type. As auxiliary data in this process, original topographic charts from DSG, scanned in TIFF format, the State DEM, and the vegetation cover map of Mato Grosso do Sul State (SILVA et al., 2011a) were used. Figure 2 illustrates an example of a spatial data subset used to adjust the hydrographic network.

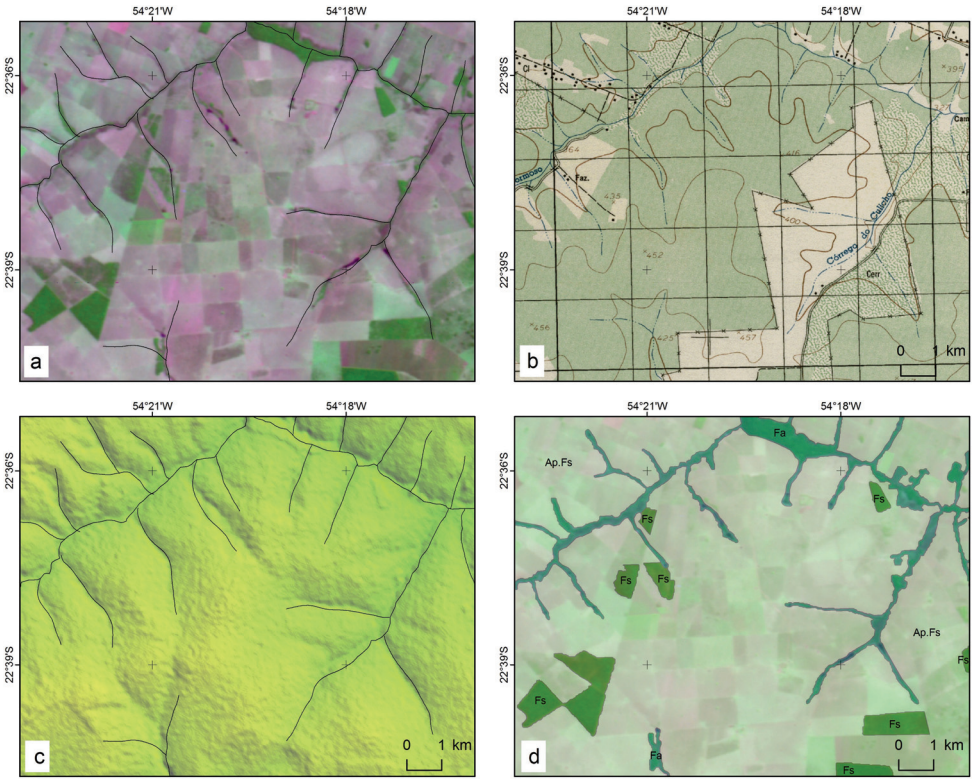

Figure 2 – Examples of dataset used: (a) original digital vectors overlaid on CCD/CBERS-2B images; (b) scanned topographic chart from DSG; (c)DEM from TOPODATA; (d)digital map of vegetation cover overlapped on CCD/CBERS-2B image

Finally vector data were converted from the UTM to the geographic projection. The articulation between charts at 1:100,000 and their mosaics followed the spatial subsets of the 15 sub-basins or UPGs from the State.

RESULTS AND DISCUSSION

Figure 3 illustrates the final map of water resources for the entire Mato Grosso do Sul State, upgraded with the new boundaries of hydrographic sub-basins and the digital drainage network. The new hydrographic sub-basins which contribute directly to the Paraná and Paraguai rivers are also shown.

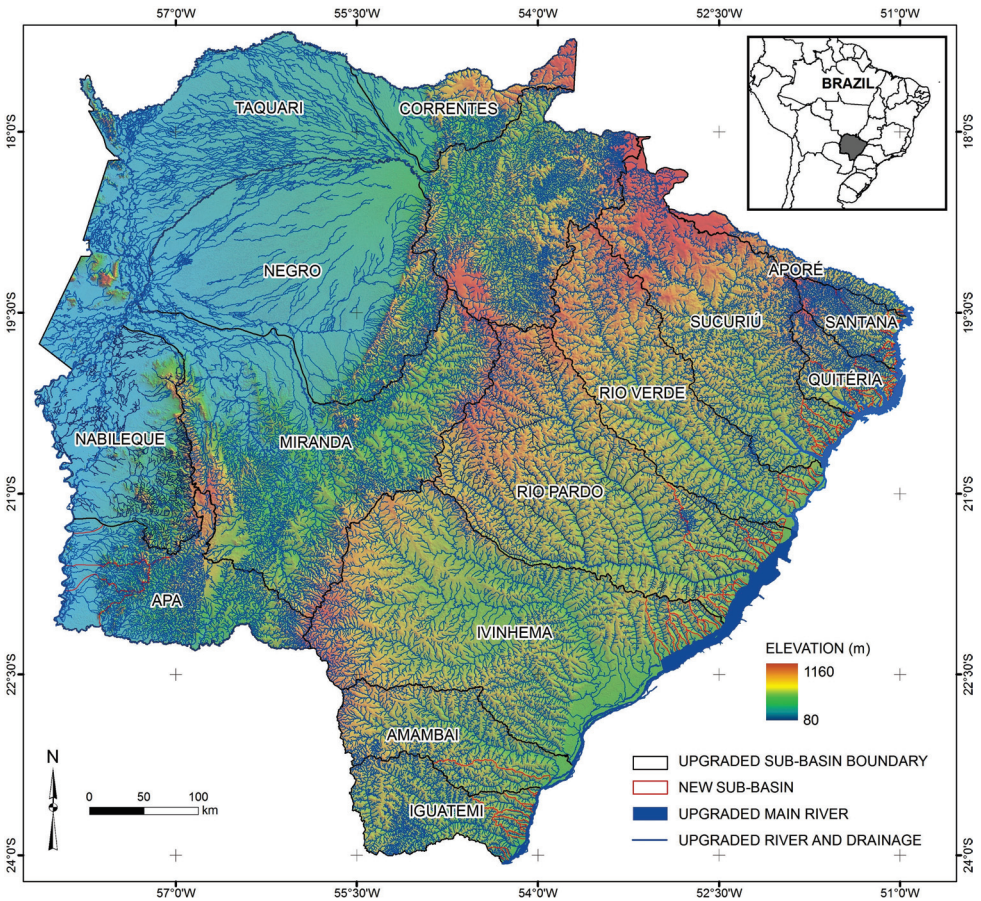

Figure 3 – Final map of water resources of Mato Grosso do Sul State with the upgraded drainage network and the new boundaries of hydrographic sub-basins

Results of upgrading the geographic boundaries of hydrographic sub-basins

Details of results can be observed in the regions illustrated in Figure 4, which represent areas close to the watersheds, where it is possible to compare, at a more adequate scale, the actual boundaries of the sub-basins and their new delimitation and overlaid on them, the digital hydrographic mesh at scale 1:100,000. The new borders are at a more detailed scale and more coherent with the altimetry of the State.

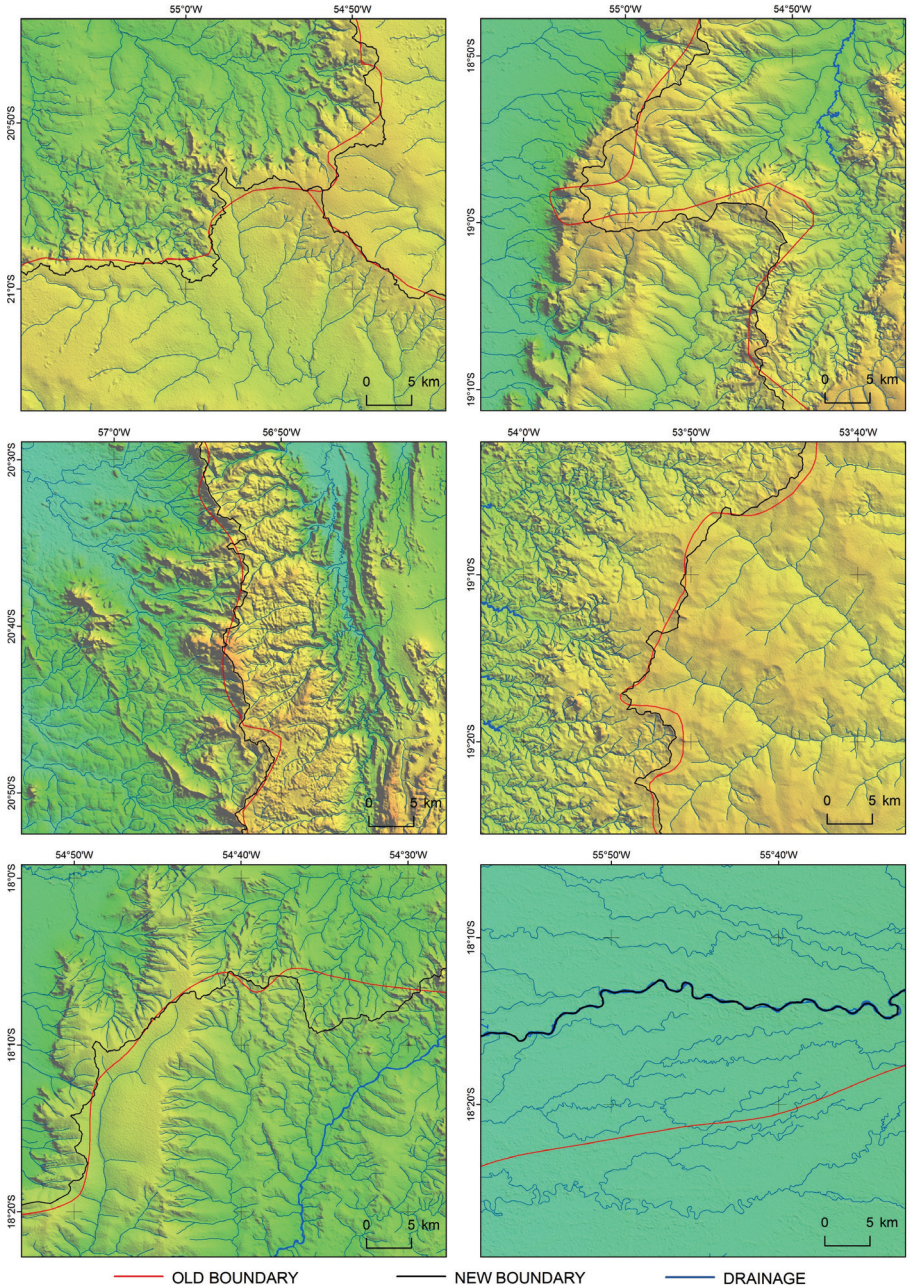

Figure 4 – Spatial subsets of six regions of the State and the comparison between the new and the old boundaries of hydrographic sub-basins, overlaid on the DEM

Many discrepancies, which occurred in the older delimitation due to the mapping scale , where the borders of sub-basins crossed the drainage, were corrected. The tendency of the new delineation was to follow the watersheds more rigorously, representing more faithfully the real localization of the basin boundaries. Obviously the level of detail reached was limited to the spatial resolution of 30 m from the DEM used in the process, as well as to the characteristics of the software used.

The best results were generally obtained in regions with stronger relief variation, where the directional flow could be easily defined, allowing more precise calculations from the contributing areas. However, in flat areas such as Pantanal, the results were of lower quality, because in such places the low or nil altimetry variations precluded the efficient detection of the water flow direction using this algorithm, and consequently those areas of water accumulation could not be defined. The conventional algorithms for processing DEMs, such as D8, present failures for the definition of water flow direction in flat surfaces. However, if these elevations have the same height, ambiguous results are generated (GETIRANA et al., 2009). In these cases, such as the last example in figure 4, which shows the borders between the sub-basins of Taquari and Negro rivers, the considered reference was the old delineation of the UPGs, which took into account the riverbed as the watershed, that was redefined with CCD/CBERS-2B images. In fact, the automatic delimitation of basins in flat areas has been a complex task, mainly due to the difficulty to generate realistic drainage networks from conventional DEMs, as discussed by Getirana et al. (2009). These authors also emphasize the fact that DEMs are not free of failures. They can show inconsistencies derived from the methods by which they were generated, as reported by Valeriano et al. (2006), who found out the influence of the forest canopy in SRTM altimetry data.

Referring to the new sub-basins, 104 units were visible at scale 1:100,000, being 100 in sub-basins draining to Paraná River and 4 emptying at Paraguai River. Figure 5 illustrates, at a more detailed scale, the new sub-basins identified at the UPG of Iguatemi River, in the extreme south of the State. In this process for the identification of new sub-basins, it was of fundamental importance to use auxiliary data, such as the CCD/CBERS-2B images and the hydrographic digital net at scale 1:100,000, which allowed a better understanding of the terrain and the water logic.

The option to process the DEM in regional spatial subsets allowed a higher agility and did not interfere in the results, because such subsets were defined based on the existing UPG delimitation. There was no field validation of the results presented here, due to the difficulty of its execution. Considering however the detail difference between the older UPG delimitation and the new one proposed here, seen at the DEM and compatible with the digital hydrographic network from the State, it is evident that the results presented constitute an improvement on the quality of information available for the Mato Grosso do Sul State. The vector dataset resulting from this work will be disclosed by SISLA (SISLA, 2012) and will contribute for more detailed management of water resources of the State. It is emphasized that the automatic method used was an auxiliary tool in the delineation process of hydrographic sub-basins and it is the user's final decision on the definition of its boundaries.

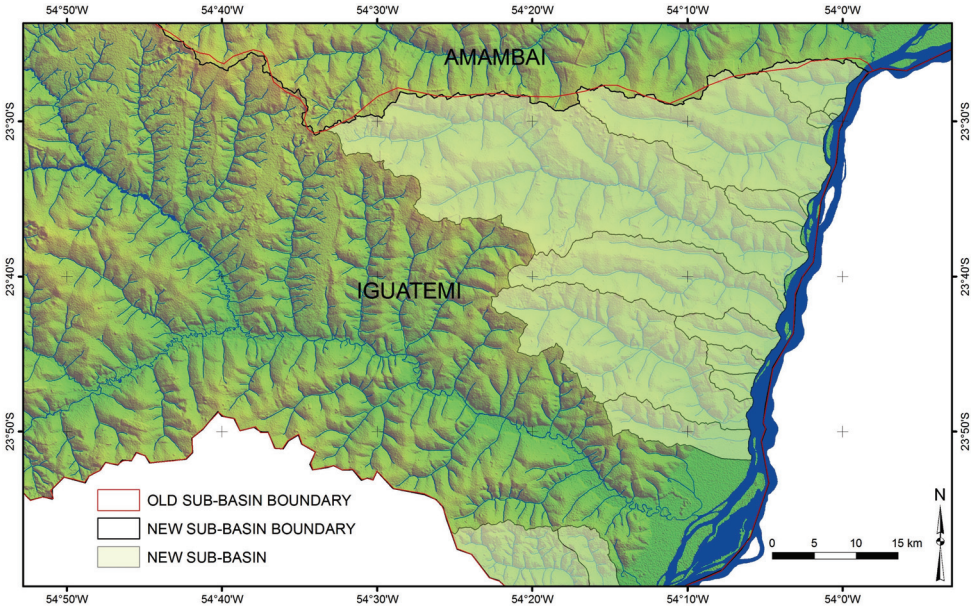

Figure 5 – New sub-basins draining to Paraná River, mapped at the Rio Iguatemi sub-basin, extreme south of the State

Results of upgrading the digital hydrographic network

During the upgrading process from the digital hydrographic network, corrections were made on the displacement among vectors from the original vector net (based on DSG charts) and CCD/CBERS-2B images, where generally such displacements resulted from the confection and digitalization procedure of DSG charts. However, very often, especially in very flat areas, the displacements were due to hydro-morphological changes which have occurred in the last 50 years, resulting in discrepancies among the original vector base and CBERS images from 2007.

Some difficulties were found in this vector adjustment procedure, especially due to the spatial resolution of CCD/CBERS-2B images, which did not always allow the visualization of narrow rivers and brooks. In this case, the existence of riparian forests along the drainage was an important factor for the visual interpretation and the correct delineation of rivers. In cases of absence of riparian forest, a DEM was used as a reference, which enabled the topographic pattern visualization of the terrain and the identification of the lowest regions. From the spatial subsets in a more detailed scale, shown in figures 6 and 7, it is possible to compare the results obtained with those from the original data. The subsets on the left showed the drainage before the correction process and those on the right, the corrected, upgraded and nominated drainage.

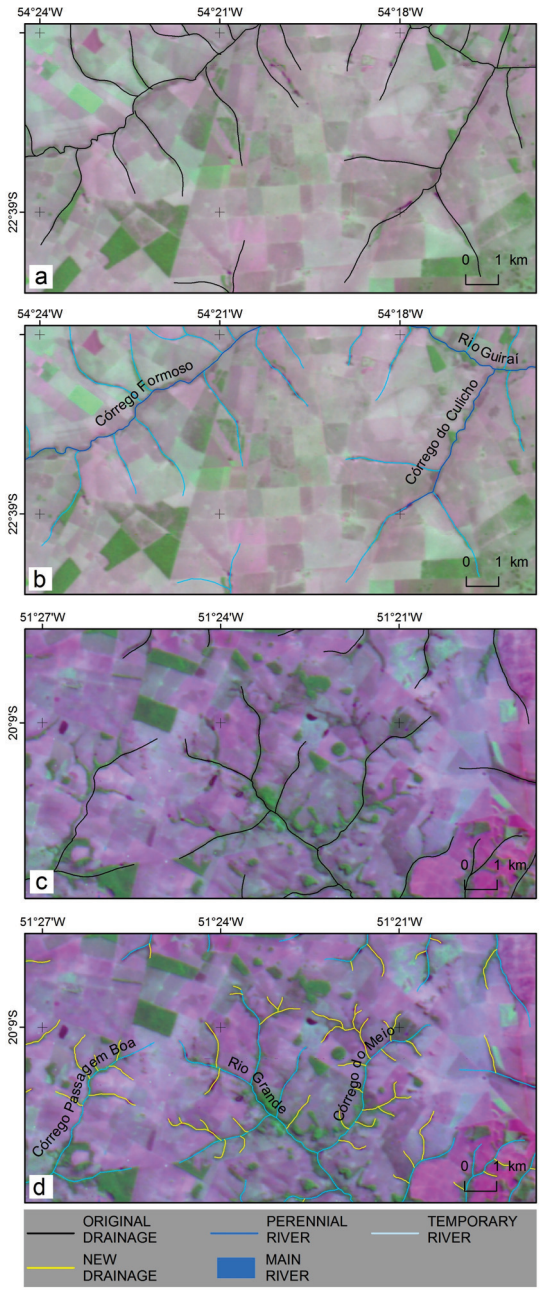

Figure 6 – Spatial subsets with drainage details before (a and c) and after (b and d) the correction and upgrading process, overlaid on CCD/CBERS-2B images

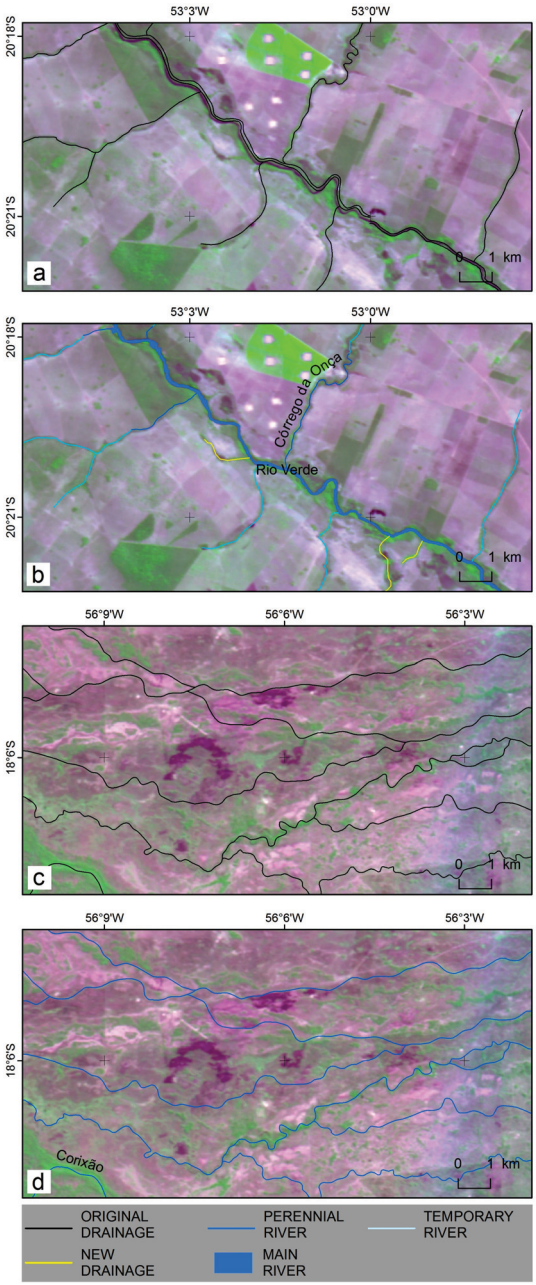

Figure 7 – Spatial subsets with drainage details before (a and c) and after (b and d) the correction and upgrading process, overlaid on CCD/CBERS-2B images

The upgraded digital mesh is composed by linear vectors, representing the temporary, perennial and new drainage, as well as polygonal vectors, representing larger rivers (double rivers). The new drainage, with higher density in figure 6d, shown in yellow lines, was not available on the original base and was mapped by the Embrapa Agricultural Informatics team. It was not classified as to its type or to its nomenclature. In the vector files of perennial and temporary drainage, a table of attributes was added, and the names of rivers, streams and brooks, etc. which had been on the DSG charts, were registered. The double rivers were extracted from land use/land cover map of the State, where the borders of margins were identified.

In Pantanal flat areas , in the West of the State, and in some regions on the margin of Paraná River to the East, the level of difficulties for the corrections was higher, due to the low slope and the impossibility to improve the understanding of the drainage system in these floodable areas. In some areas of Pantanal, as illustrated in Figures 7c and 7d, the original lines were not changed, due to the difficulty of interpreting satellite images. The low slope of these areas, associated to the absence of conventional drainage patterns, did not allow the correction of vector data in these regions, even when using satellite images obtained in dates close to the dry season of Pantanal. In these flat areas, drainage lines were found beginning or ending in flooded areas (not mapped in this work), which explains the reason why some of these lines are "loose" on the map, as observed in Figure 3, especially at the sub-basin of Negro River.

It is important to emphasize that the results presented here were obtained from the interpretation of medium spatial resolution images, whose detailing is lower than that of the aerial photographs which originated the mapping made by DSG, and as such are error-prone. In spite of the difficulties found in floodable regions, the geometric accuracy and the age of the satellite images used, enabled a significant improvement on the quality of the original digital drainage network, available for the State of Mato Grosso do Sul.

Considering the definition of hydrographic basins as territorial units for the application of the National Policy for Water Resources, the organization and articulation of the digital drainage network in mosaics and sub-basins or UPGs, instead of maps at 1:100,000 scale, is also a result of this process, facilitating data handling and information loading in a GIS.

The upgraded digital maps of the drainage network will also be disclosed by SISLA (SISLA, 2012) and could contribute to the accuracy of the analysis from the surroundings and spatial consultation done by the system for the evaluation of environmental licensing processes in the State, especially for the definition of Permanent Protection Areas (APP) along watercourses. It is highlighted that the process for upgrading maps of natural resources must be a continuous activity, and remote sensing can be considered a source of permanent information, due to its regular updating and to the development of new sensor systems with improved spatial resolution.

CONCLUSIONS AND PERSPECTIVES

The computer techniques used improved the upgrading process of the geographical boundaries of the hydrographic sub-basins of Mato Grosso do Sul State. The best results were obtained in those regions with higher relief variation. In flat regions, such as Pantanal, the results were poorer due to the characteristics of the method used. The methodology used represents a viable and low cost alternative to support the activities for the delineation of hydrographic basins, based on free available data and on a low cost computer program. New algorithms for the delineation of basins in flat areas can be tested in the Pantanal region to improve the results presented.

Geo-processing and remote sensing is adequate for those activities of upgrading the digital hydrographic network of the State. In spite of the difficulties found in floodable regions, the geometric accuracy, and the age of the satellite images used, a significant improvement was obtained on the quality of the digital hydrographic drainage network of the State. Algorithms for the automatic extraction of the drainage network in flat areas can also be tested in these almost leveled regions of the State to improve results.

The vector dataset resulting from the activities presented here will be disclosed by SISLA and will contribute to a more accurate management of the water resources of Mato Grosso do Sul State. The digital maps of the hydrographic network will contribute, with improved accuracy, to the analysis of river surroundings, to special consultation done by the system, to the evaluation of environmental licensing processes of the State, and especially to the definition of Permanent Protection Areas (APP) along rivers.

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