Detection of Deforestation within the Rio Verde Drainage, Sub-Basin of the Amazon, Using Multi-Temporal Analysis of Landsat Thematic Mapper and its Influence on the Hydrological Aspects of that Region

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Abstract - This paper summarizes the result of vegetation cover changes in Mato Grosso State in Amazonia, and changes on hydrological aspects of that region. The study area is the main soybean plantation area of Brazil along the Highway BR 163, in the Rio Verde Drainage. Using multi-temporal imageries of Landsat TM of the same area, alteration of vegetation cover was analyzed, performing unsupervised classification of NDVI images, together with visual interpretation. Evapotranspiration changes were also calculated using the rain gauge and discharge data of the related area. As a result, we concluded that the forest cover decreased from 76% in 1991 to 13% in 2009 and a slight decrease of evapotranspiration was also observed in the same area, in the last 30 years.

Keywords — Deforestation, Mato Grosso State, NDVI, Landsat TM, Evapotranspiration.

1. INTRODUCTION

Deforestation is a matter of concern all over the world, as a result of conversion by the National Projects in several developing countries. Monoculture of soybeans, sugar-cane, beans and maize has been carried out in large-scale in the Brazilian Amazon, recently. Mato Grosso (MT), one of the nine Amazonian States of Brazil, suffered also, a heavy conversion.

In Brazil, soybean is one of the main crops for export and its production increased the most in the last 30 years, occupying 49% of the total field crops area. Of the total area of Brazil, broad acres of soybean larger than 1000 ha is 43%, and small holdings smaller than 10 ha is less than 2.7% (IBGE, 2009).

Many county towns have been built along the main roads of Amazonia for soybean plantation in the last thirty years. They are Nova Mutum, Lucas do Rio Verde and Sorriso, among others, built along the Highway BR 163 in Mato Grosso. Sorriso, the town built 742 km North from Cuiabá, the capital city of MT, has the biggest crop area planted and harvested of soybeans of the world (Fig. 1), with 578 thousand hectares (IMEA – Instituto Mato-Grossense de Economia Agropecuária, 2005). Soy yield in Brazil increased 5% in 2010 compared to that in 2009 (USDA, 2010),
BR 163 is a 1765 km long highway linking Cuiabá to Santarém (a big fluvial connection port of the Amazon River in Pará State, northeastern Amazon), known as Soy Road. This highway is still under construction and it is paved: 98 km between Satarém and Rurópolis in Pará State, and 714 km between Guarantã do Norte and Cuiabá in Mato Grosso State (IMEA, 2005).

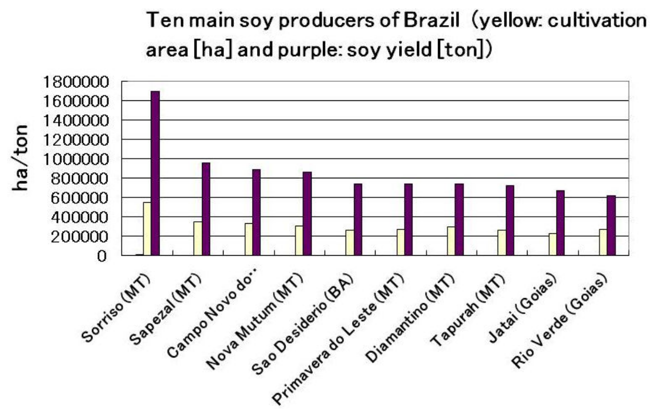

Figure 1. Sorriso (MT) is the no.1 Soy producer of the World in terms of the cultivated area. Seven out of ten main soy producers of Brazil is in Mato Grosso (MT) IBGE, 2004

This critical conversion area of Amazonia is in the Rio Verde and Rio Teles Pires drainage, and influence on hydrology is a matter of concern in that region. It is known that potential evapotranspiration is bigger from the forest compared to that from the converted area. The present study focuses on the deforestation being carried out along the Highway BR 163, which passes the cities of Nova Mutum,, Lucas do Rio Verde (Fig. 3) , and Sorriso (Fig. 2) , and find a relationship with the hydrological changes in that region.

Figure 2. Landsat 5 TM 227/69, July 28th. 2009. NDVI image of Sorriso, MT and Highway BR 163 bound for Santarem, PA. (INPE-CDSR)

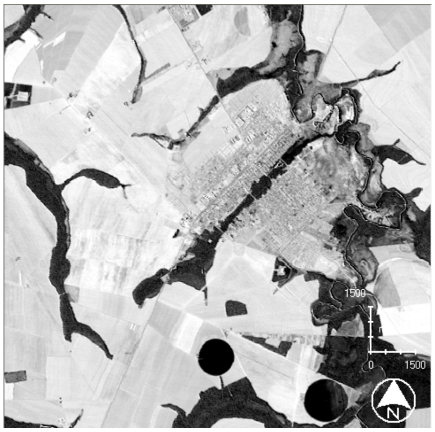

Figure 3. Landsat 5 TM 227/69, July 28th. 2009. NDVI image of Lucas do Rio Verde, MT with Highway BR 163 passing through it in the middle of the image to northeast, to Sorriso, MT. (INPE-CDSR)

According to the unsupervised classification and NDVI analysis performed to determine vegetation cover changes between August 1991 and July 2009, it was shown a significant decrease of forested areas in that region. Also, After conversion, the water cycles are interrupted by lack of sufficient water vapor. Natural forests are replaced by vegetation of lesser evapotranspiration: pasture is 1/3 of that of the Amazonian evergreen forest (Ichii and Maruyama, 2003). Deforestation is causing reduced annual rainfall and longer and more severe dry seasons. A decrease in annual rainfall and longer dry seasons are affecting the structure and composition of the remaining forest (Chagnon et al, 2005), (Marengo et al, 1998), (Marengo 2004), (Matsuyama et al. 2002).

2. DATA AND METHODS

2.1 Remote Sensing Data and Methods

The Two Landsat TM (Thematic Mapper) data are from INPE – CDSR and the following images were used for analysis: Landsat 5 TM scenes Path 227 Row 69 dated August 28, 1991(Fig. 4) and July 28, 2009 (Fig. 5).

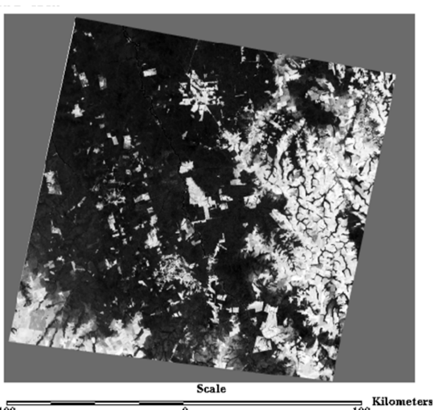

Figure 4. NDVI image of Landsat 5 TM image Path 227, Row 69 of August 28, 1991. (INPE-CDSR)

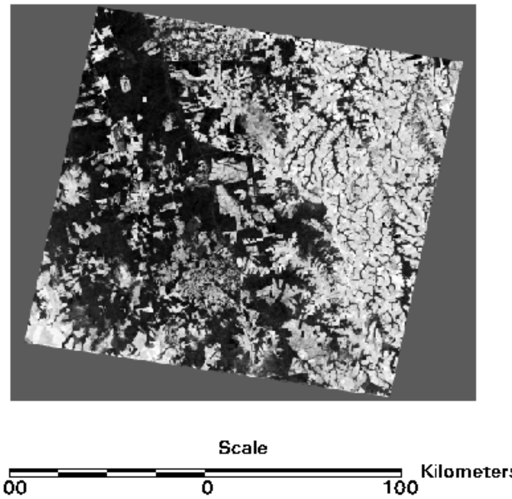

Figure 5. NDVI image of Landsat 5 TM image Path 227, Row 69 of July 28th. , 2009. (INPE-CDSR)

NDVI (Normalized Difference Vegetation Index) was used for comparing the alteration of vegetation cover, where

NDVI = (infra-red – red)/(infra-red + red). (1)

Before performing unsupervised classification (ISODATA method), the 1991 scene was resampled doing polynomial rectification (Fig. 4). For that purpose, 20 GCPs (Ground Control Points) were picked up in both imageries and taking the georeferenced coordinates of 2009 imagery as reference (Fig. 5). The relationship necessary to transform a data value in the same imagery of 1991 into its value in the image of July 2009 is

$$DN_I = a_{11}DN_A + a_{12}\,DN_B \quad DN_{II} = a_{21}DN_A + a_{22}DN_B \qquad (2)$$

Where DN_I, DN_{II} = digital numbers in 2009, DN_A, DN_B = digital numbers in 1991, a_{11}, a_{12}, a_{21}, a_{22} = coefficients for the transformation.

Categorization was used for determining water, forest, croplands, roads and urban areas. Also, deforested areas were obtained based on the summation of the cultivated areas, i.e., geometric polygons within the scenes. Each Landsat scenes were subset in 16 sub-scenes and for each of them was used measurement tool to obtain more accurate anthropogenic influences within the forests, taking as reference, the classification imagery.

2.2 Hydrologic Data and Methods

Evapotranspiration plays an important role with regard to the formation of rainfall clouds in that region. From the water balance equation,

$$P = Q - E + \Delta S \qquad (3)$$

(where P is precipitation, Q is runoff, E is evapotranspiration and ΔS is water storage (= 0), evapotranspiration can be evaluated from the observed values of P and Q. Water storage can be neglected, since ΔS in isolated years and for a long time range can be compensated mutually. As a result of anthropogenic factor, deforestation is likely to affect the local climate, turning the region drier, specially in the states of big scale deforestation such as Mato Grosso. P and Q of this Sub-Basin of the Amazon were used from the data of hydrologic stations monitored by Brazilian Water Agency (ANA). Both precipitation and discharge data were of daily basis and we calculated for each month and obtained the annual summation for comparison of different years. We tried to find out the continuous data with ten years at least and removing out the incomplete data. Even with lack of the perfect hydrologic data we could find trends of degraded features on annual average basis.

3. MULTI-TEMPORAL ANALYSIS OF IMAGES

In the present study, deforestation was detected using the variation of digital numbers of bands corresponding to the NIR (near infra red) of different sensors. As vegetation presents strong reflectance between 0.7 and 1.3μm, band four was used for reference, in order to compare images of different years to detect deforestation. Consequently, NDVI was used for analysis to check the biomass variation throughout the years 1991 to 2009.

Equation used for Landsat TM:

$$NDVI = (\text{band } 4 - \text{band } 3)/(\text{band } 4 + \text{band } 3) \qquad (4)$$

Tasseled cap conversion was also done to make clear visualization of the images during the visual analysis, for better reference. An unsupervised classification was performed using the ISODATA algorithm. This method uses the minimum spectral distance formula to form clusters, beginning with arbitrary cluster means. The means of these clusters are shifted each time the clustering repeats and the new cluster means are used for the next iteration. This sequence are repeated until a maximum number of iterations has been performed. The convergence threshold was specified as 95%, i.e., as soon as 95% or more of the pixels stay in the same cluster between one iteration and the next, the job stops processing.

4. HYDROLOGICAL ANALYSIS

The Amazonian basin is not uniform and are divided in three sub-basins: the upper Amazon, the middle Amazon and the lower Amazon basins. The present study area of Mato Grosso is in the middle Amazon basin, with the clear dry season (Fig. 6).

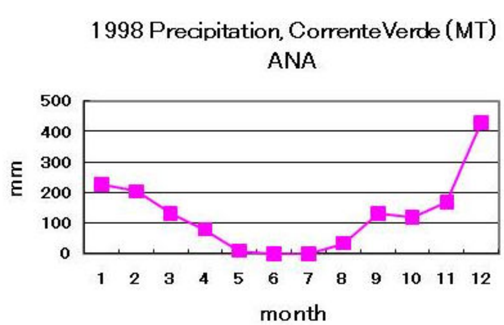

Figure 6. Annual Precipitation Trend of Mato Grosso.
Data: ANA(Agência Nacional de Águas = National Water Agency)

Decreasing trend of rainfall was observed at the hydrological stations of ANA located in Mato Grosso (Fig. 7).

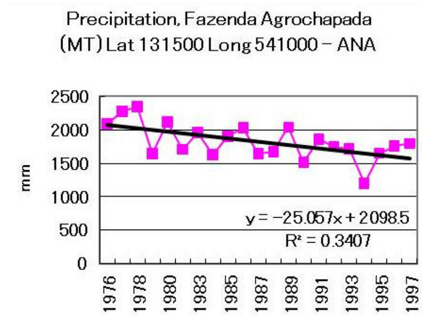

Figure 7. Decreasing trend of precipitation in Mato Grosso
Data Source: ANA

The water balance on an annual average basis was calculated using the equation (3), with dS/dt = 0. Thus, the equation (3) became

$$E = P - Q \qquad (5)$$

Runoff ratio κ was obtained with annual Q/P

$$Q = \kappa P \qquad (6)$$

In the period 1985~2009 (25 years), the average annual precipitation of the study area Porto Roncador in Sorriso County, with drainage area of 9514 km^2, was 1650.4 mm with decreasing trend (Fig. 8)

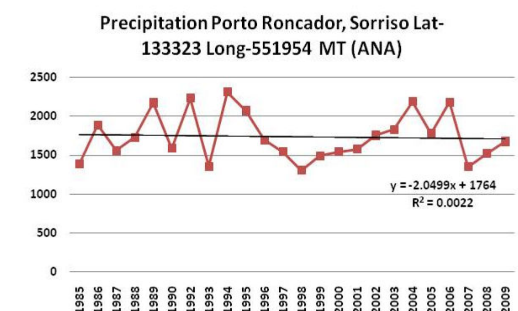

Figure 8. Precipitation of Porto Roncador, Sorriso in Mato Grosso
Data Source: ANA

As for runoff, we also used the data of Porto Roncador (Fig. 9).

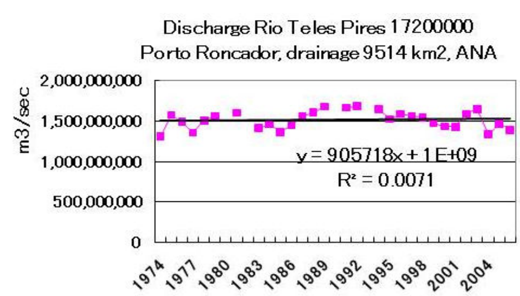

Figure 9. Discharge of Teles Pires River, Porto Roncador in Sorriso County. (Data Source: ANA)

5. RESULTS AND DISCUSSION

From the above mentioned calculation, forest cover in 1991 was 76%, whereas in 2009, it was 13% of the full scene. Soybean plantation was expanding mainly along the Highway BR 163. Compared to the 1991 scene, croplands were growing without leaving space for forests nearby the Highway in 2009, as we can see in Fig. 3.

Also, within natural forest of Landsat TM scene of 2009, we could find many clear geometric anthropogenic lines, showing the future cultivation area of some hundreds to some thousands hectares each, which was not included in our calculation of the present study (Fig. 7). If clearing takes place following those lines in the years to come, deforestation rate in that region will increase much more than presented in this study.

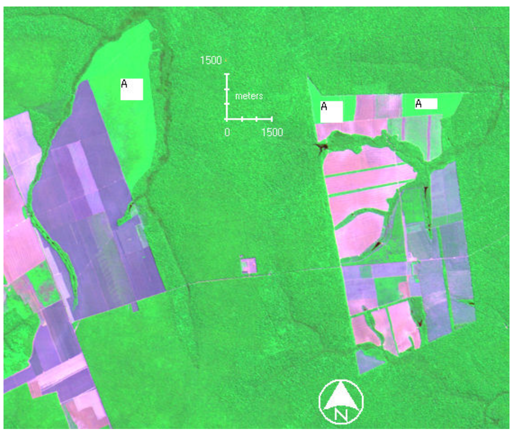

Figure 10 Expanding soybean plantation nearby Lucas do Rio Verde, MT. Landsat 5 TM image, RGB 543 Path 227, Row 69 of July 28th. , 2009. (INPE-CDSR)

From the water balance equation, applied to Porto Roncador, within the study area, we found evapotranspiration of 575.8 ~ 591.8 mm/year. Evapotranspiration of the study area in 2000's calculated from the equation above showed a decrease of 3% compared to that of 1980's.

5. CONCLUSION

The result visually shows us that the Amazonian forest in Mato Grosso is converted in large-scale, specially along paved Highway BR 163 and branches even far beyond 30 km diameter from the road, as we can see in the figs. 3and 4.

Soybean plantation in Brazil expanded 88.8% in ten years (1995-2006) (Fig.10). In Mato Grosso State, the yield between 2009 - 10 was 17.6 million tones (30% of national yield of Brazil), according to IMEA, 2009) (Fig.11).

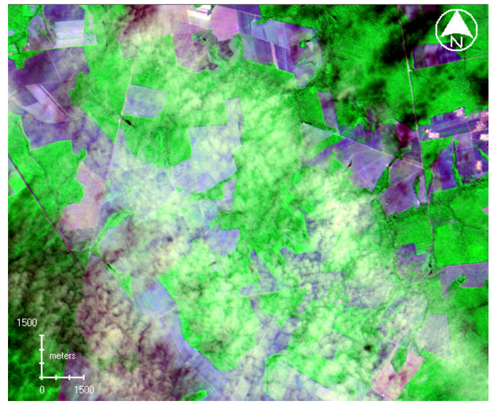

Fig.11 Forest burning for soy plantation at Lucas do Rio Verde, MT. Landsat 5 TM image, RGB 543 Path 227, Row 69 of July 28th. , 2009. (INPE-CDSR)

The present study tried to show in figures, the decreasing trend of evapotranspiration in the Brazilian Amazon, analyzing rain gauge and discharge data of ANA. In the Amazon region, real evaporation should be within the limits of 1146 ~ 1260 mm/year according to Marques et al., 1980. However, in this study, it was very low. From the calculation, we also found increasing trend of runoff rate. Deforestation is likely to affect the hydrological aspects of the region.

6. REFERENCES

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