Canopy cover and organic matter spatial distribution as indicators of soil quality for aquifer recharge

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Abstract
Maintaining perennial rivers, with water emerging in springs, is directly related to soil management, as this will determine the groundwater flow in recharge areas. Rational management in a watershed requires knowledge of several important parameters regarding the hydrology, including vegetation cover and soil organic matter (OM) amounts. The objectives of this study were to identify the existence of vegetation using the normalized difference vegetation index (NDVI) and analyze the spatial variability of the organic matter (OM) amount, in order to identify favorable points of carbon stocks and groundwater recharge in the Salto and Pitangueiras Sub-basins that are part of Jaguari River Basin. Both sub-basins are located in the county of Extrema (Minas Gerais, Brazil). For vegetation analyses, the Landsat-5 TM images acquired on Sept. 03, 2008 (INPE 2009) were used. In addition, geostatistics and kriging were performed to determine the OM spatial variability. The study area was primarily occupied by degraded pastures with dense vegetation mainly in the headwater basin. In most of the study area, there were moderate amounts of OM, with higher levels of OM in areas of high and low altitude. The study area is occupied by degraded pasture, which has less potential for carbon storage when compared to dense vegetation. Accordingly soil conservation can be impaired and thus recharging groundwater and water quality as well.

Key Words
Cantareira system, water resources, pastures, remote sensing, Atlantic forest, water producer program.

Introduction
In the southeastern region of Brazil, there is one of the largest drinking water production systems in the world (33 m^3/s); the whole reservoir system is called Cantareira. The Jaguari River Basin is the biggest tributary (22 m^3/s) for the System and for this reason it is considered a priority area for freshwater production in the country. Such regions have suffered many alterations by anthropogenic activities (69.4%). Areas covered by Atlantic Forest (native vegetation), which are essential for production and purification of water; occupy only 21% (ISA 2007). For the aforementioned reasons, the basin is part of the Water Producer Program, which aims to recover all basins with strategic importance for the nation development, through joint environmental management of water resources, land use within their ability to use and proper handling of animal production systems (livestock) and plant (agriculture and forestry) (ANA 2008). Maintaining the perennial of rivers, with water emerging in springs, is directly related to soil management, as this will determine the groundwater flow in recharge areas. Rational management in a watershed requires knowledge of several important parameters regarding the hydrology, including vegetation cover and soil organic matter (OM) amounts, consisting of the organic carbon (OC). The present study aimed to identify the presence of vegetation using the normalized difference vegetation index (NDVI) and analyze the organic matter spatial variability, to identify favorable points carbon stock and groundwater recharge in the Salto and Pitangueiras Sub-basins, part of Jaguari River watershed, which is located in Extrema County, Minas Gerais, Brazil.

Methods
The Salto and Pitangueiras Sub-basins together have an area of about 4,100 ha and are within the Jaguari River Basin in Extrema Co., MG, Brazil (22° 51'18"S, 46° 19'04"W) (Figure 1). The climate is tropical of altitude Cwb (Köppen, 1948), with an average 1,181 mm annual rainfall and 1,130 m altitude. The native vegetation is the Atlantic Forest (Figure 1). The soils found in sub-basins are Neosol, Cambisol, Red-Yellow Latosol, Red-Yellow Argisol, and Gleysol. For the vegetation analyses images from the satellite Landsat TM-5 was used. They were acquired on September 03, 2008 through the National Institute for Space Research - INPE (INPE 2009), where the image was made in the visible light (R: band 3, G: band 2, B: band 1), and the NVDI was processed using the following bands: bands 3 (red reflectance), and 4 (near infrared

reflectance) according to Rouse *et al*. (1973). Topographic effects are minimized when such index are applied, producing a linear measurement scale, which ranges from -1 (no vegetation) to +1 (high vegetation density). Information NDVI was processed using RSI-ENVI 4.5. The information network of drainage and slope were combined in ArcGIS 9.2 software in order to characterize the most degraded areas.
Soil samples were collected 47 points in the 0-20 cm depth. Organic matter was determined by hot oxidation with potassium dichromate and titration with ammonium ferrous sulfate as methodology of Raij and Quaggio (1983). The study of spatial variability and the choice of semivariogram model that best described the variability of the data were conducted using techniques of geostatistics and data interpolation by kriging, to predict and map soil organic matter amount in the region. All geostatistical analyses were made in the program through the R package GeoR (Ribeiro Jr. and Diggle 2001) and kriging in ArcGIS 9.2.

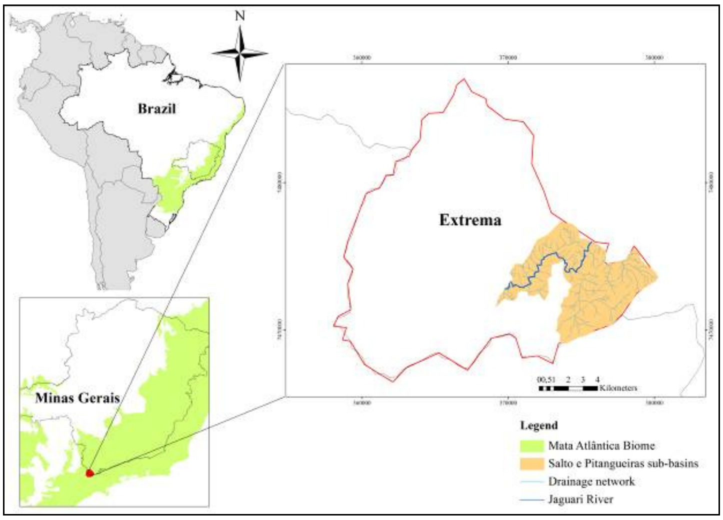


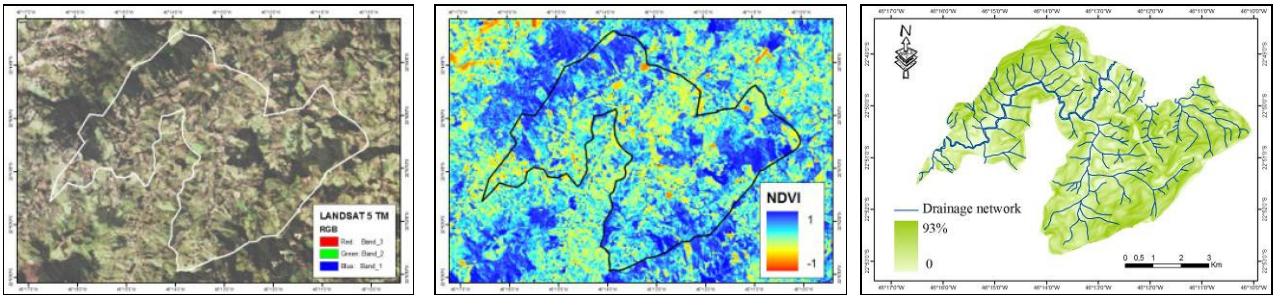
Figure 1. Location of the Extrema County in Minas Gerais - Brazil, highlighting the sub-basins studied.

Results

The RGB color composite from the amplitudes of the components 3, 2 and 1 (Figure 2a) helps in understanding land use and cover. Through that figure we can view the low vegetation cover, with large pastures use, it was also observed in the field. In Figure 2b, blue color shows areas of higher NDVI, while the cyan color shows areas of moderate NDVI and red tones indicate areas of low NDVI. The NDVI shows a vegetation from moderate to low in most of the study area (color cyan and yellow), followed by dense vegetation, i.e., with higher NDVI values. The lowest NDVI values (red areas in the map) characterize regions of exposed soil and therefore more prone to erosion. These areas, although relatively small, should be viewed carefully considering the moderate NDVI area, which can reduce or increase soil degradation depending on the grassland management (Figure 2b).

The study area was primarily occupied by degraded pasture, which undermines soil conservation, groundwater recharge, and water quality. Unlike what occurs in this kind of system, places with dense vegetation have soil that has: increase protection from the raindrop impact, increased water infiltration, level soil organic matter contents, and good soil aggregation. All these factors promote aquifer recharge. The vegetation looked at in relation to drainage and slope showed that the most areas susceptible to erosion (lower NDVI) were present along both the main network (Figure 2c), which were in the flatter areas (Figure 2c), and in the higher, steeper areas, where the highest degradation was observed. The dense vegetation was found mainly in the headwater area, however the worst soil degradation was also observed in these areas. In the more rugged topography areas the elimination of vegetation leads to a further advancement of erosion as when compared to the less steep areas. These NDVI results for grassland are important, considering that for this type of vegetation the index variation was not as intense during the year (Victoria *et al.* 2009) and can be used as a good indicator for the conservation conditions of soil and water.

The Table 1 and Figure 3 give the soil organic matter distribution for the study area. The OM ranged from 17.7 to 57.4 g /kg being classified as low to good. Only 0.1% of the area had low OM, 92.41% had moderate amounts, and the remainder 7.49%, were classified with good amounts of OM (Ribeiro *et al.* 1999). The presence of this attribute is very important as mitigate the raindrops impact, preventing compaction and splashed soil, altering pores distribution, facilitating water infiltration, and therefore creates favorable conditions for aquifer recharge (Junqueira Jr. *et al.* 2008). Comparing the OM and altitude maps, there are high amount of organic matter in both areas. Soil OM for higher altitude as the lower value, occurred possibly due to lower temperatures and oxygen restriction due to excess of water, respectively. It is noteworthy that the low areas the soil organic matter amounts were even more significant.



(a) (b) (c)

Figure 2. (a) Images from LANDSAT - 5 TM, composition of the visible spectrum RGB 321; (b) NDVI, (c) slope and drainage network, of the Salto and Pitangueiras Sub-basins in Extrema County, MG.

Table 1. Distribution of organic matter (OM) in the studied area.

Classes	Area	
g/kg	ha	%
< 20.0	3.93	0.10
20.0 – 30.0	747.48	18.20
30.0 – 40.0	3,047.17	74.21
> 40.0	307.56	7.49
Total	4,106.14	100

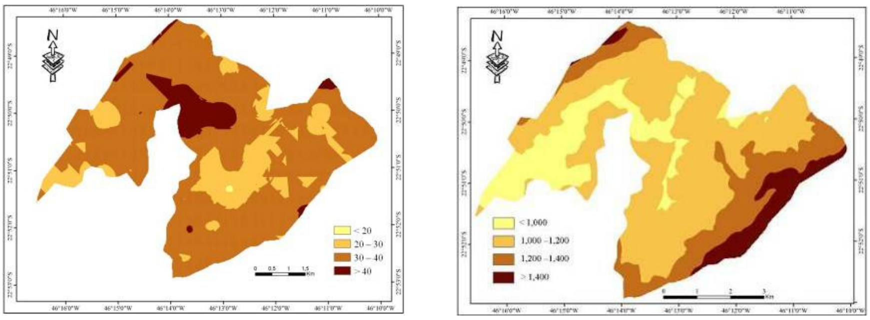


Figure 3. Spatial distribution of OM (g/kg) and altitude map (m).

Conclusion

The study area was primarily occupied with degraded pasture, which undermines soil conservation, groundwater recharge and water quality. The dense vegetation occurred mainly in the headwater basin. The OM had a moderate amount in most of the area, with high OM amounts in areas with higher and lower altitudes. The locations of dense vegetation, and where the organic matter amount was higher, indicated favorable points of carbon stock and aquifer recharge.

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