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GEOSPATIAL ANALYSIS OF REFLECTANCE AND NDVI VALUES IN THE ANGELINA FOREST ECOSYSTEM*

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ABSTRACT

The aerial photographs and subsequently remote sensed imagery have been used for decades in classified landcover mapping, forest inventory, management, and evaluation of renewable resources. However, the implementation of geostatistical methods in remote sensing is of a newer date. In this study the variogram modeling is used to analyze the spatial structure of a forest canopy. The biomass and wood production can be evaluated in the studied area using NDVI (normalized difference vegetation index) values and kriging. The study area is located within the Angelina National Forest in the Neches River Basin. The Angelina Forest is an important part of the East Texas Ecosystem and plays a significant role in all aspects of the natural and industrial development of this region including timber production, forage, wildlife, recreation and as a water resource.

1.0 INTRODUCTION

The visual inspection of remote sensing images reveals general patterns of natural resource phenomena. The systematic analysis of remote sensed imagery, however, can significantly contribute to the understanding of forest ecosystems assisting in the identification of forest types, age of stands, forest density, crown size, understory and even biomass volume. The majority of the previously mentioned characteristics of the forest ecosystem may indicate a spatial dependence. Therefore, they can be classified as regionalized variables in terms of Matheron (1963). If this is true then variogram modeling can be used to identify the spatial structure of a forest ecosystem that is inherent to remote sense images (Curran and Atkinson, 1998). The association between the remote sensing data, vegetation and geostatistical methods is of a newer date (Dungan, 1998; Atkinson, Webster, and Curran, 1992). This trend will continue to rise due to the strong presence of spatial dependence in the biosphere that is reflected in the remote sensing imagery as a continuous matrix or raster of reflectance values.

2.0 DATA AND METHODOLOGY

In this project Landsat 7 ETM data from East Texas are used to analyze the forest canopy in the Angelina Forest (Figure 1). The original data contain six layers in 30 m resolution: blue, green, red, NIR and two in moisture infrared wavelengths. The NDVI (normalized difference vegetation index) was calculated in ERDAS Imagine 8.3.1 using the following equation: NDVI = (NIR – Red)/ (NIR + Red). Then the NDVI values were stretched to 8 bit (0 – 255). The NDVI values were resampled from 30 meter resolution to 40 m, 50, and 60 meter to study the effects of resolution on determining and evaluating the structure of forest canopy using geostatistics and remote sensing imagery.

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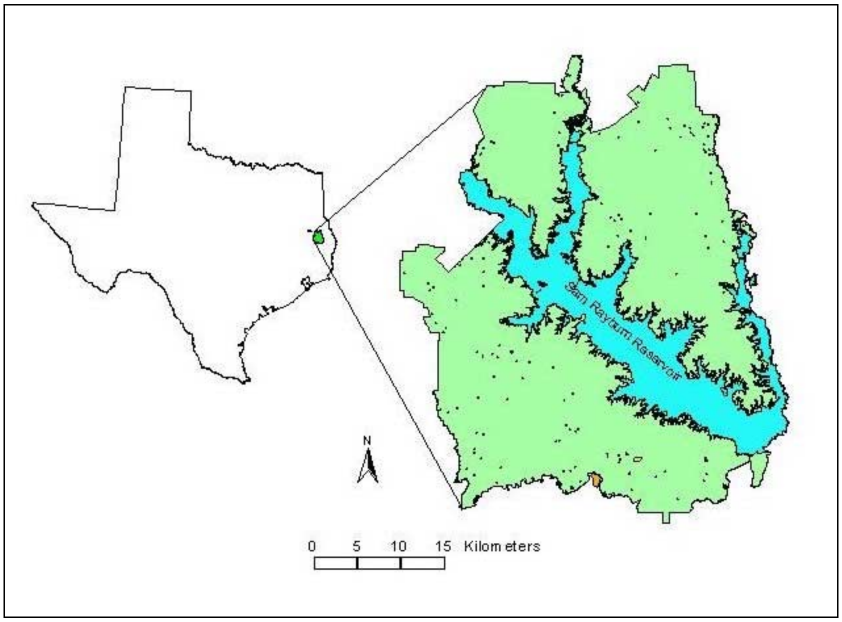

Figure 1. Location of the Angelina Forest in Texas

The objective of this study is to apply variogram modeling to remote sensing data from two different forest stands (pine plantation and hardwood) in the Angelina Forest. A variogram is derived from the moment of inertia and depicts the strength of relationship between pairs of spatially distant measurements. Therefore, the variation between measurements separated by a lag distance can be modeled using a variogram equation (1); where Z is the random variable such as reflectance values from remote sensing images or NDVI data, etc.

$$\gamma(h) = \frac{1}{2N} \sum_{i=1}^{N} \left[Z(x) - Z(x+h) \right]^2 \qquad (1)$$

The variogram appears to be an effective tool in analyzing canopy structure (Cohen, Spies, and Bradshaw, 1990). In this project the omnidirectional variograms were calculated for DN and NDVI values using a) transect and b) matrix values. The biomass can be evaluated using kriging in a GIS environment based on a two-type variogram modeling (transect and matrix). Kriging is a linear unbiased estimator that offers a minimum error variance (Isaaks and Srivastava, 1989). In this project an ordinary kriging procedure will be used to evaluate the biomass in Angelina Forest in two different forest canopy structures. This analysis will allow a comparison of biomass productivity between the pine plantation stands and the naturally occurring hardwood forest in Angelina National Forest.

3.0 PROCEDURE AND RESULTS

The close association of remote sensing data with the forest stand characteristics can be evaluated using image texture and image pattern. The texture refers to the frequency of tonal change (grain size) and ranks from fine to coarse. Fine texture is frequently associated with young stands whereas the coarse texture reflects old forest canopy. The pattern reflects the arrangement of textural components and ranks from uniform to clumpy. The previous one is associated with younger stands and the latter with older forest stands. The age of forest stands can be determined also using image contrast properties. The high range values are typical for older growths whereas younger stands have lower contrast (Cohen, Spies, and Bradshaw, 1990).

Both characteristics (texture and patterns) were studied on the east west transect line. The image was imported to the Arc/Info grid module and two transect lines were selected in each group (hardwood and pine plantation forest). The results indicated a clear difference between the pine and hardwood stands. The contrast in brightness values is significantly higher in the hardwood area. This property is well documented on the digital ortho-photo data with one-meter resolution (Figure 2).

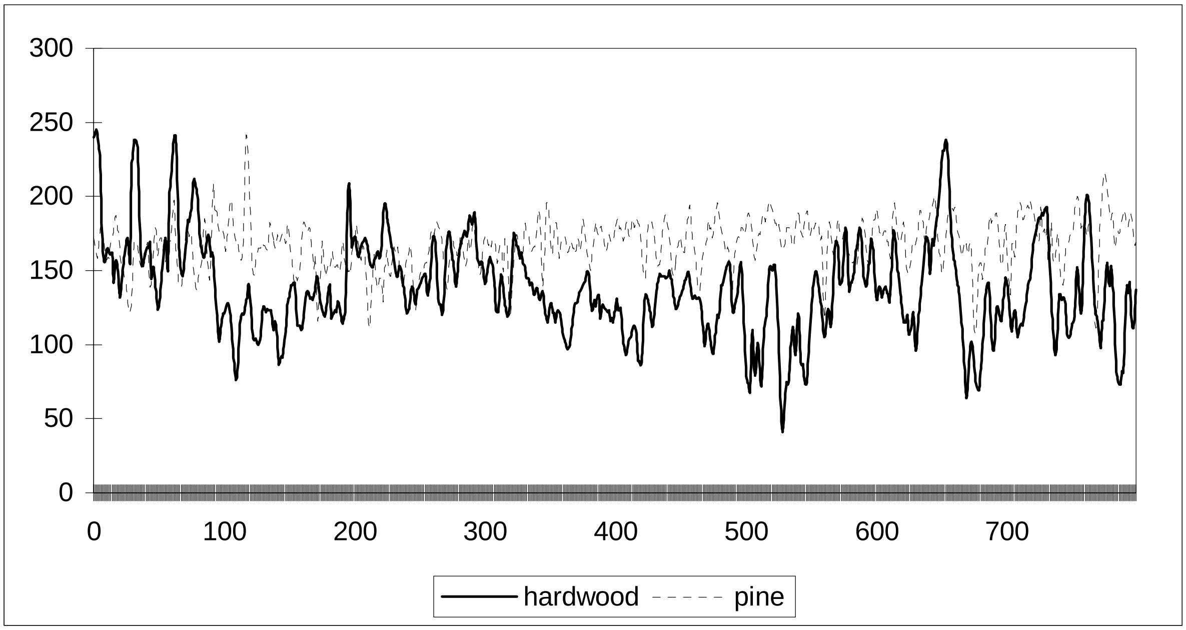

Figure 2.Variations of Digital Values Along the Transect Line

The peaks and depressions are significantly greater in the case of hardwood stands. The peaks depict individual tree crowns that have higher reflectance values as shades between them. Also the gaps and peaks are wider which is related to the age of the stands. The older trees are larger and have more space between them. Pine stands on the other hand indicate less contrast on the transect line, i.e. the differences between the high and low reflectance values are smaller and the gaps between trees are also smaller. This is due to the fact that the pine stands are younger than the hardwood forest. Another important aspect of red band one-meter DOQQ (digital ortho-photo quarter quadrangle) was that hardwood stands have, in general, lower reflectance values than pine stands and there is also a general trend from west to east. The hardwood reflectance values are the same or even higher in the west but dropped significantly below the reflectance of pine stands in the eastern part of the studied area. This pattern is even more conspicuous in the infrared and panchromatic bands of the satellite image. The reflectance values for hardwood stands are significantly higher in the western part and drop below the reflectance values of the pinewood stands in the east (Figure 3). Satellite imagery, however, has a coarser resolution (15 meters for panchromatic band and 30 meters for the near infrared band) and is not able to depict individual trees and spaces between them but rather overall clumps and vegetation subunits inside the forest ecosystem. As the figures (3 and 4) indicate the reflectance values in panchromatic and near infrared bands vary more rapidly than in the pine stands. Hence the texture and pattern of different stands can be indicated also at the lower resolution level and the major trends in the forest ecosystem can be easily determined.

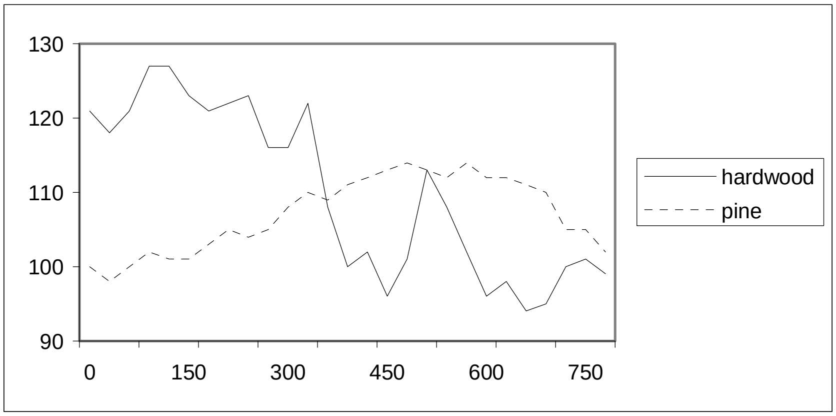

Figure 3. 30-meter Resolution Near Infrared Values Along the Transect

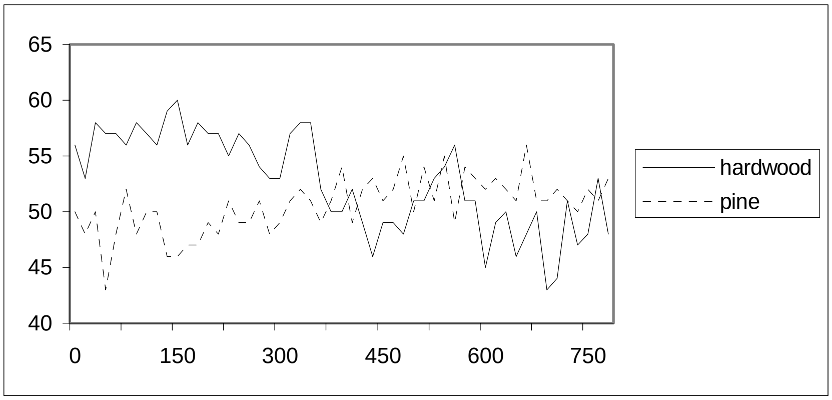

Figure 4. 15-meter Resolution Panchromatic Values Along the Transect

As it was indicated earlier, NDVI values (normalized difference vegetation index) are useful in making inferences about biomass volume in forested ecosystems. The analyses of NDVI values along transect lines indicated similar behavior as it was in the case of the reflectance values mentioned above. However, the NDVI curve is smoother and does not change as rapidly as the previously described reflectance values (Figure 5). Nevertheless, at 30 meter resolution NDVI values for hardwood were higher than NDVI values for pine in the western part of the area. On the contrary, the NDVI values for hardwood dropped below the pine in the eastern site indicating potentially lower biomass volumes of hardwood in the eastern part of the Angelina Forest. In addition, the contrast in NDVI is much larger in the eastern part than in the west for hardwood stands. The NDVI contrast for the pine stands is much smaller than for hardwood stands. This is corroborated by explanatory statistical parameters such as variance and the coefficient of variation. The variance in the near infrared reflectance values for hardwood stands is five times larger than the corresponding variance for the pine stands and the coefficient of variation determining the variation of reflectance values in the near infrared band is significantly higher than for pines, i.e. 0.1 and 0.04 correspondingly. This situation, however, is exactly opposite when NDVI values are considered; the variance in pine stands is higher than in hardwood stands, but the variation around the mean value is almost the same (0.03 and 0.04 consequently). Therefore, NDVI values vary similarly in the hardwood stands as they vary in the area occupied by pine stands. In addition, the correlation coefficient was calculated between the near infrared values and NDVI values for both pine and hardwood stands. The results indicated that at 30 meter image resolution the reflectance values in the near infrared band are highly correlated with NDVI values (0.87). However, the corresponding correlation for pine stands was significantly lower (0.62). This relationship suggests (Figure 6.) that the near infrared reflectance values indicate also a higher biomass volume in the hardwood forest ecosystem and, if used, they will significantly enhance the corregionalization model for spatial evaluation of biomass in this area.

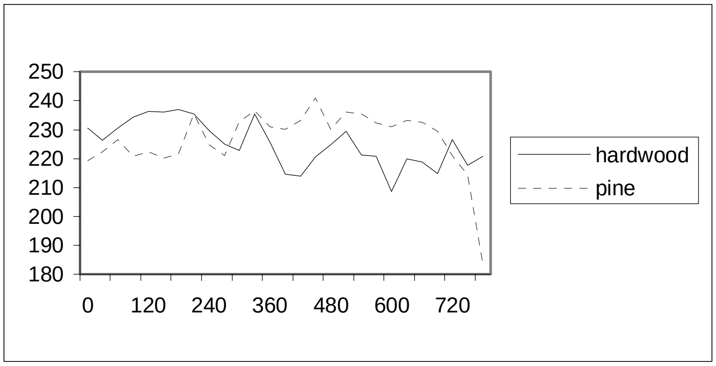

Figure 5. Variation of NDVI values Along the Transect Line

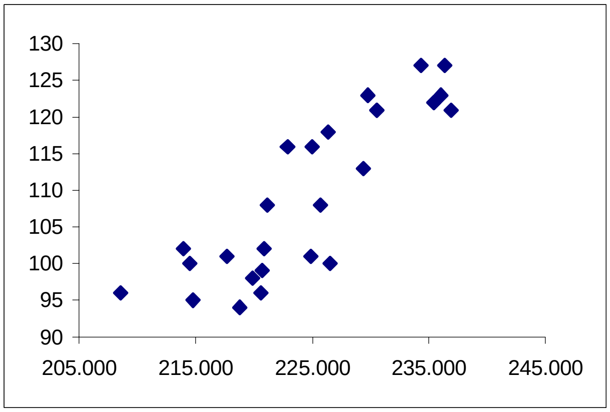

Figure 6. Correlation between Near Infrared and NDVI values in hardwood stands

The same relationship was investigated using panchromatic 15 m resolution data. It appears that the reflectance values for the hardwood stands correlate well with NDVI values; the correlation coefficient is 0.7. In contrast, the reflectance values in the panchromatic band indicated no relationship with NDVI values. Therefore, panchromatic values also contributed to the understanding of forest structure in clearly distinguishing between the hardwood and pine stands.

3.1 VARIOGRAM ANALYSIS

A number of studies noted the usefulness of variography in remote sensing applications. For example: Cohen et al. (1990) analyzed conifer canopy structure using variograms, Curran and Dungan (1989) determined the optimal spatial resolution for the remote sensing study of conifer canopy plantations, Dungan (1997) used variogram modeling and kriging to predict vegetation quantities and Atkinson et al. (1992) used cross-variography and cokriging to estimate and map vegetation properties. A variogram has three major characteristics that are useful in determining the spatial structure of studied phenomena: a) sill, b) range and c) nugget effect. The detail information about variogram and variogram properties can be found in Isaak and Srivastava (1989) or Goovaerts (1997). In this study the variograms were constructed and fitted to reflectance and NDVI values. The relationship between the range and sill of semi(variograms) and the stand characteristics was documented in Cohen et al. (1990). The coarser resolution of the remote sense imagery (30 meters) was not suitable for the estimation of the tree crown sizes using the range of variogram. The variogram range for hardwoods was 500 and for pine stands it was 388 meters. This indicates that the spatial continuity is greater in hardwood stands and the overall hardwood stand consists of vegetation subunits about 500 meters large. However, the variogram constructed from digital ortho-photo data (one-meter resolution and red band) elucidated also the individual tree structure in the stands. The variogram range for the hardwood stands is larger (10-15 meters) than the variogram for the pine stands (5 meters). Hardwood stands are older and the average tree crown diameter is approximately 10 meters (Figure 7).

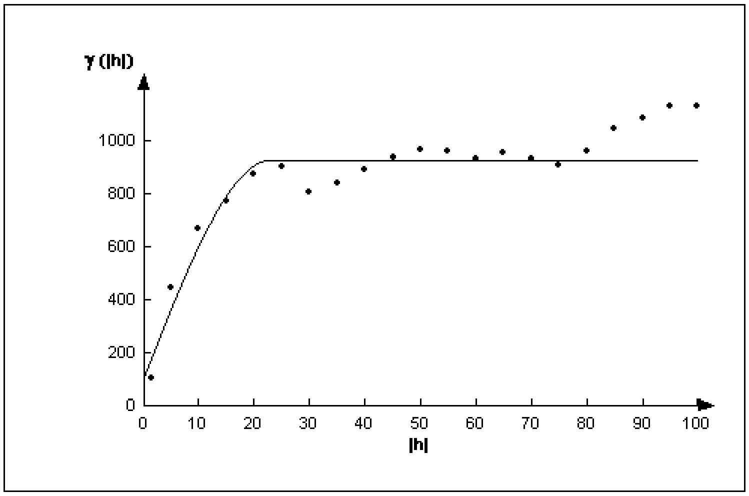

Figure 7. One-meter Resolution Hardwood Variogram from DOQQ

Young trees with the average tree crown size smaller than five meters represent the Pine plantations. The hardwood variogram has also a typical periodic pattern. This periodicity indicates repetitive spatial pattern, i.e. clumps of trees alternating with open spaces along transects. The length of the period is approximately the same as the range of this variogram. On the other hand, the pine variogram has a smooth shape of sill indicating a typical plantation scenario with young trees planted at equal distances (Figure 8). Even though the impact of variogram regularization is evident in terms of the range of variograms, the difference between the variograms constructed from the transects and matrix of data are not significant. The sill of variogram is another significant parameter depicting the structure of forest ecosystems. The size of sill is associated with the contrast of the imagery. Generally, the young stands have a smaller contrast in reflectance values and correspondingly variograms have lower sills (Cohen et al., 1992). Canopy layering, the percent of canopy cover and the age of trees are also related to the height of the variogram sill. Higher variogram sills reflect multilevel layering in older growths and a higher percentage of canopy cover. Hardwood stands in the Angelina Forest are older with a higher canopy cover and more layers in the stands. Thus the variogram sill for transect variograms is approximately 900 from DOQQs data (1 m resolution), whereas the variogram for pine stands from DOQQ has sill only 240 DN^2.

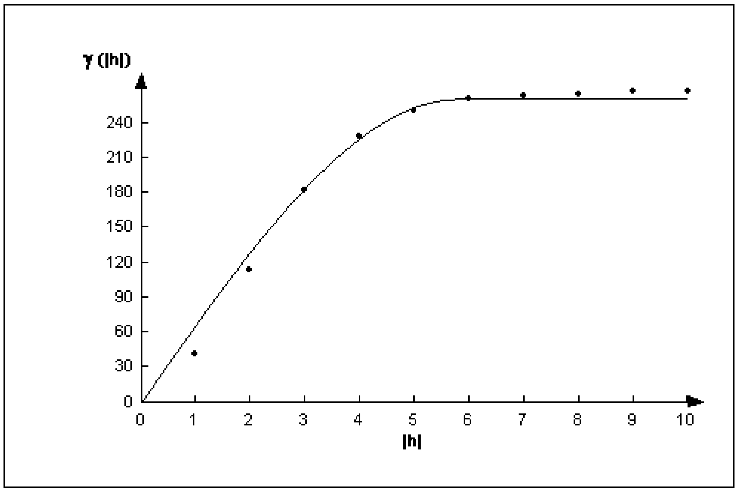

Figure 8. One-meter Resolution Pine Variogram from DOQQ

Similarly, the transect variograms for a 30 meter resolution near the infrared band indicate sill of 300 in hardwood case whereas only 40 DN^2 for the young pine plantation (Figure 9). The pine variogram fit was 40Gaussian(388.74/h). This relationship was confirmed from matrix variograms that were constructed using near infrared data (70 vs 25) and even panchromatic data (35 vs 9 DN^2). Hence panchromatic data appeared to be also useful in determining the structural differences in the Angelina Forest ecosystem and corroborated the results obtained from the analysis of near infrared or red band data. The nugget effect of (semi)variograms determined the short scale variations and random noise in the data. Theoretically, the variogram should pass through the zero value. This was the case for the majority of variograms.

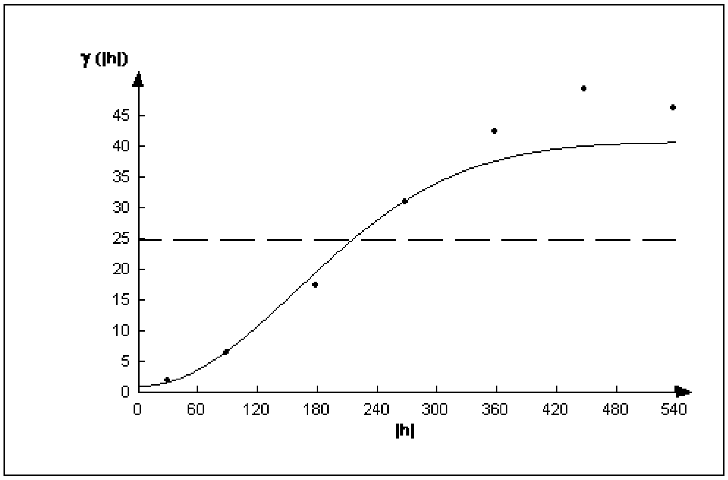

Figure 9. Pine Transect Variogram from NIR 30 m Data

The largest nugget effect was found for matrix variograms of 30 meter resolution (near infrared data) and the pine panchromatic transect variogram. This can be attributed to the presence of more than one spatial distribution in the studied area in the first case and the nature of panchromatic data and sudden changes in monotonous texture of pine plantation. The variogram modeling of NDVI values indicated also a difference between the pine and hardwood stands. While the sill was exactly the same for both stands the range was significantly greater for the pine plantation than for the hardwood forest.

4.0 CONCLUSION

The geospatial analysis of remote sensed data appears useful in determining the structural differences in forest ecosystems. The vegetation properties including biomass, LAI, canopy cover, age, layering are spatially autocorrelated and therefore can be modeled by geostatistical methods. The variograms play a key role in determining spatial dependence. They capture the underlying functional relationship that controls the spatial pattern and distribution of vegetation phenomena. In this project the structural differences between the two major components of the Angelina Forest Ecosystems (hardwood stands and pine plantations) were revealed and characterized with the help of geospatial analysis and remote sensing data. Such analysis can lead to accurate estimates of biomass in the Angelina Forest, which plays significant role in the East Texas ecosystem. The geographic location on the border of the Atlantic Forest and Southwest Desert Ecosystems underlines the importance of this analysis for maintaining a healthy and harmonically balanced environment.

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