MONITORING OF DESERTIFICATION PROCESSES THROUGH TREND ESTIMATES OF TIME SERIES

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KEY WORDS: Desertification, Classification, Time Series, Remote Sensing, Estimation Methods, Linear Regression, Quadratic Regression

ABSTRACT:

In the world, the desertification is an ecological and environmental issue, which is dealt in a serious manner. The causes are related to climatic changes, deforestation, mining, too much cultivation, inappropriate irrigation, among others. Therefore, a solution capable of monitoring and even to estimate its development trend is important for studies and environmental intervention. This work has a goal to present a model capable of carrying out this task, by using estimation methods on temporal series of images. A sequence of Landsat images has been used to validate the model. In addition, maps were created to cover the land to monitor the desertification process evolution in the city of Barreiras in the Piauí State - Brazil.

1 INTRODUCTION

Desertification is recognized as one of the most serious social-economic-environmental issues in arid, semi-arid and dry sub-humid areas, and in the whole world, about two billion are affected (Xu et al., 2009). However, one of the main obstacles in order to combat this problem has been the lack of robust assessment methods, which they should identify the political action priorities and management to monitor the impact of such actions, and to create an understanding about the factors that lead to desertification (Diez and McIntosh, 2011).

Due to the great importance given to the desertification issue in recent years, many studies have been performed and aiming to develop indicator systems for identifying and monitoring areas in which may suffer from this kind of problem. However, there is a major challenge to be overcome: develop and improve the knowledge on the subject, in order to achieve the conditions for a quantum leap towards a specific methodology for the desertification study (Matallo Júnior, 2001).

The monitoring and study about the future behavior trend of the degraded areas by desertification processes are important for implementation of public policies, which they are aiming in controlling the development of such processes.

In this context, the goal of this work is to monitor the desertification processes, trying to estimate their future behavior. To do so, estimation models of temporal series based on Linear and Quadratic Regression Methods have been used. The satellite Landsat TM (Thematic Mapper) has provided a sequence of images for the years in 1998, 2001, 2004, 2007 and 2010, which they were submitted to the algorithms developed to validate them.

2 DESERTIFICATION

The United Nations Conference on Environment and Development of 1992 defined the desertification as being the degradation of land in arid, semi-arid and dry sub-humid areas, resulting from several factors, among them, the climatic changes and human activities (UN, 1992).

Identify the desertification causes is a complex process, since the factors pointed out as the main originators of this degradation are the most varied, such as: climatic changes, deforestation, predatory exploitation, extensive cultivation, industrialization and urbanization (Sheikh and Soomro, 2006). Such changes lead to an excessive pressure on natural resources and the adoption of survival strategies that consume the resources by using the land, whose immediate causes are the inappropriate use and the soil degradation, loss of vegetative diversity and biological, affecting the structure and the ecosystem function (ME, 2004). Thus, the desertification process study is important to aid in the measure preparation that will control their effects. In addition, the fast identification of areas with these trends may reduce the consequences of such processes.

3 ESTIMATION METHODS FOR TEMPORAL SERIES

3.1 Linear Regression

The Linear Regression is a relation model between a dependent random variable y and an independent variable x. The goal is to find a straight line that fits in the observations as far as possible (Alves et al., 2009). The Linear Regression function is shown as it follows:

$$y = a + bx + e \tag{1}$$

where y is the dependent variable; x is the independent variable; a and b are the ordered par (or intercept) and inclination, respectively and e is the error came from the random feature of y.

The equation adjusted to the linear regression model is given by the equation 2, where: (x, y) correspond to the pixel coordinates of interest; $I_1(x, y, t)$ represents the pixels gray level of each sequence in the t-esima trial, or observation; t=1,2,3,...,n is the time independent variable; the subscript 1 indicates that a linear adjustment between two successive sequences of images has been used to calculate the extrapolation of a future time after the second sequence; a_1 represents the regression coefficient (angular coefficient); and, finally, b_1 represents the linear coefficient.

Thus, a_1 and b_1 represent the adjustment parameters of the linear regression in time.

$$I_1(x,y,t) = a_1(x,y)t + b_1(x,y) \qquad (2)$$

Therefore, to find an image extrapolated in time by using linear regression, it is necessary to have a sequence in a given period of time - which corresponds to the initial instant of time (t=0) and another sequence in a posterior point in time. It is also necessary to determine the values of a_1 and b_1. For this reason, b_1 can be defined by assuming that t is equal to 0 (zero) in equation 2. Similarly, a_1 can be estimated by the equation 2, assuming that t corresponds to the posterior period of time corresponding to the second sequence, and replacing the value of b_1.

3.2 Quadratic Regression

Quadratic regression is a relation model between a dependent random variable y and an independent variable x. The goal is to find a parabola that fits in the observations as far as possible (Alves et al., 2009). The Quadratic Regression function is shown as it follows:

$$y = a^2 + bx + e \qquad (3)$$

where y is the dependent variable or explained; x is the independent variable or explanatory; a, b and c are parameters the quadratic equation and e is the error came from the random feature of y.

The equation adjusted to the quadratic regression model is given by the equation 4, where: t=1,2,3,...,n is the independent variable of time and $I_2(x,y,t)$, in the same manner that $I_1(x,y,t)$ represents the pixels gray level of each sequence in the t-esima trial, or observation, in the same way, (x,y) are related to the pixel coordinates of interest; However, the subscript 2 indicates that a quadratic polynomial adjustment (of order 2), among three successive sequences, has been used to calculate the extrapolation of a future time after the third sequence; a_2, b_2 and c_2 are quadratic regression parameters and represent the adjustment parameters of the quadratic regression in time.

$$I_2(x,y,t) = a_2(x,y)t^2 + b_2(x,y)t + c_2(x,y) \qquad (4)$$

To find an image extrapolated in time by using the quadratic regression, it must have a sequence in a given period of time, which corresponds to the initial instant of time (t=0), and other two sequences in posterior time instants being different. It is also necessary to determine the values of a_2, b_2 and c_2. And to do so, c_2 can be defined by assuming that t is equal to 0 (zero) in equation 4. To define a_2 and b_2, it must to solve the linear system that is formed when they replace the different posterior time instants in equation 4 that are associated with the samples known from the temporal series in these periods of time, and replace the value of c_2 in them.

4 RELATED WORK

The most part of the works that investigate the desertification process by means of remote sensing images using techniques capable of assessing the degradation state of the vegetation and, generally, they follow three main tiers.

The first one deals with methods related to the identification and assessment of the desertification processes. The second one, in turn, deals with methods aimed to monitor the evolution of such processes. And the third one proposes some methods to estimate the evolution of the desertification processes.

Among the works that present identification methods of areas affected by desertification, we have the work of Kasimu and Tateishi (2010). In their study, data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor have been used in 2008 to map the vegetation dynamics in the Xinjiang region, in China. The goal was to generate a land cover map, and then, identify areas with of desertification risks.

In Liu (2005), the authors intend to monitor the evolution of the areas affected by desertification processes. They proposed an indices'system suitable to the desertification monitoring in large scale by using remote sensing techniques. The study area covered five countries: Uzbekistan, Tajikistan, Kazakhstan, Turkmenistan and Kyrgyzstan.

In addition to identify and monitor areas that are affected by the desertification process, some studies have been proposed to try to trend estimation in the evolution of such processes. A method based on Geographic Information System (GIS), Remote Sensing and model Cellular Automaton (CA) was submitted by Ding, Ding, Chen and Wang (2009) to simulate the spatiotemporal evolution of the desertification in Bashang and in the neighboring areas at the province of Hebei, in China.

The literature review indicates that many studies have used satellite images to study the desertification processes. Thus, this paper proposes the use of estimation methods of temporal series to monitor such processes and follow the evolution trend.

5 METHODOLOGY

5.1 Study Area

The city of Barreiras, located in the southwest of the state of Piauí, Brazil, covering an area of 1.954,8 km^2 has been chosen as the study area for this work. In Barreiras and in other cities in the Piauí as Gilbués, Monte Alegre do Piauí and São Gonçalo do Gurgueia, there is a large soil area, which is in the degradation process, and it began with the agriculture of subsistence and the wildfire practice. This process has been aggravated by the diamond discovery in that region in the mid 1940s, when many mines were opened and explored (Carvalho and Almeida Filho, 2007).

5.2 Data Used

For this study, a sequence of images of the Landsat TM from 1998 until 2010 was used to estimate the evolution trend of the desertification process in Barreiras. It is shown in Table 1 the information about the images, such as the reference year, date, scene and the bands used.

Year	Date	Scene	Bands
1998	14/08/1998	220/66 and 220/67	3, 4 e 5
2001	21/07/2001	220/66 and 220/67	3, 4 e 5
2004	13/07/2004	220/66 and 220/67	3, 4 e 5
2007	07/08/2007	220/66 and 220/67	3, 4 e 5
2010	15/08/2010	220/66 and 220/67	3, 4 e 5

Table 1: Landsat Images

5.3 Pre-processing of Remote Sensing Data

The remote sensing images are often acquired with noises that may jeopardize temporal analyzes. Thus, some pre-processing techniques have been applied make them suitable for use.

At first, the images of each year were georeferenced and radiometrically normalized. The next step was to extract the Normalized Difference Vegetation Index (NDVI) of the image sequence previously pre-processed. NDVI is an index which allows identifying the vegetation existence on the surface and to characterize their spatial distribution, as well as identify its evolution over time. In addition, the images corregistration were also done to assess the algorithm effectiveness before and after the application of this technique (SILVA et al. , 2009).

Then, to reduce the computational limitations of image processing, it has been selected a cut-off point in the images. This way, they were applied to the images corregistration techniques and the application of Linear and Quadratic Regression methods. The cut-off area is shown in Figure 1.
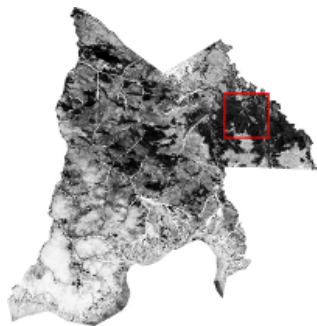

Figure 1: Cut-off area of the NDVI image in the city of Barreiras

5.4 Image Extrapolation by Linear and Quadratic Regressions

Aiming to check the efficiency and performance of the proposed algorithm, the same algorithm has been applied to sequences of known images. Thus, the sequences from 2007 until 2010 were extrapolated, using the linear and quadratic regression methods defined by equations 2 and 4, respectively.

Therefore, to extrapolate the sequences of images using linear and quadratic regression, it must use two and three sequences of previous images, respectively. Thus, to extrapolate the 2007 sequence using the linear regression method, were used the 2001 and 2004 sequences. In turn, to extrapolate 2007 using the quadratic regression method, were used the 1998, 2001 and 2004 sequences. In the same way, to extrapolate the 2010 sequence using linear regression, were used the 2004 and 2007 sequences, and for the quadratic regression, were used the 2001, 2004 and 2007 sequences. And, finally, to extrapolate 2013 using linear regression, were used the 2007 and 2010 sequences.

5.5 Classification

Finally, in order to produce thematic maps of the degraded area, it has been used the Terraview plugin called Geographical Data Mining Analyst (GeoDMA) to carry out the classification process of NDVI images in the city of Barreiras (Korting, 2009). The segmentation process used the Region Growing algorithm (Bins, 1996) with the similarity and area values, respectively, 4 and 8. In addition, the classification process used the decision tree algorithm C4.5 (Quinlan, 1993).

And, at the training stage of the classification algorithm, some regions have been selected to represent the classes: exposed soil, dense vegetation and degraded vegetation. Thus, it was possible to assess the degradation evolution process from 1998 until 2010. Furthermore, it was also estimated the classification of soil degradation in 2013.

For this study, were created three thematic classes: exposed soil, degraded vegetation and dense vegetation. It is shown in Figure 2 each one of them.
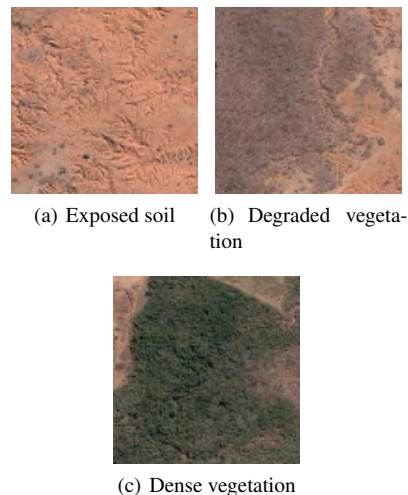

(a) Exposed soil   (b) Degraded vegetation

(c) Dense vegetation

Figure 2: High resolution Quickbird images showing the thematic classes

6 RESULTS AND DISCUSSION

To calculate the similarity level between the real image and extrapolated, it has been used an image processing library ProEikon (Kim, 2011). This library has a software named DistG, which calculates the difference between two images in gray scale, allowing quantifying numerically the accuracy of the generated images. Among other estimators, we have the Mean Absolute Error (MAE), which in statistics, is a magnitude used to measure how closes the forecasts and predictions are in relation to the final results, in addition to being a common forecast error measure in temporal series analysis. The MAE can assess the error between estimated data by numerical extrapolation and the real data. It is represented by equation 5, where x_i is the real value and y_i corresponds to the estimated data and n represents the assessment total number considered in the forecast.

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |x_i - y_i| \qquad (5)$$

Tables 2 and 3 show the output values after the implementation of DistG algorithm, where the table columns represent the regression method used, and the lines represent the different images used (before and after corregistration) and the cells content shows the value of the MAE obtained (the maximum value is 100%). Table 2 shows the analysis results performed on the real image in 2007 and its extrapolations by linear and quadratic regression methods, respectively. With a simple analysis on these tables, it is possible to notice that the linear regression method has a better result than the quadratic regression method.

Table 2 shows the analysis results performed between the real image in 2010 and its extrapolations by linear and quadratic regression methods. According to results, once again, the linear

	Linear Regression	Quadratic Regression
Before coregistration	9,5%	12,1%
After coregistration	7,8%	8,8%

Table 2: MAE (%) calculated to 2007 and its extrapolated images, before and after coregistration

regression method achieved better results when compared to values found using quadratic regression method. In addition, it is important to notice that both tables show that the results obtained were higher after of the images coregistration.

	Linear Regression	Quadratic Regression
Before coregistration	7,9%	8,9%
After coregistration	6,0%	7,6%

Table 3: MAE (%) calculated to 2010 and its extrapolated images, before and after coregistration

Since the linear regression method and the coregistration data have obtained better results, they have been used to estimate the 2013 behavior. Figure 3 shows the image obtained by the linear regression method after coregistration technique for 2013.
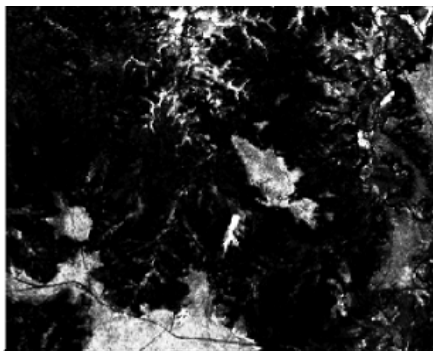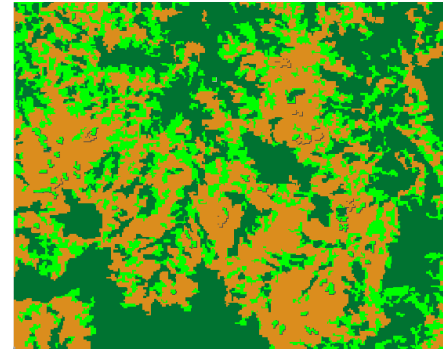

Figure 3: Extrapolation of the year 2013 by linear regression

After the end of the image extrapolation process, a temporal analysis has been carried out between 1998 and 2010 to assess the desertification process evolution in the selected area.
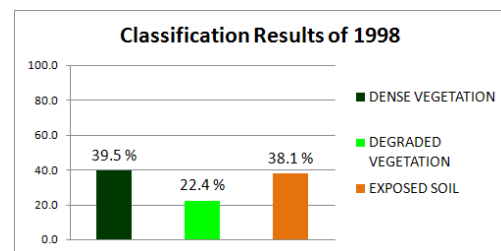
Figure 4(a) shows the result obtained after the classification process applied to the image in 1998 and the Figure 4(b) presents a graph showing the percentage of presence in the thematic classes separately.

Figure 5 shows the result obtained after the classification process applied to the image in 2010 and a graph with the percentage of thematic classes. According to results between 1998 and 2010, it has been detected that there was an increase of 7.6% in the exposed soil class. In turn, the degraded vegetation decreased 0.5% and the dense vegetation decreased 7.1%.

Finally, the image estimated by linear regression method in 2013 was classified. The results are shown in Figure 6. According to classification result when compared to 2010, the trend is that the exposed soil is reduced to 3.8%. In turn, the degraded vegetation class tends to increase by 2.3%, and dense vegetation class tends to increase by 1.5%.
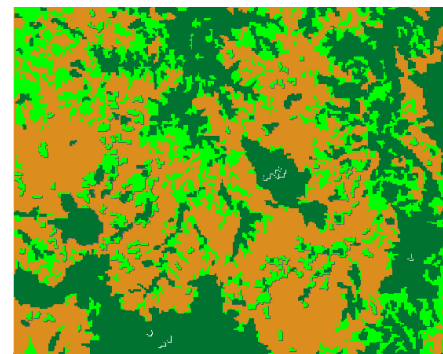
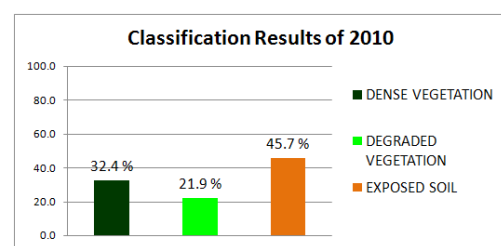

(a) Soil cover map in 1998

(b) Percentage of Thematic classes in 1998

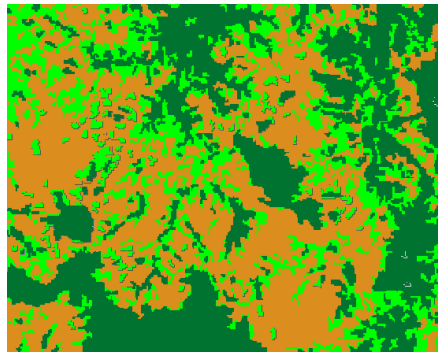Figure 4: Classification results in 1998

(a) Soil cover map in 2010

(b) Percentage of Thematic classes in 2010

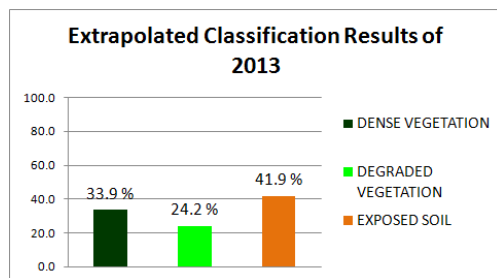Figure 5: Classification results in 2010

7 CONCLUSIONS AND FUTURE WORK

Estimate the future behavior of the desertification processes is an open question and is an extremely important area, due among other things, to the fact that it can help in the implementation of public policies to control and avoid this process. To perform this task, this work has proposed estimation techniques of temporal series using linear and quadratic regression methods.

When calculated in both methods, the errors shown in Tables 2 and 3 reveal that the linear regression method is more suitable to temporal series' estimation of images, since the errors are lower if compared to other ones using quadratic regression method.

(a) Soil cover map in 2013

(b) Percentage of Thematic classes in 2013

Figure 6: Classification results of the extrapolated image in 2013

According to results obtained in Section 6, the reached conclusion was that the images' projection using linear regression techniques is a viable alternative to monitor and estimate the evolution trend of the desertification processes. In addition, it has been noticed that the corregistration applied the temporal series has a very important effect in images' estimation, since the results after the corregistration application were better if compared to results found in the images without using this technique.

However, it is important to point out a limitation in the use of NDVI, taking into account that it is an index sensitive to the four seasons, besides other factors. Thus, it is important that the image sequence may be acquired in the same period of one year. Otherwise, the results will be affected. This is a limiting factor; since not always is possible to have appropriate images to conduct studies on a given area in a given period.

ACKNOWLEDGEMENTS

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