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Dynamic modeling for simulation in the sandification process in Western Rio Grande do Sul, Brazil

[1]Emanuel Araújo Silva, [2]Elisiane Alba, [2]Juliana Tramontina, [2]Pierre André Bellé, [2]Anelisa Pedroso Finger, [3]Rudiney Soares Pereira

[1]Department of Forest Sciences, Federal University Rural of Pernambuco, Recife – PE, Brazil.
[2]Postgraduate in Forestry Sciences, Federal University of Santa Maria, Santa Maria, RS, Brazil.
[3]Department rural engineering, Federal University of Santa Maria, Santa Maria – RS, Brazil

Address For Correspondence:
Emanuel Araújo Silva, Department of Forest Sciences, Federal University Rural of Pernambuco, Rua Dom Manoel de Medeiros, s/n, Dois Irmãos, 52171-900. Recife. Brazil.
Phone: +55(81) 981067514; E-mail: emanuel.ufrpe@gmail.com

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ABSTRACT

Background: The intensification of degradation of native vegetation have contributed to the infertility of the soil in the south of Rio Grande do Sul states, Brazil, generating arenization processes. One of the techniques that can contribute to the understanding of the sandy patch process is the dynamic modeling, which over time, has excelled in forestry, biology, geography, among others. **Objective:** This study aims at application of a model to simulate the sandification process in the microregion of Campanha Ocidental, Rio Grande do Sul, from the land use maps from 1996 and 2011. **Material and Methods:** To obtain the land use maps, was used Landsat 5/TM images, and these were georeferenced and processed in the SPRING software. Posteriorly, these maps were inserted in the Dinamica EGO software, together with the geophysical and socioeconomic variables. To reach the parameters of probabilistic model analysis of the dynamics of sandification process, was held the calculations: of percentage of class change through transition matrices; of tracks for discretization of continuous variables and the evidence weights. After, was held the correlation analysis between the weights of the input variables for all transitions, allowing simulation of future scenarios. **Results:** The constant decay function yielded indexes ranging from 0.620 to 0.925 pixels in different windows, while the exponential decay function defined ratios ranging from 0.549 to 0.660. The expected results for 2026 indicate that the sand will decrease from 0.37% in 2011 to 0.33% in 2026 and its concentration in the Northeast and around the drainage Ibicuí River. **Conclusion:** This model was adequate to understand the sandification process in study region, allowing simulations of future scenarios considering the variables encompassed in the study.

INTRODUCTION

The increase in world population and demand for food that meet the need of mankind, caused the man to transform the environment and expand the agricultural borders. It is true that man besides being the most causative agent of degradation, can also be a conservation agent. But uniting the economic, social and environmental factors, equally, in a community that increasingly needs food, still a challenge for the present civilization, because the economic factor is always priority.

After the industrial revolution, increasing consumption of food and raw materials for the industry caused significant changes in land use and cover. Such changes lead to many problems inherent to each region, in a way, transformed the quality of life in communities handicapping their coexistence with the environment where they live.

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It is important to relate the survival of communities with the understanding of the resources that are associated with a landscape as it is determinant for the development of solid foundations on three levels: cultural, social and economic. Changes in the dynamics of land use and land cover has been the focus of studies (Latip *et al*., 2015; Rawat & Kumar, 2015; Vignesh & Thyagharajan, 2015), which aim to demonstrate the change processes of the natural landscape, contributing to possible mitigation measures. In this context, it highlights the Southwest of Rio Grande do Sul, more precisely in the micro region of Western Campaign, set in the region of the Pampas that comes over time suffering from the process called sandification (Silva, *et al*. 2014).

Which has intensified due to the expansion of soybean, rice and overgrazing, causing soil degradation and infertility of "campeira" landscape. Several authors have discussed about the process of sandy "desertification", and observed different views on the subject. Marchiori (1995), whose thinking is shared with Suertegaray (1995), defends the natural genesis of sand. On the other hand, authors such as Lamb and Smith (1975) and Souto (1984) believe that the origin of sandy patch process is linked to land degradation, having its origin in human activities linked to overgrazing and poor land use. Currently, there is a consensus that natural conditions and agricultural activities interact and contribute together to the emergence or intensification of soil degrading processes (Ab'saber, 1995; Suertegaray, 1995).

One of the techniques that can contribute to the understanding of the sandy patch process is the dynamic modeling, which over time, has excelled in forestry, biology, geography, among others. The purpose of dynamic modeling is to simulate spatio-temporal changes in environmental attributes tied to a geographic territory. Its design allows the understanding of the influential mechanisms that determine the shift function and thus assess how a system evolves on a set of circumstances defined by the modeler (Benedetti, 2010).

In geoprocessing, a key challenge is to develop methods that allow modify essentially static systems, tools capable of representing the reality of space-time process. In this case, the dynamic modeling seeks to transcend the current limitations of this technology, still heavily based on a static and two-dimensional view of the world. This research constitutes the application of a model to simulate the dynamics of sandy desertification patches process in the southwest of Rio Grande do Sul, called microregion of Campanha Ocidental, for the year 2026.

MATERIAL AND METHODS

This research was conducted in Mesoregion Southwest of the Rio Grande do Sul, where it operates the microregion of Campanha Ocidental, located between latitudes 27º56'37 " S and 30º33'41 " S and between longitudes 54º42"7 " W and 57º41'28 " W, covering the cities of Alegrete, Barra do Quaraí, Garruchos, Itaqui, Maçambara, Manoel Viana, Quaraí, São Borja, São Francisco de Assis and Uruguaiana (Silva, *et al*., 2014). In 2010, the population of this region was estimated at 364.249 inhabitants, with a density of 11.70 inhabitants / km² and HDI of 0.768 (IBGE, 2010). According to Müller Filho (1970), geologically this region is part of the sandstone-basaltic province with lithologies arranged in sequence, with basalt little thick, is characterized by lithological formations Botucatu (sandstone) and Serra Geral (basalt) (Suertegaray, 1998).

According to Köppen, the climate of the region Southweast is classified as Cfa, humid subtropical without dry season and average temperatures ranging from 14.3 ° C in winter to 26.3 ° C in summer, averaging annual rainfall of 1400 mm (Moreno, 1961). The wind speed in the region ranges from mild in autumn-winter and intense in spring-summer (Souto, 1984; Suertegaray, 1998). The relief of this region is gently undulating to flat areas, due to the geological wear, comprising a lower flat surface, which contrasts with the silicified sandstone plateaus of the regional landscape (Souto, 1984).

Geology is formed, especially for areas of Botucatu sandstone, which characterizes the fragility of the soil and the presence of grasses that provide low average coverage, with the fields to physiognomically resembling steppes (Medeiros *et al*., 1995). Rovedder (2007), points out that the vegetation of the region is strongly influenced by soil characteristics, with a predominance of grasslands that provide scarce coverage, like the poaceae. Together with grassland, sparsely distributed, occurs shrub of twisted conformation, similar to savannah vegetation. Along rivers and streams occurs riparian forest. There are also large tracts of planted pine and eucalyptus forests.

The creation of the database and the processing of the images were made with SPRING (Sistema de Processamento de Informações Georreferenciadas) version 5.2.1). The methodology process steps of georeferencing, segmentation, classification and mosaic was defined for Silva, *et al*. (2014). The reliability of digital classification of land use and land cover was evaluated using the confusion matrix of the areas of training that have been classified by applying the Kappa coefficient.

The simulation model was composed of dynamic and static variables. As dynamic variables, the thematic maps of land use and cover were used land for the years 1996 and 2011. As static variables, road maps, hydrography, hipsometry geology, slope, urban population concentration, rural population concentration, per capita income, gross national product, sheep and cattle on the study area. The vector maps listed above were converted to raster format and edited to contain the same spatial resolution, number of rows and columns and the same coordinate system.

The spatial dynamic modeling itself, corresponds to four stages: construction, model calibration, validation and simulation for future scenarios. All steps were carried out in Dinamica EGO software in version 2.4.1. For the construction and calibration of the model, were defined the historical transitions matrices, which indicate how the use and land cover classes vary in two different moments of time. Obtained at this stage the multiple step and single step matrix, which have, respectively, the transitions occurring annually and transitions occurring throughout the study period, which in this case is 15 years elapsed between the years of 1996 to 2011.

Through the weighing of evidences method, based on Bayes' theorem of conditional probability, which adopted by Dinamica EGO, transition probabilities were established with reference transitions rates calculated in the previous step. Resulting of this process a skeleton file evidence´s weight, used as input for the calculation of coefficients.

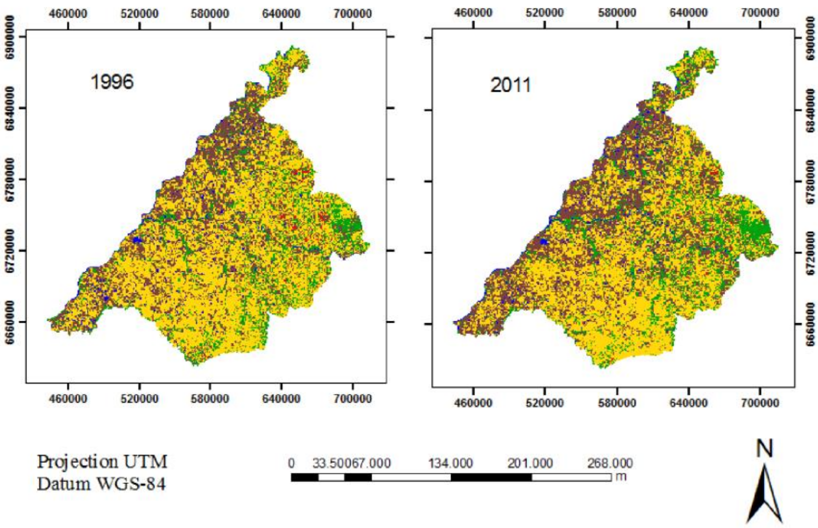
The method of Evidence´s weights assumes that the input maps should be spatially independent. Thus, to evaluate the correlation of the variables two indexes were used the Cramer index and the Join Information Uncertainty. As a requirement for the selection of variables remaining in the model, a correlation criteria of 0.5 was defined. Therefore the variables that correlated above 0.5 were discarded, in a range of zero to one, the variables are fully independent when its value is zero and completely dependent when it is equal to one.

The simulation model of change of land use and cover classes, was defined from the patcher and expander algorithms, incorporated into the Dinamica EGO, plus the variance of the changing area calculated thru the change´s map and isometrics index. By varying the input parameters, tests were performed to obtain the most appropriate model.

The acceptance of the model was carried out through its validation, which occurred by the fuzzy similarity comparison test between the simulated map of 2011 and the reference map to the same date. This test is an adaptation of fuzzy similarity index developed by Hagen (2003) for application in Dinamica EGO software, and uses exponential decay and constant decay functions (Soares-Filho *et al*., 2009), which were assessed in study. The closer to 1, the higher the similarity between the maps.

RESULTS AND DISCUSSION

A Thematic maps of land use and cover generated by the Landsat 5 image classification for the years 1996 and 2011 describe the quantification of land use and cover classes found to the assessed periods, in hectare and percentage, respectively, are represented in Figure 1. The accuracy rates of classifications - kappa index- for the years 1996 and 2011 corresponded to 0.9986 and 0.9972, respectively. By the qualification presented by Landis & Koch (1977), the accuracy rates are considered excellent.



Legend	1996 Area (ha)	1996 (%)	2011 Area (ha)	2011 (%)
Water	82,273.41	2.67	80,997.49	2.63
Forest	420,624.37	13.67	437,403.04	14.22
Agriculture	822,481.69	26.73	991,585.94	32.23
Field	1,734,035.50	56.36	1,555,366.89	50.55
Sands	17,357.61	0.56	11,419.22	0.37

Fig. 1: Thematic maps of land cover use generated by the Landsat image classification, for the years 1996 and 2011.

Assessing the classification results, there is a trend of increasing forested areas in the study area over the reported period, as well as increase of agricultural areas, which may be related to government tax incentives, improving and modernization of production, linked to the decrease in field areas. The water coverage diminued during the study period. This result is associated with rainfall in the region during the study period. Sand patch class showed a decrease over time. Much research is being carried out, as well as reforestation and investments of private companies, which corroborates Suertegaray (1987), that evaluates this phenomenon as a natural occurrence, but that could suffer anthropogenic influences, both for its increase as to decrease.

Agriculture and Field classes were those that had the highest values in hectares throughout the study period. Over time, these two classes showed an inverse relationship in which the extent that the increased areas of agriculture, the field areas were reduced considerably. This relationship is a global trend, due to new agricultural areas, to meet the population needs.

Based on the rates obtained in the transition matrix, we proceeded to the second stage of model calibration, the selection of the variables that constitute the model. The choice of variables was made through the evaluation of Cramer Score and Joint Uncertainty, indicating the spatial dependence between variables. In this relation, were taken out from the model static variables because they had Cramer Index (V) and the Joint Information Uncertainty (U) greater than 0.5. The variables that showed higher values of these indexes were urban population, sheep population and road, to all land use and cover change.

At this stage, we defined the parameters for the patcher and expander algorithm. After some testing to get the expected result, visually comparing land use changes during the period, the following parameters were obtained: 6.25, 6.25 and 1.8 for Mean patch size, Patch size variance and Patch isometry, respectively, in which the first two parameters are defined by the unit area hectare, and isometric ranges from 0 to 2. Finally, the simulation was done. The maps of the spatial distribution of sand areas in the years 1996 and 2011 and the predicted scenario for the year 2026 in Western Campaign of Rio Grande do Sul, are showed in Figure 2.

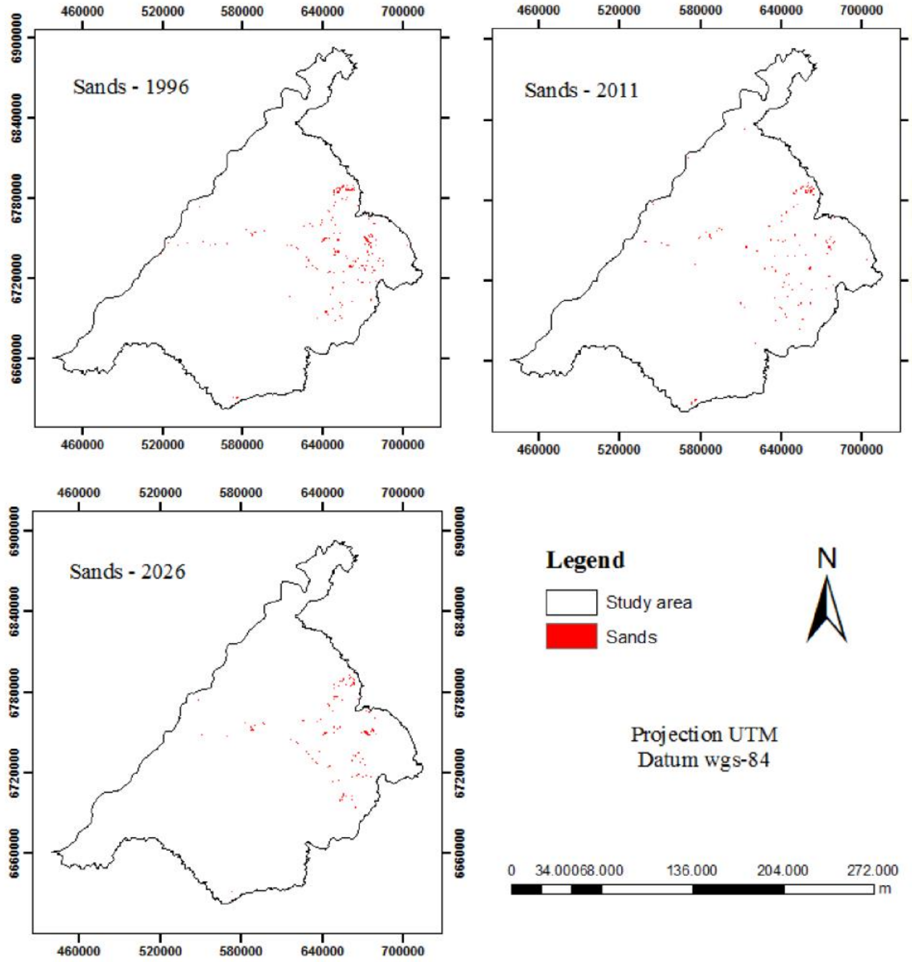


Fig. 2: Spatial distribution maps of sand patches in the years 1996 and 2011, and the predicted scenario for the year 2026 in Western Campaign of Rio Grande do Sul.

The similarity indexes in constant and exponential decay function obtained from the fuzzy method in evaluating the results of the final simulated map. The constant decay function yielded indexes ranging from 0.620 to 0.925 pixels in different windows, while the exponential decay function defined ratios ranging from 0.549 to 0.660.

Rossetti *et al*. (2013) found values between 0.57 and 0.71 in the windows 3 x 3 and 9 x 9, evaluating changes in land use in urban areas using the dynamic spatial modeling by cellular automation. Macedo *et al*., (2013) making dynamic spatial modeling of coverage and land use changes related to sugarcane expansion, found values of 0.52 for 11 x 11 windows size.

Table 1 quantify each class for the year 2026 simulation conducted by Dinamica EGO. About sandy sail patches, Trinidad *et al*. (2008), analyzing vegetation of Southwest of Rio Grande do Sul under grazing and grazing exclusion, concluded that the exclusion of grazing determines greater vegetation cover and diversity, compared to grazed, and the natural vegetation under grazing is more susceptible to sandy patch process.

Table 1: Quantification of use and land cover in Western-RS Campaign, in hectares, and their respective percentages predicted for the year 2026.

Years	Sand Area (ha)	Percentage of the total area (%)
1996	17,357.61	0.56
2011	11,419.22	0.37
2026	10,043.75	0.33

Andrades Filho *et al*. (2008), identifying neotectonic deformations through SRTM images, and its relationship with the genesis of the sand areas in the south west of Rio Grande do Sul, has identified that there are possible points of neotectonic anomalies near the areas of sand pockets. This indicates a relationship between the anomalies and sand areas, therefore there is possible that uplift and or sinking by failure, exposing the sandstone and the consequent level erosion base, before uplift, trigger the process of sandification. Ravines and gullies are the genetic elements of the formation of sand and the base level of search is just the intensification of erosion.

According Suertegaray *et al*. (2008), studying the morphostructural influence in the genesis of sandy desertification processes in Rio Grande do Sul, considered that given the relationship between the structural lineaments with the provision of drainage, orientation of the strands and the occurrence of sand, there is a possibility that these variables are strongly associated with soil structure in that region. The sands of the study area are concentrated in small portions around the terrain hydrography, in areas of rugged topography and geological feature of Botucatu sandstone.

Conclusion:

The Dinamica EGO software made possible simulate scenarios of future predictions in the study area, stating the intensity and location of changes in sandification process for the year 2026 in a satisfactory manner. Model created proved to be an efficient tool in monitoring the sand transitions processes. The expected results for 2026 indicate that the sand will decrease from 0.37% in 2011 to 0.33% in 2026 and its concentration in the Northeast and around the drainage Ibicuí River.

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