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Wind Speed Seasonality in a Brazilian Amazon-Savanna Region from the Global Land Data Assimilation System

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ABSTRACT

The objective of this study was to develop a methodology for the use of remote sensing data for the planning of wind energy projects in Maranhão. Monthly wind speed and precipitation data from 2000 to 2016 were used. Initially, wind velocity data were processed using the principal component analysis (PCA) technique. Next, the grouping technique known as k-means was used. Finally, a linear regression analysis was performed with the objective of identifying the parameters to be used in the validation of the data estimated by the Global Land Data Assimilation System (GLDAS) base against the data measured by the meteorological stations. Four homogeneous zones were identified; the zone with the highest values of monthly average wind speeds is in the northern region of the state on the coast. The period of greatest intensity of the winds was identified to be in the months of October and November. The lowest values of precipitation were observed during these months. The analyses carried out by this study show a favorable scenario for the production of wind energy in the state of Maranhão.

Keywords: Energy planning; Environmental modeling; Remote sensing

1 INTRODUCTION

Knowledge of the potential for energy production from wind speed generates information to help plan the possible establishment of energy generation projects. This is because the lack of information on favorable climatic conditions that is necessary to identify areas with greater wind potential is the main difficulty in the implementation of wind-based power generation plants.

Wind energy is considered a source of clean and renewable energy, because, unlike other leading energy resources in the world matrix, it does not release pollutants into the air during its generation. Furthermore, its natural resources (winds) are never exhausted by

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use; they can be continuously consumed without fear of depletion. It is worth mentioning that they contribute to a reduction in the emission of greenhouse gases, though they present economic risks related to the climatic variations. (FEITOSA *et al*., 2018).

Since ancient times, man has used energy to promote his own well-being and development. Without the exploitation of energy resources, it would not have been possible to achieve and build the world and society we live in today (Norman, 2018). The massive use of energy resources has become relevant since the industrial revolution. This is when, with the beginning of the use of the first steam engines, the first industries were born, and they began to use fossil fuels more intensively.

The world we live in today is intrinsically connected by a social, political, and economic environment related to the use of energy. The exploitation of energy resources, especially fossil fuels, has created new problems around the world, such as pollution, global warming, and the greenhouse effect, etc. These reasons are forcing current policies to change in the sector so that the use of fossil and non-renewable fuels is reduced, while the use of renewable resources is encouraged. (NORMAN, 2018)

The earliest records of the use of wind energy to produce electricity are from the late nineteenth century. The use of wind energy involves technology that transforms the kinetic energy of winds into electrical energy. The use of wind energy is a viable strategy that has gained worldwide popularity from the outset to the present day. International competition, coupled with years of improvement in manufacturing, research, and development, has resulted in advances in wind turbine efficiency, cost reduction, and increased production. In particular, wind energy is seen as the most promising source of renewable energy due to the benefits it offers and the production of energy from the movement of air masses that are inexhaustible (PREM 2018).

Winds comprise molecules of air that are in motion, and are caused by the rotational and translational movements of the Earth as well as by the variation of atmospheric pressure resulting from changes in the Earth's surface temperature (STEFAN 2018).

Wind behavior varies according to the geographic characteristics of each region, such as the terrain's relief, climate, latitude, and longitude. Because of this, an in-depth study is necessary to aid in the decision-making process regarding the wind power potential of a region (PREM 2018).

Wind energy is considered a source of clean and renewable energy because, unlike other leading energy resources in the world's energy matrix, it does not emit pollutants into the air during its generation, and its natural resources are not exhausted by its use. In addition, the implementation of wind power plants gives rise to socioeconomic development through tourism, job creation, and the increased income of the affected communities.

The objective of this work was to identify the homogeneous zones related to the potential of wind energy production in the state of Maranhão, using remote sensing techniques.

2 METHODOLOGY

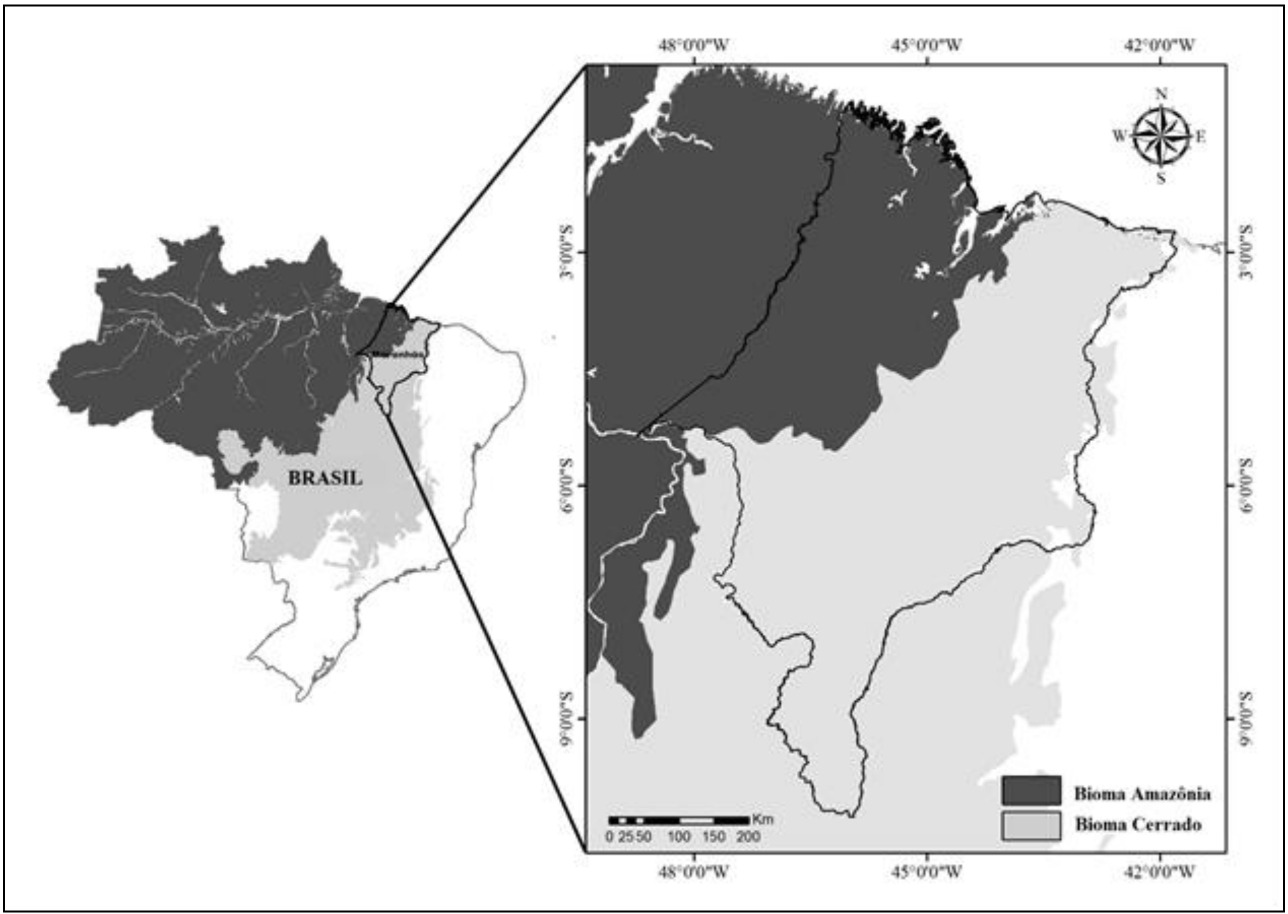
1.1 Study Area

The state of Maranhão is located in the extreme west of the Northeast of Brazil and in the extreme east of the Amazon Basin (Figure 1). The state is home to a transition area between the Cerrado and Amazon biomes. This area demonstrates high climatic variability, as well as a great deal of internationally recognized biodiversity, because it houses three RAMSAR sites (SILVA *et al.*, 2016). A RAMSAR site is a wetland site designated to be of international importance under the Ramsar Convention.

Regarding climatic diversity, the state exhibits a warm and humid tropical climate to the northwest, typical of the Amazon region. In the Southeast, the region is marked by a warm and semi-humid tropical climate. The vegetation reflects the transitional aspects of the climate and soil conditions of the region between the Amazon (wet) and Northeast (semi-arid) regions. Varied ecosystems have developed because of these transitional features—from coastal environments with mangroves and flooded areas, to the dense ombrophilous forest that is characteristic of the Amazon (FEITOSA *et al.*, 2018).

According to the National Energy Balance of 2016, 19.59% of the electricity generated in Maranhão comes from hydroelectric plants, 80.40% is from thermoelectric plants, and 0.01% is obtained from solar energy, sugarcane bagasse of sugar (biomass), and diesel oil. Regarding the energy generated by fossil sources, the state highlights its production of natural gas (EPE, 2016).

Figure 1 - Study area highlighting the location of the state of Maranhão in a transition area between the Amazon and Cerrado biomes



1.2 Data Acquisition, Processing and Analysis

The monthly wind speed data used in this study were obtained from the Global Land Data Assimilation System (GLDAS) database provided by the National Aeronautics and Space Administration (NASA). The data comprises 204 images as a time series over 16 years (from 2000 to 2016) with a monthly temporal resolution, and a spatial resolution of 0.25°. The validation of the data was carried out through conventional meteorological stations provided by the National Institute of Meteorology (INMET).

A principal component analysis (PCA) was performed on wind speed data in order to reduce the dimensionality of the data and to represent the maximum spatial variability. The first image from the PCA was used to perform a cluster analysis technique known as k-means, to generate an image which is zoned according to the different classifications (homogeneous zones) of the speed of winds (FEITOSA *et al.*, 2018). This classification was necessary because the wind speed data exhibited maximum spatial variability.

From the zones identified in the cluster analysis the monthly mean wind velocity and precipitation were calculated, thus generating the time series of each zone.

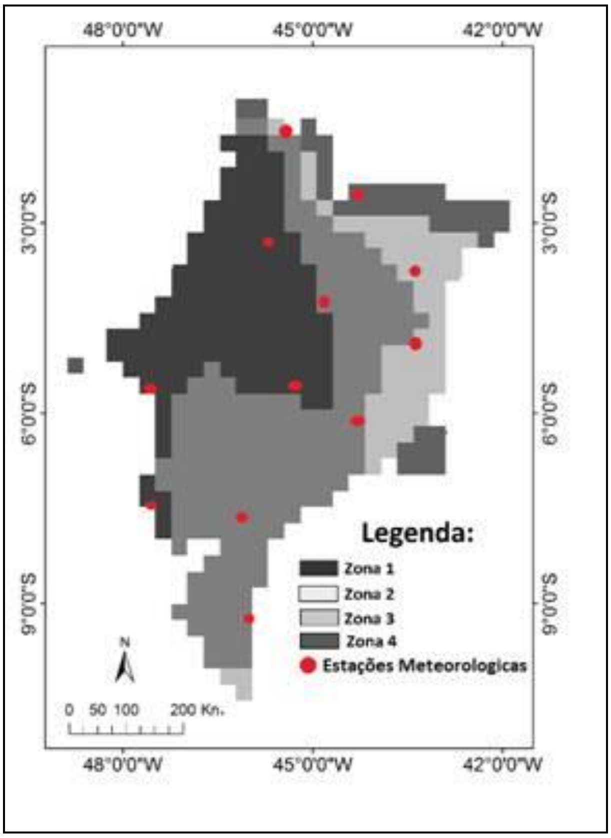
Finally, a linear regression analysis was performed to identify the parameters required to reconcile and validate the data estimated by the GLDAS database with the data measured by the meteorological stations.

3 RESULTS AND DISCUSSIONS

3.1 Regionalization of Wind Speed

The four homogeneous zones related to wind speed that we obtained from our methodology is presented in Figure 2. Zone 1 covered the entire coastal area, zone 2, and zone 3 covered the central and eastern portion of the Cerrado biome, and zone 4 only covered the western portion of the Amazon biome.

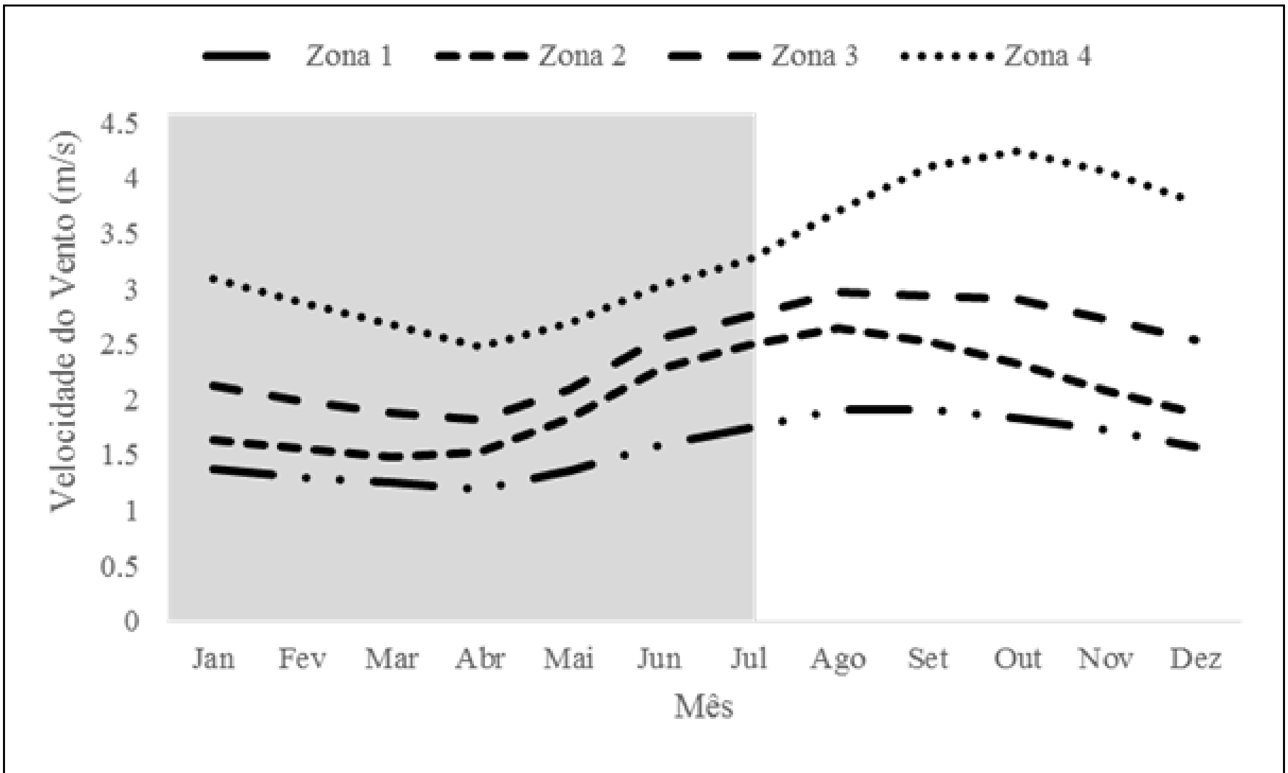
Figure 2 - Wind speed zoning map in Maranhão highlighting the location of the weather stations



3.2 Wind Speed Seasonality

In all zones, the minimum wind speeds were observed from March–April (rainy season) and the maximum speed was observed during August to September (dry season) (Figure 4). These differences are related to variations in the sun's declination throughout the year. The declination is associated with a set of astronomical factors such as the translational motion and the inclination of the Earth's axis (KRISHNAMURTHY 2018).

Figure 3 - Variation of monthly average wind speeds



The highest wind speed value was identified in zone 4 with an average of 4.24 m/s and the lowest wind speed value was found in zone 1 with an average of 1.25 m/s (Table 1).

Table 1 - Maximum and minimum wind speed values (m/s) in each identified zone

	Month	Min	Month	Max
Zone 1	March	1,25	September	1,92
Zone 2	March	1,48	August	2,65
Zone 3	April	1,82	August	2,97
Zone 4	April	2,47	October	4,24

The area with the highest winds is located in the north of the state due to two factors: the influence of the sea—primarily the temperature variation between the continent and the ocean resulting in “sea breezes” and “land breezes”, and the proximity to the equator, where are the trade winds.

3.3 Validation

The average of the coefficients of determination (R^2) was 0.75. The coefficients ranged from 0.30 (Turiaçu Station – South Region – Amazon Biome) to 0.92 (Balsas Station – North Region – Savanna Biome) (Table 6).

Table 2 - Parameters used for validation between data estimated by the GLDAS database and data measured by weather stations.

Stations	Biome	Mean Absolute Error	Mean Square Error	Relative Quadratic Error	R^2
Alto Parnaíba	Savanna	0,01	0,03	1,73	0,86
Bacabal	Amazon	-0,27	0,16	7,87	0,62
Balsas	Savanna	-0,05	0,02	1,22	0,92
Barra	Amazon	0,23	0,09	5,97	0,86
Carolina	Savanna	0,19	0,11	7,20	0,65
Caxias	Savanna	-0,22	0,10	4,22	0,90
Chapadinha	Savanna	-0,26	0,21	8,61	0,74
Colinas	Savanna	0,11	0,07	3,43	0,87
Imperatriz	Savanna	-0,04	0,68	43,85	0,74
São Luís	Amazon	0,23	0,49	14,75	0,84
Turiaçu	Amazon	-0,26	0,76	22,79	0,30
ZéDoca	Amazon	-0,06	0,02	1,52	0,79
Average	-	-0,03	0,23	10,26	0,75

From the analysis, we realized that the north of the state (Zone 1) is the zone most favored by the climatic conditions, due to its coastal position. Zone 2, located in the eastern part of the state, was the second most favored region due to its low levels of precipitation and the low occurrence of nebulosity conditions. The south-central region had two zones that were identified with lower data values (Zones 3 and 4)—one in the central region (Cerrado biome) and one in the western region (Amazon biome).

4 CONCLUSION

According to the results obtained, it is understood that the areas most favored by the climatic conditions for the implementation of wind power plants are located in the northern region of the state, while the south-central area has the least favorable conditions. However, more research is necessary, as well as better experimental measures for wind speed assessment (such as a standard anemometer), as the parameters that were analyzed react differently to astronomical and climatic conditions.

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