

Climate Characterization of the Machado-Mg Region through Geotechnology Techniques and Tools

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Abstract

The characteristics of a region and its environmental changes are directly associated with the characteristics of the climate and the changes that occur in it. The importance of the study of the climate of a region is widely known in agriculture, by the size of the impact that the climate has on the productivity and final quality of the products. From the studies of these spatial and temporal changes in climatic and environmental information, excellent results have been obtained in understanding the variability of atmospheric phenomena that occur throughout. The objective of the present work was to perform the climatic characterization of the Machado-MG region, analyzing data collected on the elements of the climate, applying methodologies that allow its spatialization, from geotechnology tools, more precisely, the techniques of interpolation and manipulation of spatial data in the Geographic Information Systems (GIS) environment. For this purpose, it has been used the climatic data obtained from meteorological stations of the National Institute of Meteorology-INMET, located in the state of Minas Gerais, referring to the monthly and annual averages of a historical series of 55 years (1961-2015). The results obtained allowed to characterize the climate of the municipality, which presented an average temperature around 15°C to 25°C and with average rainfall between 100 - 200 mm in the rainiest periods. The relative humidity of the air presents throughout the year values in the average of 60% to 80%. From the spatialization maps of temperature, precipitation and relative humidity of the air, it becomes possible to analyze the spatial behavior of the climatic elements and thus to have the perception of the climate dynamics in the region.

Keywords

Agrometeorology, Kriging, Geographic Information Systems

1. Introduction

Earth's climate has varied considerably during the last decades, with significant extremes. This fact has caused several environmental disasters and catastrophes, with great financial liabilities in different regions worldwide [1] [2] [3]. Studies on spatial and temporal changes with regard to climatic and environmental information provided in-depth understanding on the variability of the Earth's atmospheric phenomena, mainly due to disordered population increase and to human intervention on the environment, with the climate highly affected by the processes involved [4] [5] [6].

A region's characteristics and its environmental changes are directly associated with climate changes, highly important for agriculture due to the great impact on productivity and quality [7] [8] [9] [10]. According to Craparo *et al.* [11], climate changes and global warming will trigger a new geographic configuration for the planting and the production of the coffee shrub (*Coffea* sp.) in all producing countries, with enormous economic losses.

Brazil produces almost 30% of world coffee. According to Assad *et al.* [12], within the worst scenario, approximately 33% of the area proper for coffee plantation in the country may become inadequate or climatologically risky. Critical hydrological events and climate changes directly affect the region's coffee production.

The land-locked state of Minas Gerais shares one half of Brazilian coffee production. The coffee produced in the south of the state constitutes most of the state's coffee production, the most important in the state, with high employment and income rates [13]. The coffee region in the south of Minas Gerais has a national, social and economic importance which may be jeopardized by the consequences of further climate changes.

Coffee culture in Machado, Minas Gerais, Brazil, is the main agricultural activity of the municipality and it is prevalent within its borders. In fact, it has a relevant social and economic role in the municipality due to the generation of employment and income for rural families and for most of the population which participates in agricultural activities and in the municipality's agricultural and cattle-breeding production chain [14] [15] [16].

Geo-technologies are the essential techniques and tools for monitoring climate and environmental changes, based on the technological progress that occurred throughout the years in other areas, such as agrometeorology, climatology, remote sensing, geoprocessing and database technologies, which also underwent great progress [17] [18].

Climatic information and technological process have significantly improved

the possibility by which farmers adjusted their activities to climate variability and changes with a decrease in agricultural risks [18] [19].

According to Santos *et al.* [17], geo-technologies were crucial for agro-climate zoning established by data collected during 30 years of climate data harvested by the region's meteorological stations. They were also relevant for agro-climate zoning with new data indexes on the climate, simulating changes that may occur following the IPCC report on climate changes, and revealing decrease in coffee plantation areas if the report's forecasts proved to be true. Eugenio *et al.* [20], employed spatial interpolation techniques by several geo-technologies to design agro-climate zoning for *Coffeacanefera* in the state of Espirito Santo, Brazil.

In fact, geo-technologies were greatly relevant in research by Malamos *et al.* [21], by which they estimated monthly evapotranspiration for the region under analysis through an independent algorithm with specific software plus climate data collected at climatological stations.

Current assay analyzes and characterizes the climate of the municipality of Machado MG Brazil, through a series of climatic factors of the region, associates climate data by SIG, and performs spatialization, mapping and analysis of spatial behavior in temperature, rainfall and relative humidity of the municipality.

2. Materials and Methods

2.1. Description of Study Area

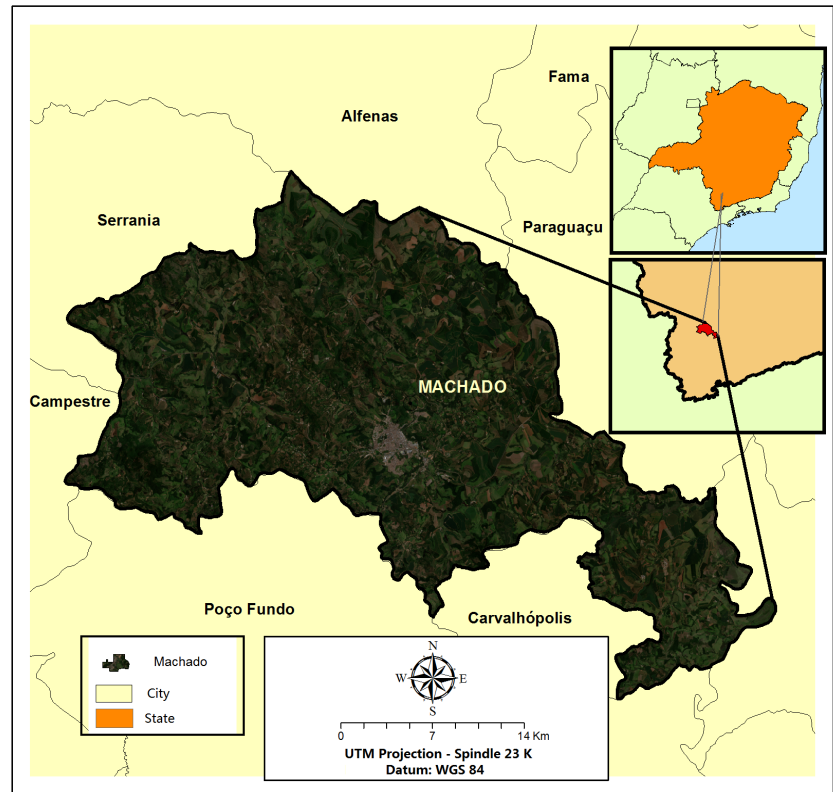
The studied area is the municipality of Machado in the micro-region of Alfenas, and in the meso-region of southern Minas Gerais in Brazil (**Figure 1(a)**), with an area of approximately 586 km², in the 21°40'30"S and 45°55'12"W. Agriculture is its main economic resource, especially coffee culture as the main economic product and relevant job generator [19] [22].

2.2. Organization of Database

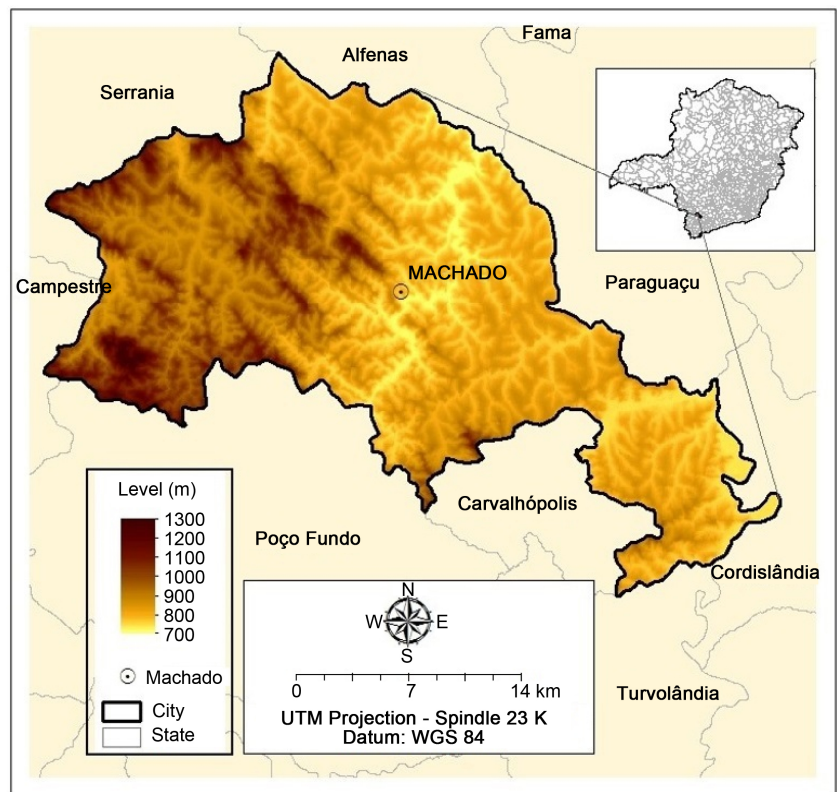
Interpolation and spatialization techniques were employed in a climatic series representative of 31 meteorological stations in Minas Gerais. The choice of the meteorological stations used was determined by their location and availability of data, with those that contained the complete data, with a longer period of distribution, and those available on the INMET website.

Meteorological database on temperature, rainfall and relative humidity was transferred to an electronic spread sheet to provide a database with information on the climatological stations of the municipality, altitude, latitude, longitude, monthly series and yearly average (**Table 1**).

The data underwent a mathematical treatment that consisted in the listing in average monthly values. In the case of temperature, it first obtained the mean of the maximum and minimum for each month and then calculated the annual average. For the rain, he added the monthly averages to obtain the annual precipitation height. For the relative air humidity the monthly averages were calculated and then the annual average was calculated.



(a)



(b)

Figure 1. (a) Study area; (b) Digital Elevation Model (DEM) of SRTM project.

Table 1. Information retrieved from INMET meteorological stations.

METEOROLOGICAL STATIONS	LATITUDE	LONGITUDE	LEVEL	T	P
	(Decimal Degrees)		(m)	(°C)	(mm)
Araxá	-19.6	-46.94	1024	20.89	1547.74
BambuÍ	-20.03	-45.00	661	20.79	1411.15
Barbacena	-21.25	-43.76	1126	18.18	1391.35
Belo Horizonte	-19.93	-43.93	915	21.23	1504.82
Bom Despacho	-19.68	-45.36	695	21.54	1338.09
Caldas	-21.91	-46.38	1150	18.19	1488.17
Capinópolis	-18.71	-49.55	621	23.38	1378.64
Coronel Pacheco	-21.55	-43.26	435	21.19	1537.68
Curvelo	-18.75	-44.45	672	22.86	1046.72
Divinópolis	-20.17	-44.87	788	21.70	1379.20
Florestal	-19.88	-44.41	760	20.03	1384.13
Frutal	-20.03	-48.93	544	24.15	1164.98
Ibirité	-20.01	-44.05	815	20.68	1456.50
Ituiutaba	-18.95	-49.52	560	24.01	1390.97
Janaúba	-15.8	-43.29	516	24.92	765.40
Januária	-15.45	-44.00	474	24.27	895.81
João Pinheiro	-17.73	-46.17	760	23.16	1328.27
Juiz de Fora	-21.76	-43.36	940	22.27	1538.70
Lavras	-21.75	-45.00	919	20.05	1420.39
Lambari	-21.94	-45.31	878	18.79	1634.69
Machado	-21.66	-45.91	873	19.48	1487.52
Montes Claros	-16.68	-43.84	652	23.05	998.69
Paracatu	-17.24	-46.88	712	22.88	1386.51
Patos de Minas	-18.51	-46.43	940	21.33	1410.49
Pompéu	-19.21	-45.00	691	22.63	1153.41
São Lourenço	-22.10	-45.01	820	19.22	1523.36
São Sebastião do Paraíso	-20.91	-47.11	820	20.83	1684.78
Sete Lagoas	-19.46	-44.25	732	21.31	1287.34
Uberaba	-19.73	-47.95	737	22.14	1480.16
Unai	-16.36	-46.88	460	24.25	1326.47
Viçosa	-20.75	-42.85	712	19.79	1190.47

T = average temperature; P = average annual precipitation height.

2.3. Data Processing and Interpolation

Satisfactory locations were considered where the lack of data was minimal, so the choice of localities aimed at the best spatial-temporal distribution possible. The worksheets had to be reorganized and new worksheets were generated for each chosen point. All mean and sum calculations were performed in Excel®, which was also the tool used in the preparation of tables and climograms.

Transference of spread sheets on temperature, rainfall and relative air humidity was performed by SIG, ArcGIS® 10, providing specific spatial vectorization (**Figure 2**) with its respective tables of attributes and featuring all fields involving the above climatic factors [17] [23] [24]. Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM), freely available at the electronic site of the Brazilian Enterprise for Agricultural and Cattle-breeding Research (EMBRAPA), scale 1:250.000 on the WGS 84 cartographic projection (**Figure 1(b)**), vector and matrix images with state and municipality borders, and images from Landsat-8 available at IBGE and INPE sites, were transferred to ArcGIS® to provide altimeter data [20] [25].

Annual and monthly averages on the series of climate data were employed in the case of spatialization of climatic factors which, coupled to Kriging techniques, recommended by [17] [23], produced yearly and monthly maps (January



Figure 2. Site of INMET meteorological stations in the state of Minas Gerais, Brazil.

to December) on rainfall, temperature and humidity data.

Kriging was the method of interpolation that responded better to the spatialization of the means, and other methods were tried. Kriging comprises a set of geostatistical adjustment techniques used to approximate data by the principle fixed to a point in space, the points in its surroundings are more relevant than those further away. This presupposes the existence of dependence between the data, requiring to know how far this correlation matters. It is a method to estimate the unknown value associated with a point, area or volume, from a set of n data $\{Z(x_i), i = 1, n\}$ available [23].

Results were retrieved by Kriging spatial interpolation tools available at ArcGIS 10.3 Spatial Analysis Toolbox with a 90 m pixel spatial resolution. Finally, the maps underwent a treatment seeking the best possible visualization according to the color palette chosen for each map.

3. Results and Discussion

Climate and other research-related data and further data retrieved by remote sensing and geoprocessing techniques were employed for the production of maps to better understand and interpret results on the climate characterization of the area under analysis. Data interpolation provided maps on 55 year data spatial distribution with regard to temperature, rainfall and relative air humidity from 31 INMET climatological stations.

According to Marin *et al.* [3], Monteiro *et al.* [5], Assad *et al.* [12], rainfall, temperature and solar radiation are the main meteorological variables that trigger growth, development and productivity in crops, influenced by photoperiod, relative air humidity, wind direction and evapotranspiration.

Climograms are extremely useful graphs in climate studies. They provide us information about the monthly distribution of rainfall and the average temperatures for each month, according to the time scale used. In this study the climograms were elaborated with average values within the period of 55 years. The climograms also serve as models about the kind of weather in a particular location. Thus, from the graphs of the climatic elements, an idea is created about the climate, the seasonal distribution of rains, temperature, relative humidity of the air and others.

However, the maps allow a richer analysis, mainly spatially, with respect to climograms. With the maps, we verified how the elements are distributed throughout the study area, making it more specific.

3.1. Analysis of Rates of Climatological Variables

3.1.1. Rainfall

When analyzing the data, it was observed that the average annual precipitation in the municipality of Machado revolves around $1500 \text{ mm} \cdot \text{year}^{-1}$ (Table 1), with the highest volumes found in the period from November to March, with average volumes around 200 to $300 \text{ mm} \cdot \text{m}^{-1}$, already in the months of June, July and August, the situation is opposite, being the period in which are the smallest pre-

precipitated volumes with averages around 20 to 50 mm·m⁻¹ (**Figure 3**).

According to Monteiro *et al.* [5], Matiello *et al.* [26], the above enhances the economic development of the coffee culture-oriented region. Since the coffee shrub is a sub-forest plant, it needs rain-provided amounts of air and soil humidity, with best rainfall lying between 1200 and 1800 mm·year⁻¹.

Monteiro *et al.* [5] State that understanding the best climate conditions for specific crops decreases risks in culture production, reduces management costs and phytosanitary issues, improves harvest and the product's final quality, with better market results. According to the same authors, hydric availability is one of the main factors that affect the productivity of the coffee shrub and the most demanding phenological phases, or rather, water, vegetation phase, formation of leaf buds, flowering and fruit maturation. On the other hand, the hydric deficiency between July and August, prior to flowering, is beneficent and favors a more uniform flowering during the first rains in September. These conditions occur in the region as climatic data reveal.

3.1.2. Rainfallspatial Behavior

Map of Total Rainfall (**Figure 4**) shows the spatial behavior of the sum of mean rainfall in all months during the period under analysis. Data by Alves e Rosa [27] revealed the biggest rainfall volumes on the highest regions, with great influence of ground relief for the formation of clouds and orographic rains. Further, the occurrence of torrential rainfall and even hail at certain times of the year was also greatly probable. In fact, mountainous regions had the biggest mean rainfall volumes during November, December and January (**Figure 4(b)**), a significant characteristic in the Brazilian south-eastern area studied by Sant'AnnaNeto [28].

Mean monthly rainfall maps reveal that the biggest rainfall volumes occur between November and March. Highest rates occur in December and January, with levels equal to or higher than 200 mm of rainfall in the lowest regions, whereas rainfall was close to 150 mm in the remaining area.

The region features rainfall indexes close to those by Viola *et al.* [29], between

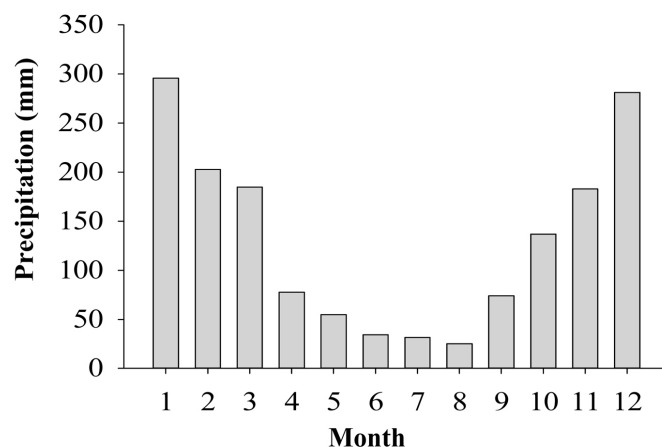
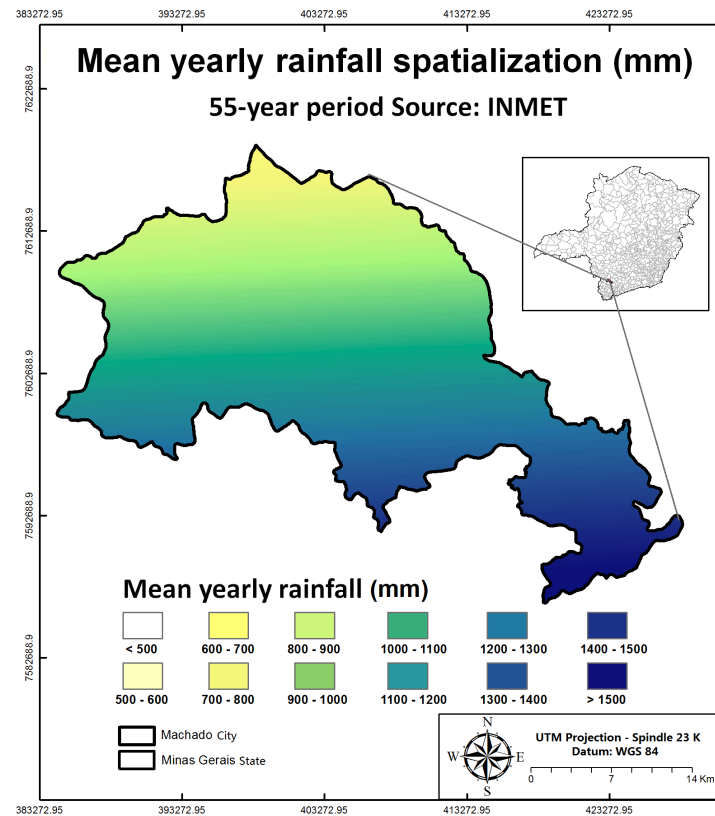
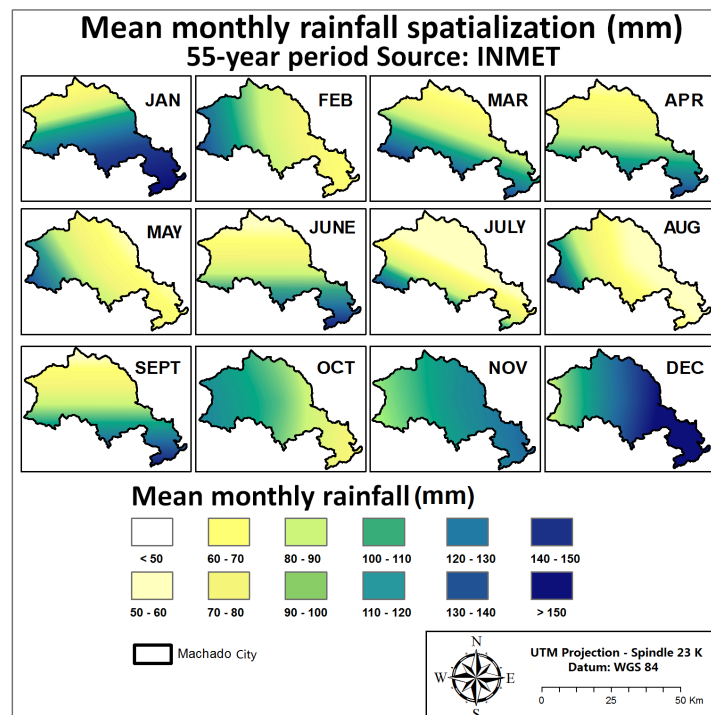


Figure 3. Mean rainfall in the region of Machado MG Brazil, between 1961 and 2015.



(a)



(b)

Figure 4. (a) Spatialization of mean yearly rainfall (mm) between 1961 and 2015 in Machado MG Brazil; (b) Spatialization of mean monthly rainfall (mm) between 1961 and 2015 in Machado MG Brazil.

May and August, the driest months, in spite of different rainfall concentrations.

3.1.3. Temperature and Relative Air Humidity

Total mean temperature throughout the studied period has been characterized by not very high rates, varying between 15°C and 25°C. Great temperature variations occur during the winter, especially in June and July, with mean temperatures close to 15°C (Figure 5).

In their studies on the impacts of climatic changes on agro-climate zoning, Assad *et al.* [12], Sediya *et al.* [30] underscore that a possible increase in mean global temperature will cause a drastic decrease in coffee culture in the main producing regions during the next years.

Relative air humidity is adequate throughout the year, with mean rates between 60% and 80%. August and September feature the lowest air humidity rates, characteristic of a region with temperate climate, distinct seasons, with hot and wet summers and cold and dry winters (Figure 5).

Coltri *et al.* [31], Steinke [32] insist that air humidity is a variable indirectly affecting crops. Very dry environments cause excessive transpiration rates in most plants, whereas in some cases they cause indirect damages caused by physiological and biochemical disorders.

Air humidity is greatly relevant for the interaction between plants and micro-organisms, especially fungi and bacteria, causing diseases which jeopardize production and provoke liabilities for the producers during the post-harvest period Monteiro *et al.* [5] Matiello *et al.* [26].

On the other hand, lack of humidity and dry conditions directly affect the evapotranspiration of crops, the extraction of wetness by the roots and, consequently, the distribution of the root system, canopy size, development and production rates and the absorption of nutrients from the soil Marin *et al.* [3] Monteiro *et al.* [5] Vianello e Alves [33].

Temperature climatic data in the Machado region is proper for coffee culture due to favorable temperatures for the development of crops. In the case of coffee shrubs, Monteiro *et al.* [5] Matiello *et al.* [26] underscore that thermal aptitude is

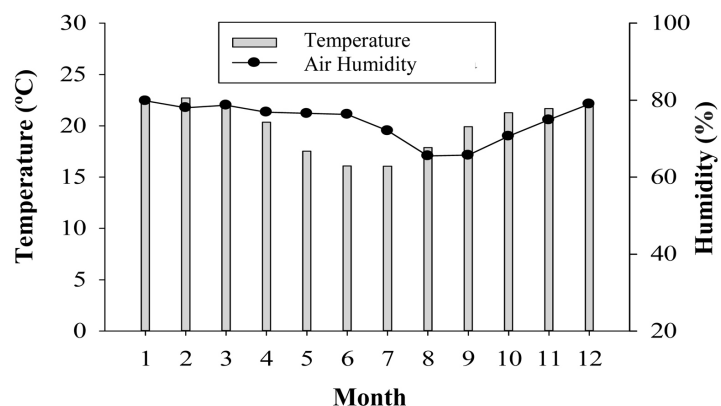


Figure 5. Mean temperature and relative Air Humidity in the region of Machado MG Brazil, between 1961 and 2015.

given by mean annual temperature bands, classified as adequate between 18°C and 23°C; borderline between 17°C and 18°C or between 23°C and 24°C; inadequate when lower than 17°C or higher than 24°C.

According to Monteiro *et al.* [5], when annual mean temperature is close to 23°C, the coffee shrub normally decreases growth during the summer, with intense symptoms of leaf discoloration caused by the heat. Floral abortions and bad flower formation, called starlets, are common in the case of annual mean temperatures above 23°C, causing low productivity.

3.1.4. Temperature and Relative Air Humidity Spatial Behavior

Total mean temperature, or rather, the average of mean temperatures throughout the period under analysis, is characterized by not very high rates, varying between 18°C and 30°C. The central and northern regions were characterized by hotter temperatures, whereas the western and south-western regions were the coldest regions, or rather, high altitude tropical climate region (**Figure 6(a)**).

The mean monthly temperature map (**Figure 6(b)**) demonstrates the mean total for the period analyzed. June, July and August in the monthly mean temperature maps are characterized by low temperatures, between 15°C and 25°C; averages increase and lie between 23°C and 30°C from November to February.

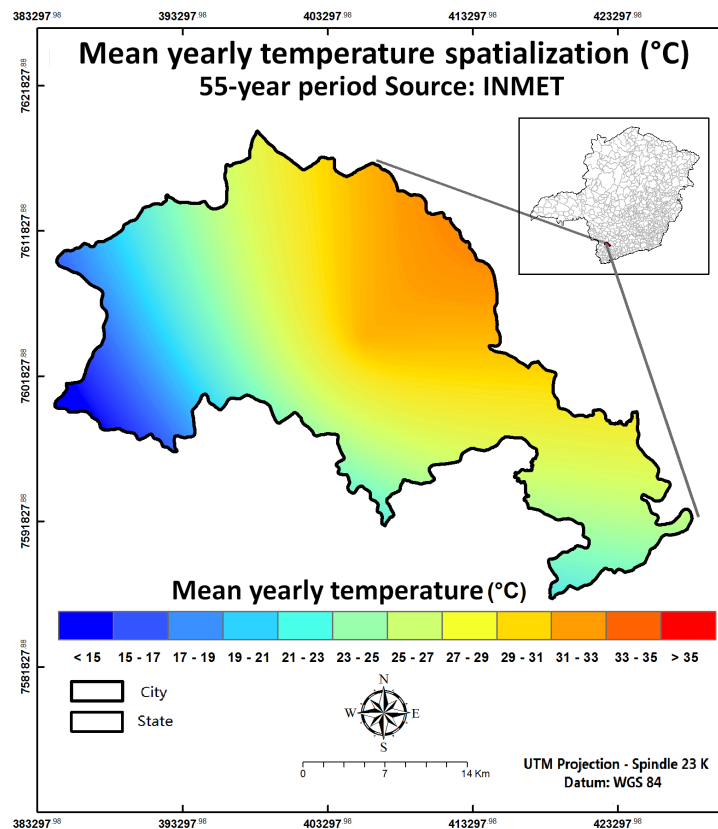
The town of Machado lies in the central region of the municipality, with a less hilly topography, with altitudes ranging between 700 and 800 meters. Small sections of the northern region also feature high temperatures, followed by a tiny segment in the south-eastern region of the municipality. Lombardo [34] underscores that in downtown areas, with scanty vegetation, temperatures may reach maximum rates.

Mean relative air humidity map (**Figure 7(a)**) shows the sum of mean relative humidity for all months during the period analyzed. Highest rates in relative air humidity occur in the south-eastern region of the municipality, ranging between 75% and 80% and, as a general rule, in the municipality's central region; they vary between 60% and 70% throughout the entire northern, northeastern and western regions.

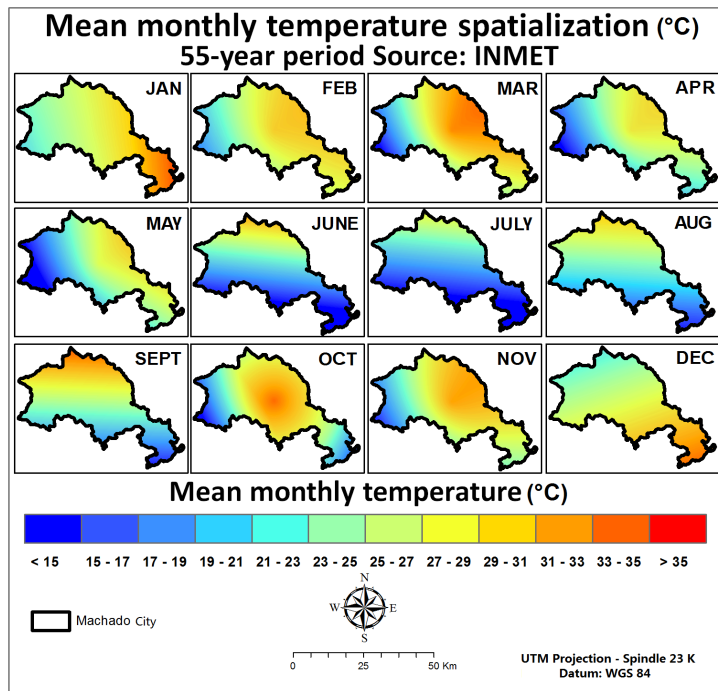
Mean weekly relative humidity maps (**Figure 7(b)**) reveal that the period between October and March featured the highest humidity rates, coupled to the highest mean temperatures as the biggest rainfall volumes. According to Carvalho *et al.* [35], data on relative air humidity plus data for maximum and minimum temperatures are the best information to estimate reference evapotranspiration by the Penman-Monteith's method when meteorological data are deficient.

3.1.5. Insolation, Wind Speed and Evapotranspiration

Climate data from the Machado region reveal that mean insolation rate has only slight variations throughout the year, with rates close to 5 and 6 hours a day. Highest rates occurred in July and August, and are related to winter, with few clouds and low rainfall. These conditions affect the rates of insolation hours

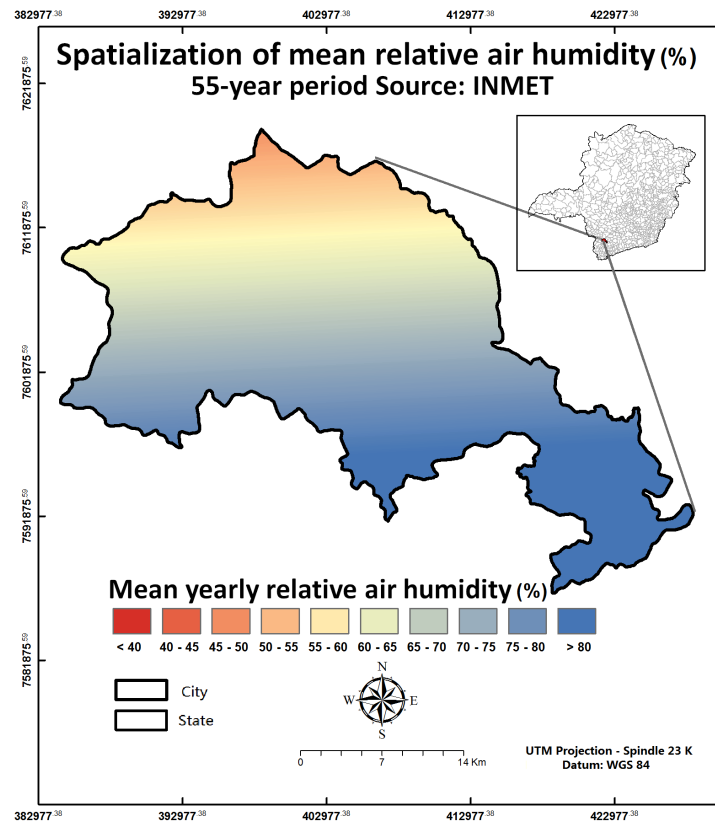


(a)

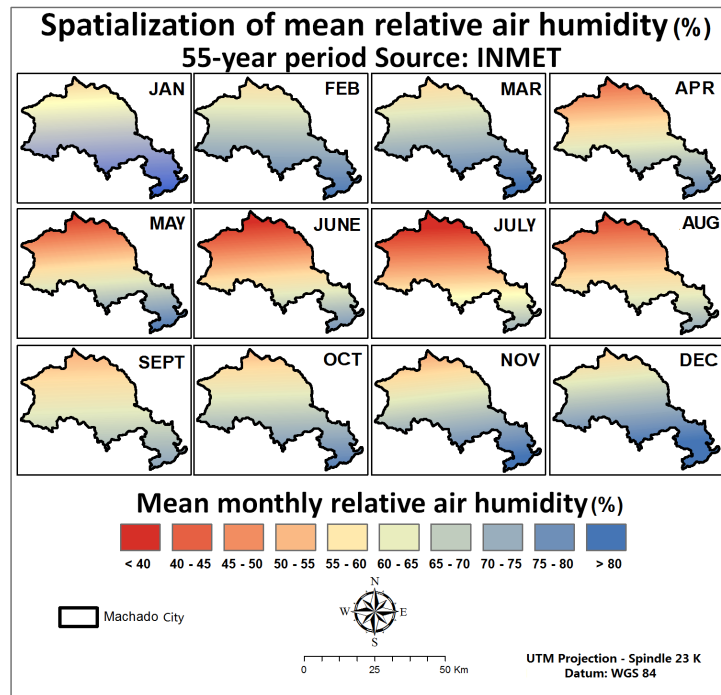


(b)

Figure 6. (a) Spatialization of mean yearly Temperature (°C) between 1961 and 2015 in Machado MG Brazil; (b) Spatialization of mean monthly Temperature (°C) between 1961 and 2015 in Machado MG Brazil.



(a)



(b)

Figure 7. (a) Spatialization of yearly mean relative air humidity (%) between 1961 and 2015 for Machado MG Brazil; (b) Spatialization of monthly mean relative air humidity (%) between 1961 and 2015 for Machado MG Brazil.

throughout the year since clouds and rainfall occur in all seasons (**Figure 8**).

In the case of mean wind speed in the Machado region during the period analyzed, rates vary approximately between 0.8 and 1 m·s⁻¹. Speed is low and moderate for the region's characteristics (**Figure 8**).

According to Gois e Baltrusch [36], wind indirectly affects crops. Knowledge on velocity and direction gives us important information for agriculture, such as spraying timetable, sizes of windbreaks, construction of stables and corrals. In fact, its influence may be positive or negative according to velocity.

At low to moderate speeds, winds contribute towards the renewal of CO₂ supplementation and the maintenance of plants' transpiration. However, excessive speeds increase plants' transpiration, with the closure of the stomata and decrease in the number of leaves and in the foliar area, with a sudden fall in photosynthesis. Further, winds at great speed cause mechanical damage in plants such as their mowing down and fall of leaves and branches Marin *et al.* [3] Steinke [32] Vianello [33].

Highest evapotranspiration rates in Machado range between 100 and 120 mm during the hottest months of the year (November to March) when temperature, rainfall, relative air humidity and wind speed also enhance evapotranspiration (**Figure 9**).

According to Pereira *et al.* [6], potential evapotranspiration (PET) depends on the air's evaporating capacity which is determined by solar radiation, wind speed, humidity and air temperature; further, real evapotranspiration (RET) measures not merely the above factors but also characteristics inherent to crops and to factors related to the soil's physical qualities. In other words, real evapotranspiration is defined as the amount of water transferred to the atmosphere by evaporation and transpirations within field conditions featuring atmospheric factors and soil humidity.

When soil humidity corresponds to field capacity, RET is highest and may be equal to PET. As the soil dries, real evapotranspiration is less than potential

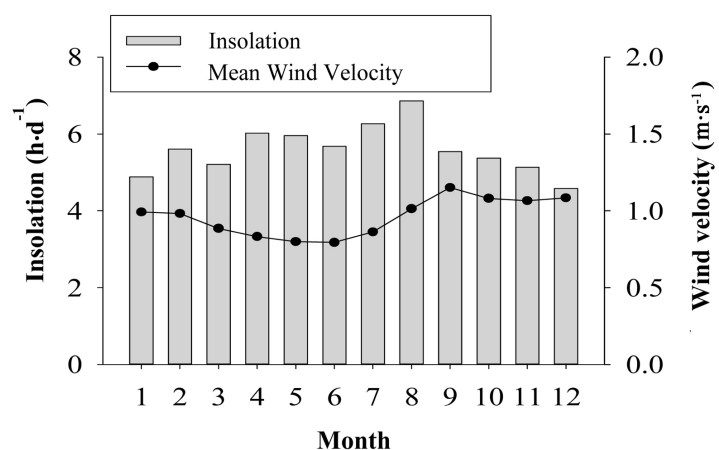


Figure 8. Insolation and mean wind speed in the region of the town of Machado MG Brazil, between 1961 and 2015.

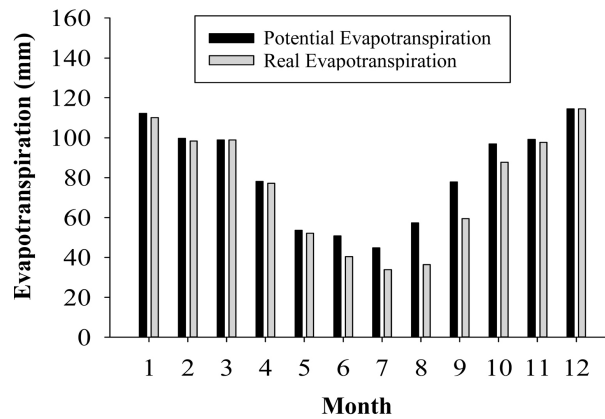


Figure 9. Mean evapotranspiration in the region of Machado MG Brazil between 1961-2015.

evapotranspiration.

4. Conclusions

The daily collection of characteristics and information on the climate is highly relevant in studies on changes in climate, spatialization and mapping of the climatic factors.

Maps revealed that climate factors are distributed spatially, with more precise analyses, especially when compared to spread sheets and tables.

Specialized information on the climate provides agricultural zoning and defines regions with different agricultural traits for a specific crop. It may simulate scenarios with possible climate changes and define new agricultural and geographical configurations for a culture's capacity.

Methodology used in current assay may be applied for other municipalities through the use of climatic data collected by several meteorological stations available.

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