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Guarda Chuvas: program for access and visualization of historical rainfall data of the State of Pernambuco

Guarda Chuvas: programa para acesso e visualização de dados históricos de chuvas no Estado de Pernambuco

Guarda Chuvas: programa de acceso y visualización de datos históricos de precipitaciones del Estado de Pernambuco

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Abstract

Rainfall precipitation in Northeastern Brazil (NE) is characterized by high spatial and temporal variability. However, the availability of rainfall data is still limited in this region, for many reasons. Access to rainfall data could provide useful information to better understand rainfall distribution and support ecosystem management. In this paper, we present the program Guarda Chuvas, which makes viable access and visualization of historical rainfall data of the state of Pernambuco, NE Brazil, within a user-friendly environment. The trend surface analysis interpolation method was used to estimate values of monthly precipitation ($mm \cdot month^{-1}$) for the state of Pernambuco on a grid with a resolution of 0.01 degree, totaling 81,544 monthly precipitation series spatially distributed over the state of Pernambuco. The program was developed in C language, with a graphical user interface developed using an application programming interface for Windows. The historical series

provided by the program can be used as input for simulation models, and the program can support studies directed to the development of agricultural, water, environmental and socioeconomic policies for the state of Pernambuco. In addition to the regional interest in the data output from the program, the current approach should be found useful for applications in other parts of Brazil and the world.

Keywords: Pernambuco; Precipitation; Interactive visualization; Interpolation methods.

Resumo

A precipitação no Nordeste do Brasil (NE) é caracterizada por apresentar alta variabilidade temporal e espacial. No entanto, a disponibilidade de dados de precipitação ainda é limitada nesta região, por vários motivos. O Acesso a dados de precipitação fornece informações úteis para melhor entender a distribuição da chuva e apoiar gerenciamento do ecossistema. Neste artigo, apresentamos o programa Guarda Chuvas, o qual viabiliza o acesso e visualização de dados passados de precipitação pluviométrica do estado de Pernambuco, NE, Brasil, por meio de uma interface de fácil uso. O método de interpolação, trend surface analysis, foi utilizado para estimar a precipitação mensal ($\mathrm{mm \cdot month^{-1}}$) para o estado de Pernambuco em uma grade com resolução de 0,01 grau, totalizando 81.544 séries mensais de precipitação distribuídas espacialmente para estado de Pernambuco. O programa foi implementado em linguagem C, com uma interface gráfica construída utilizando interface de programação de aplicativos para o Windows. As séries históricas fornecidas pelo programa podem ser usadas como insumo para modelos de simulação e apoiar estudos direcionados ao desenvolvimento de políticas agrícolas, hídricas, ambientais e socioeconômica para o estado de Pernambuco. Além do interesse regional nas informações fornecidas pelo programa, a abordagem atual deve ser considerada útil para aplicações em outras partes do Brasil e do mundo.

Palavras-chave: Pernambuco; Precipitação; Visualização interativa; Métodos de interpolação.

Resumen

La precipitación en el noreste de Brasil (NE) se caracteriza por una alta variabilidad temporal y espacial. Sin embargo, la disponibilidad de datos de precipitación todavía es limitada en esta región, por varias razones. El acceso a los datos de las precipitaciones proporciona información útil para comprender mejor la distribución de las lluvias y respaldar la gestión del ecosistema. En este artículo presentamos el programa Guarda Chuvas, que permite acceder y visualizar datos pasados sobre precipitaciones en el estado de Pernambuco, NE, Brasil, a

través de una interfaz fácil de usar. Se utilizó el método de interpolación de análisis de superficies de tendencia para estimar la precipitación mensual ($mm \cdot month^{-1}$) para el estado de Pernambuco en una cuadrícula con una resolución de 0.01 grados, totalizando 81,544 series de precipitación mensual distribuida espacialmente al estado de Pernambuco. El programa se implementó en lenguaje C, con una interfaz gráfica construida usando una interfaz de programación de aplicaciones para Windows. La serie histórica proporcionada por el programa puede utilizarse como insumo para modelos de simulación y estudios de apoyo orientados al desarrollo de políticas agrícolas, hídricas, ambientales y socioeconómicas para el estado de Pernambuco. Además del interés regional en la información proporcionada por el programa, el enfoque actual debe considerarse útil para aplicaciones en otras partes de Brasil y del mundo.

Palabras clave: Pernambuco; Precipitación; Visualización interactiva; Métodos de interpolación.

1. Introduction

The knowledge of spatiotemporal precipitation behavior is the key to avoid climatic risks since drought or floods determine the most significant losses in the agricultural sector and prolonged periods of drought compromise water supply and energy generation. Thus, understanding of precipitation variability is important for proper planning and development of industrial, agricultural, and forestry activities on a regional scale (Martin et al., 2008). Historical rainfall series also represent a fundamental input for numerical simulation models. Important examples of such models are CENTURY, which was developed by Parton et al., (1987), to simulate dynamics of organic matter in the plant-soil system, and the numerical weather prediction model ETA (Black, 1994).

One of the major problems arises when the historical record of precipitation observations is limited mostly to land areas where rain gauges can be deployed. Measurements from those instruments are sparse over large and meteorologically important regions, and there are missing data (Ebert et al., 2007). Precipitation data in Brazil is not always readily available, in particular for remote rural areas. As Pernambuco state, with an area of 98,312 km2, belongs to the underdeveloped Northeast region of Brazil, where precipitation data are often scarce both in terms of position, and the limited length of available observations. The Pernambuco State Agency for Water and Climate (Agência Pernambucana de Águas e Clima – APAC) is currently in charge of most of the rain stations. However, in

most cases, many of the series from these stations present missing data, either due to the lack of measurements (in the case of conventional stations) or due to equipment failures (in the case of automatic stations) (Bier & Ferraz, 2017).

The comparison and use of mathematical models (interpolation methods) has been extensively studied in the literature (Bier & Ferraz, 2017; Borges et al., 2016; A. S. A. Silva et al., 2019; Vicente-Serrano et al., 2003; Wang et al., 2014), aiming to identify which method presents the best performance in the estimation of precipitation and the filling of missing data. Considerable research efforts in this area have resulted in several computer programs (LARS-WG (Semenov & Barrow, 1997), ClimGen (Stöckle et al., 1999), WeaGETS (Chen et al., 2012) and PGECLIMA R (Virgens Filho et al., 2013)) for precipitation series simulation, based on previous studies.

Given the scarcity of precipitation data for the state of Pernambuco, and their importance both to feed prediction models and to develop studies aimed at surveying agricultural, water, environmental and socio-economic policies, the present work focuses on the development of a software tool (program) for ease of access and visualization of spatially explicit historical precipitation data for the state of Pernambuco. To achieve this objective, trend surface analysis (Silva et al., 2019) interpolation method was used to generate a monthly precipitation database for the period 1950 to 2012. The software was named “Guarda Chuvas,” meaning “Rain Keeper” in Portuguese.

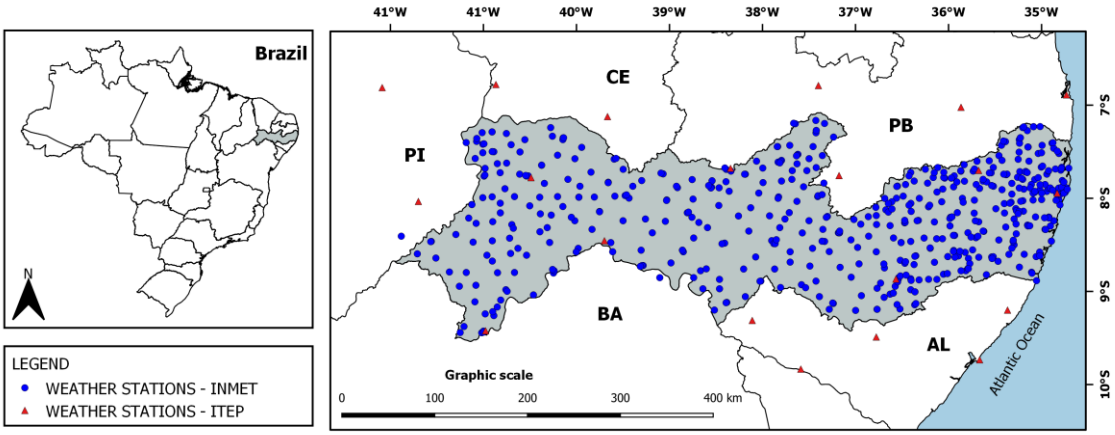
2. Methodology

2.1 Data and study area

This is a quantitative research (Pereira et al., 2018). The state of Pernambuco is located in the Brazilian Northeast between the parallels 7˚18’17” and 9˚28’43” South latitude and the meridians 34˚48’15” e 41˚21’22” West longitude. Specifically, Pernambuco is limited to the North by the Ceará and Paraíba states, to the West by the Piauí state, to the South by the Bahia and Alagoas states, and to the east by the Atlantic Ocean. Pernambuco has a total area of 98,281 km 2 constituted by 184 municipalities, divided into three major geo-economic regions: Litoral/Zona da Mata, Agreste, and Sertão/SãoFrancisco. The territory of Pernambuco is subdivided into five mesoregions: Sertão do São Francisco, Sertão, Agreste, Zona da Mata and Metropolitan Recife Region (Silva et al., 2006).

The data used in this work consist of a union of two precipitation databases for the state of Pernambuco. The first database is formed by monthly rainfall records provided by the Meteorology Laboratory of the Pernambuco Institute (LAMEP/ITEP), and the second contains daily rainfall information provided by the National Institute of Meteorology (INMET). The daily precipitation series provided by INMET were integrated to provide additional monthly cumulative precipitation information. The spatial arrangement of the rainfall measurement stations provided by the ITEP and those supplied by INMET are represented in Figure 1.

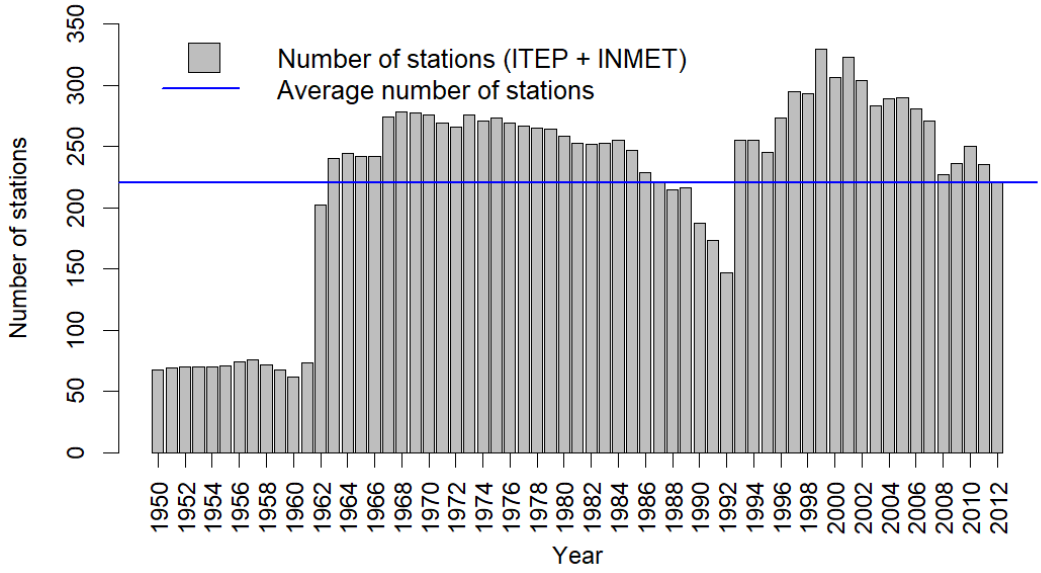
Figure 1. Geographical location of the state of Pernambuco, Brazil, and spatial arrangement of the ITEP (circles) and INMET weather stations (triangles).



Fonte: Autores.

The monthly precipitation series provided by ITEP are records dated during the period 1950 to 2012. The number of stations varies from year to year, and a specific year can assume a total of between 68 and 308 stations. The time series provided by INMET are daily precipitation records collected and selected between 1961 and 2012, totaling 21 stations located in the outline (14 stations) and the interior (seven stations) of the state of Pernambuco. The two databases are merged in order to enhance the spatial distribution across the state, and in particular on the administrative boundaries (Borges et al., 2016). The resulting database contains anywhere between 68 and 329 stations for the years between 1950 and 2012, with an average of 220 stations per year, as shown in Figure 2. It is seen from Figure 2. that periods 1963-1986 and 1993-2011 have the number of weather stations above the average, while for the rest of the years the number of stations with available data is below the average.

Figure 2. Total number of rainfall stations (LAMEP/ITEP and INMET) considered per year in the period from 1950 to 2012 in the state of Pernambuco. The average number of stations is represented by the horizontal line.



Source: Authors.

Silva et al., (2019) conducted extensive research based on rainfall records provided by ITEP and INMET, with the aim to identify which of the interpolation methods, inverse distance weighting (Shepard, 1968), modified Shepard method (Franke & Nielson, 1980), natural neighbor (Sibson, 1980), nearest neighbor (Thiessen, 1911) radial basis function (Fornberg et al., 2006), kriging (Gebbers & Bruin, 2010) and trend surface analysis (Webster & Oliver, 2007) (totaling 26 distinct interpolation schemes), presented the best performance to represent the monthly rainfall of the state of Pernambuco. To this end, the cross-validation procedure (Borges et al., 2016; Vicente-Serrano et al., 2003; Xie et al., 2011), followed by measures (mean bias error, mean absolute error, mean squared error, root-mean-square error, model efficiency, Willmott's D and coefficient of determination) used in the literature (Borges et al., 2016; Li & Heap, 2011; Luo et al., 2008; Paredes-Trejo et al., 2017; Tabios & Salas, 1985; Vicente-Serrano et al., 2003) to evaluate the performance of interpolation methods, were used to identify the best method. It was found that the trend surface analysis ($n = 4$) method presented the best results, and therefore it was adopted as the method of choice for preparing data incorporated in the current software tool Guarda Chuvas.

2.2 Trend surface analysis

Trend surface analysis (polynomial regression) is a deterministic interpolation method consisting of a polynomial fit to georeferenced data through a multiple regression process between observed values and geographic locations (Webster & Oliver, 2007). Denoting by $\boldsymbol{r} \equiv (x, y)$ the position of an arbitrary point within the interpolation region, the usual expression for trend surface analysis is given by

$$F(\boldsymbol{r}) = \sum_{l=0}^{n} \sum_{i=0}^{l} \sum_{j=0}^{l-i} c_{ijl} x^i x^j + \varepsilon \tag{1}$$

where n is the polynomial order, ε is the stochastic error term, and coefficients c_{ijl} are determined through least-squares fitting by minimizing the sum of squared deviations from the trend surface

$$S = \sum_{k=1}^{N} [F(\boldsymbol{r}_k) - f(\boldsymbol{r}_k)]^2 \tag{2}$$

where $f(\boldsymbol{r}_k)$ is the value observed at the point $\boldsymbol{r}_k$. The trend surface analysis with $n = 4$ was used here to interpolate monthly precipitation values for the 63 years under study, from 1950 to 2012. The interpolation was performed on a grid with a resolution of 0.01 degrees, equivalent to about 1 kilometer and 113 meters, totaling of 81,544 monthly precipitation series uniformly spatially distributed over the state of Pernambuco.

2.3 Development of the Guarda Chuvas interface

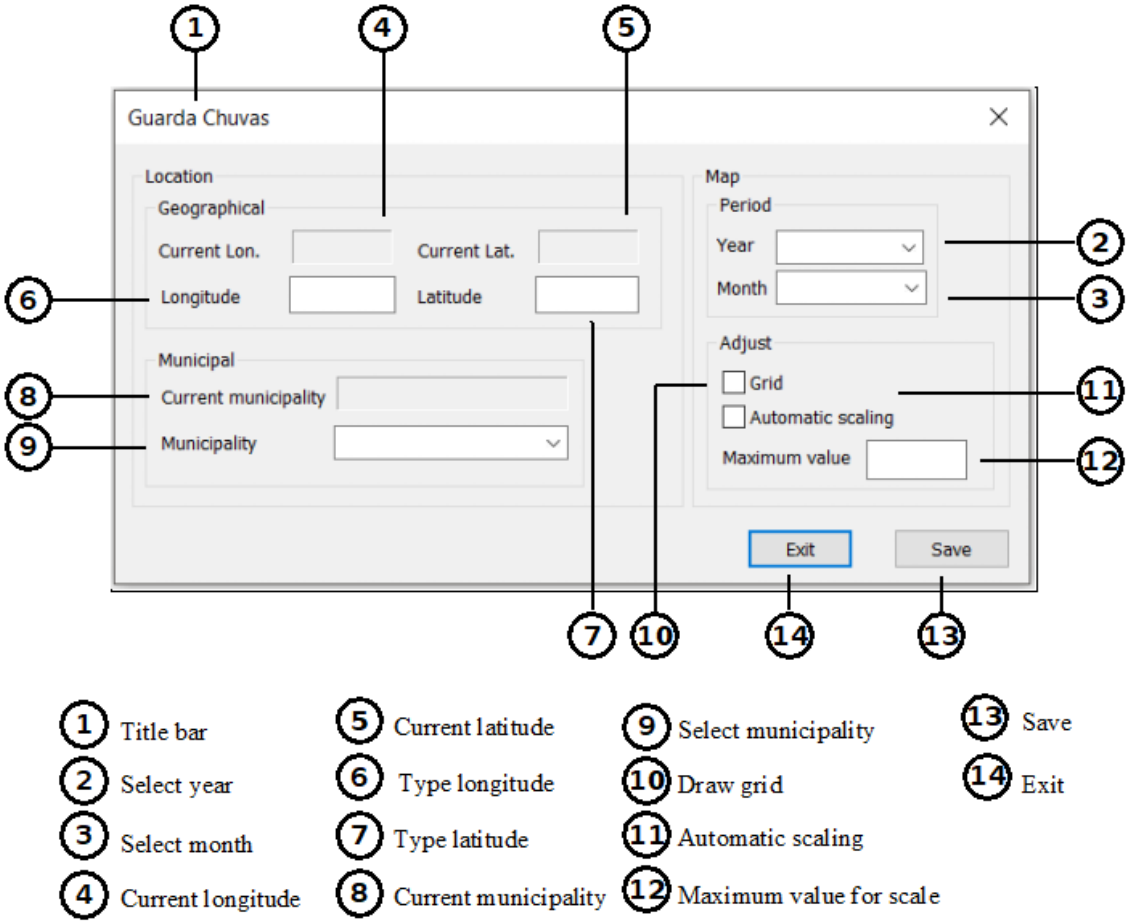
Based on the monthly precipitation series grid for the state of Pernambuco, the program was developed for ease of access and visualization of this information. The program was developed in C language, with a graphical user interface (GUI) developed using an application programming interface (API) for Windows.

The code was implemented to read the interpolated precipitation data, for manipulation through a control dialog box and a graphical interface. The graphical interface displays a color-coded precipitation data map for a given (chosen) month, and the control dialog box contains fields for location (geographical and municipal), choice of the period of the historical series, visual adjustments of the limit (fixed or moving) monthly rainfall, and a button for saving the current choice of precipitation values in an ASCII file.

3. Results and Discussion

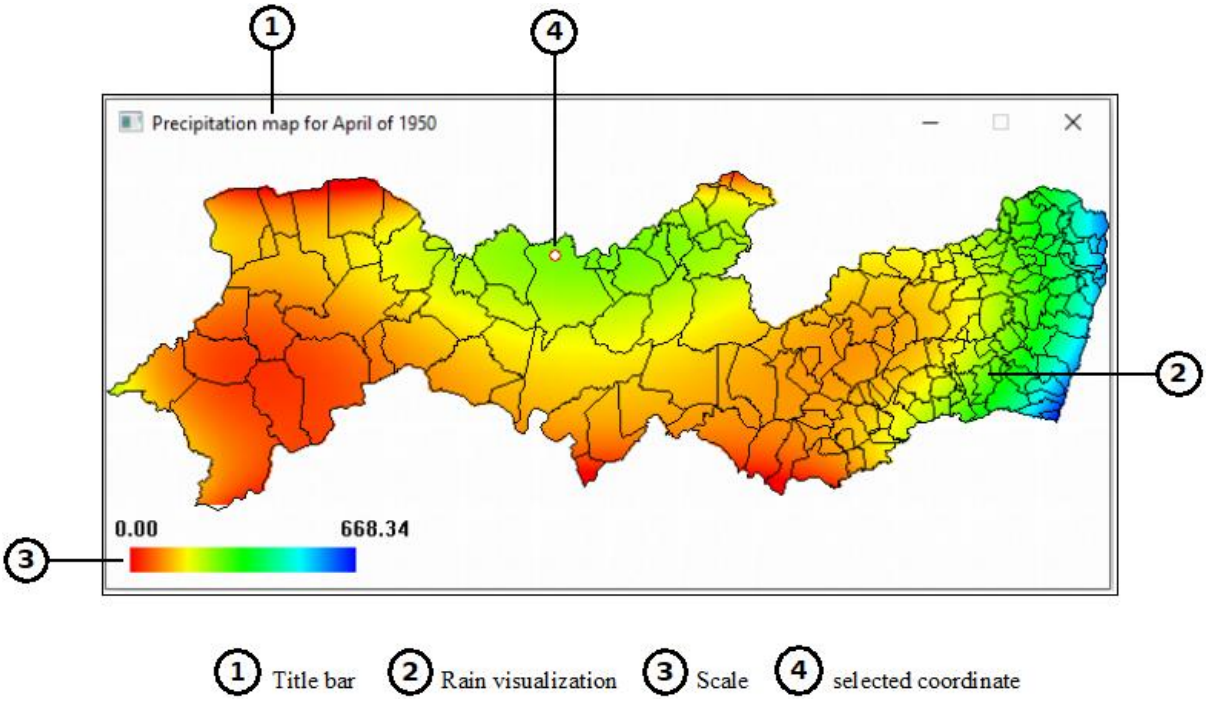
The developed program has the objective of accessing the historical series of monthly precipitation for each of the 81,544 coordinates, as well as the spatially explicit visualization of the monthly rainfall for the state of Pernambuco. To this end, the designed program consists of two windows that interact with each other: the main window (Guarda Chuvas interface, Figure 3) and the spatially explicit window of the historical monthly precipitation of Pernambuco (Figure 4). Figure 4 shows the color-coded precipitation map for the month of April 1950.

Figure 3. Guarda Chuvas program interface and the function of its components.



Source: Authors.

Figure 4. Spatially explicit visualization window for the monthly precipitation (mm) of the state of Pernambuco and the precipitation map for April 1950.



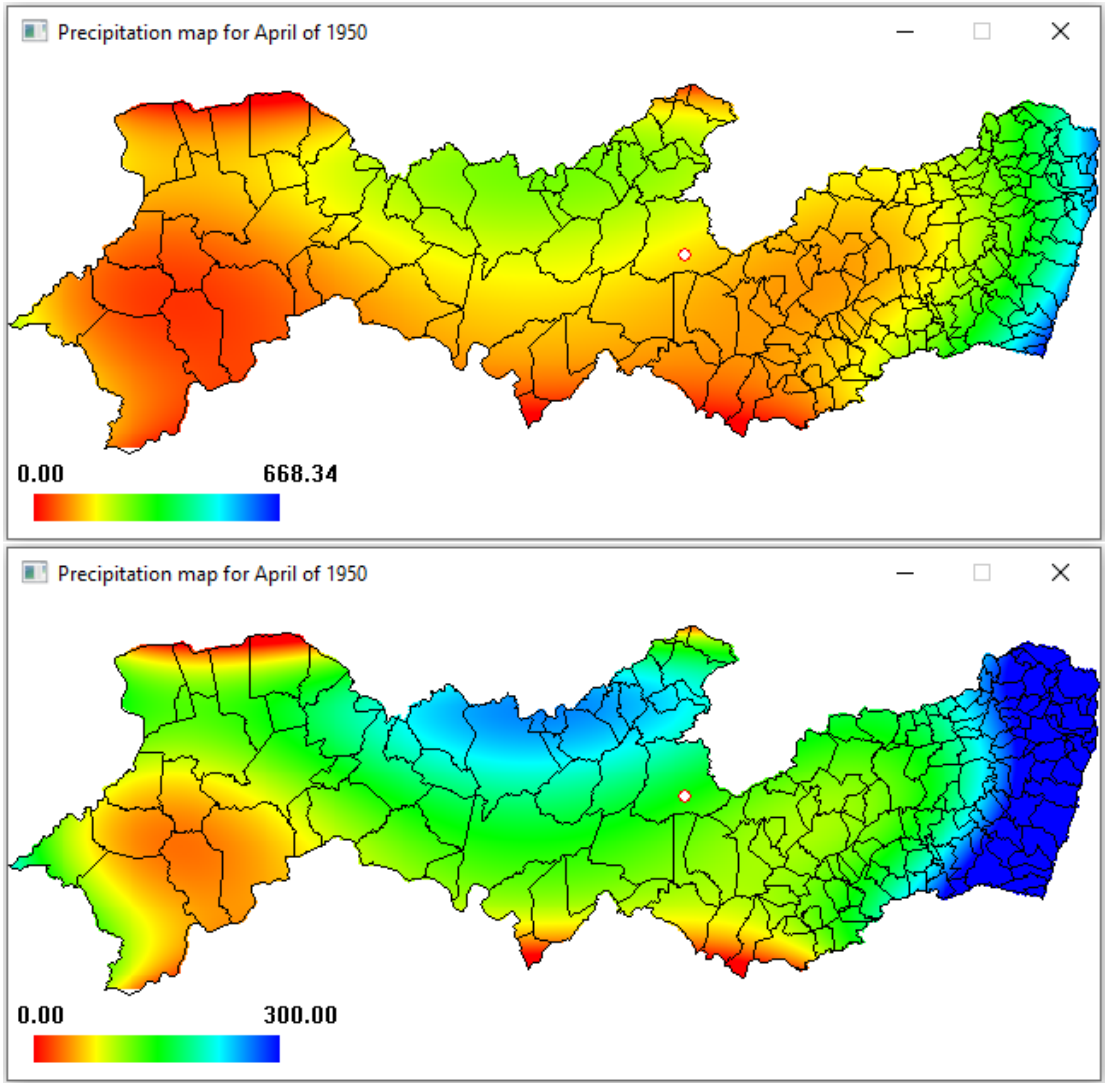
Source: Authors.

The Guarda Chuvas control dialog contains the Location and Map groups, subdivided into Geographical and municipal subgroups, and period and adjusts subgroups, respectively. The spatially explicit visualization window displays the municipal map of the state of Pernambuco, in which the color-coded monthly precipitation map, for the current choice of year and month, is shown over the entire state. For the different color intensity shown on the map, red tones correspond to low precipitation values, green tones to intermediate or moderate precipitation values, and blue tones to high precipitation values.

Through the Year and Months fields of the Period subgroup in the Guarda Chuvas control dialog, one can select for which year (1950 to 2012) and month (January to December) the spatially explicit behavior of precipitation is displayed in the visualization window, the lower and upper precipitation value bounds of the color scale (component 3 in Figure 4) corresponding respectively to red and blue. The maximum value shown in the color scale can be modified (component 12, Figure 3) by typing a number between the lowest and the highest precipitation value. Thus, the monthly precipitation shown in the viewing window is recalculated and redisplayed based on the choice of the precipitation value upper bound. This is illustrated in Figure 5, where the precipitation map for April 1950 127 is shown (top) for color-coded values between 0 and 668.34 $\mathrm{mm} \cdot \mathrm{month}^{-1}$ (maximum value obtained

through interpolation) and between 0 and 300 $\mathrm{mm} \cdot \mathrm{month}^{-1}$ (bottom), after setting the Maximum Value field (component 12, Figure 3).

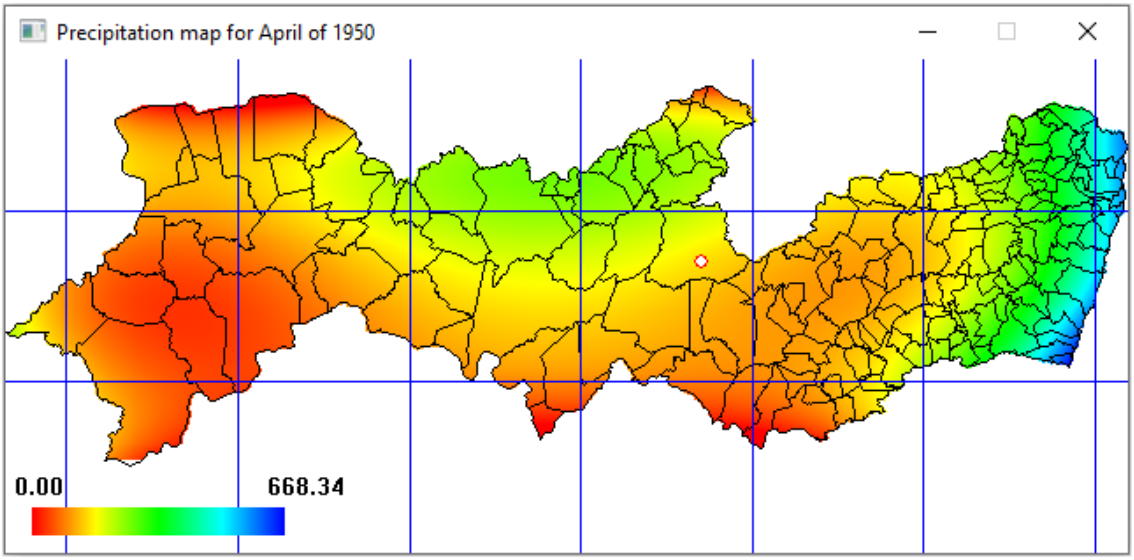
Figure 5. Spatially explicit map of precipitation ($\mathrm{mm} \cdot \mathrm{month}^{-1}$) in Pernambuco for April 1950: (top) precipitation map for values obtained in interpolation (0 - 668.34 $\mathrm{mm} \cdot \mathrm{month}^{-1}$); (bottom) precipitation map for upper bound entered in the Maximum value field (0 - 300 $\mathrm{mm} \cdot \mathrm{month}^{-1}$).



Source: Authors.

In the display window, a grid over the entire map can be superimposed by checking the Grid checkbox (component 10, Figure 3), aiming at assisting the visual identification geographical location of cells with a specific characteristic of precipitation (Figure 6).

Figure 6. Spatially explicit visualization window with a grid, for the monthly precipitation ($\mathrm{mm} \cdot \mathrm{month}^{-1}$) in the state of Pernambuco for April 1950.



Source: Authors.

Access to the historical series of monthly precipitation in each of the 81,544 points distributed over the state of Pernambuco can be performed in two ways. The first is assigning the desired longitude and latitude coordinates respectively in the Longitude and Latitude fields. The second way is to move the mouse over the map of Pernambuco in the viewport (the Current Longitude/Current Latitude and Current Municipality fields respectively reflect the current longitude/latitude coordinates and the current municipality), followed by a single click with the left mouse button to select the desired coordinate. In both ways of obtaining the historical series, it is necessary to press the Save button (component 13, Figure 3) to save the information a file. The data is kept in an ASCII (American Standard Code for Information Interchange) file, tab-separated, with extension *.dat and name referring to the selected coordinate and municipality. The file has a format that can be opened in spreadsheets, database, and statistical software.

The choice of trend surface analysis as a method of interpolation was made due to its performance in estimating monthly rainfall (Gomes et al., 2015; A. S. A. Silva et al., 2019). Silva et al., (2019) compared seven different methods (amounting to 26 distinct techniques) of spatial interpolation applied to monthly precipitation data for the state of Pernambuco, Brazil, in the period from 1950 to 2012, demonstrating that the trend surface analysis of degree $n = 4$ yields the best results in comparison with all the other considered methods. This methodology was also used by Gomes et al., (2015) as a tool to perform a comparative

analysis of the average monthly precipitation in the state of Paraíba, Brazil. The results obtained indicated that the polynomial regressions yield the best fit of the observed data for the surfaces of degree $n = 3$ and 4, corroborating the results obtained in Silva et al., (2019).

Computer programs, such as the Guarda Chuvas, developed to overcome the problem of missing data and the availability of records where there are no rainfall stations have been extensively studied in the literature. However, the vast majority take into account probabilistic models. The LARS-WG program (Semenov & Barrow, 1997) uses a semi-empirical distribution adjusted from the observed data; the ClimGen (Stöckle et al., 1999) simulates rainfall through the Weibull distribution; and the WidGETS (Chen et al., 2012) generates rain data from the Exponential or Gamma distribution. In Brazil, the PGECLIMA R (Virgens Filho et al., 2013) uses the Gamma distribution in the simulation of daily rainfall series. It is also possible to find computer programs that estimate temperature, such as the Estima_T program (Cavalcanti et al., 2006; Silva et al., 2006), which is able to estimate the temperature (average, minimum and maximum) for the Northeast region of Brazil, on the basis of geographic coordinates and sea surface temperature anomalies.

4. Final Considerations

The program presented in this work goes hand in hand with simulation models, in the sense that one can obtain historical rainfall series to feed models for the execution of simulations at a given location (regardless of whether precipitation data had been collected at that location by rainfall measurement stations, or not), as well as large-scale simulations. Through the interface, it is also possible to interactively analyze the large-scale behavior of the monthly precipitation in the state of Pernambuco over the years, being fundamental to identify the year, month and region with lower or higher rainfall intensity. Thus, the result of this work serves as an important tool to support studies on agricultural, water, environmental, and socioeconomic policies for the state of Pernambuco. Future studies are aimed at expanding the study region to the Northeast of Brazil and the time series for the current date.

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