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ORIGINAL ARTICLE

ACCURACY OF ORBITAL PRECIPITATION IN THE FURNAS RESERVOIR WATERSHED

Acurácia da precipitação orbital na bacia hidrográfica do reservatório de Furnas

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Abstract

Net precipitation is one of the variables in the water balance that shows significant spatial variability. It is the main energy input into the river basin system and needs to be monitored and understood. In this context, the Furnas Reservoir watershed serves multiple uses of water resources, such as power generation, irrigation, supply and tourism. This study aims to assess the accuracy of the Climate Hazards Group InfraRed Precipitation with Stations in detecting the net precipitation in the Furnas reservoir catchment area during the Climatological Normal period from 1981 to 2010. Accuracy was assessed by analyzing the Mean Absolute and Root Mean Squared Error between conventional and orbitally estimated rainfall data using a free statistical package and spreadsheet. The errors were then spatially inferred using a spatial interpolator. The results show that the orbital precipitation showed greater errors in regions of rugged terrain, such as December, January, February and March. This study aims to contribute to the monitoring of the precipitation in the Furnas basin, as well as to the thoughtful use of orbital-based precipitation data.

Keywords: CHIRPS, Hydrology, Water Resources, Remote sensing, Error analysis.

Resumo

A precipitação líquida é uma das variáveis do balanço hídrico que apresenta expressiva variabilidade espacial, sendo a principal entrada de energia no sistema bacia hidrográfica, necessitando ser monitorada, bem como compreendida. Enquadra-se neste contexto, a bacia hidrográfica do reservatório de Furnas, que atende a múltiplos usos dos recursos hídricos, tais como a geração de energia, irrigação, abastecimento, turismo dentre outros. Desta forma, objetiva-se avaliar a acurácia do *Climate Hazards Group InfraRed Precipitation with Stations* na detecção de precipitação líquida na bacia hidrográfica do reservatório de Furnas, no período da Normal Climatológica de 1981 a 2010. A avaliação da acurácia foi realizada em função da análise do Erro Médio Absoluto e da Raiz do Erro Médio Quadrático, entre os dados pluviométricos convencionais e estimados de forma orbital, utilizando-se de pacote estatístico livre e planilha eletrônica. Posteriormente, os erros foram inferidos espacialmente por meio de interpolador espacial. Resultados demonstram que a precipitação orbital apresentou maiores erros em regiões de relevos acidentados, tal qual nos meses de dezembro, janeiro, fevereiro e março. Almeja-se com este estudo, contribuir no monitoramento da precipitação na bacia de Furnas, bem como na utilização ponderada de dados de precipitação de base orbital.

Palavras-chave: CHIRPS, Hidrologia, Recursos hídricos, Sensoriamento remoto, Análise de erro.

1. INTRODUCTION

Precipitation is all the water from the atmosphere that reaches the Earth’s surface in different forms, such as dew, rain, hail, sleet and snow and is differentiated by the state in which the water is when it reaches the surface (BERTONI; TUCCI, 2009). It is one of the most important meteorological variables for climate studies (TERCINI *et al.*, 2024) and is characterized by its spatial and temporal variability. Its importance is due to human needs and the consequences of what they can cause, when in excess or deficit, for the productive sectors of the society, both from an economic and an environmental point of view, causing overflows, droughts, floods, silting up of rivers, falling of barriers, among others (CALBETE *et al.*, 2003).

According to Louzada (2016, p. 14), “the knowledge of the amount of precipitation in a region is fundamental for the strategic planning of water resources and all the activities that make use of these resources”, providing contributions in various activities such as climatological characterization, water balance, crop irrigation, flood control, drought monitoring, among others.

As a main input into the watershed system, precipitation must be monitored, and its spatio-temporal dynamics must be understood (SOUSA *et al.*, 2023). The knowledge of the intensity and the amount of precipitation is essential for understanding the cycle of global water flows and the energy balance of the Earth system (HOU *et al.*, 2014; SERRÃO *et al.*, 2016). While measuring precipitation at a given location using surface-based instruments is relatively simple, establishing a network of observation posts over extensive regions is complex and costly, given the spatial and temporal variability, type and occurrence of precipitation (NÓBREGA *et al.*, 2008).

It is worth noting that rain gauges and pluviographs have a small catchment area, measuring the rainfall of certain locations punctually, a condition that is hampered by the complex topographies that exist and can present several flaws in their monitoring, such as isolated rainy events that may not be captured by the devices and impair the analyses of the surface runoff and the water balance (ALMEIDA, 2017).

In this context, with technological advances, satellites have made a significant contribution with their images for the monitoring of precipitation, both spatially and temporally (REBELO *et al.*, 2023). Collischonn (2006) gives reasons for using satellite precipitation data in regions with large basins, such as Brazil, that lack rain gauge stations and are characterized by areas that are difficult to access, making it impossible to install instruments and measure precipitation.

In recent decades, studies using these approaches have matured, given the availability of acquisition and better spatial coverage of orbiting sensors, making them an important tool, especially in regions that do not have ground-based monitoring stations (LOUZADA, 2016).

Thus, several studies have contributed to the use of satellites to estimate precipitation in Brazil, such as those by Collischonn *et al.* (2006), Araújo *et al.* (2007), Collischonn *et al.* (2007), Saldanha *et al.* (2007), Pereira *et al.* (2013), Louzada (2016), Gama (2016), Aires *et al.* (2016), Castelhano *et al.* (2017), Pereira *et al.* (2018), which aim to estimate precipitation by satellite to ascertain the precision and the accuracy of the sensors for making estimates, contributing to the analysis of precipitation in various states and regions of Brazil.

The studies mentioned above show that the technique of estimating rainfall via orbital data performs well in measuring rainfall, as is the case of Louzada (2015) in his work on satellite rainfall analysis in the Doce River basin, concluding that the Tropical Rainfall Measuring Mission (TRMM) performs satisfactorily in estimating annual rainfall.

Araújo *et al.* (2007) used the Climate Prediction Center Morphing Technique (CMORPH). They stated that precipitation inferences from the CMORPH satellite have significant potential for use in various hydrological applications. Castelhano *et al.* (2017) analyzed three satellites: TRMM, Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) and CMORPH. They pointed out that the satellites show a significant correlation in the monthly and annual time frame, with the CHIRPS satellite standing out with values of 0.86 and 0.85, relating to monthly and annual data, respectively. At the same time, the other sensors had values of 0.55 (TRMM) and 0.51 (CMORPH).

Studies show that estimating rainfall by satellite has proved beneficial, presenting significant results that help water planning in large areas (DAMASCENO *et al.*, 2022), such as the hydrographic basins in Brazil. These supporting regions lack conventional rainfall stations.

Works on orbital-based precipitation have also been carried out in Africa, as demonstrated by Katsanos *et al.* (2016), who researched the validation of precipitation from the CHIRPS satellite over East Africa, showing that the satellite provides data with good correlations in daily and monthly analyses.

It is worth remembering that these techniques need to be assessed for their accuracy, i.e. their ability to estimate rainfall in a way closer to the real thing and not just based on correlations. Accuracy must be assessed using statistical techniques between observed and estimated data. To do this, the observed data used are the precipitations obtained from the network of rain gauges and/or pluviographs, and the estimated data used are the precipitations from remote sensing techniques.

The statistical evaluation of the accuracy of the orbital precipitation estimates aims to determine the degree of hit/ miss error that the satellite presents in the analysis region (MÔNICO *et al.*, 2009). To this end, there are some of the most commonly used statistical techniques, including three error analyses and two correlation analyses: absolute error, relative error, root mean square error (RMSE) and their respective averages, as well as the correlation coefficient (R) and the coefficient of determination (R^2).

Once the accuracy of these products has been verified, they can be used to support hydro-climatological monitoring, water resource planning and management, and can also contribute to energy planning (generation and reservoir level/volume control).

Therefore, analyzing the performance of the orbital precipitation estimates in the Furnas reservoir watershed will contribute to the planning and management of water resources, the forecasting of flows in tributary basins, the evaluation of stored energy, as well as the determination of the amount of energy to be generated by Furnas S.A. In addition, the knowledge of spatio-temporal dynamics will support actions aimed at the management and conservation of soil and water, as well as the estimation of water balances and security, based above all on human supply and animal desiccation.

The aim of this research is to evaluate the accuracy of monthly orbital precipitation data from the CHIRPS satellite, based on the rainfall stations of the National Water and Sanitation Agency (ANA), for the Furnas reservoir watershed in the base period of the Climatological Normal from 1981 to 2010.

2. MATERIALS AND METHODS

2.1. Location and characterization of the study area

The Grande River basin is an integral part of the Paraná basin and is one of the country's most important basins due to its hydroelectric generation cascade system. It also covers an area of 143,255km², of which 40% is in São Paulo, and the remaining 60% belongs to Minas Gerais (ANA, 2017). The upper reaches of the Grande River are home to the Furnas reservoir (Figure 1), which covers approximately 51,950km² (CAMPOS; LATUF, 2017).

According to the data provided by Furnas (2023), the Hydroelectric Power Plant was the first plant built by Furnas Centrais Elétricas S.A. The dam is located on the Grande River, on the stretch commonly known as “Corredeiras das Furnas”, between the municipalities of São João Batista do Glória and São José da Barra, in the state of Minas Gerais, with an installed capacity of 1,216MW. The dam was constructed in 1958, and the first unit began operating in September 1963 (FURNAS, 2023).

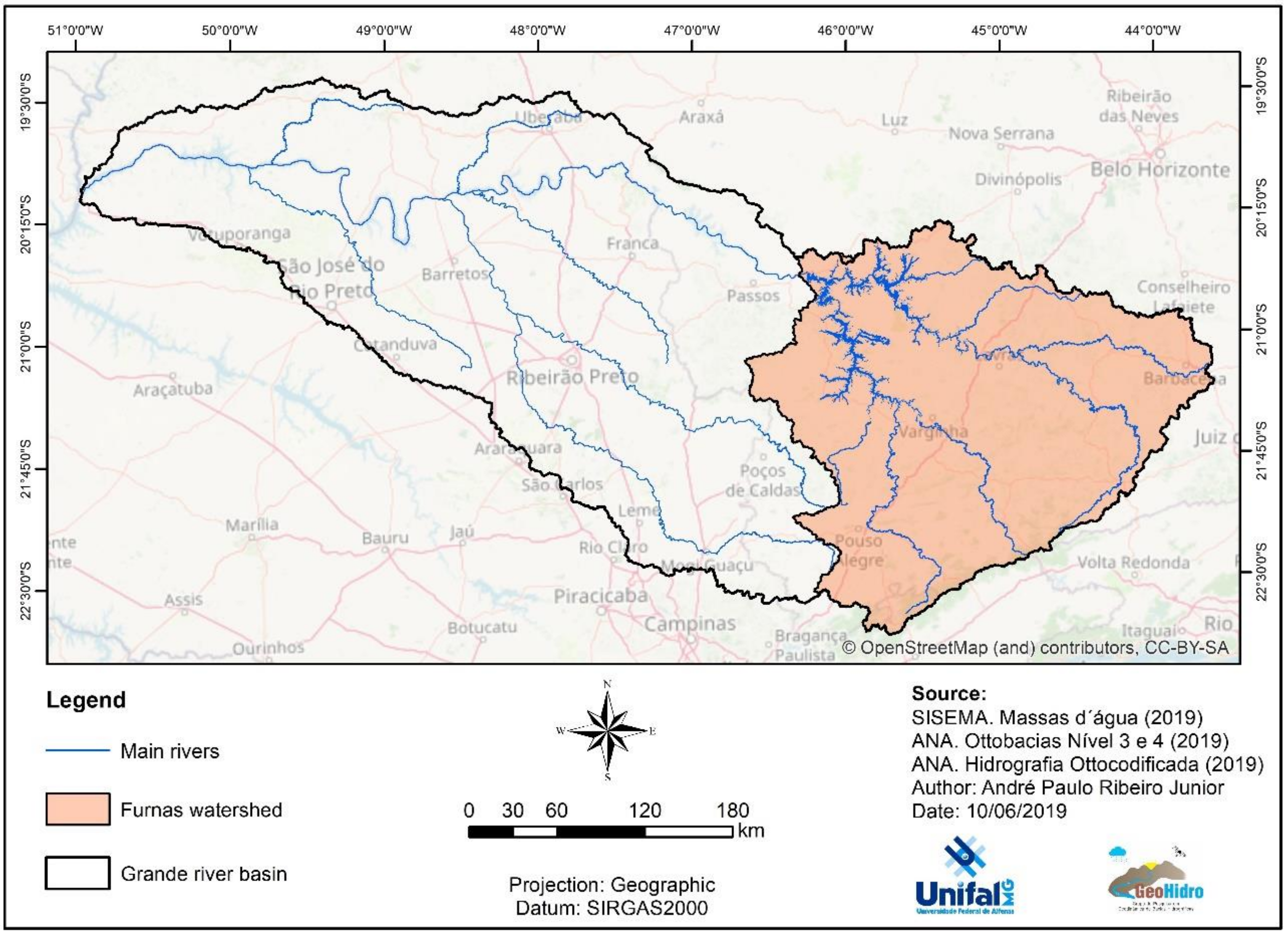


Figure 1 - Location of the Furnas reservoir watershed in the Grande River basin
Source: ANA, 2019.

In the south-southwestern region of Minas Gerais, where the Furnas reservoir watershed is located, according to the Köpper-Geiger classification, the Cwa climate (humid temperate climate with dry winters and hot summers) and the Cwb climate (humid temperate climate with dry winters and moderately hot summers) predominate. According to Reboita (2015), this is due to the influence of high-altitude regions, causing temperatures to be slightly lower than in areas with the Aw climate.

According to the Integrated Water Resources Plan drawn up by the National Water and Basic Sanitation Agency (ANA, 2017), the basin is highly exploited by various segments that use water resources, mainly to generate hydroelectric power (e.g. Furnas Centrais Elétricas S.A and CEMIG), including a significant anthropized area, such as agricultural and livestock areas.

The reservoir's waters are used in various ways, with the main uses on the "south branch" (regionally known as Sapucaí River) being coffee plantations, extensive beef and dairy farming, and corn and sugarcane crops. On the "north branch" (regionally known as Grande River), the main uses are mining companies and extensive beef and dairy farming (LEMOS JÚNIOR, 2010).

2.2. Methodological procedures

Rainfall data from conventional stations were acquired through the ANA's National Water Resources Information System (SNIRH) portal (https://www.snirh.gov.br/hidroweb), which provides access to the daily database containing records collected by the National Hydrometeorological Network.

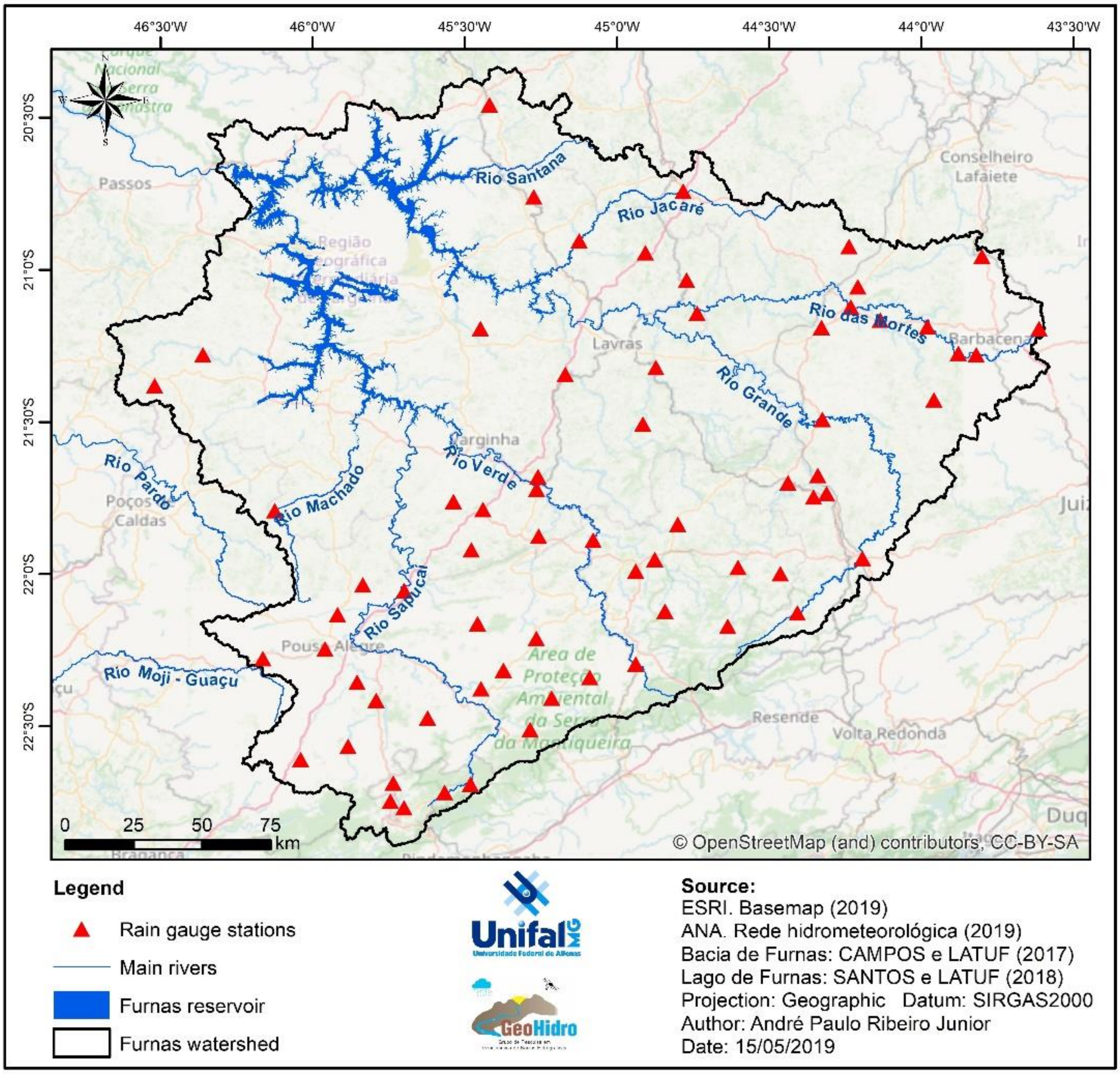
After acquiring the data, it was necessary to carry out a filtering procedure to identify the stations that belonged to the study area, thus obtaining 220 rainfall stations from the Furnas reservoir watershed.

Observing the recommendations of the World Meteorological Organization (WMO) and the National Institute of Meteorology (INMET), the Climatological Normal from 1981 to 2010 was adopted as a base period. According to the WMO, the Climatological Normal presents the average of a given parameter over at least 30 consecutive years (INMET, 2019).

Thus, given the analysis period, only 69 stations met the criteria as mentioned earlier (Figure 2). Notably, the coverage of stations in the northwestern part of the basin, around the reservoir, is unsatisfactory compared to other parts of the basin.

The data from the 69 ground stations were processed using the Hidro 1.3 software (https://www.snirh.gov.br/hidroweb-mobile/mapa), in which they were imported in the .mdb format to obtain monthly slides for the period between 1981 and 2010. Each station in the study area was checked for any gaps in its historical series, as well as any dubious or estimated data. Once these occurrences had been identified, the month with these characteristics was excluded. Once the above procedures had been completed, the monthly data were exported to a spreadsheet environment.

The orbital-based monthly precipitation data were acquired from the website of the Climate Hazards Group at the University of Santa Barbara in the United States (https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_monthly/tifs), with the base period of the Climatological Normal from 1981 to 2010, totalling 360 files. The data are provided in Geographic projection, WGS84 horizontal datum and GeoTiff format.



Source:
ESRI. Basemap (2019)
ANA. Rede hidrometeorológica (2019)
Bacia de Furnas: CAMPOS e LATUF (2017)
Lago de Furnas: SANTOS e LATUF (2018)
Projection: Geographic Datum: SIRGAS2000
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Figure 2 - Location of conventional rain gauge stations.
Source: ANA, 2019; CAMPOS; LATUF, 2017; LATUF; SANTOS, 2023.

After obtaining the orbital base data, it was necessary to cut the 360 rasters to the limits of the research area since they are available with a global scope. To this end, the Geographic Information System (GIS) ArcMAP™ 10.6.1 was used, adopting the basin boundary proposed by Campos and Latuf (2017).

After the earlier stage, the values contained in the coincident pixels were extracted for each land station between 1981 and 2010. For this purpose, conventional rainfall data from the ANA were used as ground truth, and the data estimated by CHIRPS were extracted using the Extract Values to Points module of the ArcMAP™ 10.6.1 GIS.

The statistical evaluation of the accuracy of the orbital precipitation estimates aimed to determine the degree of hit/error that the satellite presents in the analysis region. To this end, this article used two error analysis descriptors: Absolute Error (AE) and Root Mean Squared Error (RMSE).

The Absolute Error was used to show the difference between the rainfall estimated from the orbital data and the rainfall observed at the conventional rainfall stations (Equation 1). As a result, data with positive and negative values can be obtained, resulting in overestimated or underestimated deviations, respectively.

$$EA = P_{est} - P_{obs} \qquad (1)$$

Where,

AE: Absolute error (mm)

$P_{est:}$ Precipitation estimated by CHIRPS (mm)

P_{obs}: Precipitation observed by conventional stations (mm)

With regard to the RMSE metric, the expression shown in Equation 2 was used. RMSE data always have values in the same unit as the original data, which makes it easier to analyze (CARMO; SILVA, 2023).

$$RMSE = \sqrt{\frac{\sum(P_{est} - P_{obs})^2}{n}} \qquad (2)$$

Where,

RMSE: Root Mean Square Error (mm)

P_{est}: Precipitation estimated by CHIRPS (mm)

P_{obs}: Precipitation observed by conventional stations (mm)

n: number of samples

Once we had the estimated and observed rainfall values for each conventional station, we exported the data in the 69 attribute tables to the spreadsheet format. Then, we imported them into the RStudio 1.2.1335 software (R CORE TEAM, 2019) to create graphs and analyze outlier data using the interquartile range method (PEREIRA *et al.*, 2018).

In order to regionalize the average monthly errors, it was necessary to interpolate the errors obtained in the previous stage using the Inverse Distance Weighting (IDW) method by the ArcMAP™ 10.6.1 GIS, which aims to infer values from unsampled locations based on the distance between samples (ALMEIDA, 2017). From this procedure, it was possible to observe, spatially, where the greatest errors are regionalized in the Furnas reservoir watershed, whether positive (overestimates) or negative (underestimates).

3. RESULTS AND DISCUSSION

In order to understand the results, it is necessary to highlight some characteristics of the topography surrounding the Furnas Reservoir watershed (Figure 3). The south-southwestern region of Minas Gerais is marked by high topographies such as the Serra da Mantiqueira and Serra da Canastra, with the highest altitudes being found in the south-southeastern portion of the basin, with altitudes of over 1,600m.

The orographic layout around the basin has an impact on the precipitation regime, causing orographic rainfalls near the Mantiqueira mountain range, which is an obstacle for the Atlantic Tropical Mass (mTa) in summer and for one of the branches of the Atlantic Tropical Mass (mPa) in winter. This orography influences the precipitation regime and the dynamics of the air masses that act directly on the Furnas reservoir watershed.

Therefore, the dynamics of the air masses and the relief interfere with the occurrence of precipitation in the region under analysis, which is why it is important to use remote sensing technologies to detect precipitation due to the irregular distribution of rainfall stations.

In this way, the following analyses assess the accuracy of the CHIRPS satellite's estimates of the Furnas reservoir watershed's monthly rainfall between 1981 and 2010 (30 years). Figure 4 shows the graphical analysis of the boxplots of the average monthly absolute errors for the 69 support stations selected in the basin. There is greater dispersion in the rainy months (October to March), especially December, and less dispersion in the dry months (April to September), especially July.

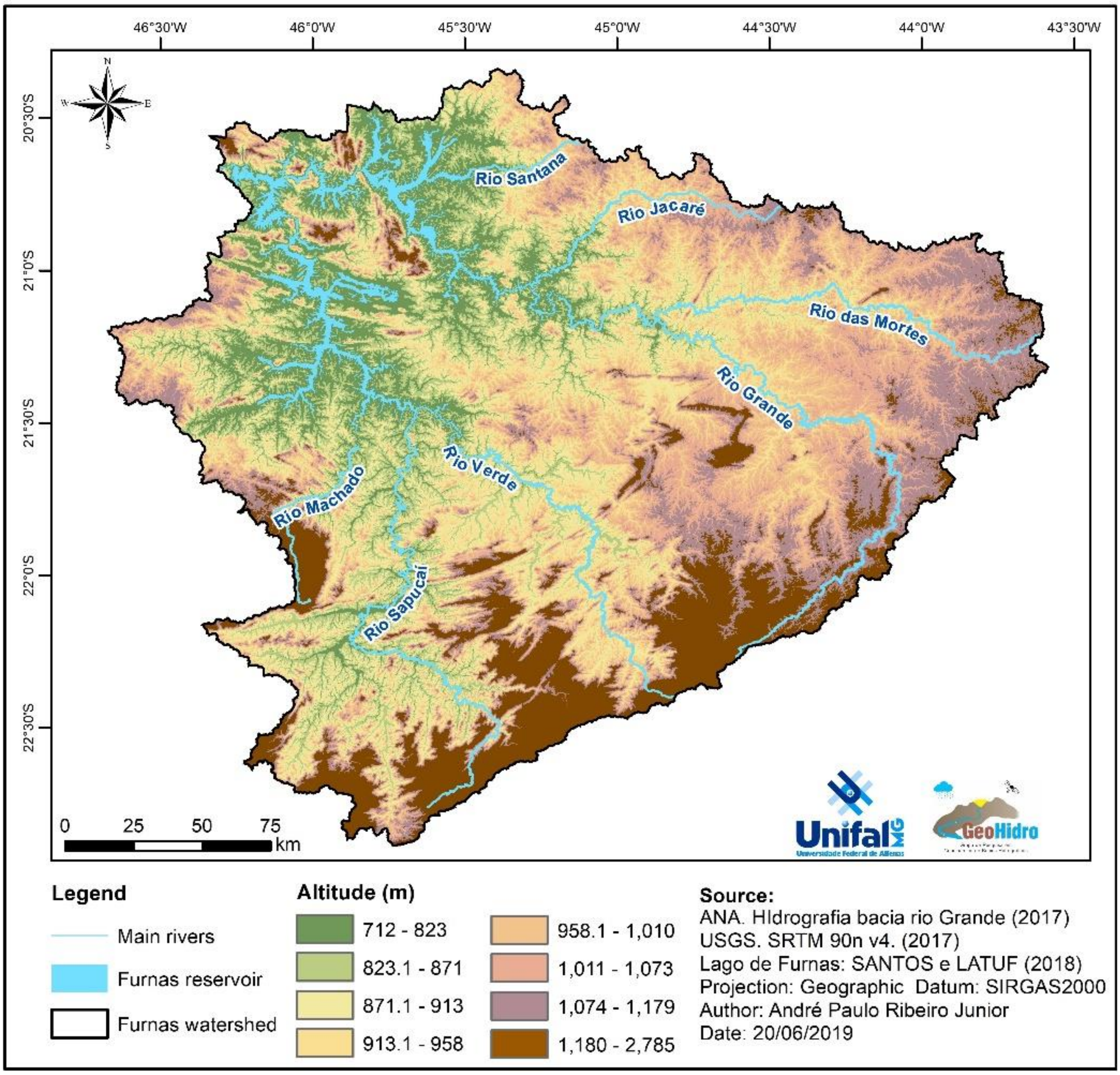


Figure 3 - Topography of the Furnas Reservoir watershed
Source: CAMPOS; LATUF, 2017; USGS, 2017.

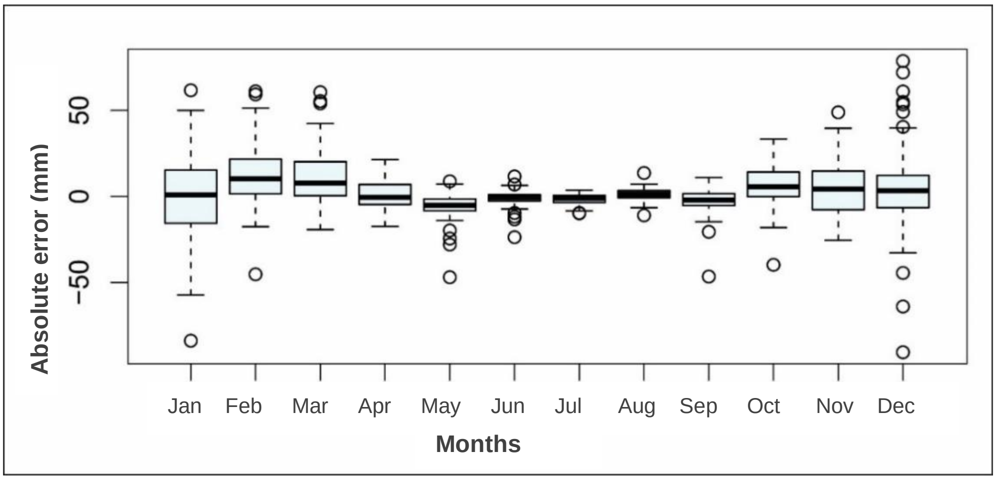


Figure 4 - Absolute error of average monthly rainfall (1981-2010)
Source: Authors.

The months from November to March showed greater amplitudes in their data, with significant overestimates and underestimates, such as December (EAmax: 61.0mm and EAmin: -90.6mm), January (EAmax: 61.7mm and EAmin: -83.9mm) and February (EAmax: 61.6mm and EAmin: -45.3mm), of which it is worth noting that these are months during the rainy season in the Furnas reservoir watershed region, with the greatest occurrence of convective-type rainfalls, coming from the mTa and mEc air masses.

The months from April to August show values with lower error amplitudes, such as July (EAmax: 3.6mm and -9.8mm) and August (EAmax: 13.6mm and EAmin: -11.0mm), months that belong to the dry season in the basin and with more frequent precipitations of the frontal type, mostly due to the effects of mPa.

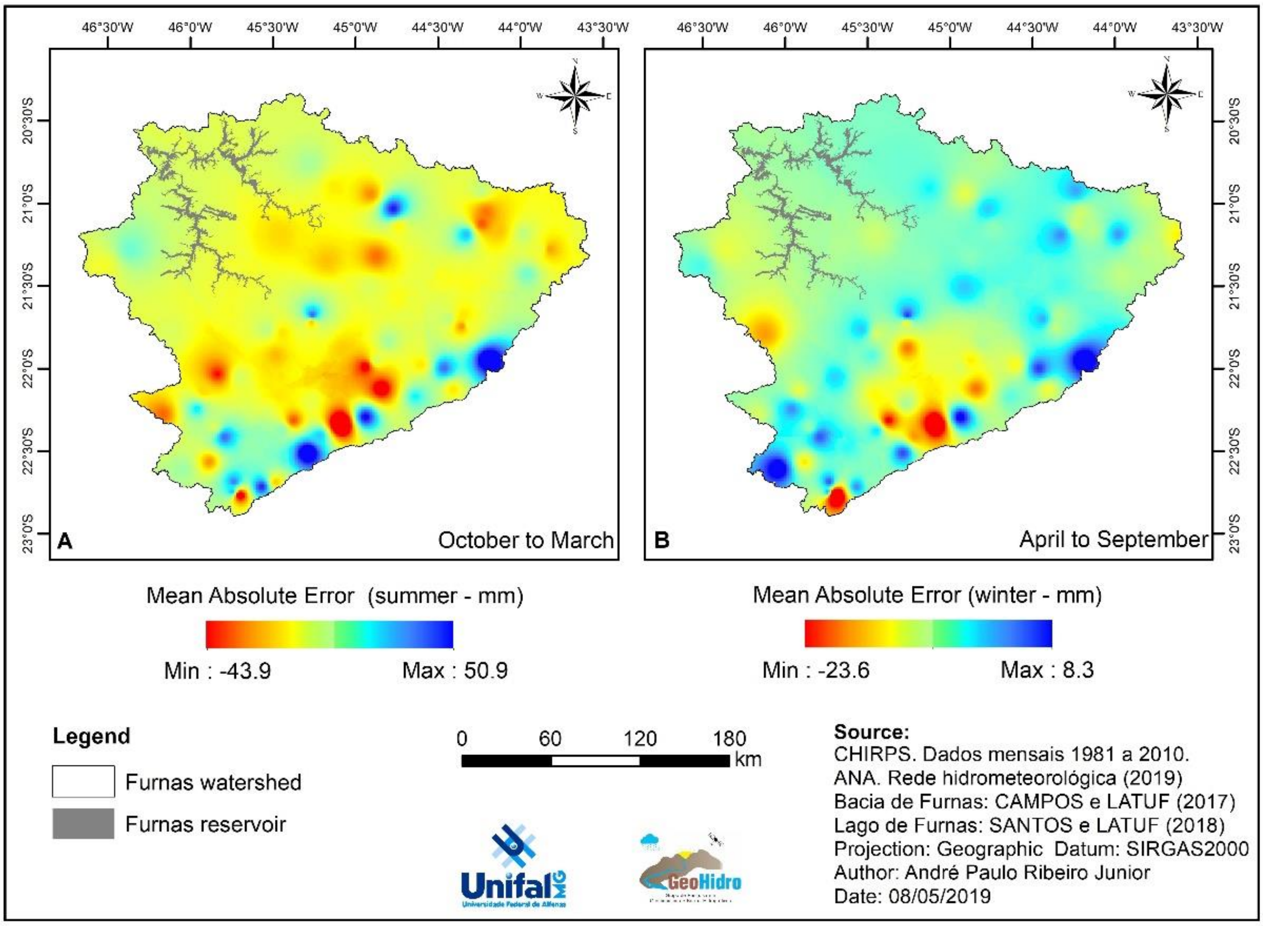
It is noticeable that the largest amplitudes occurred in the months with the highest incidences of precipitation in the basin, showing that the orbital data from the CHIRPS satellite tend to show greater absolute errors in the period when the mEc (Continental Equatorial Mass) and mTa (Atlantic Tropical Mass) air masses are in action. On the other hand, the dry season showed less amplitude between maximum and minimum values, coinciding with the effects of the mTc (Continental Tropical Mass) and mPa (Atlantic Polar Mass) air masses in the reservoir basin.

Figure 5 shows the distribution of the regionalized mean absolute errors in the Furnas reservoir watershed between 1981 and 2010, during the rainy season (Figure 5A) and the dry season (Figure 5B), intending to identify the regions with the largest and smallest errors spatially.

There are significant negative and positive absolute errors in summer, but in the regional context, there is a slight inclination towards underestimation. In winter, the spatial tendency is for the average absolute errors to be more biased towards subtle overestimates. However, in both seasons, significant errors in locations are associated mainly with the Mantiqueira mountain range.

The smallest errors observed occur in the centre-north/south of the Furnas reservoir watershed, mainly in winter (Figure 5B), when precipitations come mainly from frontal rains due to the passage of the mPa. In contrast, the opposite happens in summer, when precipitations occur mainly due to convective factors associated with the mEc.

It should be noted that the highest mean absolute errors occur near the Mantiqueira mountain range. This was also observed by Shrestha *et al.* (2017), Sharifi *et al.* (2019) and Lopez-Bermeo *et al.* (2022).



October to March

April to September

Source:
CHIRPS. Dados mensais 1981 a 2010.
ANA. Rede hidrometeorológica (2019)
Bacia de Furnas: CAMPOS e LATUF (2017)
Lago de Furnas: SANTOS e LATUF (2018)
Projection: Geographic Datum: SIRGAS2000
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Date: 08/05/2019

Figure 5 - Seasonal mean absolute error for the Furnas reservoir watershed (1981-2010)
Source: Authors.

The analysis of the average monthly absolute errors (Figure 6) was interpolated from the absolute errors per rainfall station (n = 69) from January to December to ascertain the spatial variation of the absolute errors from the CHIRPS satellite estimate in the Furnas reservoir watershed between 1981 and 2010.

When we look at the monthly maps of absolute errors, we initially see a variable behaviour throughout the Furnas reservoir watershed for isolated points, either with positive or negative errors. This behaviour stems from the characteristics of the interpolator used, which is local, based on proximity and strongly influenced by spatial dependence (YAMAMOTO; LANDIM, 2013).

In the months with the lowest rainfalls (April to September), there were maximum positive errors in the north, especially in July, in the municipalities of Lavras/MG, Resende Costa/MG, Oliveira/MG, and Santana do Jacaré/MG, and in the east and south in the regions near Bom Jardim de Minas/MG, Cambuí/MG and Pouso Alegre/MG.

Concerning negative errors, regions were identified in the south-central part of the basin (Virgínia/MG, Maria da Fé/MG, Campos do Jordão/SP and Cambuquira/MG), in the west (Muzambinho/MG and Poço Fundo/MG) and northwest (Coqueiral/MG), in the north (Oliveira/MG and São João del Rei/MG) and in the northeast (Tiradentes/MG and Carandaí/MG).

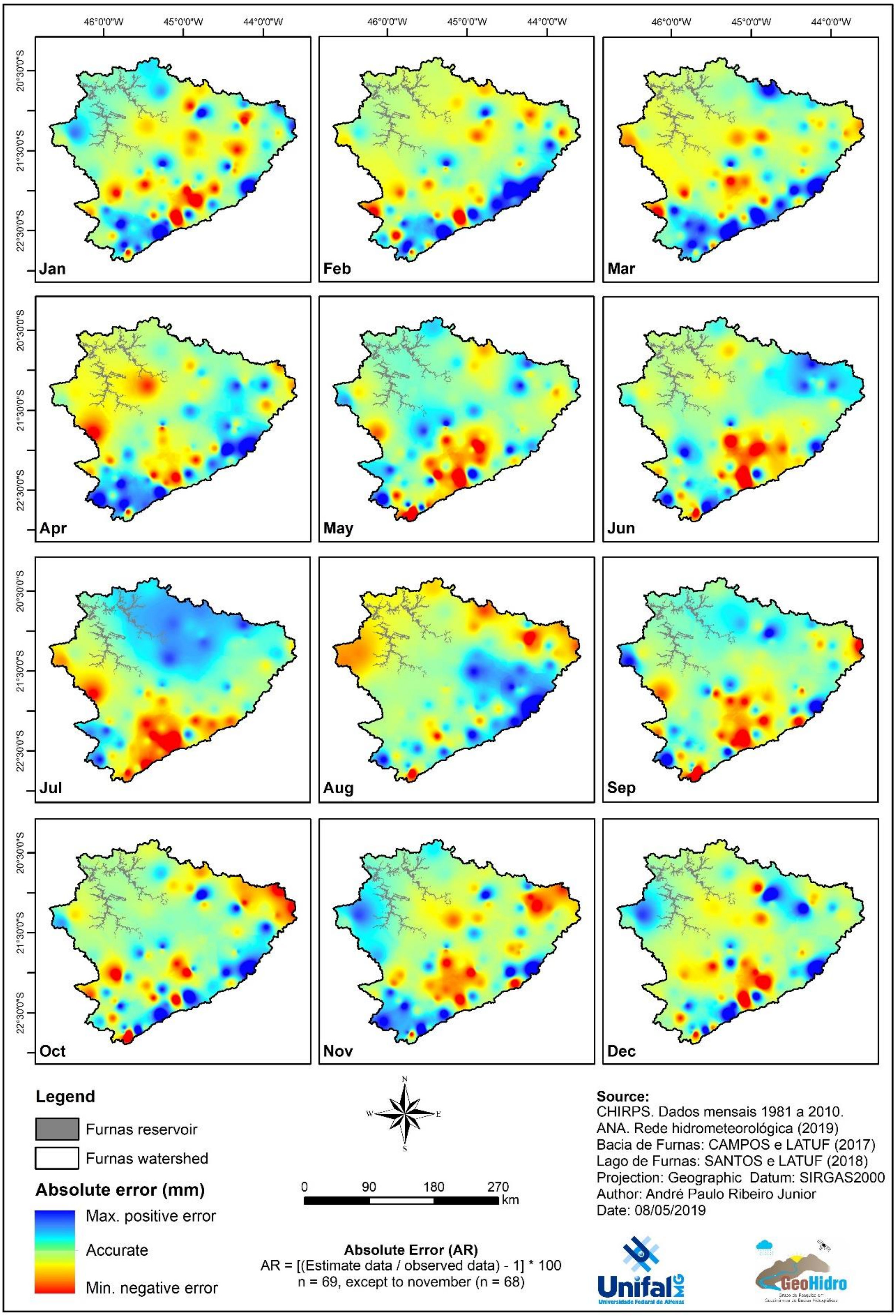
What strikes us is that, regardless of whether the error is an overestimate or an underestimate, there is a spatial pattern associated with the Mantiqueira mountain range or even in regions with more expressive geographical features. One hypothesis for this is that in these regions, not only the orographic factor is influencing, but also the issue of winds, which may be affecting the accuracy of the CHIRPS orbital estimate, since in regions of high altitude, wind speeds tend to be higher (MOREIRA; PEREIRA, 2004), in addition to the turbulence due to the wind circulation.

Figure 7 shows the monthly average of the Absolute Error, which shows that there is a seasonal pattern of error since in the rainy season, only the month of January stands out with a negative value (underestimate), while in the dry season, only the month of August obtained a positive value (overestimate).

The other months that make up the rainy season, excluding January, have values greater than zero, i.e., an average overestimate of 7.4mm, with a maximum value of 11.6mm in February. In the same context, the months that comprise the dry season, excluding August, have average values of -2.1mm, with the maximum average underestimate in May (-5.1mm).

It indicates that there may be a pattern in the Furnas reservoir watershed, which should be better studied, of overestimates in rainy periods and underestimates in dry periods. In addition, different types of precipitation are involved in the analysis since most rainfall in the rainy season comes from convective cells. In contrast, in the dry season, precipitations come from frontal systems.

Concerning the Root Mean Square Error (RMSE) metric, the average monthly behaviour obtained for the Furnas reservoir watershed is shown (Figure 8), with the greatest discrepancy detected in December (RMSE = 233.4mm), while the smallest deviation was observed in September (RMSE = 13.7mm).



Source:
CHIRPS. Dados mensais 1981 a 2010.
ANA. Rede hidrometeorológica (2019)
Bacia de Furnas: CAMPOS e LATUF (2017)
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Absolute Error (AR)
AR = [(Estimate data / observed data) - 1] * 100
n = 69, except to november (n = 68)

Figure 6 - Average monthly absolute error in the Furnas Reservoir watershed (1981-2010)
Source: Authors.

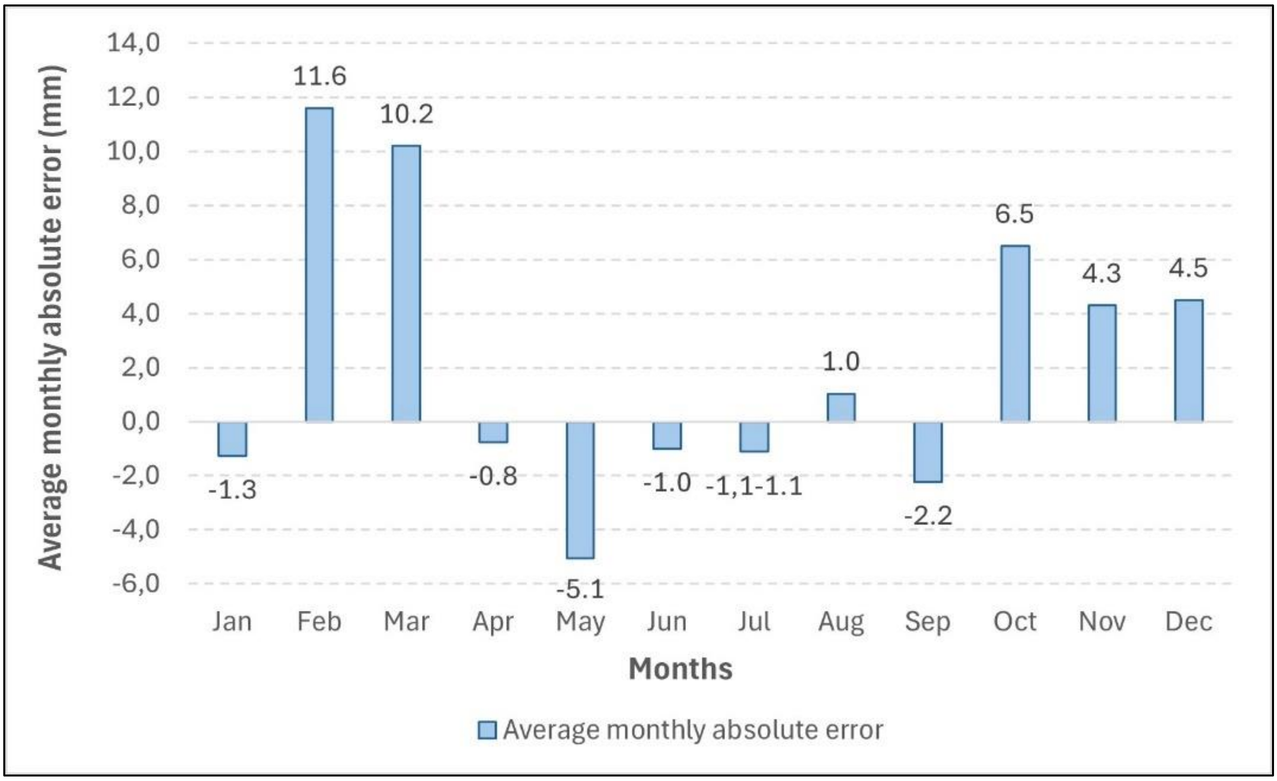

Figure 7 - Average monthly absolute error of precipitation estimates by CHIRPS in the Furnas reservoir watershed (1981-2010). **Source:** Authors.

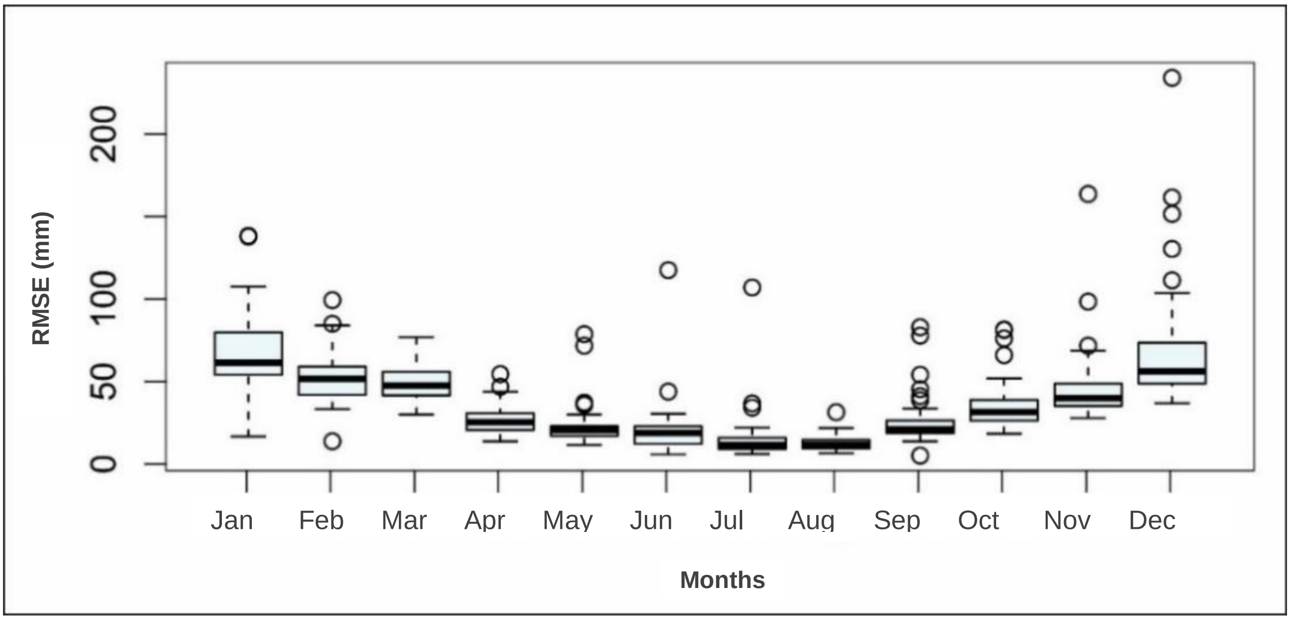

Figure 8 - Root mean squared error of monthly rainfall (1981-2010)
Source: Authors.

A more detailed analysis shows that the median ranged from 11.6mm in July to 61.5mm in January. The largest outliers were recorded in December (RMSE = 233.4mm), November (RMSE = 163.6mm), June (RMSE = 117.5mm) and July (RMSE = 107.0mm).

Figure 9 shows the RMSE monthly average, which shows that the highest values occurred in the months with the highest rainfall, from October to March, with maximum values of 67mm (December and January). Between July and August, the period saw the lowest RMSE indices, with 14.2mm and 12.5mm values, respectively.

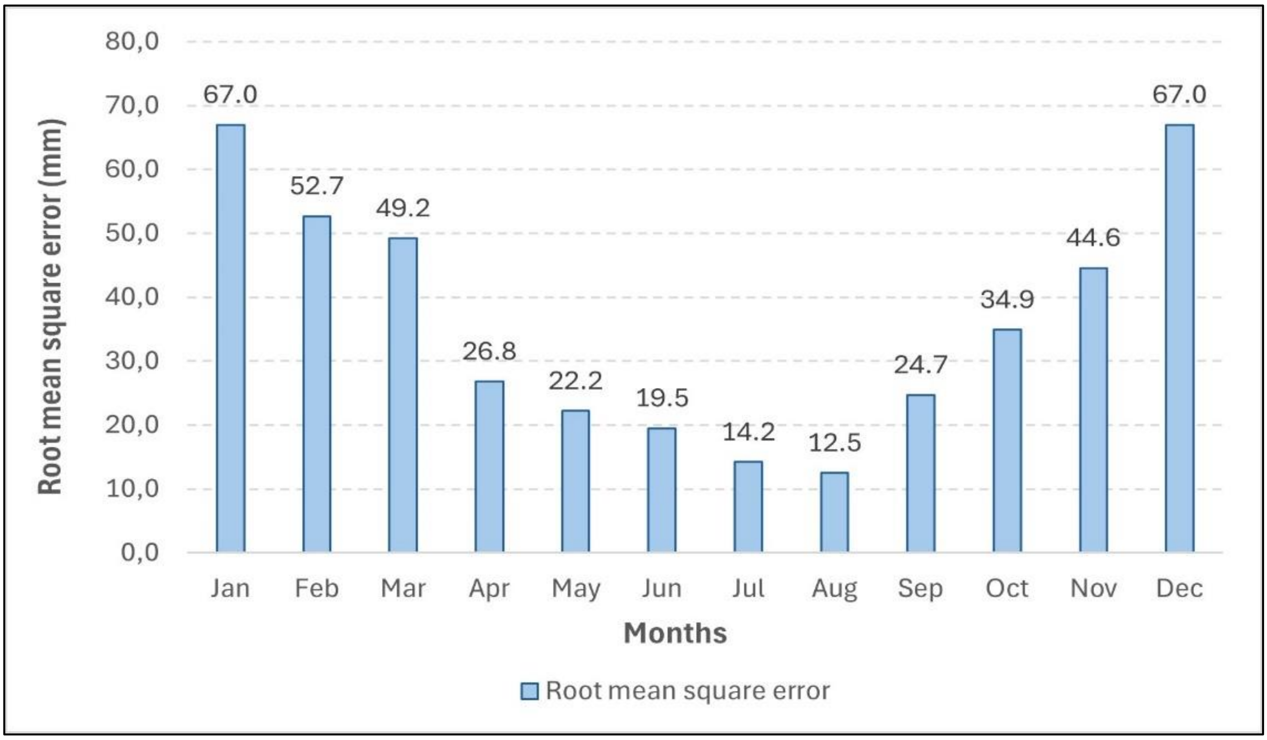

Figure 9 - RMSE monthly average of precipitation estimates by CHIRPS in the Furnas reservoir watershed (1981-2010). **Source:** Authors.

These figures may be intrinsically related to the different rainfall characteristics in the two periods mentioned: in the rainy season, the net rainfall is mostly due to convection and orography near the Mantiqueira mountain range, influenced by the mEc and mTa, respectively. During the dry season, the region has lower rainfall rates, and when they occur, it is mainly due to the passage of cold fronts caused by mPa.

On the other hand, based on the spatial understanding of the RMSE in the basin, Figure 10 shows the average monthly behaviour of the deviations in the Furnas reservoir watershed.

The monthly average obtained for the RMSE in the Furnas basin during the Climatological Normal period from 1981 to 2010 was 36.3mm. However, there are regions where the maximum RMSE values are close to the elevated regions in the reservoir basin (Figure 3), especially along the Mantiqueira mountain range, in the southern and eastern portions of the basin, in the Sapucaí and Verde river sub-basins, as well as in the upper Grande river basin.

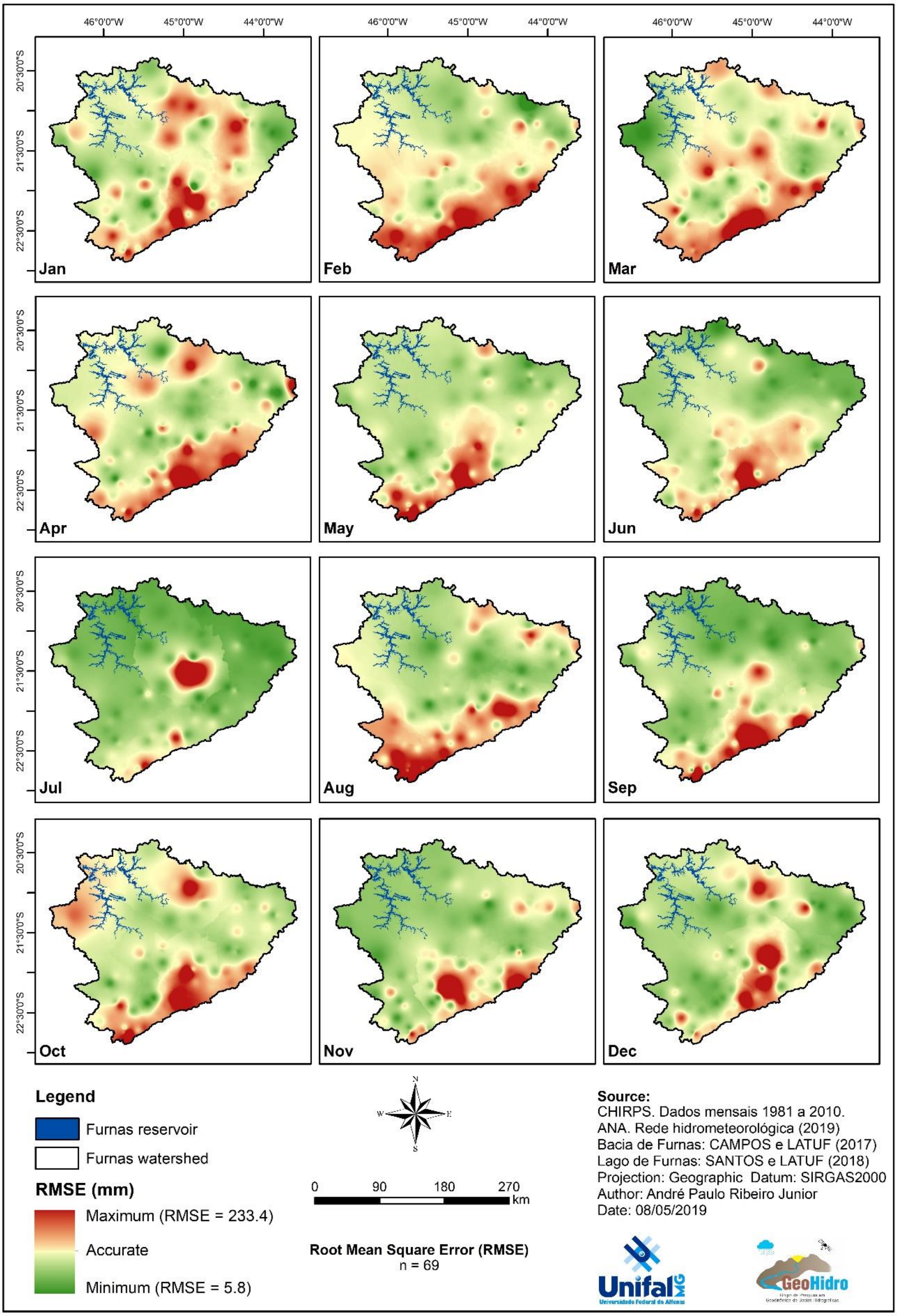

Figure 10 - Regionalization of the RMSE monthly average in the Furnas reservoir watershed (1981-2010)
Source: Authors.

There is a discrepancy between July and the others recorded in the municipality of Luminárias/MG, with a figure of 117.5mm. There is also a “certain coincidence” in the vicinity of the municipalities of Bom Sucesso/MG, São Tiago/MG and Santo Antônio do Amparo/MG, which should be investigated in greater detail. This region has higher RMSE values in April, June, October and December than its surroundings.

The minimum values, i.e. the best CHIRPS estimates concerning the data measured in situ by the ANA stations, are mostly found in the regions far from the Mantiqueira mountain range, especially in the months with the lowest rainfall levels and, concerning October to March (the rainy season), there are some more significant deviations located in the north of the basin.

4. FINAL CONSIDERATIONS

Net precipitation data estimated by satellites can guarantee seamless historical series and spatial continuity in different regions of the planet. Many databases are free and easily accessible via download or even cloud computing.

CHIRPS is one of these products with one of the best temporal resolutions (daily data) and an adequate pixel size for the context in which it was designed, of approximately 5km. For these reasons, it is one of the most widely used orbital data in climatological and hydrological analyses worldwide. However, it should be noted that these data are <u>estimated</u> and are not free from <u>inaccuracies</u> or <u>deviations</u>.

The results obtained by this research indicate that the orbital-based precipitation estimates made by CHIRPS for the Furnas reservoir watershed are a valid source and can be used in the planning and management of water resources, in the operation of the Furnas reservoir, as well as in climatological analyses, with the necessary caveats for some regions of the basin, especially near rugged terrains such as the Mantiqueira mountain range.

These facts can be observed in other regions that use orbital-based data in Brazil and other countries. Therefore, it is recommended that when using orbital precipitation data, the data’s accuracy be evaluated to know the errors in the estimates so as not to compromise the desired analysis.

It can be seen that the tests carried out between the data from the ANA station sampling points and the CHIRPS estimates indicate a greater discrepancy in rainy seasons between October and March, <u>which is a problem</u>. However, these errors are located regionally in parts of the basin where the Mantiqueira mountain range or more rugged terrains are found.

Therefore, these data should be used carefully to understand the orographic and altimetric influence on satellite precipitation detection, whether due to the orographic disposition, the dynamics of air masses, or the types of precipitation.

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