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Evaluation of precipitation data generated by ERA5 reanalysis for the Mirim-São Gonçalo watershed, Brazil

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A B S T R A C T

The transboundary Mirim-São Gonçalo watershed (MSGW) is of paramount importance for the development of its region, mainly for the agricultural sector. Obtaining climate data is fundamental in the management of water resources, as it allows estimating missing data, making long-term forecasts and checking possible trends. The European Center for Medium-Range Weather Forecasts (ECMWF) produces numerical weather forecasts, being the fifth generation of reanalysis (ERA5) the most recent. This work aimed to evaluate the efficiency of ERA5 in representing precipitation for the Brazilian side of MSGW, comparing its grid points data with the observed ones from rain gauges. For this purpose, the ERA5 and observed monthly climatological 1981-2020 rain data of the MSGW was calculated. The stationarity of the data was evaluated by applying the Mann-Kendall's (MK) and Sen's Slope (SS) tests, while the data homogeneity was verified with the Pettitt (Pt) test. For data validation, the Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE) and Pearson's correlation coefficient (rpearson) were calculated. MK and SS tests verified that there is no significant trend in the majority of the precipitation series, while the Pt test pointed out that there is no significant changing point (5% of significance level). The error measures (MAPE and RMSE) were low while the rpearson presented high correlation values (strong and positive), indicating the good performance and the potential of the ERA5 model in representing the precipitation data in the MSGW.

Keywords: Pampa biome; South America; Water resources; Management.

Avaliação dos dados de precipitação gerados pelas reanálises do ERA5 para a Bacia Hidrográfica Mirim-São Gonçalo, Brasil

R E S U M O

A bacia hidrográfica transfronteiriça Mirim-São Gonçalo (BHMSG) é de suma importância para o desenvolvimento de sua região, principalmente para o setor agrícola. A obtenção de dados climáticos é fundamental na gestão dos recursos hídricos, permitindo estimar dados ausentes, fazer previsões a longo prazo e verificar possíveis tendências. O Centro Europeu de Previsões Meteorológicas de Médio Prazo (ECMWF) produz previsões meteorológicas numéricas, sendo a quinta geração de reanálise (ERA5) a mais recente. Este trabalho teve como objetivo avaliar a eficiência do ERA5 em representar a precipitação do lado brasileiro da BHMSG, comparando dados gerados em ponto de grade com os observados em pluviômetros. Para tanto, foram calculados dados mensais de chuva observados de 1981-2020 e os gerados no ERA5. A estacionariedade dos dados foi avaliada com os testes de Mann-Kendall (MK) e Sen's Slope (SS), enquanto a homogeneidade foi verificada com o teste de Pettitt (Pt). Para validação, foram calculados o Erro Percentual Médio Absoluto (MAPE), a Raiz do Erro Quadrado Médio Médio (RMSE) e o coeficiente de correlação de Pearson (rpearson). Os testes MK e SS verificaram que não há tendência significativa na maioria das séries de precipitação, enquanto o teste Pt apontou que não há ponto de mudança significativa (ao nível de 5% de significância). As medidas de erro (MAPE e RMSE) foram baixas enquanto o rpearson apresentou altos valores de correlação (fortes e positivos), indicando o bom desempenho e o potencial do modelo ERA5 em representar os dados de precipitação para a BHMSG.

Palavras-chave: Bioma Pampa; América do Sul; Recursos Hídricos; Gestão.

Introduction

The economic and social impacts that climate change causes to the population are increasingly observed by governments and researchers, and it is very common to use climate projections based on models that estimate temperature and precipitation (IPCC, 2021; 2022). These changes manifest themselves in several climatic variables, highlighting the increase in global temperature, rising sea levels, changes in precipitation regimes and extreme events (Bento et al., 2024).

As much as climate change, natural climate variability demands attention from the scientific community. Carrying out long-term forecasts aiming to indicate possible seasonal anomalies of precipitation associated with El Niño or La Niña events is of paramount significance, as well as knowing their magnitude within some periods (Lenssen et al., 2020; Williams et al., 2023). Therefore, understanding and estimating climate change is essential as a way of finding ways to face and mitigate possible impacts that these changes may cause in terms of water availability and scarcity (Bezerra et al., 2023; ; Giustarini et al., 2023; Silva Tavares et al., 2023; Wu et al. 2023), which due to global warming occur with greater frequency, intensity and duration, affecting ecosystems (IPCC, 2022).

However, historical series of climate variables often present errors, and in some regions there is a lack of meteorological data, which is a problem frequently observed in Brazil (Freitas et al., 2023; Ribeiro Neto et al., 2020; Santos et al., 2022; Silva et al., 2021). As a result, the use of alternative sources of meteorological variables is increasingly common, and data from reanalysis of global atmospheric models are one of the main tools used for long-term studies (Sales et al., 2023; Tang et al., 2022; Wu et al., 2022).

Forecast data estimates are commonly used in hydrology and meteorology, as they are capable of estimating long-term time series, presenting coherence on a global scale. However, it is essential to evaluate its performance in a given region (Cardoso and Quadro, 2017; Cebolla et al., 2023; Wu et al., 2022 and 2023, Wang et al., 2021), and it is essential that they present reliability in their results, thus representing the climate in the most reliable way possible.

The Mirim-São Gonçalo watershed (MSGW) is part of the South Atlantic hydrographic region, being the Mirim Lagoon a very important system in South America. Since MSGW covers both Brazil and Uruguay, it is considered a transboundary watershed (Kotzian and Marques, 2004; Sosinski, 2009; SEMA, 2023). In Brazil, this watershed includes several municipalities of southern Rio Grande do Sul State (GOVRS, 2023), and it is of great importance as a source of freshwater reserves for the region's development, acting as a strong ally in rice farming (Couto et al., 2016), and this activity has its productivity directly influenced by adverse weather conditions (Boeira et al., 2021; Oliveira et al., 2022).

For MSGW, modeling is a tool for the management of water resources, since its water has several uses in social-economic activities, such as industry, human consumption and agriculture. The latter is the one that demands greater volumes of water, already having limitations imposed for its extraction, especially in times of drought (Beltrame and Tucci, 1998; Santiago et al., 2021). In addition, as this watershed has 53% of its territory in the neighboring country, Uruguay, and so being under a regime of shared waters, the management of common interests such as the Mirim Lagoon water resources is complex (Fernandes, 2021).

Thus, knowing the social relevance of the basin and how grid point precipitation data can be an important tool in climate analysis, this study aimed to evaluate the efficiency of ERA5 in representing the observed precipitation data in the Brazilian side of MSGW, to verify if this reanalysis has the potential to aid the water resources management, as presented, for example, in Ougahi and Mahmood (2022), Jiang et al. (2023) and Rudisill et al. (2023).

Material and methods

Study area and observed precipitation data

Located in the southeast of the state of Rio Grande do Sul, the MSGW (Figure 1) is a transboundary watershed and is located between the geographic coordinates of 31°30' to 34°30' South, and 52° to 56° West. Its area is approximately 65,250 km², of which 47% is located in Brazilian territory and 53% in Uruguayan territory (ALM, 2020).

The MSGW contemplates 20 municipalities on the Brazilian side, where some have their entire area within the watershed, and others just a portion. Among those are Pelotas, Rio Grande, Capão do Leão, Arroio do Padre and São José do Norte, which together form the so-called Southern Urban Cluster, contemplating approximately 68% of the population of the southern Rio Grande do Sul (FEE, 2015). The basis of the MSGW's economy comes from livestock and agricultural activities, with rice and soybeans standing out. Observed precipitation data was obtained in two Brazilian databases: the Hidroweb system from the National Water and Sanitation Agency (ANA) and the Meteorological Database for Education and Research (BDMEP) from the Brazilian National Institute of Meteorology (INMET). On the ANA website, it was possible to find 144 rain gauges at the MSGW, of which just 61 are in operation. On the INMET website, 7 rain gauges within the area of interest were found, but some have too short historical precipitation series.

After the download of the precipitation data from all the rain gauges in operation at the MSGW, we selected only the ones that had rainfall total monthly values for the period from 1981 to 2020, covering the historical period of interest. In total, we used in this study 14 precipitation series from ANA and 1 from the INMET (Figure 1).

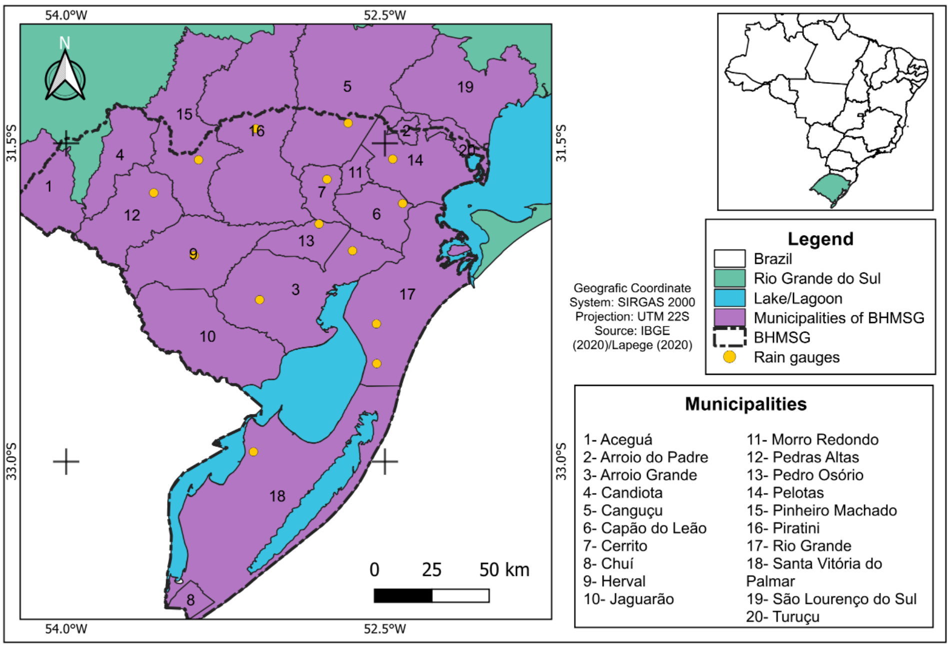

Figure 1. Location map of the study area (MSGW) in Brazil, with highlights of its municipalities and the rain gauges used in this study.

Pluviometric data consistency

Gap filling and double-mass curve

According to Mello et al. (2020), the existence of failure or lack of data in historical series is something recurrent, especially due to technical problems or, in Brazil, the absence of the responsible for the monitoring. Thus, to check the consistency of the monthly total series already provided in the files, we choose to obtain the monthly total precipitation series by summing up the total daily precipitation. By doing this procedure, we removed some failures previously identified, summing the daily precipitation for the given month.

In Brazil, it is common that the files provide the raw and consistent dataset. So, when we find out these two values, we excluded them and selected the one that came from the consisted dataset to ensure the accuracy of the series values. Furthermore, when the consisted dataset presented “zero” values and the raw dataset had non-zero precipitation values, we considered the raw data to constitute the monthly total precipitation series.

Despite being careful in choosing the most adequate precipitation data to constitute the monthly total precipitation series, the series still presented some gaps. Thus, we carried out the gap-filling procedure, which is only indicated for monthly and annual time-step. There are many ways of filling gaps in historical series, being most indicated the ones consider the precipitation data from the neighboring rain gauges (Collischonn and Tassi, 2008).

Among those methodologies, we chose the multiple linear regression, in which the data from neighboring rain gauges are used to fill the gaps of the series in question by correlating the datasets (Tucci, 2001; Collischonn and Tassi, 2008; Mello et al., 2020; Ruezzene et al., 2021). For each precipitation series containing failures, we chose the data from rain gauges that are not only neighboring the one in question but also the similarities between their geographical characteristics, such as relief, proximity to the ocean, proximity between the rain gauges, etc, were considered.

Besides, we also tested the similarity of the precipitation regime presented in the precipitation series used to fill the gaps, being those most discrepant discharged from the linear regression process. After this procedure, if the series still had failures, we chose to fill it with the climatological mean of the municipality in which the rain gauge is, provided by the Rice Institute of Rio Grande do Sul (IRGA) (https://irga.rs.gov.br/medias-climatologicas), considering that this mean value is obtained with 30 years of precipitation data (1981 – 2010).

According to Tucci (2001), after the gap-filling procedure, it is important to verify if the final dataset is consistent at a regional level. Thus, for this purpose, we applied the double-mass curve method, for each of the 15 monthly total precipitation series. The double-mass curve method was developed by the Geological Survey (USA) and works by drawing a graph with the annual total precipitation of the series in question versus the mean annual total precipitation of all precipitation series used in the gap-filling procedure (Tucci, 2001; Collischonn and Tassi, 2008; Mello et al., 2020).

Pluviometric data generated by ERA5

In this study, we utilized data from ERA5 atmospheric reanalysis. This dataset is the fifth generation of reanalysis of the ECMWF, in which the precipitation data is available in a grid with spatial resolution of 31 km and 137 levels from the earth's surface to 80 km of altitude. Furthermore, the ERA5 still provides the uncertainties of its variables in reduced spatial and temporal resolutions (ECMWF, 2020). Many studies have been using ERA5 data for different purposes around the world (e.g. Piersante et al., 2021; Low et al., 2022), including in the study area, such as Ogassawara et al. (2021), Ramos et al. (2021), Santiago et al. (2021) and Santos et al. (2022). Based on 5637 stations from 2001-2020, Lavers et al. (2022) indicates confidence in monthly ERA5 data for monitoring precipitation in extratropics.

The monthly total precipitation from ERA5 was obtained for the location (geographic coordination) of the 15 rain gauges used in this study (Table 1), being the ERA5 grid point data nearby the location of the rain gauges. Thus, these representative ERA5 coordinates were selected by the nearest neighbor method. The selection of coordinates occurred via Python, using commands from the Numpy library (Harris et al., 2020). From this, the mean monthly precipitation in the watershed was calculated, which corresponds to the 1981-2020 climatological normal.

Table 1. Rain gauge coordinates and ERA5 representative coordinates.

Nº	Rain Gauge name	Municipality	Longitude	Latitude	Longitude ERA5	Latitude ERA5	Data's source
1	Arroio Grande	Arroio Grande	-53,0897	-32,2372	-53,00	-32,25	ANA
2	Canguçu	Canguçu	-52.6733	-31.4044	-52,75	-31,50	ANA
3	Capão do Leão	Capão do Leão	-52.4166	-31.7833	-52,50	-31,75	INMET
4	Estação Experimental de Piratini	Piratini	-53.1078	-31.4308	-53,00	-31,50	ANA
5	Ferraria	Piratini	-53.0539	-31.7375	-53,00	-31,75	ANA
6	Granja Cerrito	Rio Grande	-52.54	-32.3506	-52,50	-32,25	ANA
7	Granja Coronel Pedro Osório	Arroio Grande	-52.6528	-32.0061	-52,75	-32,00	ANA
8	Granja Osório	Santa Vitória do Palmar	-53.1189	-32.9539	-53,00	-33,00	ANA
9	Granja Santa Maria	Rio Grande	-52.5386	-32.5381	-52,50	-32,50	ANA
10	Herval	Herval	-53.3978	-32.0286	-53,50	-32,00	ANA
11	Pedras Altas	Pedras Altas	-53.5881	-31.7333	-53,50	-31,75	ANA
12	Pedro Osório	Pedro Osório	-52.8103	-31.8797	-52,75	-32,00	ANA
13	Pinheiro Machado	Pinheiro Machado	-53.3769	-31.5775	-53,50	-31,50	ANA
14	Ponte Cordeiro de Farias	Pelotas	-52.4631	-31.5739	-52,50	-31,50	ANA
15	Vila Freire	Cerrito	-52.7728	-31.6694	-52,75	-31,75	ANA

Mean precipitation and climatological normals of the MSGW

Due to the spatial variability of precipitation, it is necessary to estimate the mean precipitation over an area (Mello et al., 2020), in this case, the MSGW. There are many methodologies available for this purpose, but it's important to consider not just the precipitation observed within the limits of the watershed, but also from its neighborhood (Tucci, 2001).

Among the existent methodologies, we used the Thiessen polygons one, which works with the spatial distribution of the points, where the mean is the result of weighting the precipitation value of a station (P_i) by its area of influence (A_i). The areas of the polygons formed by the bisectors of the straight segments that connect adjacent rain gauges and watershed divisors are called areas of influence (Mello et al., 2020).

The climatological normal is the arithmetic mean corresponding to a number of years that is sufficient to represent the behavior of the variable under study. The World Meteorological Organization (WMO) indicates the period of 30 years, starting the count in the first year of each decade (INMET, 2023). Here, an even longer period was chosen, from 1981 to 2020, both for the observed data and for the data from ERA5.

Statistical analysis of the pluviometric data

Verifying changes in meteorological data is fundamental for carrying out engineering studies that require the analysis of historical series since the probability theories and simulations are made considering some important assumptions, treated in the form of hypotheses and analyzed through non-parametric tests (Mello et al., 2020). Thus, in this study, the assumptions of stationarity and homogeneity were tested (Naghettini and Pinto, 2007).

Trend test

To the trend analysis in the precipitation data, the non-parametric Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975), at a 5% significance level, was applied. According to Brito et al. (2022), the MK test is indicated by the WMO to carry out the analysis of increasing and decreasing trends in the time series of environmental data. The test aims to verify the null hypothesis (H_0), that is, if there is no trend in the data series. Therefore, we tested the H_0 statistics according to Equation 1:

$$S = \sum_{j=1}^{n-1} \sum_{i=2}^{n} signal(x_i - x_j) \tag{1}$$

Where S is the statistic of the test, x_i and x_j are values of the precipitation series; and n is the number of elements in the time series. The mathematical signal is determined according to Equation 2:

$$Signal = \begin{cases} 1, if(x_i - x_j) > 0 \\ 0, if(x_i - x_j) = 0 \\ -1, if(x_i - x_j) < 0 \end{cases} \tag{2}$$

The variance of S is calculated if the value n is too large, thus making S tend to normality, according to Equation 3:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \tag{3}$$

where n is the number of observations; t_p is the number of equal values in a group p; and q is the number of groups that have equal values in the data series of a group p.

Subsequently, with the S value calculated, it is replaced in Equation 6, and then the Mann-Kendall value (ZMK) is calculated, thus evaluating the existence of a statistically significant trend in the series under analysis:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, ifS > 0 \\ 0, ifS = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, ifS < 0 \end{cases} \tag{4}$$

From this result, if $S > 0$, it is considered that the trend is increasing, and if $S < 0$, the trend is decreasing. Positive values for the ZMK coefficient indicate an increasing tendency for the variable and a decreasing tendency when the coefficient is negative. The decision as to whether the identified trend is significant or not is based on the p-value of the test, which, when lower than the significance level, indicates a significant trend. For the series analyzed, a significance level of 5% ($\alpha = 0.05$) was considered.

The Sen Slope test (Sen, 1968) aims to determine the magnitude of the trend in the historical series, if it occurs, where the slope of the line is obtained, assuming that this trend is linear, as indicated in Equation 5:

$$f(t) = Qt + B \quad (5)$$

where $f(t)$ is the evolution function of the historical series, either increasing or decreasing, t represents time, Q is the slope of the line and B is constant. At first, the slopes of all pairs of data were calculated, as shown in Equation 6:

$$Q_i = \left[\frac{x_j - x_i}{j - i}\right] \quad (6)$$

where x_i and x_j are the historical series data at the time i and j, where $j > i$. If there are 'n' values of x_j, the Q_i slope estimates will be given by:

$$N = \frac{n(n-1)}{2} \quad (7)$$

The 'N' values of Q_i must be sorted in ascending order, and the median of the slope estimator (Q_{mean}) is calculated according to Equation 8:

$$Q_{mean} = \quad (8)$$

Positive Q_{mean} values indicate a positive trend in the data series, and the opposite indicates negative values. It should be noted that the Mann and Kendall and Sen Slope test was applied with a 5% significance level, as performed in studies by Moreira and Naghettini (2016), Lira et al. (2020), Duarte et al. (2021) and Rodrigues et al. (2023).

Homogeneity test

To carry out the analysis of homogeneity in the data series, the Pettitt test (Pettitt, 1979) was used, at a 5% significance level, which allows finding the point of sudden change in a time series. Therefore, it checks whether two subsamples (X_1, ..., X_t and X_{t+1}, ..., X_N) are from the same population, considering the following equations:

$$U_{t,N} = U_{t-1,N} + \sum_{j=1}^{N} signal(x_t - x_j) \quad (9)$$

where:

$$signal = (x)\begin{cases} 1 if x > 0 \\ 0 if x = 0 \\ -1 if x < 0 \end{cases} \quad (10)$$

Therefore, the test counts the number of times the value of the first sample is greater than that of the second. The null hypothesis admits that there is no change point. Through the $k(t)$ statistic, the significant change point 't' is obtained, in which the value of $|U_{t,N}|$ is maximum and is linked to the significance level P, according to the following equations:

$$k_{(t)} = max_{1 \le t \le N} \vee U_{t,N} \vee \quad (11)$$

$$P = 2e^{\left\{\frac{-6(K_N)^2}{(N^3+N^2)}\right\}} \quad (12)$$

where P is the significance level, K_N is the critical value and N is the number of years in the historical series. This test is commonly applied in precipitation series, as in Ferreira et al. (2015), Fraga et al. (2020), Lira et al. (2020), and Rodrigues et al. (2023), among others.

Validation of the precipitation data

The first statistical method applied was the Mean Absolute Percentage Error (MAPE) (Equation 13), which indicates the percentage of errors (in absolute value). The smaller the MAPE value, the better the prediction made.

$$MAPE = \frac{100}{n}\sum_{t=1}^{n} \hat{y}_t - y_t/yt \quad (13)$$

where n is the number of samples, t is the period, y_t is the value observed in period t and $\hat{y}_t$ is the value of the data generated by ERA5 during period t.

Subsequently, the Root Mean Squared Error (RMSE) was performed, which allows the verification of the mean magnitude of the errors. Its value will always be positive, and the closer to zero, the better is considered (Ruezzene et al., 2021). The RMSE is given by Equation 14:

$$RMSE = \sqrt{\frac{\sum_{j=1}^{n}\left(O_j - x_j\right)^2}{n}} \quad (14)$$

where O_j are the observed precipitation values, x_j are the estimated values, and n corresponds to the number of observations.

As a last analysis, the Pearson Correlation Coefficient ($r_{pearson}$) (Equation 15) was used, as a means of estimating how two sets of data are associated (Martins, 2014). In this case, the correlation between the observed precipitation data and the data estimated by the ERA5 reanalysis was calculated:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(-\overline{y})}} \quad (15)$$

where n is the number of samples; t is the period; x_i is the observed value in period t; x is the average of the observed values; y_i is the data value estimated by ERA5 for period t; and y is the average of the estimated values. According to Mukaka (2012), the correlation values can be interpreted as shown in Table 2:

Table 2. Suggestion for the interpretation of Pearson's correlation coefficient.

Magnitude of the correlation	Meaning
0,90 a 1,0 (-0,90 a -1,0)	Very strong and positive (negative) correlation
0,70 a 0,90 (-0,70 a -0,90)	Strong and positive (negative) correlation
0,50 a 0,70 (-0,50 a -0,70)	Moderate and positive (negative) correlation
0,30 a 0,50 (-0,30 a -0,50)	Weak and positive (negative)correlation
0,00 a 0,30 (-0,00 a -0,30)	Insignificant correlation

Source: Mukaka (2012).

Results and discussion

Climatological normal for the MSGW

Table 3 presents monthly climatological normals for the observed data and for the ERA5 data, obtained through the methodology of Thiessen Polygons.

Through the methodologies used, the observed average annual precipitation of the MSGW was 1394.69 mm, and 1340.67 mm for the ERA5 data. Such values are similar to the obtained by Silva and Campos (2011), who found average annual rainfall of 1400 mm in analysis during the period from 1977 to 2006 for the extreme south of RS, where the watershed under study is located, and to obtained by Radin et al. (2017), 1386 mm for the period from 1961 to 2010 for the Great Lagoons region, where the MSGW is located.

The climatological normals for September and December agree with a study carried out by Silva et al. (2021) for the municipality of Rio Grande during the period from 1913 to 2016, which indicates that September is the month with the highest rainfall volumes, and December is the month with the lowest volumes. The ERA5 overestimates the observed precipitation in 2 months (November and December) and underestimates in 10 months (January to October), with May having the highest underestimate (11.88%) and November the highest overestimate (7.54%).

January was the month with the smallest error, with a difference of 0.51% between the observed precipitation data and those estimated by the ERA5. Concerning the seasons, summer (DJF) has the smallest difference, reaching 10 mm, and the biggest difference is in winter (JJA) at 31.90 mm.

Table 3. Climatological normals of precipitation observed and obtained by ERA5 for MSGW

Month	Observed precipitation (mm)	ERA5 precipitation (mm)
January	117,6	117,0
February	131,0	126,6
March	99,9	97,04
April	124,7	120,4
May	116,2	102,4
June	114,5	106,6
July	122,3	109,3
August	118,9	107,9
September	133,5	129,6
October	125,1	120,5
November	99,5	107,0
December	91,4	96,4

Statistical analysis of the pluviometric data

Trend and homogeneity tests

Table 4 illustrates the results of the Mann-Kendall and Sen's Slope test, obtained for the observed and generated by ERA5 series of monthly total precipitation, at the 5% significance level.

Therefore, in both the Mann-Kendall test and the Sen's Slope, the H_0 hypothesis is accepted (5% of significance level), that is, there is no significant trend in the series of total monthly precipitation observed. This hypothesis was also tested by Caballero et al. (2018), for the municipality of Pelotas from 1982 to 2015, and no significant trend was identified for the precipitation series considering the same confidence interval.

In a study carried out by Silva et al. (2015) in series from 1961 to 2002, including the one from the municipality of Pelotas, any significant trend was found, at a significance level of 5%. Gonçalves and Back (2018) analyzed trends in the precipitation series for the southern region of Brazil from 1976 to 2015, using the Mann-Kendall test at a significance level of 5%, and no significant trend was observed for the series under study either.

For the precipitation series generated by ERA5, the H_0 hypothesis was also accepted for almost all of the series, except for October, where both the Mann-Kendall test and the Sen's Slope test the hypothesis was rejected; that is, a significant increasing trend in October's precipitation was found out, with a magnitude of 1.51 mm. The results of the Pettitt test (significance level of 5%), used to verify the homogeneity of the series of observed values monthly total precipitation indicate that there was no point of significant abrupt change in any of the series inhere analyzed.

The Pettitt test results corroborate the Mann-Kendall results which, for most months, also did not show a significant trend in the investigated series. The same behavior of the tests is indicated by Santos (2015) and Lira et al. (2020), where the Mann-Kendall test indicated significant changes in the series, as well as the Pettitt test.

In a study carried out by Cardoso et al. (2022), in which the Mann-Kendall, Sen's Slope and Pettitt tests were used to analyze the behavior of precipitation series derived from climate models for southern Rio Grande do Sul State, it was found that some climate models did not show a significant trend, nor did they show any significant point of abrupt change in the series, with these same tests.

Table 4. Results of the Mann-Kendall and Sen's Slope tests for the observed and generated by ERA5 precipitation.

Month	Observed precipitation					ERA5 precipitation				
	Mann-Kendall			Sen Slope		Mann-Kendall			Sen Slope	
	p value	Z_{MK}	Trend	SS	Trend	p value	Z_{MK}	Trend	SS	Trend
January	0,93	0,08	No	0,08	No	0,95	0,06	No	0,07	No
February	0,20	1,27	No	1,43	No	0,07	1,81	No	1,62	No
March	0,67	0,43	No	0,33	No	0,48	0,71	No	0,47	No
April	0,70	0,38	No	0,39	No	0,20	1,27	No	1,40	No
May	0,58	0,55	No	0,46	No	0,81	0,24	No	0,26	No
June	0,32	0,99	No	0,81	No	0,20	1,27	No	0,85	No
July	0,37	0,90	No	1,06	No	0,18	1,34	No	1,18	No
August	0,30	1,04	No	0,85	No	0,81	0,24	No	0,21	No
September	0,26	1,13	No	0,78	No	0,37	0,90	No	0,51	No
October	0,08	1,76	No	1,50	No	0,03	2,16	Yes	1,51	Yes
November	0,10	1,67	No	1,43	No	0,12	1,57	No	1,16	No
December	0,24	1,18	No	0,58	No	0,57	0,57	No	1,16	No
Annual Total	**0,72**	**0,36**	**No**	**1,83**	**No**	**0,24**	**1,18**	**No**	**4,47**	**No**

Evaluation of the precipitation data

The results of the error measures and the Pearson correlation coefficient are shown in Table 5.

According to the MAPE results, it can be seen that most of the months presented values of up to 30%, indicating the good performance of the ERA5 in representing the precipitation observed in the watershed. The good performance of ERA5 precipitation data has already been reported in the studies of Dullaart et al. (2020) and Ullah et al. (2020). It is observed (Table 5) that March presented the highest value for the MAPE, equal to 41.4%, which may be an indication of a possible interference of the occurrence of climatic phenomena such as the El Niño-Southern Oscillation (ENSO) that influences the precipitation regimes in the region, as mentioned by Caballero et al. (2018) and Guedes et al. (2019).

Table 5. MAPE, RMSE and Pearson's correlation coefficient results for precipitation data.

Month	MAPE (%)	RMSE (mm)	$r_{pearson}$
January	26,0	37,2	0,8
February	28,7	36,9	0,9
March	41,4	36,2	0,8
April	30,7	35,4	0,9
May	30,8	52,4	0,7
June	26,8	34,4	0,8
July	17,0	30,8	0,9
August	26,7	37,4	0,8
September	22,5	37,1	0,7
October	26,7	39,3	0,8
November	26,0	23,3	0,9
December	30,6	33,1	0,8
Annual Total	8,4	143,7	0,9

Regarding the RMSE, there was a greater proximity between the observed data and those generated by the ERA5 in the winter season, corroborating the results found by Santos Junior et al. (2022) which indicates that in June and July, there was a greater similarity between the observed and estimated precipitation data, as well as Lavers et al. (2022), which pointed out the best performance of ERA5 precipitation data in winter.

Regarding Pearson's coefficient (r), all months showed high correlation values between observed data and data generated by ERA5. The months of May and September had the lowest values (0.7), which is still considered a strong positive correlation, as in most months. For

February, April and July, the correlation was classified as very strong and positive, according to Mukaka's classification (2012). In this context, Fischer Filho and Fuzzo (2022) carried out a study seeking to evaluate the accuracy and precision of the ERA5 reanalysis of some climatic variables for the northern region of the State of São Paulo, and observed a strong and positive correlation for the precipitation data (r = 0.86). Castro et al. (2019) evaluated meteorological parameters generated by ERA5 reanalysis for the municipality of Seropédica - RJ, and found good correlation values for pressure at mean sea level and air temperature. The errors found are in line with what was pointed out by Hersbach et al. (2020), within a 70% correlation between observed data and ERA5 reanalysis.

Conclusions

In this study, we concluded that the monthly precipitation data from ERA5 reanalysis represents the observed precipitation data in the Brazilian side of MSGW, despite the underestimation of the observed monthly total precipitation in most months of the year, and that the mean annual precipitation generated is similar to the observed one. The underestimation does not affect the good performance of ERA5 in representing the observed precipitation data, since strong and positive correlation were found between the two datasets.

Furthermore, the ERA5 precipitation data can aid in the management of water resources of the Mirim-São Gonçalo watershed (MSGW) and in regions nearby that lack this information. The availability of estimated precipitation data has the potential to contribute to improving the forecast on the subject of droughts, and also reducing its social, economic and environmental impacts in Rio Grande do Sul State, Brazil.

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