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DATA QUALITY ASSESSMENT AND HOMOGENIZATION OF RAINFALL TIME SERIES IN DATA-SCARCE REGIONS: A CASE STUDY OF THE UPPER OUM ER-RBIA BASIN, NORTHERN MOROCCO

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Abstract: Data quality is crucial for the reliability and accuracy of hydroclimatic studies. In data-scarce regions, time series are often incomplete, with many gaps and outliers. Moreover, changes in station location, instrument, or other conditions can cause shifts unrelated to natural variability, leading to false conclusions about climate trends. This study evaluates the quality and homogeneity of rainfall time series to fill in missing values and identify non-climatic inconsistencies. It focuses on the Upper Oum Er-Rbia basin in northern Morocco. To ensure the integrity of monthly rainfall data in six-gauge stations from 1970 to 2022, the Standard Normal Homogeneity Test (SNHT) method is employed in the R environment. As a result, quality control detected 12 outliers. The homogeneity test highlighted four breaks. The one observed in station S1 can be related to the construction of the Ahmed El-Hansali dam. The homogenized series consists of 79.3% of observed data, 6.3% of filled-in data, and 14.4% of corrected data. The RMSE calculated on the anomaly series shows low values with an average of 15.4 mm, indicating good performance of the SNHT test. The findings highlight the significance of employing rigorous statistical methods like SNHT to detect anomalies and ensure the reliability of climatic datasets.

Keywords: rainfall data, messing values, quality control, inhomogeneities, SNHT

1. INTRODUCTION

Climatic data is crucial for global water cycle understanding and environmental science research. As a fundamental climate variable, precipitation data plays a central role in efficiently managing water resources (Trenberth & Asrar, 2014). They are key in monitoring climate trends and finding applications in various environmental fields (Hayek, 2021). However, these data records are frequently subject to artificial disruptions that do not accurately reflect real climate variations. These disruptions could be caused by relocating the station, replacing instruments, adjusting the observational protocols, or changing the site's surrounding environment (Gubler et al., 2017; Hunziker et al., 2018; WMO, 2020). Along with this, the quality of climate data remains frequently uncertain in developing countries (Romanovska et al., 2023; Singh et al., 2018; Yimer et al., 2021), and as Kessabi (2022) recently pointed out, their coverage in terms of both space and time is limited. Therefore, the risk of using questionable data, requiring adjustment, completion, or even elimination, persists. In this context, assessing the quality and homogeneity of climatic data before using them is necessary. This is a recommended approach for analyzing the variability of climatological series (Aguilar et al., 2003; Beaulieu et al., 2008; Gubler et al., 2017; Peterson & Easterling, 1994; Venema et al., 2012).

A variety of homogenization approaches are presented in the literature (Aguilar et al., 2003; Beaulieu et al., 2007, 2008; Venema et al., 2012). The

Geostatistical methods like DSS and gsimclim are effective in spatial-temporal correlation, but they require dense data networks (Ribeiro et al., 2016, 2017). The Relative Homogenization method, which utilize nearby station data, are less effective in sparse networks (Domonkos, 2024; Gubler et al., 2017). The statistical methods like the Standard Normal Homogeneity Test (SNHT) are commonly used (Pandžić et al., 2020).

The Haut Oum Er-Rbia basin in northern Morocco, characterized by its ecological and hydrological importance (Boudhar et al., 2014), is a critical region for such studies. This work looks at the comprehensive analysis of a 52-year series of monthly data, observed from 1970 to 2022 in six rainfall stations dispensed throughout the basin. This research aims not only to improve our understanding of historical withdrawal models, but also to guarantee the quality and homogeneity of monthly rainfall data in the upper Oum Er-Rbia basin. This assessment aims to fill missing values, identify non-climate inconsistencies or inhomogeneities that compromise the reliability of the data, and correct them.

To achieve this, we used the SNHT test (Elzeiny et al., 2019; Khaliq & Ouarda, 2007; Ruqayah & Miklas, 2023), in R environment through the Climatol package (Addou et al., 2022; Hanchane et al., 2022; Kessabi et al., 2022). The application of this test is explained by the fact that it is a widely recognized statistical method used to identify potential inhomogeneities and detect abrupt and gradual changes in data sets (Beaulieu, 2009).

This research aims to guarantee the homogeneity and quality of rainfall data in the upper Oum Er-Rbia basin for 52 years. The adoption of such an innovative approach that integrates advanced statistical techniques and computer tools, notably the R environment, makes it possible to identify any temporal deviation or anomaly in the precipitation series. In addition, it provides essential information on their possible impact on hydrological systems and water resource management in the region.

2. MATERIALS & METHODS

2.1. Study area

The study area covers the Upper Oum Er-Rbia basin (UOER), at Ahmed El Hansali dam (Figure 1). The UOER extends over 3389 km^2 in the southwestern part of the Middle Atlas region, which marks the transition zone between the folded and tabular sections. The area is characterized by a mediterranean mountain climate. The average minimum and maximum temperatures are approximately -5 °C during winter and 40 °C during summer, respectively (Faouzi et al., 2022). The average annual rainfall is 666 mm (Souilmi et al., 2019). The main river is Oum Er-Rbia, its collects, with its tributaries, the waters of the Bekrit syncline and the Oum Er Rbia sources and flows towards the Ahmed El Hansali dam in the southwest. The geology of the study area shows that the main substrates encountered in the basin are Paleozoic shales in discordance with Triassic dolerites and red clays, Lias dolomites and limestones, as well as quaternary alluvium.

On the hydrogeological level, the karstified and highly permeable carbonate formations of the Lias constitute the principal aquifer of the study area. This important reservoir causes the permanent resurgence of many vaucluse springs, the most important are those of the Oum Er-Rbia, which regulate the OER river (Bentayeb & Leclerc, 1977).

2.2. Rainfall time series

The data analyzed in this study are obtained from the Oum Er-Rbia Hydraulic Basin Agency (ABHOER). These are monthly precipitation series collected from six pluviometric stations (Table 1) distributed in the upper Oum Er-Rbia (Figure 1). The available time series covers the period from 1970 to 2022, with gaps that vary from one station to another.

The evaluation of homogeneity can be carried out on different time scales (annual, monthly, daily, and sub-daily). However, the high variability of daily series lowers the capacity of detection of inhomogeneities (Beaulieu, 2009; Szentimrey, 2013). On the other hand, processing on an annual scale often fails to identify seasonal inhomogeneities (Ahmed et al., 2018). For these reasons, we decided to work with data at monthly time intervals.

The analysis of the raw data, as part of an initial quality check, showed that for each series all data seems to be normal for monthly precipitations. In addition, no sequences are composed of the same value repeated several times, except for the 0 value normally repeated in the absence of precipitations.

Regarding the availability of data throughout the study period (Figure 2a), it is observed that 93.7 % of the data for the six stations were available. However, it should be noted that series 5 is the only one that is complete, while the other series are fragmented, with gaps either in the middle or at the beginning of the study period.

Figure 2b presents the amount of data existing at each time step. Overall, between 1970 and 1980, the amount of data collected has increased. After that,

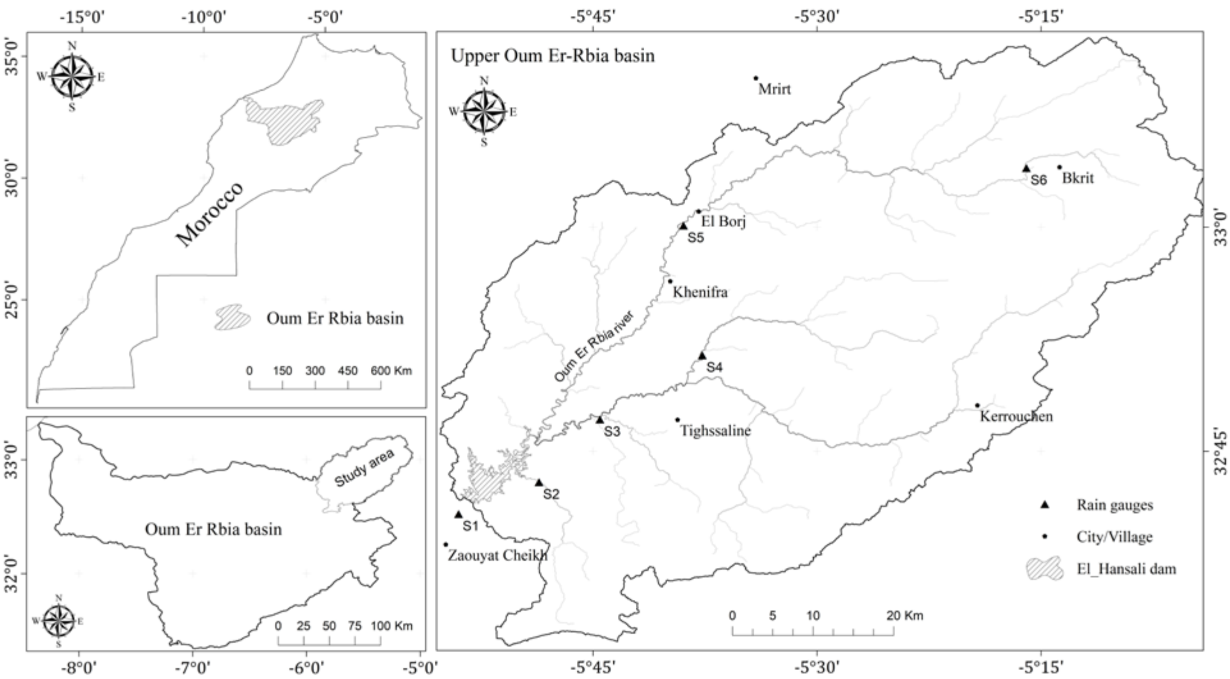

Figure 1. Location map of the upper Oum Er-Rbia basin

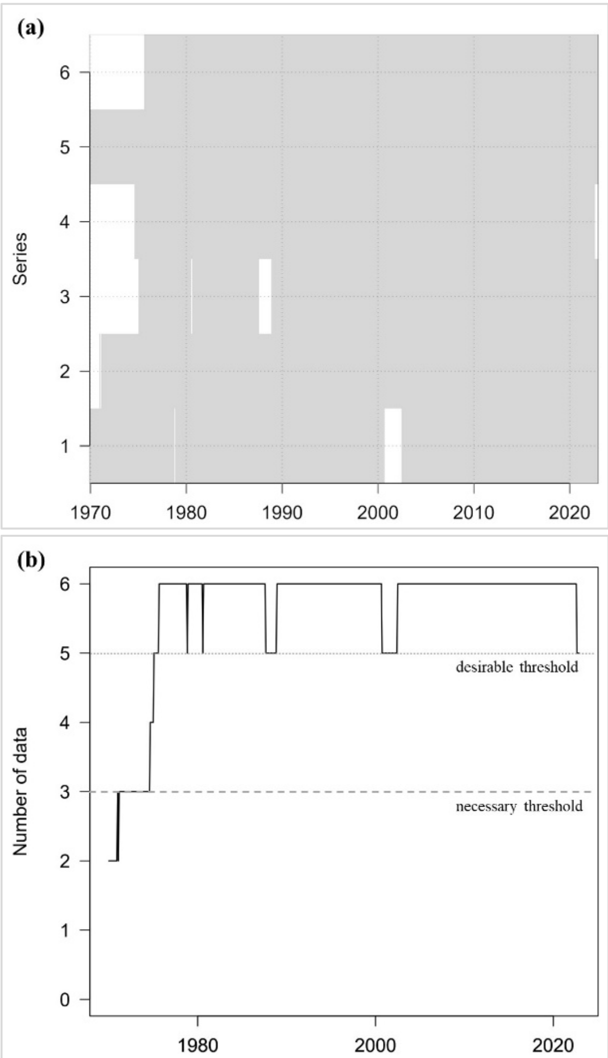

Figure 2. Data availability throughout the study period, at each station (a) and by time step (b)

Table 1. Rain gauges in the upper OER

Stations	Code	Lat	Long	Z (m)
Dchar El Oued	S1	-5.90	32.68	595
Taghzoute	S2	-5.80	32.71	690
Chacha N'Amellah	S3	-5.74	32.78	685
Aval El Heri	S4	-5.63	32.86	830
Tarhat	S5	-5.65	33.00	1036
Tamchachat	S6	-5.27	33.07	1685

the network got relatively dense, with some slight temporary drops that never fell below the desired minimum threshold in terms of data. The dotted and dashed horizontal lines mark, respectively, the minimum desirable threshold (5 data) and the minimum necessary threshold (3 data) to process this data.

2.3. Quality control and homogenization

The rainfall data collected from the stations is usually affected by inhomogeneities related to non-climatic factors, such as changes in location, local environment, measuring instruments, observers, observation procedures, adjustments in data processing, digitization, and errors in databases (Gubler et al., 2017; Hunziker et al., 2018; WMO, 2020). These inconsistencies impact the accuracy of the data and need to be considered during analysis. Quality control and data homogenization are therefore essential to ensuring data integrity, filling in missing values, and detecting outliers likely to bias the studies in which they will be used (Kessabi et al., 2022; Peterson et al., 1998; Ribeiro et al., 2016; Shi et al., 2019; WMO, 2020). This work was carried out using the Climatol package version 4.0 within the R platform (Guijarro, 2023). The procedure estimate the missing data for each series, using orthogonal regression widely known as Reduced Major Axis (RMA), by calculating simple or weighted means and standard deviations of neighboring series in normalized form (Meseguer-Ruiz et al., 2018; Venema et al., 2012). The means and standard deviations for each series will be recalculated, and this process will be repeated until the difference between the most recent mean and the previous iteration's mean is less than half the resolution of the data (Meseguer-Ruiz et al., 2018). During these cycles, quality control is carried out by generating a sequence of anomalies by deducting the estimated values from the observed ones and eliminating anomalies that are greater than a predetermined rejection threshold (Guijarro, 2023).

The SNHT test is then used to verify homogeneity (Alexandersson, 1986). This helps to identify any non-climatic inhomogeneities and adjust them. The principle is to calculate the difference in means before and after each point on the series of anomalies, and breaks will be identified where this difference reaches its maximum. Probable explanations should be provided based on the station’s metadata (Ribeiro et al., 2016). This test is also performed in an iterative process until no SNHT value exceeds a predetermined threshold. Homogeneity is applied in two steps on the anomaly series, first, the SNHT is applied on overlapping time windows, and then on the whole series. The last step is devoted to the final filling of all missing data in all series. The Root Mean Square Error (RMSE) statistical index evaluate the performance of the SNHT test on the series of anomalies and assess the quality of the

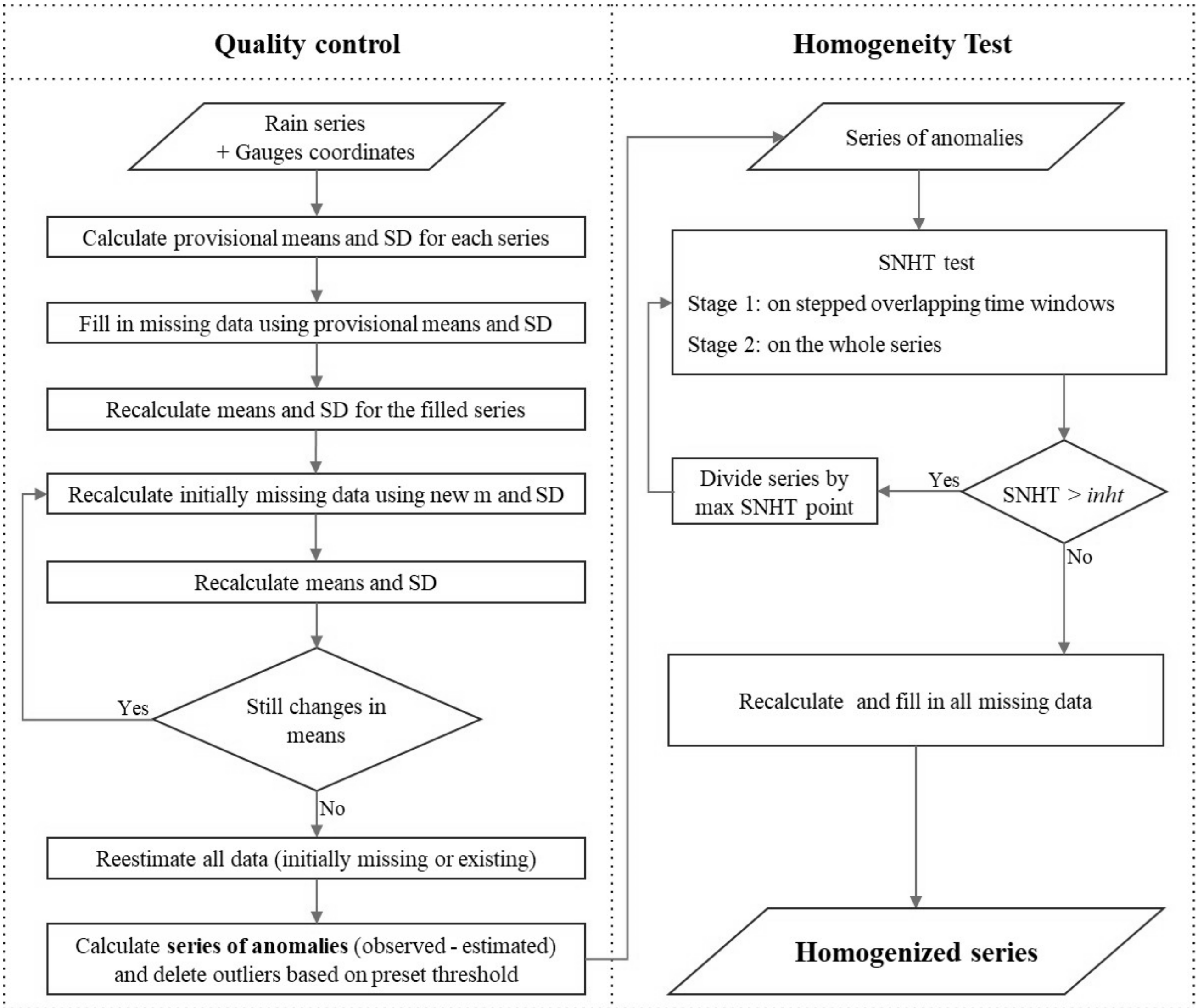

Figure 3. Quality control and homogeneity test steps in the Climatol package

homogeneity process (Abahous et al., 2020; Addou et al., 2022; Kessabi et al., 2022). The steps followed to achieve this work are summarized in the flowchart in Figure 3, based essentially on the user's guide of the Climatol R package (version 4.0), developed by Guijarro (2023).

3. RESULTS AND DISCUSSION

3.1. Quality control

During an initial data quality check using the default parameters, the *homogen* function of the Climatol package allowed to detect twelve suspicious observed values (Table 2). Three of them (the most extreme) have been automatically deleted. Based on the examination of the detected outliers, we decided to use 4.8 and 8 standard deviations as thresholds for detecting and deleting outliers, respectively. Thus, the final quality control eliminated 4 anomalous values (Table 2), located between 8 and 9 standard deviations in absolute value (Figure 4).

Whether they are outliers or not, the elimination of extreme values before homogenization is essential. Otherwise, it will cause unwanted changes in neighboring series (Guijarro, 2023).

Table 2. Detected outliers at initial data quality check

Code	Date mm/yyyy	Observed	Suggested	Anomaly (std.devs.)	Deleted
S1	01/1971	164.4	79	5.44	0
S1	05/1982	137.9	64.5	5.41	0
S1	01/1997	0	120.5	-8	1
S2	01/1971	30.2	152.9	-8.57	1
S2	12/2009	233.4	168.8	4.8	0
S3	12/2003	227.2	169.6	4.8	0
S4	01/1996	496	334.4	8.59	1
S5	08/1973	160	3.9	8.09	1
S5	12/1996	377.7	259.8	6.45	0
S5	04/2002	99.2	187.3	-4.81	0
S6	11/2010	375.3	173.2	5.81	0
S6	03/2013	433.5	165	7.71	0

3.2. Homogenization

Using the *homogen* function, the homogeneity test based on the SNHT method was carried out on the monthly precipitation series at the 6 rainfall stations. The default threshold for this test (SNHT > 25) was retained. The results show the existence of 4 breaks in total (Table 3), detected by abnormal changes in the average. A first break was detected during the first stage (Test on overlapping temporal windows), with a maximum SNHT of 27. This is the one observed in the Aval El Heri series (S4), generating two sub-series (S4 and S4-2) that will be treated separately in the next step. During stage 2 (Test on the whole series), three other breaks were highlighted; two of them concern the Aval El Heri-2 series (S4-2), and the one that remains concerns the Dchar El Oued series (S1), with max SNHT values of 49, 25, and 30, respectively.

The rupture observed in the Dchar El Oued series can be explained by the installation of the Ahmed El Hansali dam, since the date of the rupture detected coincides with the start of the construction works. The three other breaks concerning the Aval El Heri station series cannot be explained in the absence of metadata containing the history of the station.

Figure 5 illustrates the standardized anomalies series (in blue), on which the breakpoints are indicated with a vertical red dotted line, with the SNTH test value mentioned on its top.

After adjusting all series and applying corrections by filling in all missing data, the final homogenized series obtained for the six stations consists of 3816 monthly values from 1970 to 2022. 79.3 % of them are observed data (original values), 6.3 % are filled-in data (initially missing values), and 14.4 % are corrected data (due to inhomogeneities or excessive anomalies). Figure 6 illustrates the reconstruction of the complete series from homogeneous subseries. Only the two most modified stations (initially affected by the inhomogeneities)

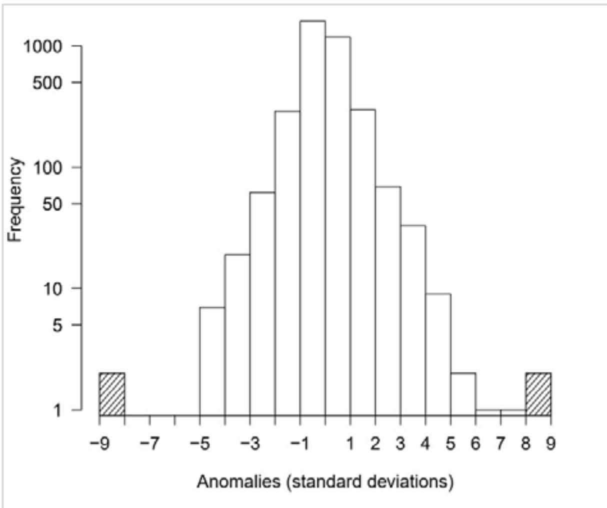

Figure 4. Histogram of standardized anomalies showing rejected data (hatched)

Table 3. Breaks detected during shift analysis (stages 1 & 2)

Code	Station	Date	SNHT
S1	Dchar El Oued	8/1/1999	30.7
S4	Aval El Heri	1/1/1978	25.4
S4	Aval El Heri	3/1/1995	49.6
S4	Aval El Heri	3/1/1998	27.8

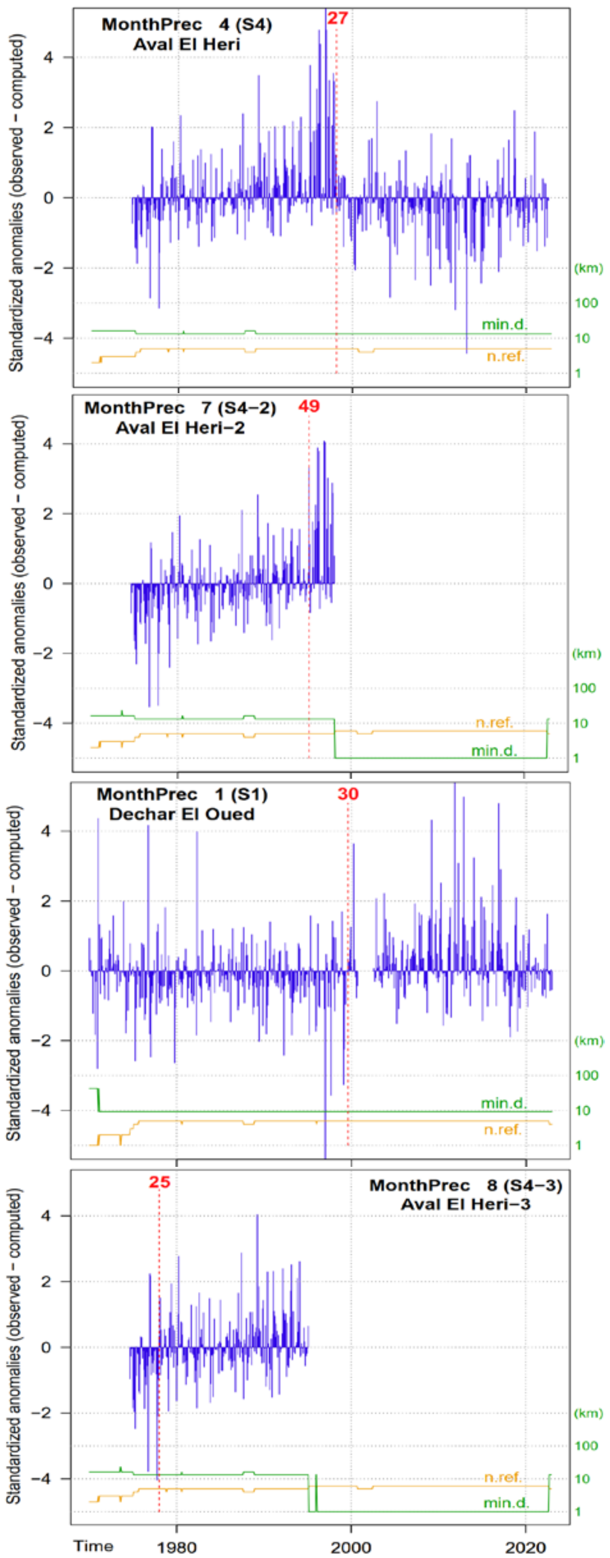

Figure 5. Graphs showing the location of breaks when each inhomogeneity series' mean changes

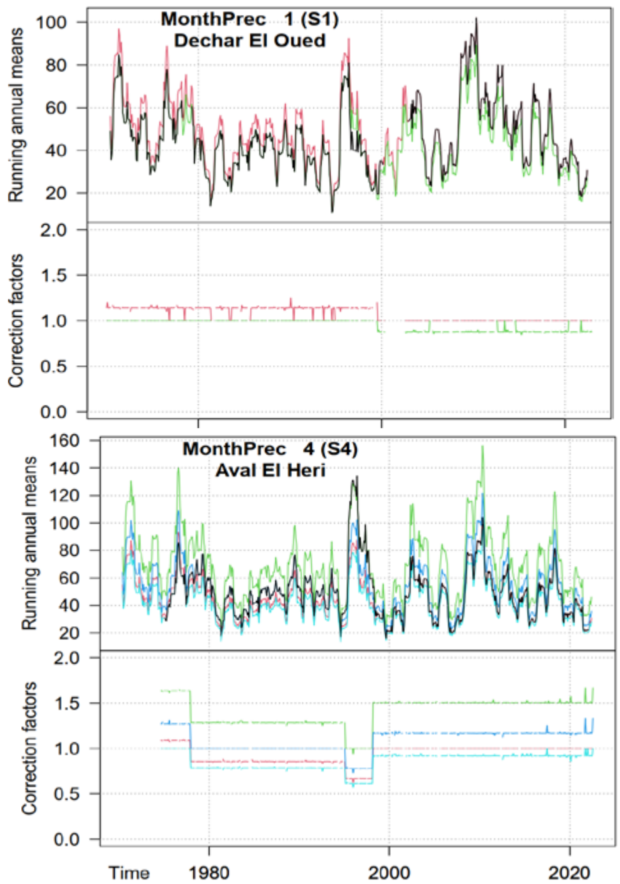

Figure 6. Final reconstructed series for the two stations Dchar El Oued and Aval El Heri

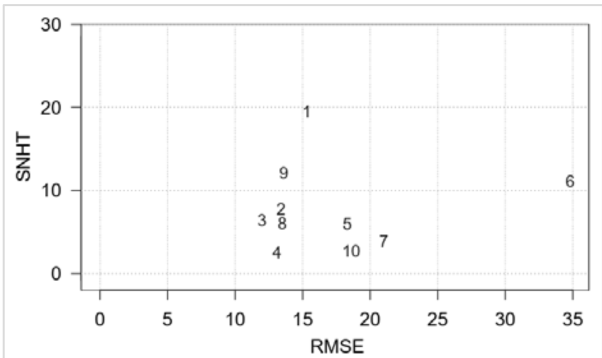

Figure 7. Station’s quality/singularity

are presented in this figure. The upper part of the graph shows the moving annual averages of the reconstructed series. The original series is drawn in black, and the reconstructed ones are colored. The lower part shows the corrections applied to the series, plotted in different colors. These corrections have seasonal variations, and the peaks are due to aberrant rejections (cases of S1 and S4).

To evaluate the quality of the homogenization process, the statistical index RMSE was calculated on the series of anomalies (Figure 7). A high value indicates a low-test quality, but it could also be the result of the station's location in an area with a distinct microclimate (Guijarro, 2023; Trilles et al., 2020). With the exception of station S6, the results obtained show low RMSE values between 12 and 21 mm per month, with an average of 15.4 mm indicating good performance of the SNHT test (Addou et al., 2022). Tamchachate station (S6) has a relatively high RMSE

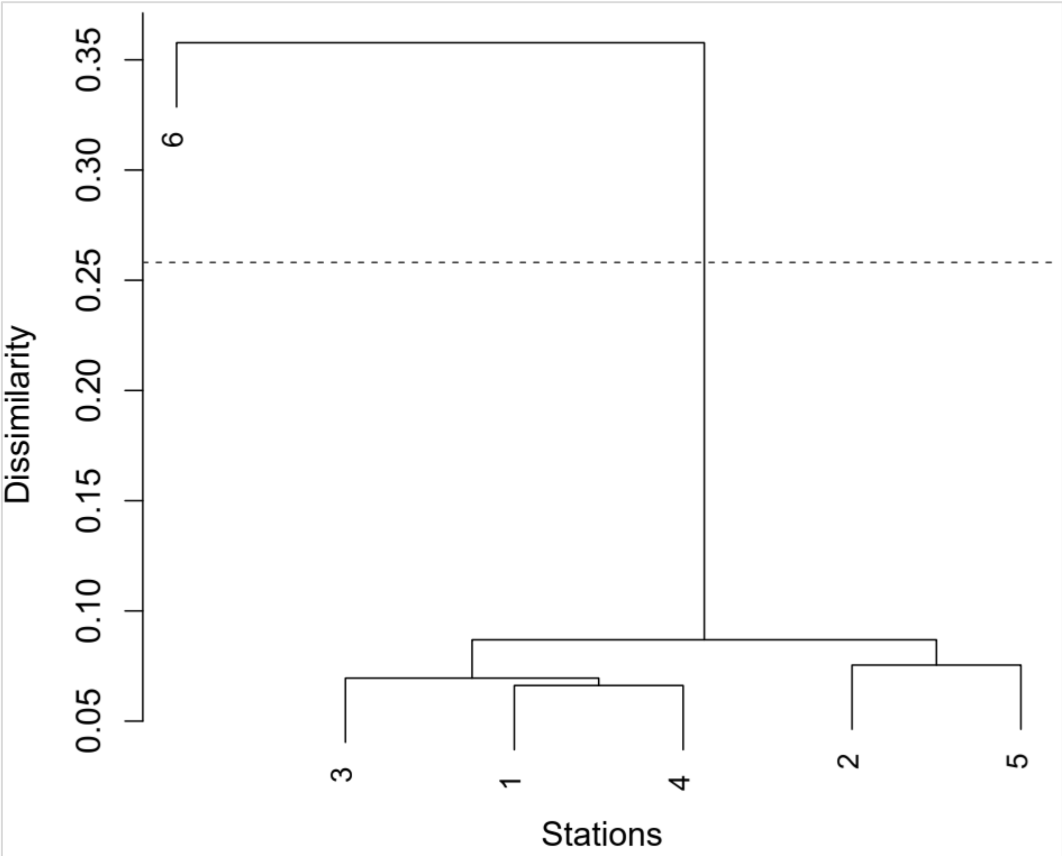

Figure 8. Dendrogram of station clusters

of 34.8. This is explained, as indicated above, by the singularity of this station given its geographical location and its altitude compared to other stations.

The dissimilarity rate displayed by the dendrogram of the station clusters (Figure 8) validates these observations.

These results highlight the importance of using SNHT as a rigorous statistical method to detect anomalies and ensure the reliability of climate datasets (Khaliq & Ouarda, 2007).

4. CONCLUSION

Meteorological data are the basis of any climate characterization. Their importance extends to several scientific disciplines, such as climatology, hydrology, environment, ecology, and agriculture. Therefore, particular attention should be paid to their reliability and consistency (Guijarro et al., 2023).

In this paper, the critical analysis of monthly precipitation under R using the Climatol package led to the identification of numerous anomalies. Using the homogen function, quality control and homogenization operations were carried out on time series of more than 50 years (1970-2022). Monthly precipitations observed at six stations distributed in the upper Oum Er-Rbia were used. A preprocessing based on orthogonal regression (RMA) made it possible to produce estimated series. These were used with the observed series to construct series of anomalies, which served as support for the processing carried out.

Quality control detected 12 suspicious values, of which four outliers were removed. The SNHT homogeneity test highlighted the existence of four breaks that affect the two series Dchar El Oued and Aval El Heri. That observed in the Dchar El Oued series is most likely linked to the installation of the Ahmed El Hansali dam, while the explanation of the three others affecting the Aval El Heri series unfortunately remains inaccessible in the absence of metadata providing the history of the station.

The final product is the homogenized series of the six stations. They are made up of 3816 monthly values: 79.3 % of them are original observed data, 6.3 % are filled-in data, and 14.4 % are corrected data.

To evaluate the quality of the homogenization process, the RMSE index was calculated based on a series of anomalies. Except for station S6, the results obtained show low RMSE values between 12 and 21 mm per month, with an average of 15.4 mm indicating good performance of the SNHT test.

This work has revealed the significant influence that anthropogenic activities can have on precipitation patterns (Zhang & Shang, 2023). The impact of the dam construction, highlighted here, is a spectacular example of non-climatic factors that can significantly affect climate data. The results highlight the importance of rigorous statistical processing of raw climate data time series before any exploitation (Guijarro et al., 2023). This allows them to be free of anomalies and thus guarantees their reliability (Faybishenko et al., 2022).

The importance of this study's results extends beyond the Upper Oum Er-Rbia basin. The methodology adopted has been tested in several geographical contexts (Addou et al., 2022; Azorin-Molina et al., 2019; Guijarro et al., 2023; Skrynyk et al., 2023; Trilles et al., 2020; Varotsos et al., 2023; Zhang et al., 2020). The results have always been satisfactory. It can therefore be used in similar contexts in Morocco and elsewhere. Furthermore, the statistical analysis applied in this work for precipitation can be generalized to other climatic factors, including temperature (Varotsos et al., 2023) and wind (Zhang et al., 2020).

Ensuring data consistency and accuracy enables researchers, policymakers, and stakeholders to make informed decisions and develop appropriate strategies to manage water resources and address climate-related challenges in regions where data is scarce (Ouatiki et al., 2019; Ruqayah & Miklas, 2023).

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