New Drought Index Implementation at Station 15130, Valle de Bravo, Mexico

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Abstract: *This research focused on meteorological drought problem a phenomenon that has affected several countries and has had significant impacts on various water uses, including human, agricultural, and industrial consumption. To address this problem, the NDI index was applied, which uses precipitation and mean air temperature data, and the RASP method to the annual data of the Presa Valle de Bravo weather station, in Edomex., Mexico. This analysis allowed the identification of two periods of severe drought: one of approximately 8 years and another that began in 2019 and seems to continue. In addition, a decreasing trend was detected in the daily runoff volumes to the Presa Valle de Bravo from 1994 to early 2024. These results are indicative of the need to conduct regional studies to confirm the duration of droughts and to implement resource management policies that allow for anticipation and water shortage prevention contingencies due to meteorological droughts.*

Keywords: *Valle de Bravo Reservoir, Precipitation, Droughts, Daily inflow volumes, Trend*

1. Introduction

Droughts are prolonged scarce precipitation climatic events that can have significant effects on water availability. In various parts of the world, an increase in the frequency and intensity of droughts has been observed, affecting water security and sectors such as agriculture, livestock, and the supply of water for human consumption. In this research, an analysis was carried out with annual data of annual precipitation and mean air temperature from the Presa Valle de Bravo station15130, Edomex., Mexico, using the new drought index NDI (New Drought Index in English) described in the methodology of Bonacci et al., 2023 [1].

2. Methodology

In simple terms, a drought is defined as the decrease or absence of rainfall relative to the annual index and, contrary to what is assumed, it is a normal and recurring event that occurs cyclically in all climatic zones of the world, although with greater intensity and recurrence in arid and semi-arid zones. In Mexico, these phenomena occur cyclically and when they occur, they cause a water imbalance in the water cycle, as the availability of the resource is insufficient to meet the needs of living beings. A drought can last on average from one to three years, and it ends when the rains return and the normal precipitation index is recovered and the functioning of the water bodies is restored.
Drought is mainly classified into three types: meteorological, agricultural, and hydrological. These different typologies of drought "identify the beginning, the end, and the degree of severity of the same". All types of drought originate from the same cause: the lack of rain, therefore, when "only rain is taken into account", we are talking about meteorological drought. It is this type of drought that is attributed to the beginning of the hydrological imbalance, as it is when an interruption in the weather is perceived for one or more seasons; this type of drought is difficult to specify, since its effects or incidence are different depending on the place where it occurs; for example, in Bali, meteorological drought is defined as "the period with absence of rain in six days", while in Spain it is considered as meteorological drought a period that can reach up to two consecutive years without precipitation [2] (Esparza M, 2014). Drought, when combined with scarcity, often generates

a social catastrophe, as the situation of scarcity worsens. Although drought is a less spectacular phenomenon, its impact is silent and progressive. Often, it is not easily perceived until its attack is already underway. The lack of rain and the decrease in water resources can have devastating consequences on the availability of food, the health of the population, and the local economy. Awareness and proper management of drought are fundamental to mitigate its effects and prevent social crises.

2.1 New drought index (NDI)

The drought indices traditionally used consider the main variable to be precipitation and/or evapotranspiration of the analyzed site [3-6], Bonacci et al.,2023 [1] proposed to include in the analysis of droughts and in a standardized form both total precipitation and mean air temperature, taking into account that this variable is commonly reported at weather stations and that evapotranspiration depends on it, which is more difficult to estimate. The new drought index (NDI) is calculated with equation (1)

$$NDI_i = \left(\frac{\mathrm{P}_i - \mathrm{P}_m}{S_p}\right) - \left(\frac{\mathrm{T}_i - \mathrm{T}_m}{S_T}\right) \quad (1)$$

where NDI_i is the new drought index in year *i* or month *i*, P_i is the total precipitation in year *i*, P_m is the mean precipitation of the entire recording period, S_p is the standard deviation of the precipitation of the entire recording period; T_i is the mean temperature in year *i*, T_m is the average temperature of the entire recording period and S_T is the standard deviation of the mean temperature over the entire recording period.

2.2 RAPS Method

The Rescaled Adjusted Partial Sums (RAPS) method aids in defining statistically significant time periods in which changes in average values occur throughout a time series [7]. This method estimates the series of partial sums with equation 2.

$$RAPS_i = \sum_{i=1}^{k} \frac{(y_i - y_m)}{S_y} \quad (2)$$

where y_i, represents la analized variable in a given time interval, *i*, y_m, the average value of the entire analysis series, S_y, the standard deviation, *n*, the number of data in a series, *k ∈(1, 2…, n)*, the counter of sums for the *k* analyzed time unit in a series of the total, *n*.
In t case of applying this method directly to the NDI_i, the ΣNDi sums were calculated as it is a standardised variable.

2.3 Identification of potential drought periods and their severity

Trend, homogeneity, and independence tests were applied to the annual precipitation and temperature series (Escalante and Reyes, 2002) [8]. Additionally, with the RAPS and the NDi sums, time periods are identified in which increasing and decreasing behaviors are observed in the series, upward and downward trends; and to these time periods, statistical tests are applied, for example, the Student's t-test to accept or reject a null hypothesis; in this analysis, the null hypothesis for the sums of the temperature series, precipitation, and NDI was that there is a significant change it means the analyzed period compared to complete original series mean, a significance level of 0.05 was considered. Additionally, linear regressions were performed whose lines slopes help to classify droughts and in this way their severity is investigated.

2.4 Study site

Climatological Station 15130 Valle de Bravo is located at municipality of Valle de Bravo, state of Mexico. It is situated at an altitude of 1,840 meters above sea level and has a temperate sub-humid climate with summer rains. This station was founded in 1948 and is operated by the National Meteorological Service (SMN) of Mexico. It measures a variety of meteorological parameters, including temperature, humidity, precipitation, wind speed, and wind direction [9]. The meteorological station 15130 Presa Valle de Bravo was selected, located near the dam of the same name, which is part of the main dams of the Cutzamala System that supply water to the State of Mexico and Mexico City.

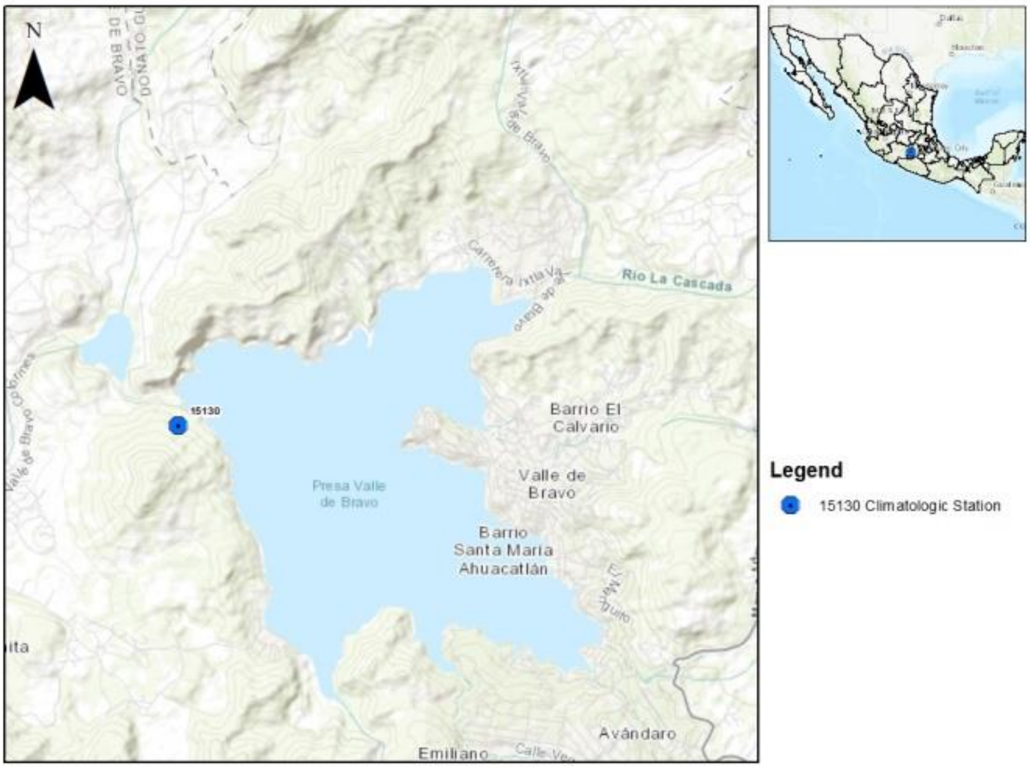

Fig. 1. Climatological station 15130 location Presa Valle de Bravo, Valle de Bravo, Edomex, Mexico. Source: Own design

Monthly average Records air precipitation and temperature were almost complete for period from 1969 to 1989 and from 2009 to 2020. From these data, annual series, maximum values, minimums, and their statistical mean and standard deviation were estimated. (Table 1).

Table 1: Minimum values, maximums, mean, and standard deviation of the total annual precipitation and the average annual temperature. Station 15130 Valle de Bravo, Mex.

Value	Precipitation, mm	Temperature, °C
Min	685.8	18.16
Max	1116.4	20.21
Mean	896.27	19.01
Standard Deviation	112.25	0.56

3. Application and results

3.1 Precipitation Data Series

In Figure 2, Data from annual precipitation series and the observed trend lines in two identified groups are observed. The series turned out to be independent, homogeneous, and without a trend.

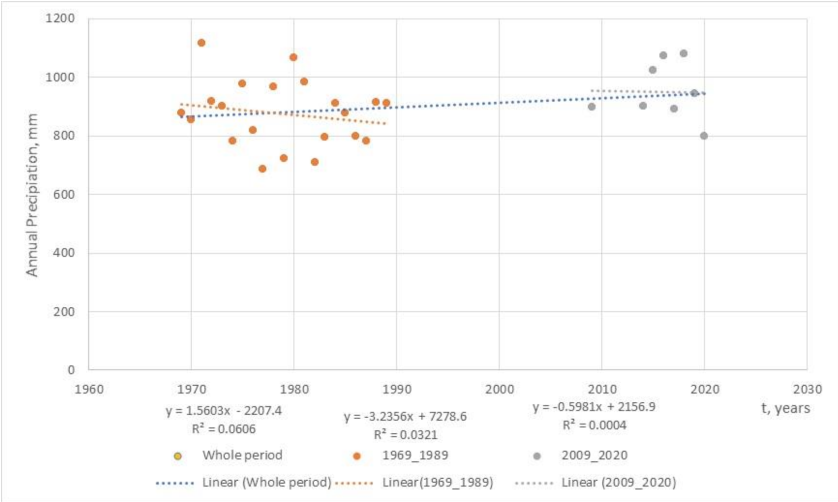

Fig. 2. Total annual precipitation series, Station 15130 Valle de Bravo, Edomex., Mexico

3.2 Average Air Temperature Data Series

In Figure 3, data from the annual precipitation series and the observed trend lines in two identified groups are observed. Series turned out to be dependent, non-homogeneous, and with a trend.

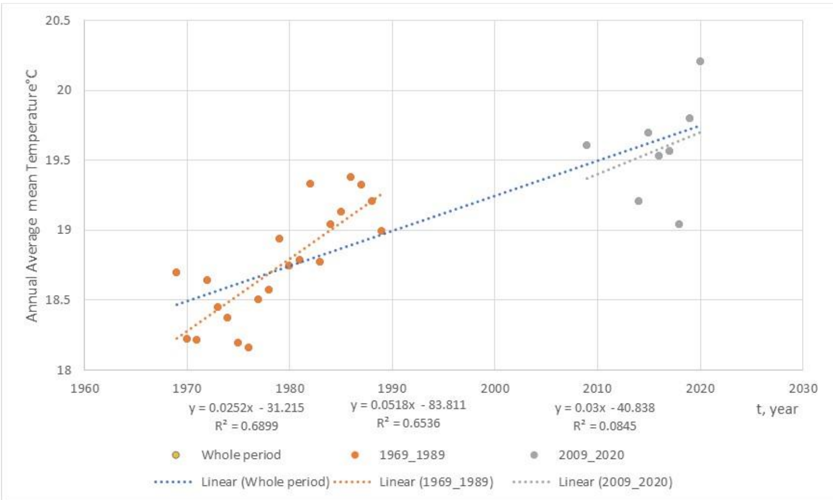

Fig. 3. Annual average temperature series, Station 15130 Valle de Bravo, Edomex., Mexico

3.3 NDIi

Annual drought indices are observed in Figure 4.

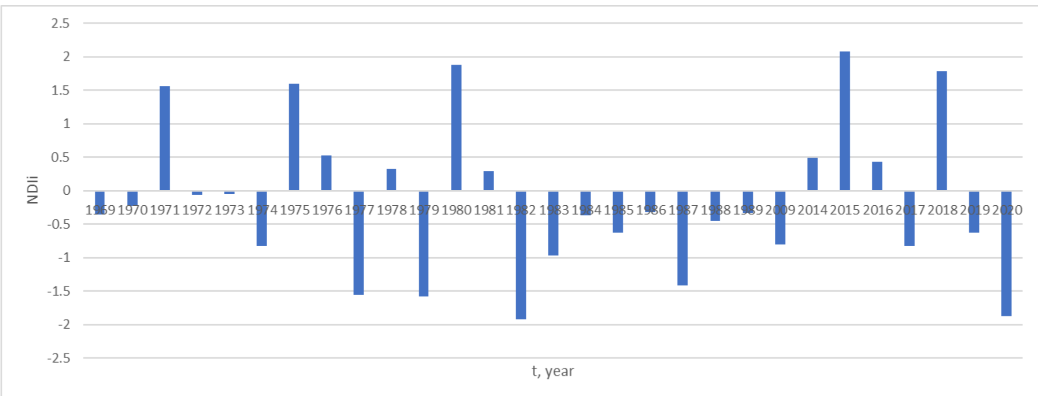

Fig. 4. Annual NDIi, Station 15130 Valle de Bravo, Edomex., Mexico

3.4 RAPSi and ΣNDIi

RAPSi of precipitation and average annual temperature as well as SNDIi appear in Figures 5 to 7 and in Tables 2 to 4 the identified periods of variation of the RAPSI and of the SNDi sums are indicated with their statistics and probability value student's t-test p.

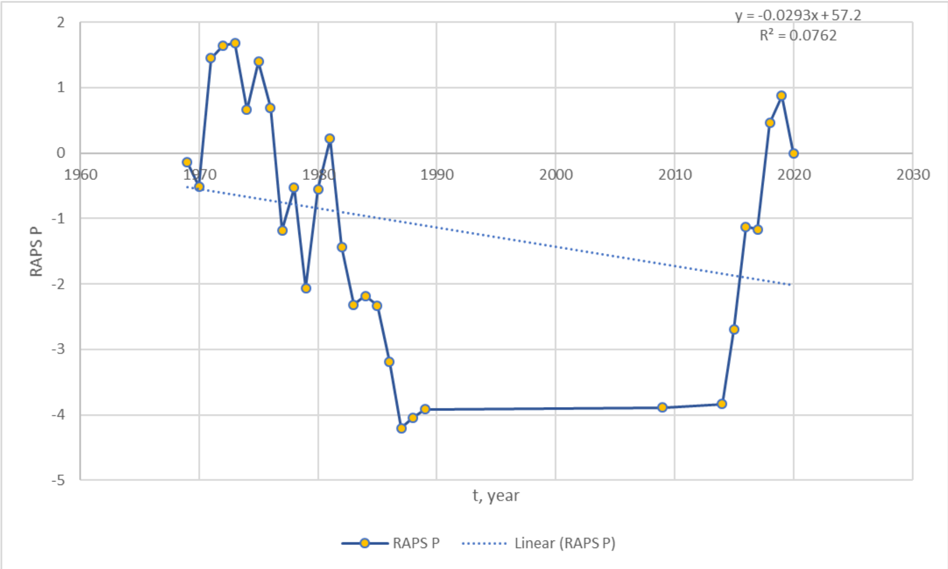

Fig. 5. RAPs of annual precipitation

Table 2: Periods identified with changes in the RAPSi, statistics and result from Student's t-test p. Annual precipitations

Periods	Mean	Standard deviation	p $_{t\text{-test}}$	Result
1969-1981	898.176923	126.661913	0.94	Mean are not different
1982-1987	813.5	72.053841	0.12	Mean are not different
1988-1989	912.6	2.54558441	0.87	Mean are not different
2009-2020	951.16125	98.9425115	0.22	Mean are not different

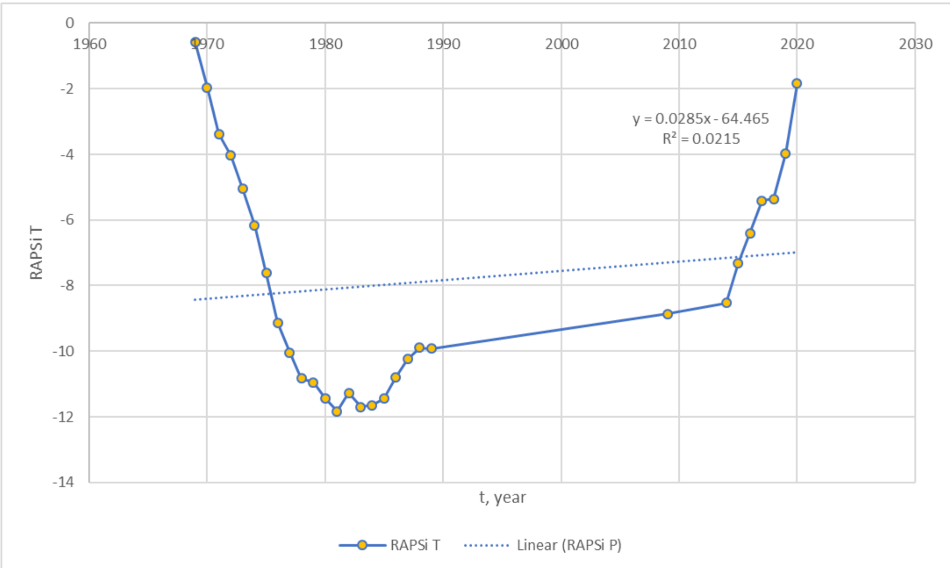

Fig. 6. RAPs of Average annual temperature

Table 3: Periods identified with changes in the RAPSi, statistics and result from Student's t-test p. Average annual temperature

Periods	Mean	Standard deviation	p $_{t\text{-test}}$	Result
1969-1981	18.50	0.25495214	0	Means are different
1982-1989	19.15	0.21	0.56	Means are not different
2009-2020	19.25	0.36	0.07	Means are not different

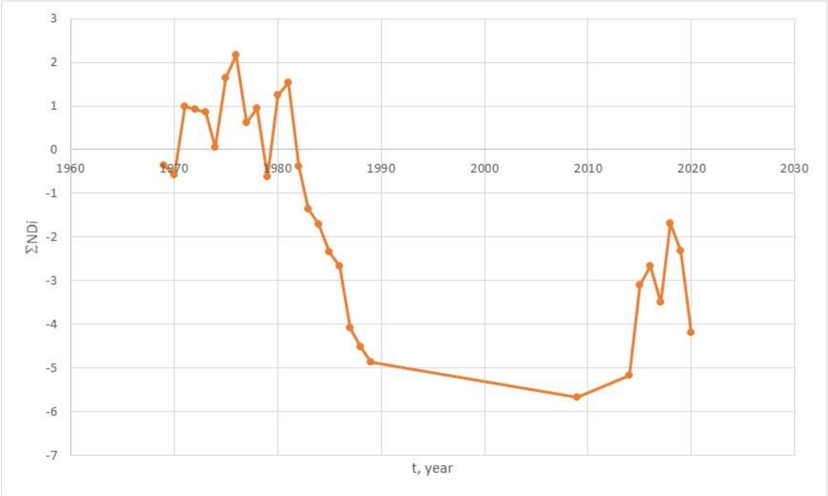

Fig. 7. Annual ΣNDIi annuals

Table 4: Periods identified with changes in the RAPSi, statistics and result from Student's t-test p. Average annual temperature

Periods	Mean	Standard deviation	p $_{t\text{-test}}$	Result
1969-1981	0.73	0.88	0	Mean is different
1982-1989	-2.74	1.61	0.54	Mean is not different
2009-2018	-3.63	1.52	0.1	Mean is not different
2019-2020	-3.26	1.33	0.31	Mean is not different

Finally, linear trend lines were obtained for each identified period of the SNDIi to establish the severity of the drought at the site of the climatological station Presa Valle de Bravo with the help of their slopes. In Figure 8, generated by Python, these results are observed.

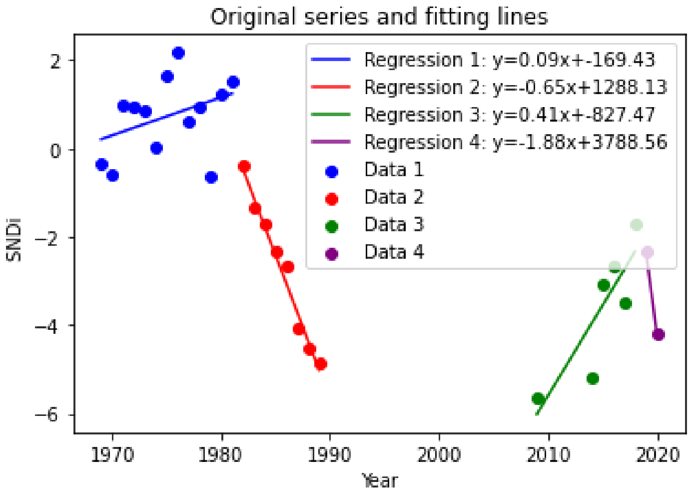

Fig. 8. SNDi Regressions at periods for droughts severity identification on analyzed site

From Figure 8 and taking into account strongly negative slope, it is observed that in the period from 1982 to 1989 a severe drought episode occurred, but a severe drought is notable in the period from 2019 to 2020, in which the slope in absolute terms is almost three times steeper.

3.5 Inflow volume Behavior into Presa Valle de Bravo

Daily volumes series of inflow to the Presa Valle de Bravo is observed in Figure 9, which illustrates the variation over time of the main dams that feed the Cutzamala system in Mexico.

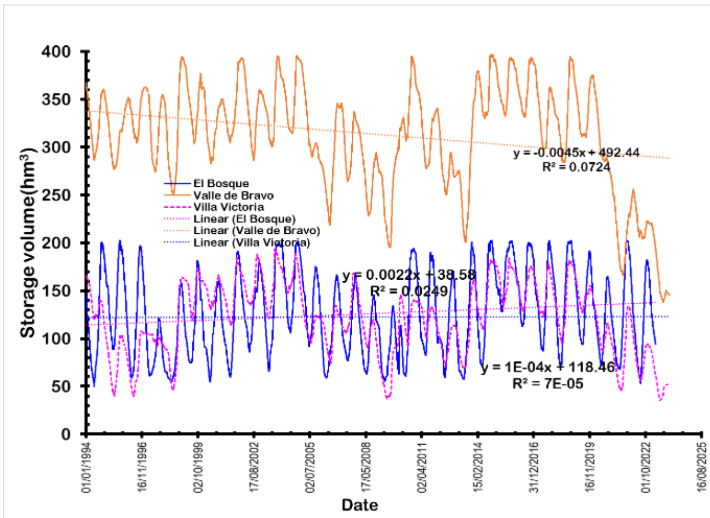

Fig. 9. Behavior of inflow volumes to the main dams of the Cutzamala System, Mexico

From Figure 9, a downward trend line is observed from daily runoff volume into the Presa Valle de Bravo, observing a descent that is becoming increasingly pronounced from 2019 and until the beginning of 2024.

4. Conclusions

A newly proposed drought index application for climatological station situated in an area prone to severe droughts yielded promising results. This index, which integrates both precipitation and temperature data, effectively addresses the challenge of evapotranspiration estimation uncertainty encountered in other methods.
By subjecting precipitation and temperature data to independent reviews, including tests for independence, homogeneity, and trends, along with employing the RAPSi method, no statistically significant changes in the mean of precipitation data during the analyzed periods were detected. However, notable deviations from randomness, non-homogeneity, and a discernible trend were observed in the temperature data. Notably, changes in the mean temperature were noted between 1969 and 1981, but such changes were not evident thereafter.
The analysis conducted for New Drought Index (SNDi) sums revealed statistically significant mean differences compared to the total series from period spanning 1969 to 1981. However, no differences were observed in subsequent periods. Linear regressions facilitated the identification of two significant drought periods: one lasting 8 years and another potentially initiating in 2019 and extending into 2020, with indications of persistence fueled by recent local precipitation scarcity reports contributing to the dam near to study site. Concurrently, daily runoff volumes to the Valle de Bravo dam exhibited a declining trend, notably from 2019 onwards.
The aforementioned research on precipitation and temperature patterns also has significant implications for addressing anthropogenic actions affecting water usage. A comprehensive analysis of stations at nearby reservoirs is essential to understand how human activities are impacting water availability and distribution in the region. This, in turn, can provide critical insights to develop water management policies and practices that mitigate negative human activities impacts and promote sustainable use of this vital resource.

Acknowledgments

We appreciate the official data sources available for free use on the internet.

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