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Estimation of water recharge using the Water Table Fluctuation method in an alluvial aquifer: Case study in Upper Capibaribe River, semiarid region of Pernambuco

Estimativa de recarga hídrica utilizando o método Water Table Fluctuation em aquífero aluvionar: Estudo de caso no Alto Rio Capibaribe, região semiárida Pernambucana

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Abstract: The Brazilian semi-arid region experiences low precipitation and high evapotranspiration rates, making it challenging to store surface water resources. Given this reality, the population seeks alternative ways to use and store water, often resorting to groundwater stored in alluvial aquifers, especially in riverside and rural communities. In this context, this study aims to understand the phenomenon of groundwater recharge in an alluvium in a Brazilian semi-arid region using the Water Table Fluctuation (WTF) method. Additionally, it aims to analyze the influence of constructing a subsurface dam on water recharge. From September 2020 to September 2023, four wells in the alluvium of the upper Capibaribe river, in the municipality of Santa Cruz do Capibaribe, a semi-arid region of Pernambuco, were monitored both by installed level sensors and manually. Precipitation during this monitored period was above the historical average from 1987 to 2023, with an average monthly precipitation of 37.70 mm. The average water recharge in the wells was 27.40%, ranging from 15.71% to 32.82%. The water level in the wells was observed to be more stable, especially in the well closest to the underground dam, which blocks the underground flow in the alluvium, causing water accumulation upstream and protecting it from solar radiation. However, a larger dataset is needed to confirm this expected trend.

Keywords: Underground water recharge; Water Table Fluctuation (WTF); Underground dam.

Resumo: O semiárido brasileiro possui baixas taxas de precipitações e altas taxas de evapotranspiração, dificultando o armazenamento de recursos hídricos superficiais. Diante dessa realidade, a população busca maneiras alternativas de utilização e armazenamento de água, muitas vezes recorrendo às águas subterrâneas armazenadas em aquíferos aluviais, principalmente comunidades ribeirinhas e rurais. Nesse contexto, esse trabalho visa compreender o fenômeno de recarga hídrica subterrânea, em uma aluvião, em uma região semiárida brasileira utilizando o método *Water Table Fluctuation* (WTF). Além disso, objetiva analisar a influência da construção de uma barragem subterrânea na recarga hídrica. Durante o período de setembro de 2020 a setembro de 2023, quatro poços na aluvião do Alto Rio Capibaribe, no munícipio de Santa Cruz do Capibaribe, região semiárida de Pernambuco, foram monitorados tanto por meio de sensores de nível instalados, quanto manualmente. A precipitação neste período monitorado foi superior à média histórica de 1987 a 2023, que tem precipitação mensal média de 37,70 mm. A recarga hídrica nos poços foi em média, 27,40%, variando entre 15,71% e 32,82%. Observou-se maior estabilidade no nível de água dos poços, principalmente no poço mais próximo a barragem subterrânea, o qual barra o fluxo subterrâneo na aluvião, causando o acúmulo de água no trecho de montante, protegendo-a da radiação solar. No entanto, é necessária uma série maior de dados para confirmar essa tendência esperada.

Palavras-chave: Recarga hídrica subterrânea; *Water Table Fluctuation* (WTF); Barragem subterrânea.

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1. Introduction

In recent years, the concern about water availability in the semi-arid areas of northeastern Brazil has intensified, reflecting the growing worry about its scarcity and access. Population growth and the increasing demand for this natural resource highlight the importance of preserving its quality and quantity to promote the region's sustainable development (SANTOS, 2017). Population growth and climate instability have caused a water imbalance, reducing available water resources per person, both in quantity and quality. Given the scarcity of surface water resources, the utilization of groundwater becomes essential and strategic (CIRILO et al., 2007).

Areas with a negative water balance characterize the Brazilian semi-arid region due to average annual precipitation below 800 mm, average annual sunshine of 2800 hours, average annual temperatures ranging from 23º to 27º C, potential evaporation reaching 2,000 mm per year, and average relative humidity around 50% (Moura et al., 2007). The Capibaribe region is subdivided into upper, middle, and lower Capibaribe, with the study area located in the Upper Capibaribe, the most affected by water scarcity due to its semi-arid climate (BRAGA, 2016).

In Santa Cruz do Capibaribe city, Pernambuco, located about 10 km from the analyzed region, the climate is characterized by low annual precipitation, with an average of around 450 mm per year (ANA, 2023). The analyzed region is characterized by alluvial deposits, which consist of clastic sediments such as gravel, sand, and fine particles. These sediments are mainly formed by fluvial erosion and are transported by surface runoff. Over several years, these materials are deposited in the riverbed and banks, forming layers that can significantly influence the local hydrology (SÁ; DINIZ, 2012).

When there is no surface water runoff in the Brazilian semi-arid region, it is expected to resort to the use of artesian wells, such as "cacimbões" and "cacimbas," which are built in emergencies (PAIVA et al., 2014). Additionally, there are techniques that help in the storage of groundwater. According to Melo et al. (2009), research conducted in northeastern Pernambuco showed that using underground dams to capture rainwater is a practical and effective solution to raise the water level in wells. This practice not only ensures water supply for human and animal consumption but also plays a fundamental role in supporting agricultural production in rural communities (MENDONÇA et al., 2012).

Therefore, analyzing the behavior of aquifer recharge is essential to determine the volume of slowly renewable groundwater resources (PARALTA et al., 2003). Estimating aquifer recharge is considered complex because the variables are very volatile both in space and time (PINTO et al., 2010).

According to Hirata, Zoby, and Oliveira (2010), although groundwater is widely used in Brazil, knowledge about its quantity and quality is still quite limited, mainly due to the lack or precariousness of monitoring systems. According to Santos et al. (2023), there are still gaps in obtaining data and climate monitoring in Brazil. Silva et al. (2020) highlight the significant costs associated with the installation, maintenance, and operation of monitoring systems, especially in the North and Northeast regions of the country.

Several approaches are used to estimate groundwater recharge, one of which is the Water Table Fluctuation (WTF) method, which can be consulted in detail by Healy and Cook (2002) and Healy (2010). This method is based on the idea that unconfined aquifers are recharged by the downward flow of water reaching the water table, resulting in a volumetric increase in the groundwater reserve (HEALY; COOK, 2002; SCANLON; HEALY; COOK, 2002).

Coelho et al. (2017) conducted a study in the semi-arid region of northeastern Brazil, specifically in the Ipanema River basin, in the Mimoso stream, between 2011 and 2012. The study compared the results obtained through the WTF method with those of the Water Balance (WB) method. The results indicated a total recharge rate of 13.3% in relation to precipitation by the WTF method, while the WB method showed a total recharge rate of 10.3%.

Albuquerque et al. (2015) analysed the Upper Ipanema basin region, near Pesqueira, comparing the WTF method with the Thornthwaite & Mather (TM) water balance method from 2002 to 2011. According to the TM method, the year with the highest recharge was 2004, recording 28.63%, while the WTF method recorded a total recharge of 27.47% for the same period. The study reveals a Pearson correlation (r = 0.97) between the two methods, indicating a minimal difference of only 1.9% in the recharge estimate relative to total precipitation.

Several authors have estimated well water recharge using the WTF method worldwide, such as Crosbie et al. (2019) in northern Australia, Delottier et al. (2018) in France, Yimam et al. (2023) in Ethiopia, and Boumis et al. (2022) in North Carolina, USA.

According to Wendland, Barreto, and Gomes (2007) and Crosbie et al. (2019), the WTF method proves to be more effective in aquifers that show large variations in water levels, which is characteristic of the aquifers in the analyzed region. Thus, the main objective of this analysis is to estimate groundwater recharge in an unconfined aquifer unit using the WTF method. Additionally, it seeks to analyze the impacts of installing of an underground dam in the Capibaribe River basin, in Santa Cruz do Capibaribe city, a semi-arid region of Pernambuco.

2. Methodology

The project was conducted in the semi-arid region of the Northeast, specifically in the Capibaribe River basin, in the Upper Capibaribe area, near the city of Santa Cruz do Capibaribe and the district of Poço Fundo, in the state of Pernambuco (Figure 1). Due to the project's budget limitations, only four wells were analyzed (P1 to P4), reflecting the available capacity for sensor installation.

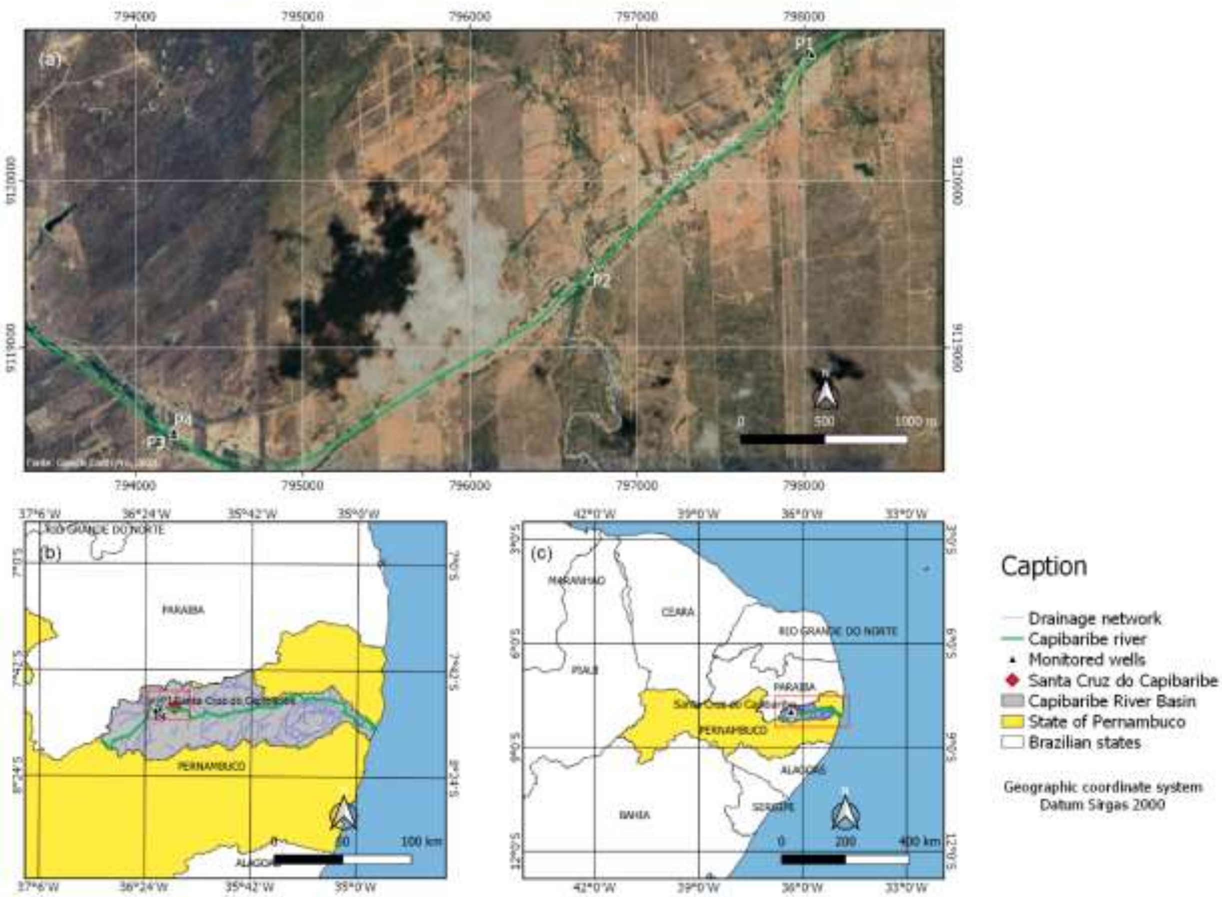

Figure 1 – Location of the study area in the upper Capibaribe River.
Source: Authors (2024).

The geographic parameters such as latitude, longitude, altitude, and depth of the analyzed wells are listed in Table 1. Well P1 is located approximately 85 m from the PE-160 highway, with a diameter of 1.50 m. Well P2 is located about 600 m from the PE-160 highway and also has a diameter of 1.50 m. Wells P3 and P4 are situated approximately 140 m from the PE-160 highway and have the same diameter of 3.40 meters. It is important to note that wells P3 and P4 are located close to each other (Figure 2).

For monitoring the water level in the "cacimbão" wells, a Dalo 105 datalogger from Ampeq was used in each well to record the static water level every 5 minutes. All four sensors were installed in September 2021. Data collection was planned to occur once per month, also to verify the sensor's condition (e.g., calibration). With this schedule, an average of 8,640 monthly data points were collected from each well, which is highly relevant for understanding groundwater recharge behavior. Data download was performed using USB ports on a notebook connected to the Datalogger via a standard AM type cable, commonly used for printers. The scope of this study includes analyzing well recharge over up to three years, concluding analysis by September 2023 for all wells. Except for Well P1, which was only analyzed for two years due to being buried before September 2021. Additional information included an evaluation of the rainfall history from station Code 736041 (ANA, 2023) located in Santa Cruz do Capibaribe, covering data from 1987 to 2023.

Table 1 – Selected wells in the study area.

Well	Level (m)	Latitude	Longitude	Depth (m)	Start of monitoring	End of monitoring
P1	451	7°56'43.60"S	36°17'48.20"O	3.00	Sep/21	Sep/23
P2	452	7°57'26.66"S	36°18'30.76"O	3.30	Sep/20	Sep/23
P3	453	7°57'58.64"S	36°19'52.33"O	3.50	Sep/20	Sep/23
P4	453	7°57'58.02"S	36°19'52.33"O	3.25	Sep/20	Sep/23

Source: Authors (2024).

In estimating groundwater recharge, the WTF method relies on analyzing water table measurements in monitoring wells or piezometers over a specific period. This method is based on the premise that positive fluctuations in groundwater static levels are related to precipitation waters that percolate through the soil and reach the groundwater table, thereby causing recharge (HEALY; COOK, 2002). Groundwater recharge can be calculated using the WTF method through Equation 1.

$$R = S_y \frac{dh}{dt} \therefore R = S_y \frac{\Delta h}{\Delta t} \quad (1)$$

Where:
R = Groundwater recharge (mm);
Sy = Specific yield (dimensionless);
Δh = Variation in water level height (mm);
Δt = Chosen period for estimation (day, month, year).

The variation in water level is then correlated with other data, such as local precipitation, which in this case was measured at Station 736041 managed by ANA, located about 10 km from the wells under analysis in Santa Cruz do Capibaribe municipality. From September 2020 to September 2021, water level readings were exclusively done manually, with sensors installed only from September 2021 onwards.

Equation 1 is applied individually for each peak in water level elevation, where Δh represents the difference between the lowest and highest peaks of each recharge event, which can occur multiple times throughout the year (MAZIERO; WENDLAND, 2005). To determine Δh, it is necessary to analyze the difference between the upper peak and the projected lower peak if the precipitation event did not occur (Figure 2).

Healy and Cook (2002) noted that there is no specific type of function for drawing the extrapolated recession line; however, Wendland, Barreto, and Gomes (2007), and Coelho (2016) chose to use the potential function (Equation 2), which was also adopted in this study.

$$N_c = a.(P-P_0)^b \quad (2)$$

Where; Nc represents the calculated level (m); P is the number of days since the beginning of level monitoring; while a, b, and P0 are parameters to be determined. With the identification of the recession function parameters, this function is applied to the other recession periods. The extrapolation of the curve should extend to the beginning of a new recessionary period (COELHO, 2016).

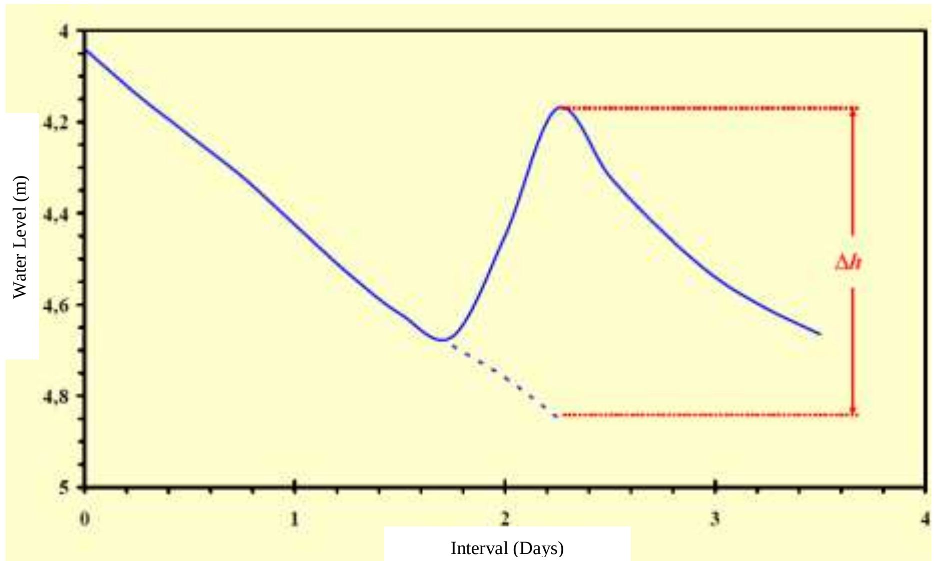

Figure 2 – Hypothetical example of water level rise in a well due to precipitation recharge.
Source: Maziero and Wendland (2005).

Sy can be defined as the amount of water in the soil that, after saturation, is drained by gravity, which can occur when there is a drawdown in aquifers (MEINZER, 1923). The values of Sy can be determined through an empirical formulation proposed by Biecinski (PAZDRO, 1983 cited in ALVAREZ; NIEDZIELSKI, 1996), relating Sy to hydraulic conductivity (Equation 3). Sy is a dimensionless coefficient and does not have a unit of measurement, but it can also be expressed as a percentage.

$$S_y = 0{,}117 \cdot \sqrt[7]{K} \quad (3)$$

Where:
Sy = Specific yield;
K = Hydraulic conductivity (m/day).

In this study, the value of Sy was calculated based on hydraulic conductivity (K), obtained by Silva (2015). This researcher analyzed K using the Kozeny-Carman equation method at three different locations in the Upper Capibaribe River region, at two different depths, 0.5 m and 1.0 m (Table 2). Hydraulic conductivity was then applied in Equation (3) to calculate the specific yield Sy.

Table 2 - Estimated hydraulic conductivity for the section under study in the upper Capibaribe River.

Sample	Depth (m)	Coordinates	K (m/s)
1	0.5	7° 56' 43.4" S	1.83E-06
2	1.0	36° 17' 48.6" O	2.07E-06
3	0.5	7° 57' 26.5" S	9.22E-06
4	1.0	36° 18' 30.8" O	7.64E-06
5	0.5	7° 57' 57.8" S	2.84E-05
6	1.0	36° 19' 54.6" O	2.28E-05

Source: Silva (2015).

The values of K selected for Well P1 were obtained by averaging samples 1 and 2, considering the proximity between Well P1 and the samples. The same criterion was applied to the other wells. For Well P2, the average value of K between samples 3 and 4 was used, while for Wells P3 and P4, the average of samples 5 and 6 was used.

Groundwater recharge for the wells was calculated using Equation (1), utilizing the variation in water level Δh (mm) over time Δt (month). Therefore, to calculate the recharge, the variation in groundwater level (Δh) is determined by the difference between the maximum (peak) and minimum (low point) values of the previous recession curve, which is extrapolated to the peak moment. Each time there was a recharge, this calculation procedure was repeated, and the total recharge sum over the analysis period was calculated. Additionally, the average total recharge per month during the analysis period was also calculated.

3. Results and discussion

The region of Agreste in Pernambuco, particularly the municipality of Santa Cruz do Capibaribe and its surroundings, is characterized by considerable fluctuations in rainfall. This seasonality can be observed in Figure 3, based on the historical series from 1987 to 2023, obtained from a rainfall station with Code 736041 (ANA, 2023), located in Santa Cruz do Capibaribe. The average annual precipitation is 37.70 mm, with above-average rainfall from February to July, while January and August to December typically have below-average values. Cavalcanti (2018) conducted a study in the Santa Cruz do Capibaribe region, analyzing a historical series from 1962 to 2016, and identified similar seasonal precipitation patterns to those observed in this article, with a rainy season from March to July and a dry season from August to December. It is also noteworthy that 2022 and 2023 recorded above-average precipitation for this locality.

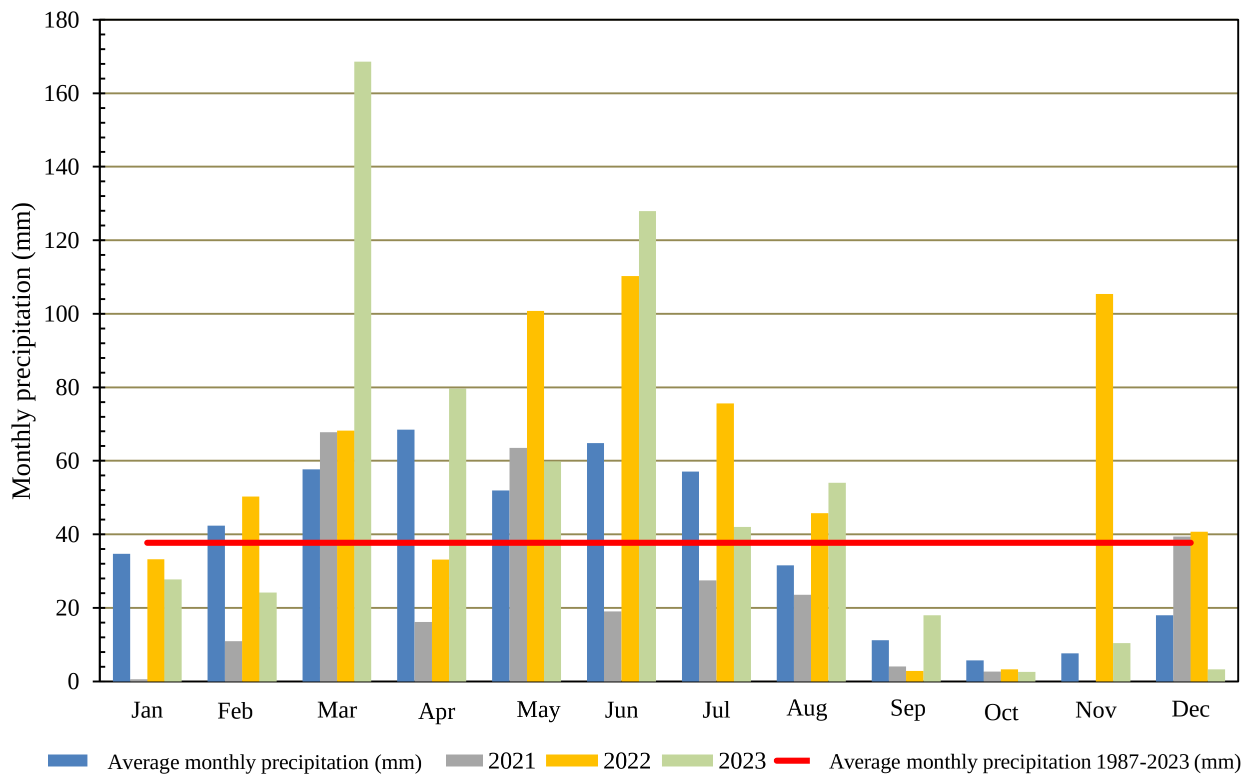

Figure 3 – Monthly precipitation at monitoring station 736041, in Santa Cruz do Capibaribe city, between 1987 and 2023.
Source: The Authors (2024).

Wells P1 and P2 show a variation in water levels that is relatively consistent until December 2022, before the construction of the underground dam. It was expected that Wells P3 and P4, due to their geographical proximity, would exhibit similar patterns of water level variation (Figure 4).

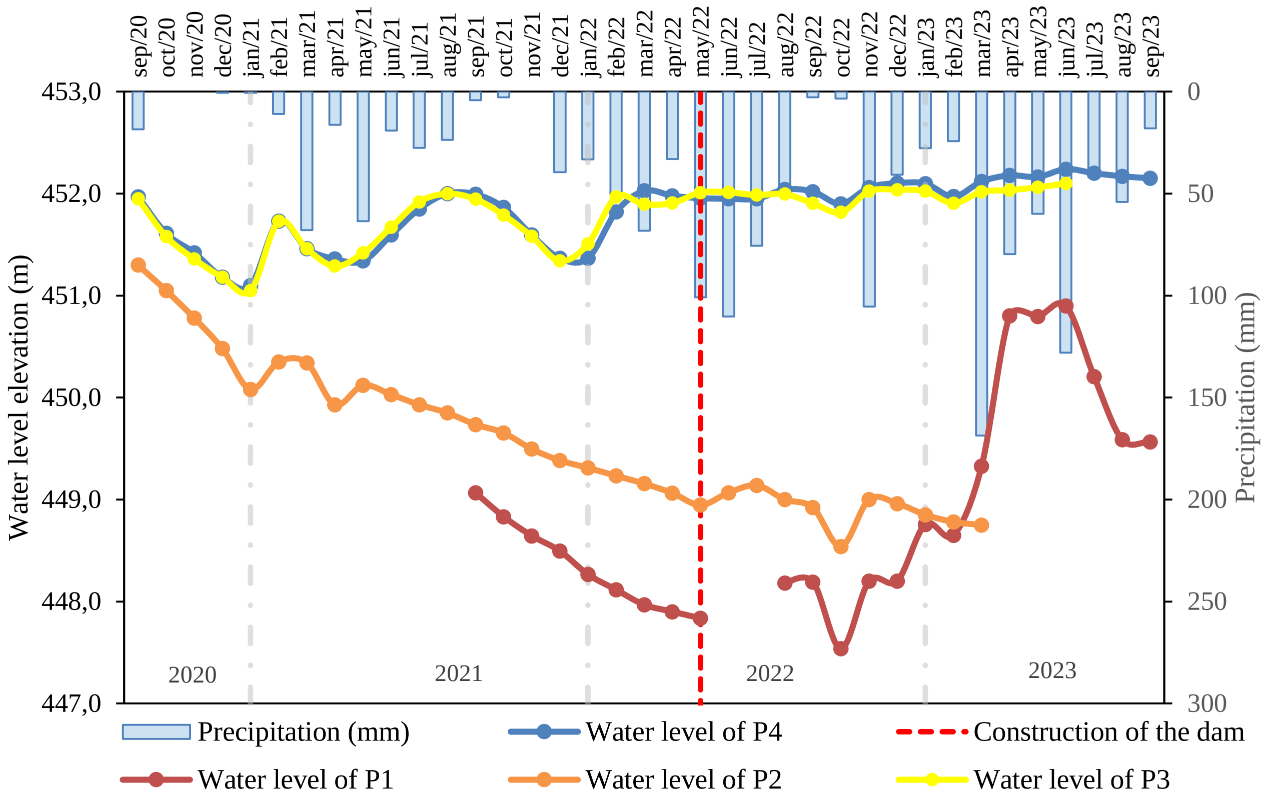

Figure 4 – Variation of water levels in monitored wells, in the alluvial area of the upper Capibaribe river, and monthly precipitation at monitoring station 736041.
Source: Authors (2024).

Analyzing Figure 4, which includes the monitored wells, a greater stability in water level variation is noted in most wells after the installation of the underground dam in May 2022. This is due to the fact that the underground dam technique involves blocking groundwater flow and consequently infiltrating recharge directly into the alluvial plain through a barrier built transversely to its path. Thus, the underground dam helps to raise the water table, keeping the soil moist for longer periods and retaining water levels in the wells. It functions as an underground reservoir, protected from direct evaporation effects. For Well P1, significant increases in water level were observed from October 2022 onwards. However, for Well P2, there were no substantial changes in water level increase after the dam installation. Equipment failure occurred from March 2023, but some effects were already noticeable in the readings from May 2022 to March 2023. This difference is evident with the damming effect observed in Well P1, which shows greater water storage downstream of the underground dam. This effect does not extend to Well P2, located approximately 1.9 km upstream from Well P1, and consequently also does not reach Wells P3 and P4, which are about 2.85 km upstream from Well P2. Regarding Wells P3 and P4, it was observed that after the dam construction, there was greater water retention, with fewer reductions in water level, maintaining a stable elevated level. Considering that the ground elevation is 453 meters and the water level remained around 452 meters (Figure 4). However, it is important to note that to confirm this behavior, a broader set of data needs to be examined to validate the results observed so far.

The period under analysis was characterized by intense precipitation that the region was not accustomed to, causing a sharp alteration in the water levels of the wells. Silva et al. (2023) analyzed precipitation variations in Santa Cruz do Capibaribe between 1988 and 2022, finding results above average for 2020 and 2022, similar to those of this study. In

March 2023, there was a precipitation of 168.6 mm, while the historical average for that month was 57.69 mm. In June 2022, 110.3 mm of rain was recorded, and in June 2023, 127.9 mm, compared to a historical average of 64.8 mm for June. Additionally, November 2022 had a precipitation of 105.4 mm, well above the historical average of only 7.61 mm for that month (Figures 3 and 4).

Over the one year from May 2021 to May 2022, Well P2 experienced the longest duration of water level decline. Subsequently, Well P1 declined period from September 2021 to May 2022. On the other hand, Wells P3 and P4 did not record significant periods of water scarcity, with the longest interval observed between September 2020 and January 2021 (Figure 4).

To calculate the specific yield (Sy), the average hydraulic conductivity (Kavg) was determined, following the same procedure for each of the wells analyzed. By using this value of Kavg in Equation 3, it was possible to obtain the specific yield Sy (Table 3).

Table 3 - Hydraulic conductivity and specific yield used in the upper Capibaribe river alluvium.

Well	Sample	K (m/s)	Kavg (m/s)	Sy
P1	1	1,83E-06	1,95E-06	0,09
	2	2,07E-06		
P2	3	9,22E-06	8,43E-06	0,11
	4	7,64E-06		
P3 e P4	5	2,84E-05	2,56E-05	0,13
	6	2,28E-05		

K - hydraulic conductivity; Kavg - average hydraulic conductivity; Sy - specific yield
Source: Authors (2024)

With the extrapolation of the curve at points where groundwater recharge occurred, the recharge patterns for each well can be observed. For Well P1, recharges occurred in November 2022, January 2023, and from March to June 2023 (Figure 5). For Well P2, recharges were observed in February and March 2021, May 2021, June and July 2022, and November 2022 (Figure 6). In the case of Well P3, recharges were recorded in February 2021, between May and August 2021, between January and February 2022, May 2022, November 2022, and March 2023 (Figure 7). For Well P4, recharges occurred between February 2021, between May and August 2021, between January and March 2022, August 2022, November 2022, March 2023, and June 2023 (Figure 8). Here, Nc represents the calculated level and R^2 is the coefficient of determination of the obtained equation.

The largest recharges were observed from March to April 2023 for Well P1, with 168.6 mm and 79.6 mm of precipitation recorded, respectively. In the case of Well P2, the peak recharge occurred in November 2022, with 105.4 mm of precipitation. As for Wells P3 and P4, the highest recharge was recorded between January and March 2022, reaching 68.2 mm of precipitation in March 2022.

Wells P1 and P2, despite showing some similarity in the water level variation behavior between September 2021 and December 2022, experienced distinct recharges, resulting in a difference of 13.83%. It is important to note, however, that monitoring data for Well P2 was interrupted after March 2023, while Well P1 had no monitoring data before September 2021. These differences in monitoring periods may have influenced the discrepancy in observed recharge. The groundwater recharge for Wells P3 and P4 using the WTF method showed significant similarities, as expected due to their proximity, with only a small difference of 1.27% in recharge between these wells.

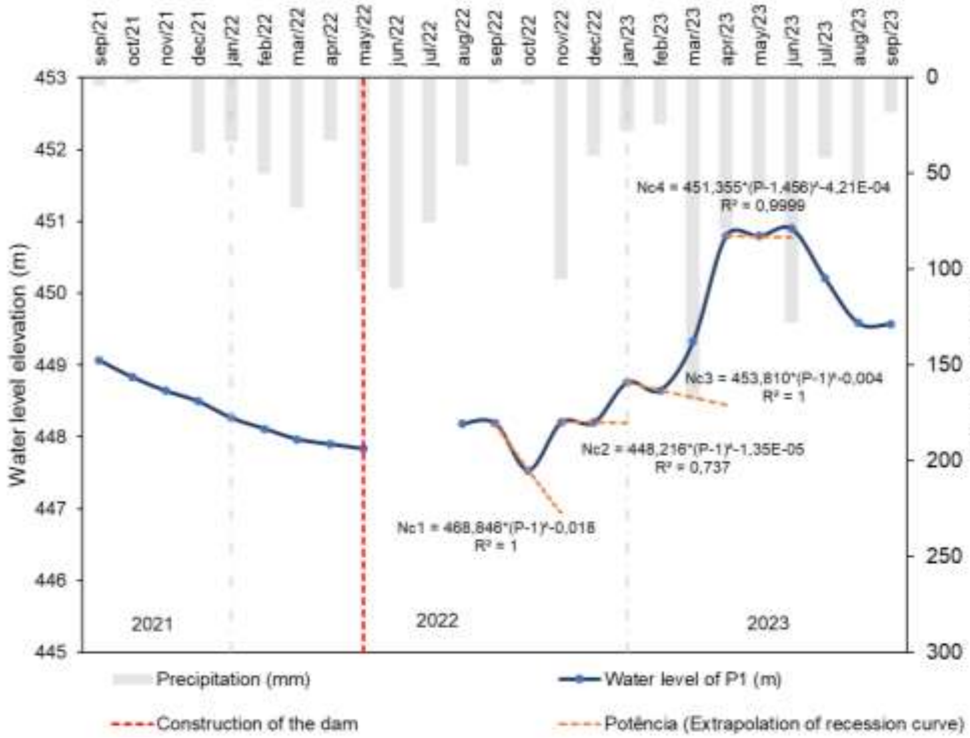

Figure 5 – Application of the WTF method in the P1 Well, from 2021 to 2023, in the upper Capibaribe River alluvium. Source: Authors (2024).

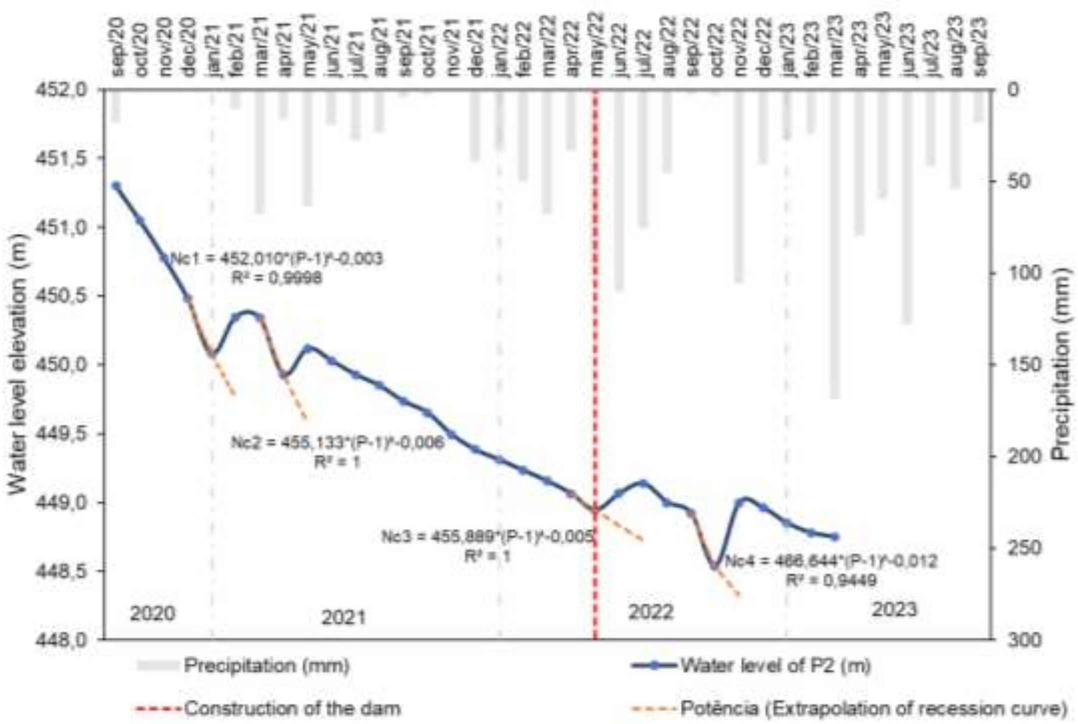

Figure 6 – Application of the WTF method in the P2 Well, from 2021 to 2023, in the upper Capibaribe River alluvium. Source: Authors (2024).

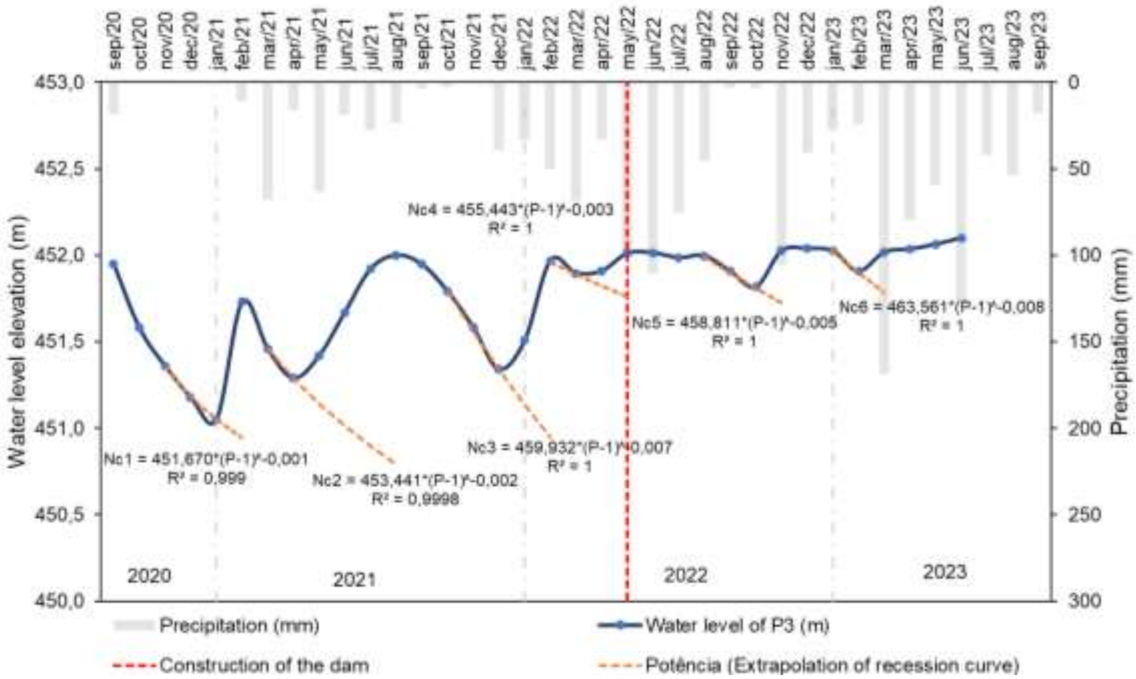

Figure 7 – Application of the WTF method in the P3 Well, from 2021 to 2023, in the upper Capibaribe River alluvium. Source: Authors (2024).

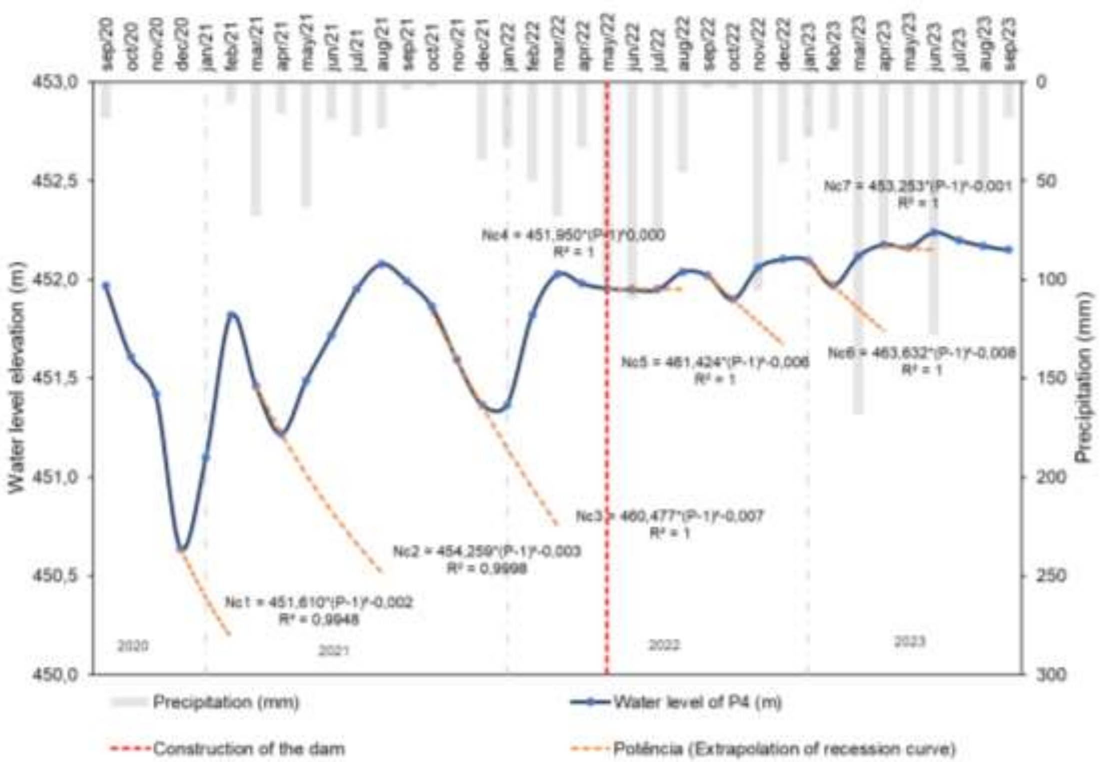

Figure 8 – Application of the WTF method in the P4 Well, from 2021 to 2023, in the upper Capibaribe River alluvium. Source: Authors (2024).

Well P1 recorded the highest Δh value, reaching 2.351 meters (Δh3), representing the largest point variation in water level among the analyzed wells. Well P2 had the highest variation of 0.676 meters (Δh4), Well P3 had 1.208 meters (Δh2), and Well P4 had 1.267 meters (Δh4) (Table 4).

Table 5 shows the estimated total recharge values, covering the entire period under analysis, for the four monitored wells.

Based on the monthly recharge of each well, it was observed that, although Well P4 recorded the highest total recharge compared to the others, Well P1 had the highest monthly recharge rate, with 16.21 mm per month. On the other hand, Well P2 recorded the lowest total recharge, with 246 mm, and a rate of 6.83 mm per month. The recharge values expressed as a fraction of precipitation varied between 15.71% and 32.82%, with an average of 27.40% (Table 5).

Table 4 – Water level variation Δh, for wells in the upper Capibaribe River alluvium, 2021 to 2023.

Δh (m)	**P1**	**P2**	**P3**	**P4**
Δh1	1,260	0,580	0,779	0,692
Δh2	0,560	0,545	1,208	0,933
Δh3	2,351	0,404	1,013	1,267
Δh4	0,120	0,676	0,249	0,09
Δh5	-	-	0,294	0,424
Δh6	-	-	0,225	0,427
Δh7	-	-	-	0,089
∑Δh	**4,292**	**2,205**	**3,770**	**3,921**

Source: Authors (2024).

Table 5 – Water recharge using the WTF method, in the upper Capibaribe River alluvium, 2021 to 2023.

Well	**Period (months)**	**R (mm)**	**Monthly R (mm/month)**	**R/P (%)**
P1	24	389,18	16,21	29,54
P2	36	246,00	6,83	15,71
P3	36	494,06	13,72	31,55
P4	36	513,85	14,27	32,82
			Average	**27,40**

Source: Authors (2024).

Coelho et al. (2017) conducted a study in the semi-arid region of northeastern Brazil, specifically in the Ipanema River basin, in Mimoso stream, between 2011 and 2012. The study compared the results obtained using the WTF method with those of the WB (Water Balance) method. The results indicated a total recharge rate of 13.3% relative to precipitation using the WTF method, while the WB method showed a total recharge rate of 10.3%.

Tesfaldet, Puttiwongrak, and Arpornthip (2019) analyzed the recharge estimation of 28 wells in Thepkasattri, Thailand, using the WTF method with data from 2012 to 2015. The estimated recharge resulted in 26% of the annual precipitation in 2015.

Other studies, such as Andrade et al. (2014), also identified a similar groundwater recharge to the average recharge in this article, showing a recharge of 27% using the WTF method for an alluvial aquifer in the semi-arid region of Pernambuco, specifically in Mimoso stream, Pesqueira municipality, during the year 2004. Teramoto and Chang (2018) also found values similar to those reported in this dissertation, recording a recharge of 33% for an aquifer in São Paulo in 2011.

4. Final considerations

The application of the WTF method demonstrated ease in estimating recharge when water level data is available over time, although the recharge values found for P3 (31.55%) and P4 (32.82%) were slightly higher than those generally reported in the literature. This is also due to the fact that the period analyzed was marked by higher than expected precipitation. The determination of Sy is a factor that directly influences the calculation of water recharge by the WTF method. This parameter varies not only with location but also with depth, making it the most complex aspect to determine in this methodology.

After the construction of the underground dam, greater stabilization in the water levels of the wells was observed, except for Well P2. The presence of the underground dam can influence the water levels found in the study by acting as a barrier to the natural groundwater flow, allowing the water to accumulate, like an underground reservoir, consequently increasing the water levels in nearby wells, maintaining stability in levels. The underground dam also reduces water loss through evaporation, which has high rates in the semi-arid region, as the water accumulates in the pores of the granular alluvium material, minimizing the effect of solar radiation directly on the water. Potentially, the underground dam, when it also reaches elevations above the initial alluvial level, can help in the accumulation of sediments, increasing the water flow infiltrating the soil, improving the efficiency of aquifer recharge. These combined factors explain the changes in water levels observed after the installation of the underground dam; however, a larger series of data is needed to confirm this already expected trend.

Overall, the potentiometric level measurements through the wells showed good performance related to water recharge during the analyzed period, with an average recharge relative to precipitation of 27.40%. The well that performed the best was Well P4 with 32.82% recharge relative to precipitation, and the one that performed the worst was Well P2 with 15.71%. Wells P1 and P2 did not show as close a relationship with Wells P3 and P4, presenting inferior performance in water accumulation compared to Wells P3 and P4.

Therefore, given the importance of groundwater for the semi-arid regions of Brazil, it is suggested that future studies consider a larger sample of wells and a more extended analysis period. This will allow a more comprehensive analysis of water recharge and enable quantification of the effects of the construction of underground dams, benefiting the local population.

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