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# VIABILITY OF PRECIPITATION FREQUENCY USE FOR RESERVOIR SIZING IN CONDOMINIUMS

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**Abstract:** The increase of house condominiums in the Brazilian cities is gradually increasing due to problems concerning traffic tie-up, air pollution level, amongst others. In these condominiums, large green areas for leisure, comfort and better life quality for the joint owners are reserved. The large house gardens need hard maintenance, which raises the water demand in the condominiums. The use of the rainwater is an alternative that could be used in Brazil and other countries to minimize the use of potable water in non-potable water needs, such as car wash, garden irrigation, etc. This paper evaluates the precipitation in João Pessoa city (capital of Paraíba state, Brazil), according to the frequency analysis and significance test. Thus, it was applied a robust tool to analyze signal frequency, named wavelet transform, which is appropriated to analyze irregular events and non-stationary series. It was analyzed two precipitation series of João Pessoa city, 1937–1970 and 1980–1996, when it was observed a significant annual signal at level 10%, which revealed the existence of an annual rainy season, which is very convenient for the water storage for further using during the dry season. Finally, the reservoir is an important item in the rainwater system and it has to be correctly design in order to make the system economically practicable. The Rippl method was used for the reservoir sizing analysis.

**Keywords:** Rainwater; frequency analysis; João Pessoa.

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## INTRODUCTION

The population increase generates high level of violence, traffic jam, sonorous and environmental pollution in the Brazilian cities, which increases the population stress level amongst other problems. In consequence of these factors, the population life quality is constantly decreasing in way that the people with better social conditions are changing to the so called *condominiums*. The launching of condominiums reached significant numbers in some Brazilian cities, consolidating itself as a new concept of housing that joins the shelter function, security, basic infrastructure and leisure. The water consumption in these condominiums is generally high due to the existing large gardens in the individual residences and in the common areas. An alternative for the reduction of the water consumption would be the rainwater use through gutters in the roofs. The rainwater is a simple and cheap alternative source to minimize the problems of water scarcity in the world nowadays. In order to the system of rainwater exploitation function with efficiency, it is necessary to carry out economic, technical and social acceptance studies. For the technical studies, a special attention must be given to the analysis of rainfall frequency within the region, because low frequency in the signal turns the system impracticable.

A robust tool for analysis of signals called wavelet transformed is a recent advance in signal processing that has attracted much attention since its theoretical development in 1984 by Grossman & Morlet (1984). Some applied sciences that work with study of signals have used wavelets, such as astronomy, acoustics, compression of data, and nuclear engineering (Farge, 1992; Graps, 1995). The analysis for wavelet trasnformed (TW) is an alternative the Fourier transformed (TF) for preserving local, non-periodic and multiscaled phenomena, it is appropriate to analyze irregularly distributed events and time series that contain nonstationary power at many different frequencies. The application of wavelets is not frequently seen in hydrology, but its use has increased, e.g., Santos *et al.* (2001), Santos *et al.* (2003) and Santos & Ideião (2006) had shown its use in the analysis of precipitation data for identification of regularities and dry/rainy periods.

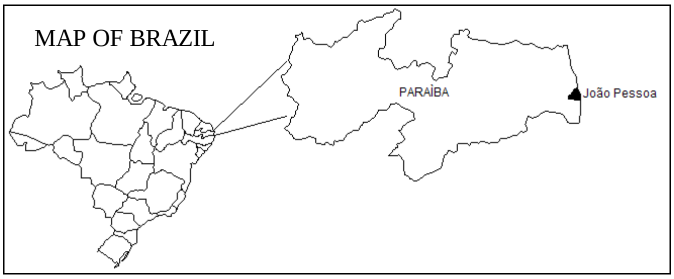


**Fig. 1** Location of João Pessoa city, Paraíba state, Brazil.

Thus, the present paper shows the analysis of the rainfall signal in João Pessoa city, Paraíba, Brazil, in order to verify the technical viability of the rainwater use for non-potable uses in condominiums and the reservoir sizing analysis based on the Rippl method.

## MATERIAL AND METHODS

### Localization of the study area

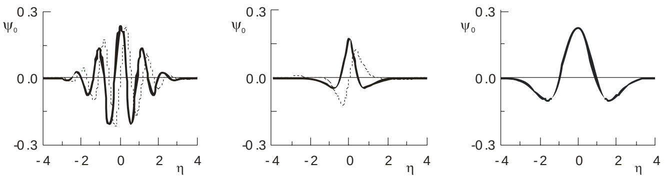
The study area is João Pessoa city **(Fig. 1)**, located in Paraíba state in the Brazilian northeastern region. It is the state capital and the most populous city of the State with 597,934 inhabitants (IBGE, 2000) and area of 210,551 km², with a strong trend for the increase of the quantity of condominiums.

### Data

Two precipitation series daily in João Pessoa city had been chosen for analysis. The first series is for the period from 1937 to 1970, which was obtained from the Brazilian National Water Agency (ANA) at www.ana.gov.br and the second one was obtained from the Laboratory of Solar Energy (LES) of the Federal University of Paraíba, for the period from 1980 to 1996.

### The Wavelet Transform

Wavelets are mathematical functions that widen data intervals, separating them in different frequency components, allowing the analysis of each component in its corresponding scale. The wavelet analysis keeps the localization of the time and the frequency, in a signal analysis, by decomposing or transforming a one-dimensional time series into a diffuse two-dimensional time-frequency image, simultaneously. Then, it is possible to get information on both the amplitude of any "periodic" signals within the series, and how this amplitude varies with time. **Figure 2** shows basic examples of wavelets or wavelets-mother, as it is called in literature. These wavelets have the advantage to incorporating a wave of a certain period, as well as being finite in extent. Assuming that the total width of this wavelet is about 10 years, it is possible to find the correlation between this curve and the first 10 years of the original series.



(a) (b) (c)

**Fig. 2** Wavelets-mother. (a) Morlet, (b) Paul and (c) Derivative of Gaussian (DOG).

This correlation gives a measure of the projection of this wave package on the data during the period; that is, how much [amplitude] does the 10-year resemble a Sine wave of this width [frequency]. By sliding this wavelet along the time series, a new time series of the projection amplitude versus time can be constructed. Finally, the scale of the wavelet can be varied by changing its width. In addition to the amplitude of any periodic signals, it is worth to get information on the phase. In practice, the Morlet wavelet, for example, shown in **Fig. 2a**, is defined as the product of a complex exponential wave and a Gaussian envelope:

$$\Psi_O(\eta) = \pi^{-1/4} e^{i\omega_o \eta} e^{-\eta^2/2} \qquad (1)$$

where $\psi_0(\eta)$ is the value at nondimensional time $\eta$; $\omega_0$ is the nondimensional frequency, equal to 6 in this study in order to satisfy an admissibility condition; i.e., the function must have zero mean and be localized in both time and frequency space to be "admissible" as a wavelet. This is the basic wavelet function, but some artifice will be now needed to some way change the overall size as well as slide the entire wavelet along in time. Thus, the "scaled wavelets" are defined as:

$$\Psi\left[\frac{(n'-n)\delta t}{s}\right] = \left(\frac{\delta t}{s}\right)^{1/2} \Psi_0\left[\frac{(n'-n)\delta t}{s}\right] \qquad (2)$$

where $s$ is the "dilation" parameter used to change the scale, and $n$ is the translation parameter used to slide in time. The factor of $s^{-1/2}$ is a normalization to keep the total energy of the scaled wavelet constant. We are given a time series $X$, with values of $x_n$, at time index $n$, where each value is separate in time by a constant time interval $\delta t$. The wavelet transform $W_n(s)$ is just the inner product (or convolution) of the wavelet function with the original time series:

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \Psi^*\left[\frac{(n'-n)\delta t}{s}\right] \qquad (3)$$

where the asterisk (*) denotes complex conjugate. This integral can be evaluated for various values of the scale $s$ (usually taken to be multiples of the lowest possible frequency), as well as all values of $n$ between the start and end dates.

### Rippl method

The Rippl method estimates the required capacity for a reservoir to regulate the average water supply, based on knowledge of the historical rainfall series. Even some limitations are detected in this method, even today, after more than a century, it has many supporters. According to McMachon (1993), the Rippl method is easy to use, and considers the seasonality and other factors.

## RESULTS

### Wavelet power spectrum

**Figures 3a** and **4a** show the monthly rainfall in João Pessoa city and **Figs 3b** and **4b** show the wavelet power spectra that represent the absolute value squared of the wavelet transform. This value gives information on the relative power at a certain scale and a certain time. These figures show the actual oscillations of the individual wavelets, rather than just their magnitude. For example, the concentration of the power in the frequency or time domains can be identified.

These figures also present a cross-hatched region which is the cone of influence, where zero padding has reduced the variance, since we are dealing with finite-length time series. The peaks within these regions have presumably been reduced in magnitude due to the zero padding. The black contours in the same **Figs 3c, 3d, 4c** and **4d** are the 10% significance level, using a red-noise background spectrum. If a peak in the wavelet power spectrum is significantly above this background spectrum, then it can be assumed to be a true feature with a certain percent confidence. For definitions, "significant at the 10% level" is equivalent to "the 90% confidence level", and implies a test against a certain background level, while the "90% confidence interval" refers to the range of confidence about a given value. The 90% confidence implies that 10% of the wavelet power should be above this level. The power spectra had shown clearly the existing concentrations in some bands, disclosing that the annual regularity was the frequency that was remained all permanent in the analyzed period. A regularity of four years also was observed from the decade of 60, as well as from the decade of 90.

### Global wavelet spectrum

**Figures 3c** and **4c** represents the global wavelet spectra that provide an unbiased and consistent estimation of the true power spectra of the time series, and thus it is a simple and robust way to characterize the time series variability. These spectra are obtained by the integration of the wavelet power spectra over time. These global spectra show that the studied time series have an annual regularity, which is a true signal feature (peaks above of the red line) for the 90% confidence level. Implying that exists in João Pessoa city a rainy station per year.

### Scale-average time series

The scale-average wavelet power (**Figs 3d** and **4d**) is a time series of the average variance in a certain band; it is used to examine modulation of one time series by another, or modulation of one frequency by another within the same time series, showing the behavior of each year for the studied series. These figures are made respectively by the average of **Figs 3b** and **4b** over all scales between 8 and 16 months, which give a measure of the average year variance versus time. This 8–16-month band was chosen to portrait all year in the studied series. The important reductions of the power within the band represent the dry periods, and the opposite represents the rainy periods. The rainy periods are identified as 1939–1942, 1944–1946, 1948–1952, 1954–1956, the year of 1960, 1963–1970, 1984–1987, 1988–1991 and 1993–1996, in accordance to the significance test of 10%.

### Reservoir sizing analysis

The value assumed for the demand of drinking water per capita per day was 250 L/person per day, of which 48% is earmarked for less noble purposes, which results in a value of 120 L/person per day for this purpose. Multiplying this value by the number of days in the month and average number of inhabitants per household, it is possible to compute the non-potable demand of each month, which resulted in 14.40 $m^3$. For this calculation, it was considered that each month has 30 days and the average number of inhabitants in each household is equal to 4. The volume of the reservoir by the Rippl method, using the average rainfall, was 46.31 $m^3$, which corresponds to 96 days of supply during the dry season. **Table 1** shows the Rippl method using the monthly mean rainfall.

## CONCLUSIONS

Since there are a great number of rainy periods in João Pessoa city, it is evident that the use of rainwater in condominiums for non-potable uses is viable. This affirmation was obtained based on the rainfall frequency analysis using a new and robust mathematical tool, wavelet transform, from which the characteristics of the signal frequency components could be identified and analyzed, without losing the time localization of the main events. The power spectra had shown clearly the existing concentrations in some bands, revealing that the annual regularity was the frequency that was remained all permanent in the analyzed period. Although, a regular four-year event was observed in 60th's, as well as for the decade of 90.

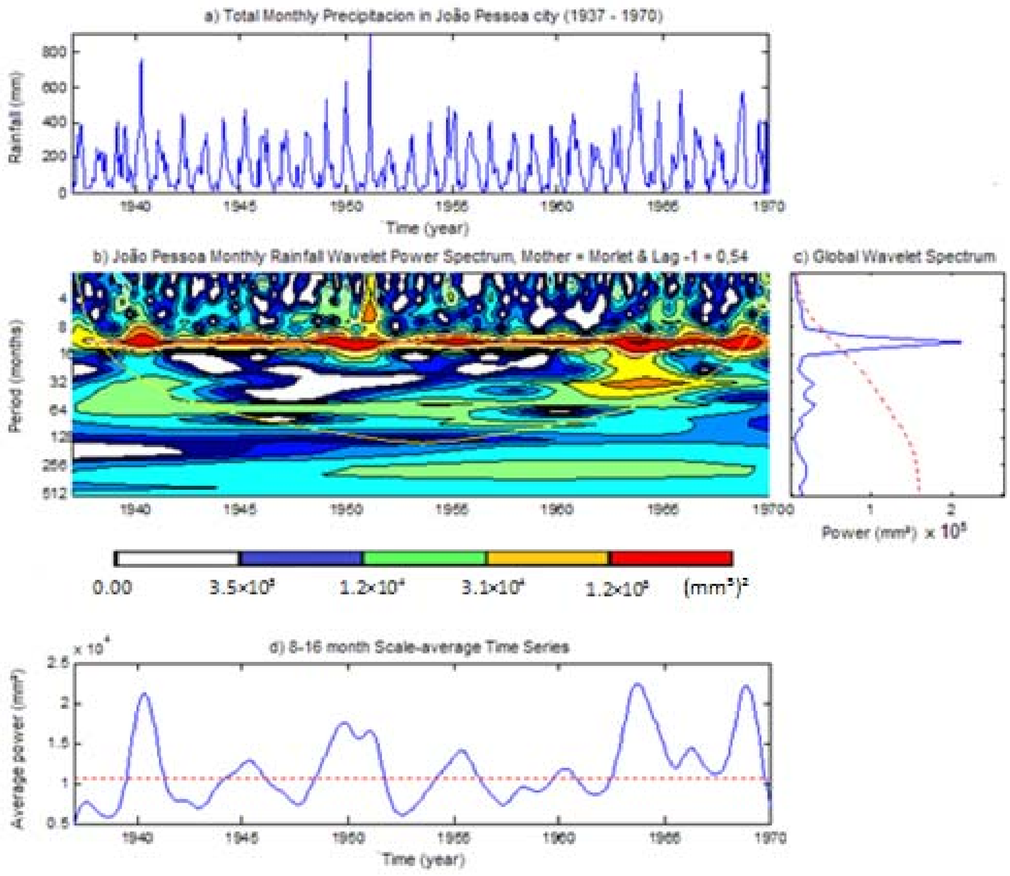


**Fig. 3** (a) Total monthly precipitation in João Pessoa city. (b) Normalized wavelet power spectrum using Morlet wavelet. (c) Global wavelet power spectrum. (d) Scale-average time series of the 8–16-month band. The red lines in (c) and (d) are the 90% confidence level red noise $\alpha = 0.54$.

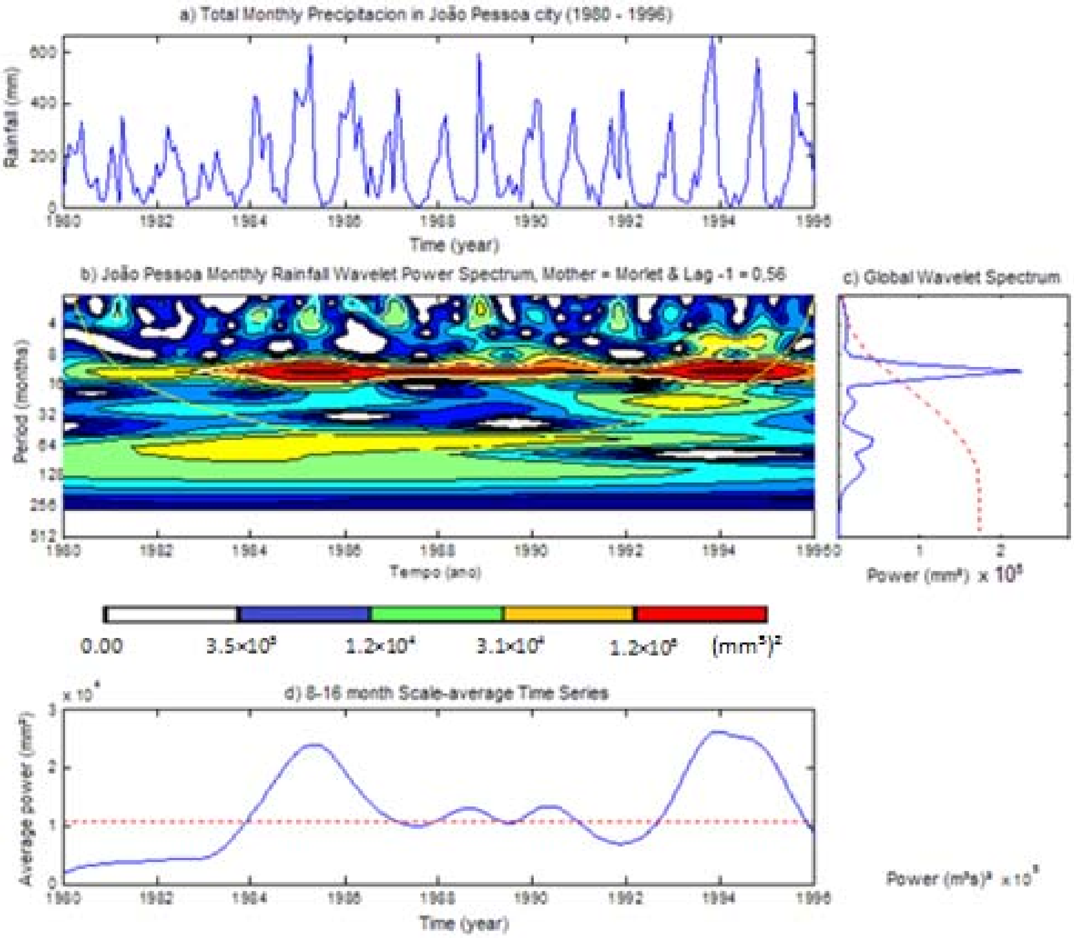


**Fig. 4** (a) Total monthly precipitation in João Pessoa city. (b) Normalized wavelet power spectrum using Morlet wavelet. (c) Global wavelet power spectrum. (d) Scale-average time series of the 8–16-month band. The red lines in (c) and (d) are the 90% confidence level red noise α = 0.56.

**Table 1.** Rippl method using average precipitation

| Months | Precipitation (mm) | Capture Area ($m^2$) | Monthly Rain Volume ($m^3$) | Non-potable Demand ($m^3$) | Differences between precipitation and demand volumes ($m^3$) | Cumulative Difference in Column 6 ($m^3$) |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Sep | 66.18 | 150 | 7.94 | 14.4 | -6.46 | -6.46 |
| Oct | 25.05 | 150 | 3.01 | 14.4 | -11.39 | -17.85 |
| Nov | 27.38 | 150 | 3.29 | 14.4 | -11.11 | -28.97 |
| Dec | 37.77 | 150 | 4.53 | 14.4 | -9.87 | -38.83 |
| Jan | 83.83 | 150 | 10.06 | 14.4 | -4.34 | -43.17 |
| Feb | 93.87 | 150 | 11.26 | 14.4 | -3.14 | **-46.31** |
| Mar | 197.33 | 150 | 23.68 | 14.4 | 9.28 | |
| April | 246.67 | 150 | 29.60 | 14.4 | 15.20 | |
| May | 286.22 | 150 | 34.35 | 14.4 | 19.95 | |
| June | 320.84 | 150 | 38.50 | 14.4 | 24.10 | |
| July | 235.64 | 150 | 28.28 | 14.4 | 13.88 | |
| Aug | 137.14 | 150 | 16.46 | 14.4 | 2.06 | |

However, the analysis through the global wavelet spectrum revealed that only the annual frequency is a true feature of the signal with 90% confidence level. Finally, through the separate analysis of the 8–16-month band it was possible to precisely identify some rainy periods, when the systems of rainwater harvesting must be used, which must use the principle to collect and store to supply condominium dweller during the dry season. This practice would contribute for the reduction of clean water consumption since the rainwater could be used for non-potable uses even during the rainy seasons. The reservoir of rainwater is an item that can harm the system as a whole, because its poor design can endear the system and should be taken into account the local rainfall, the area of collection and demand. In order to supply water for non-potable uses in the condominium, a reservoir of 46.31 m³ is proposed based on the Rippl method which dimensions could be 4 × 4 × 2.9 m.

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## REFERENCES

Farge, M. (1992) Wavelet transforms and their applications to turbulence. *Ann. Rev. Fluid Mech.* **24**, 395–457.

Graps, A. (1995) An introduction to wavelets. *IEEE Comp. Sci. Engng.* **2**(2), 50–61.

Grossman, A.; Morlet, J. (1984) Decomposition of Hardy functions into square integrable wavelets of constant shape. *SIAM J. Math. Anal.* **15**, 723–736.

IBGE – Instituto Brasileiro de Geografia e Estatística. Available at: <http://www.ibge.gov.br>. Accessed in: 20 March 2010.

McMachon, T.A. *Hydrology design for water use*. In Handbook of Hydrology, David Maidment, 1993.

Santos, C.A.G. & Ideião, S.M.A. (2006) Application of the wavelet transform for analysis of precipitation and runoff time series. *IAHS Publ.* **303**, 431–439.

Santos, C.A.G., Galvão, C.O. & Trigo, R.M. (2003) Rainfall data analysis using wavelet transform. *IAHS Publ.* **278**, 195–201.

Santos, C.A.G.; Galvão, C.O.; Suzuki, K.; Trigo, R.M. (2001) Matsuyama city rainfall data analysis using wavelet transform. *Ann. J. Hydraul. Engng., JSCE* **45**, 211–216.