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Characteristics of the precipitation and rainwater harvesting for non-potable purposes in Itajubá, MG

This work presents a study of precipitation characteristics for the city of Itajubá, MG, as well as an analysis of the viability of implantation of rainwater harvesting systems in residences. Comparisons were made between different precipitation series, being the National Water Agency (NWA) the series that presented better performance and thatwas used for simulations with different scenarios in the Netuno software. It was found that the catchment area is the most important variable with regard to higher economic potential when compared to the reservoir volume. It was also possible to show the economic potentials of potable water for each rainwater reservoir volume in various scenarios, including the green roof, which is anexcellent tool in the search for new technologies in favor of the reduction of environmental, social and economic impactsin civil construction, although in terms of water reuse this is inferior to the conventional roof. Therefore, the results obtained in this work can have important implications in studies of rainwater harvesting in residences in the city of Itajubá and, even, in cities with similar precipitation characteristics.

Keywords: Sustainability; Rainwater; Reuse; Reservoir; Green Roof.

Características da precipitação e aproveitamento de água pluvial para fins não potáveis em Itajubá, MG

Este trabalho apresenta um estudo das características de precipitação para o município de Itajubá, MG, assim como uma análise da viabilidade de implantação de sistemas de aproveitamento de água pluvial em residências. Foram realizadas comparações entre diferentes séries de precipitação, sendo que a série da Agência Nacional de Águas (ANA) apresentou melhor desempenho e foi utilizada para as simulações com diferentes cenários no software Netuno. Foi encontrado que a area de captação é a variável mais importante no que se refere ao maior potencial de economia quando comparado ao volume do reservatório. Também foi possível mostrar os potenciais de economia de água potável para cada volume de reservatório de água pluvial em diversos cenários, incluindo o telhado verde que é uma excelente ferramenta na busca de novas tecnologias a favor da redução dos impactos ambiental, social e econômico na construção civil, embora no quesito de aproveitamento de água este seja inferior ao telhado convencional. Portanto, os resultados obtidos neste trabalho podem ter implicações importantes em estudos de aproveitamento de água pluvial em residências na cidade de Itajubá e, até mesmo, em cidades com características semelhantes de precipitação.

Palavras-chave: Sustentabilidade; Água pluvial; Aproveitamento; Reservatório; Telhado verde.

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INTRODUCTION

Due to the growing demand and recurrent problems of water scarcity lived inBrazil in the last years, one of the present challenges of this country is the management of water resources that exist, privileging the adequate use of potable water. Althoughfresh water can be found in abundance on the planet, in some parts of the world the water resources can become scarce, and due to the accelerated increase on demand, the supply of this watercanbea huge problem.

According to May (2003), the reduction of this resource in several brazilian regions has been provoked by the unbalance between demographic, industrial and agricultural distributions, as well as waterdistribution. In this context, the southeast region of Brazil experienced in 2014 and early 2015 anexpressive deficit of precipitation (COELHO et al., 2015), causing a large impact in theavailability of water for public consumption, in the generation of electricity and in agriculture.

The Cantareira system, for example, which is destined forcatchment and treatment of water for São Paulo city, being one of the largest of the world, was in January of 2015 with 5% of the level of its storage capacity. This situation led the local government to install a pumping system capable of extracting water from deep reservoirlevels, to attenuate the deficit for human consumption (PORTO et al., 2014).

Taking into account the impacts generated by this major drought event, Coelho et al. (2015) performed a diagnosis of the precipitation conditions observed along a certain area of the southeast region of Brazil, including the city of Itajubá. It is worth mentioning that the rainy season in this region is influenced by the south american monsoon system (SAMS), in other words, the annual precipitation cycle is well defined, with rainy summer and dry winter (ZHOU et al., 1998; VERA et al., 2006), being the historical mean of precipitation for summer and winter seasons of 236.9 mm and 55.6 mm, respectively.

Thus, according to Coelho et al. (2015), it was observed a negative deficit of precipitation of 95.5 mm, 137.0 mm, 143.6 mm, and 106.8 mm for the months of december of 2013 and january, february and march of 2014, respectively, in the studiedregion. With this, the management of the existing water resources and reuse of rainwater integrate some of the current practices to preserve potable water, administering the rational use of water stocks, forcing the search for new technologies and privileging appropriate use of noble water.

The rainwaterharvestingsystem can be adopted for residential, commercial, industrial and agricultural purposes. In the case of residential use, the most common ones are found in toilet flush, vehicle washes, garden irrigation and firefighting systems. In industries, the rainwater can be used for cooling, industrial cleaning, vehicle washing and, in agriculture, its use is in irrigation. According to Calheiros et al. (2014), the rainwater harvesting is one of the measures that can contribute to retard the peak effect of the precipitations in the urban drainage system and contribute to the increase between flood intervals, besides needing low investment to the conditioning and use of rainwater.This system uses as surface the conventional and green roofs, also called of "Green Roof" or "Gründächer", which are still more applied in countries of germanic language of thecentral europe andhas been spreadingthrough the northern and northwestern of europe and in northern of america. In Brazil it is better known in states of the southern region of the country (WILLES, 2014).

Green roofs are structures that are characterized by the application of vegetation cover over buildings and must receive adequate treatment regarding their waterproofing, roots, drainage and other measures that become necessary according to the inclination of the roof, favoring this way their effectiveness. According to Ohnuma Junior et al. (2014), the application of green roofs in urban areas, in addition tooffering better thermal and environmental conditions, slows the surface runoff in drainage.

The reservoir dimensioning is one of the most relevant steps in the design of a rainwater harvesting system, since it is a high unit cost item and, consequently, determinant in the obtainment of the economic viability. According to item 4.3.5 of the NBR 15527 (2007), the reservoir volume must be dimensioned according to technical, economic and environmental criteria, with the possibility to use already standardized or other methods, as long as they are properly justified (MURÇA et al., 2014).

According to Gomes et al. (2010), the analysis of the relationship between the volume of the reservoir and the treated water consumption presents an asymptotic behavior in relation to the treated water consumption. As the reservoir volume increases, the treated water consumption tends to a minimum value different from zero, considerably defined by the water availability (rainfall regime) of the study location, independently of the reservoir size.

For the simulations executed in this work, the Netuno computer program was used, whose algorithm was validated by Rocha (2009), which is a software created to evaluate the potable water savings potential and the reservoirs dimensioning for use in edifications.

Duarte et al. (2010), as well as Rupp et al. (2011), performed a comparative study of the methods suggested by the NBR 15527 (2007) and the method used by the Netuno software (GHISI et al., 2009) for the dimensioning of the rainwater storage reservoir volume, demonstrating that the method used in the software presented the most satisfactory results, even for different rain regimes, percentages of water substitution as well as a wide variety of catchment areas.

Therefore, this work highlights the importance of reducing the consumption of potable water, being the reuse of rainwateran important practice in the search for water sustainability, and that can also generate savings for the consumer.

MATERIALS AND METHODS

The city of Itajubá has the coordinates 22° 25' 33" S and 45° 27' 10" O and is located in the state of Minas Gerais in the southeastern region of Brazil and, due to its location, has the characteristic of an annual cycle of precipitation, with cold and dry winter and hot and rainy summer, being part of the south american monsoon system (GARCIA et al., 2009; GARCIA et al., 2013; GARCIA et al., 2016a; SANTOS et al., 2016).

The precipitation data used in this work are from three different sources: Global Precipitation

Climatology Project (GPCP)[1], Data Collection Platform (DCP) of the National Institute of Space Research of Brazil (NISR) and National Water Agency of Brazil (NWA). Carvalho et al. (2012) compared different gridded precipitation data in theperiod of 1998-2008, being the GPCPone of them, and they observed that the large-scale patterns associated to the SAMS are well represented by all of the datasets, as well as the intraseasonal variability of precipitation.

The GPCP data have a horizontal resolution of 2.5º x 2.5º and are available as average monthly precipitation rates (in mm/day) for the period of 1979-2014. Once that the data are found gridded, the grid points closest to the location of the city of Itajubá are selected. Thus, the longitude of 44ºO was selected, but in the case of latitude, were available the grid points of 23.75ºS and 21.25ºS. Through a previous analysis (not shown), it was found that the average precipitation value of the two locations is representative of the precipitation in the region.

Observed precipitation data collected from the DCPof NIRS are also used. These data belong to the period from april 1998 to december 2014 and are provided every three hours. The data collected fromNWA are also used. For the work, it is used the last daily measurement time (21:00). The available periodin the historical meanis from 1966 to 2015, being that from 1966 to 1999 the data are consisted, and from 2000 to 2015 the data are raw. As the precipitation data to be inserted in the Netuno software cannot contain discontinuities, since that, ifthere is, it assumes that there was no precipitation, the daily rainfall climatology of the period of the consisted data is calculated and, then, the missing data throughout the period are replaced by the values referent to the climatology. The period used for this data in the present work is from 1986 to 2015. The main information from the NWA collection station can be seen in Table 1.

Table 1: Information from the NWA collection station.

Rain Gauge Station Name	São João de Itajubá
Rain Gauge Station Code	2245083(Paraná)
DENAEE Watershed	Rio Grande River
Collection Type	Conventional
Federation Unit	MG
City	Itajubá
Watershed	Paraná River

The comparison between the different data series is made through the complete series (analysis not shown) and climatological series of these sources for the common period of availability of them (1998 to 2014), with regard to the magnitude and respective annual cycles. It is worth mentioning that this comparison is important and is based on the choice of the precipitation data that will be used as input data for the Netuno software.

The input data for the Netuno software that are necessary to perform the simulations are: precipitation data, number of records and initial date of the precipitation series, discard of the initial runoff (mm), catchment area, total water demand, number of residents, percentage of total demand to be replaced by rainwater, surface runoff coefficient, upper and lower reservoirs. The average number of residents per individual residence in Itajubá according to the Brazilian Institute of Engineering and Statistics (BIES) census

[1] http://www.esrl.noaa.gov/psd/data/gridded/data.gpcp.html

of 2010is of 3.25, obtained from the division of the urban population (90,658) by the number of permanent private households (27,909).

In the test simulations, the average number of residents adopted is of 3 and in the scenarios, 2 and 4. According to Table 2, it is observed that the amount of treated water that can be replaced by rainwater, in a typical residence in Itajubá is of 7331 liters/month. The total water demand is of 166.3 liters/per day/per person, according to the table of information and indicators consolidated by the national sanitation information system of Brazil (NSIS) indicators for the locality of Itajubá. It is obtained the percentage of total water demand that can be replaced by rainwater, through the ratio between total monthly consumption, by the consumption that can be replaced as follows: 166.3 x 3 = 498.9 liters per day, which results in a monthly consumption of 498.9 x 30 = 14967 liters per month, so 7331/14967 = 0.4889 = 48.98% is the percentage that can be replaced. Therefore, the value of 50% is adopted for the simulations of test and scenario.

Table 2: Engineering parameters for estimation of residential demand of non-potable water.

Consumption	Calculation	Result (liters)
Toilet Use: Internal	(3people)x(5 flushes)x(9 liters)x(1.09 leaks)x30 days	4415
Car wash Use: External	(1car)x(4times/month)x(150 liters/wash)	600
Floor washing Use: External	(15 min)x(4times/month)x(18.6 liters/min)	1116
Lawn/garden Use: External	(2liters/day/m²)x (12 days) x (50m²)	1200
Total		7331(Liters/Month)

The flow coefficient used for conventional roofs is 0.9 and in the case of the green roof, the value used is 0.27. According to Köhler et al. (2001), approximately 75% of the annual precipitation can be stored on the green roof, being this value close to the value obtained by Khan (2001, citado por TOMAZ, 2005) where it was calculated the mean value of surface runoff coefficient equal to 0.27. Thus, test simulations are performed with the Netuno software using the three series (GPCP, DCP and NWA) for the year 2003 (year with fewer failures in all series) and for the climatology of the period of 1998-2014.

Table 3: Scenario for the reservoirs dimensioning.

Number of scenarios	Initial Discard (mm)	Catchment Area (m²)	Total water demand (liter/person/day)	Number of residents	Replacement of potable water for rainwater (%)	Flow Coefficient
1	2	100	166.3	2	50	0.9
2	2	100	166.3	4	50	0.9
3	2	150	166.3	2	50	0.9
4	2	150	166.3	4	50	0.9
5	0	100	166.3	2	50	0.27
6	0	100	166.3	4	50	0.27
7	0	150	166.3	2	50	0.27
8	0	150	166.3	4	50	0.27

In this test simulation, all of the other data necessary for the Netuno software calculated according to the BIES and NSIS bases, and tables adapted from Tomaz (2009) for the city of Itajubá are kept fixed, varying only the precipitation data, to highlight the differences between the bases and to choose the most representative series. After the initial simulation for choosing the series, simulations are carried out for the several scenarios for the city of Itajubá,beingkept fixed the precipitation data and the daily demand and varying the number of residents, flow coefficient and catchment area, as shown in Table 3. Scenarios from 1 to 4 represent a catchment in conventional roof and scenarios from 5 to 8 for catchment with green roofs. The variables: catchment area and number of residents representtypical values around thosealready presentedfor the city of Itajubá.

RESULTS AND DISCUSSION

Figure 1 shows the annual precipitation cycle referring to the GPCP, DCP and NWA data. As it can be noted, the highest precipitation values occur in the summer and the lowest values occur in the winter, which is consistent with the characteristic of rainy summer and dry winter of the NSIS regions (ZHOU et al., 1998; VERA et al., 2006; GARCIA et al., 2009; GARCIA et al., 2011; GARCIA et al., 2013; GARCIA et al., 2015; SANTOS et al., 2016; GARCIA et al. 2016a; GARCIA et al., 2016b).

Thus, in terms of magnitude, the climatologies of the series analyzed for the common period from 1998 to 2014 are very similar, being the DCP and NWA series closer to each other. Although the precipitation values of the GPCP series are slightly overestimated, the behavior of the annual cycle is maintained when compared to the observed series (Figure 1). The highest climatological values are between 240 and 260 mm/day in january and the lowest around 30 and 40 mm/day in the month of august.

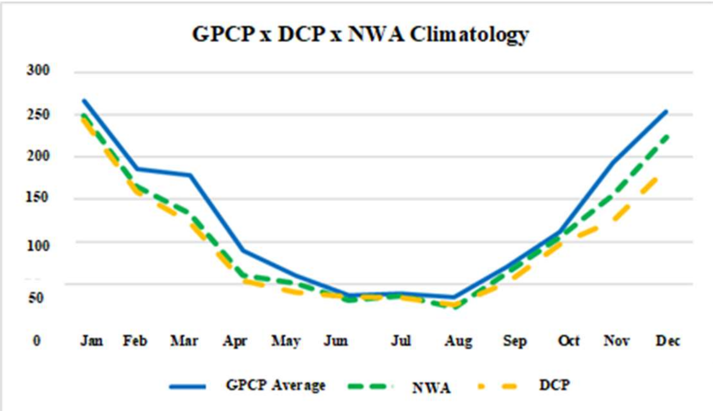

Figure 1: Monthly climatology from the GPCP, DCP and NWAdata for the period of 1998-2014.

Then, the three-precipitation series are used in the simulation of the Netuno software to verification and analysisof the differences of the simulations in the three cases for the year of 2003 and for the period from january of 1998 to december of 2014. The values used for filling of the input variables of the software for the simulation, as presented in the materials and methods section, are the values that represent a typical residence of the city of Itajubá. They are: catchment area of 100 m^2, total water demand of 166.3 liters per capita/day, number of residents equal to 3, percentage of the total demand to be replaced by rainwater of 50%, surface runoff coefficient of 0.9 (ceramic tiles), a maximum volume of 20,000 liters, interval between volumes of 250 liters and the difference between the potable water savings potentialthrough rainwater harvesting equal to 1.5%/m^2 used to indicate the ideal volume of the lower reservoir.

Figure 2 illustrates the result of the test simulationsdescribed previously for the behavior of the potable water savingspotential as a function of the size of the lower reservoir adopted, where it can be observed that the final behavior of the curves is similar for the three series, however the initial behaviour for the GPCP series demonstrates an overestimation when compared to the other data.

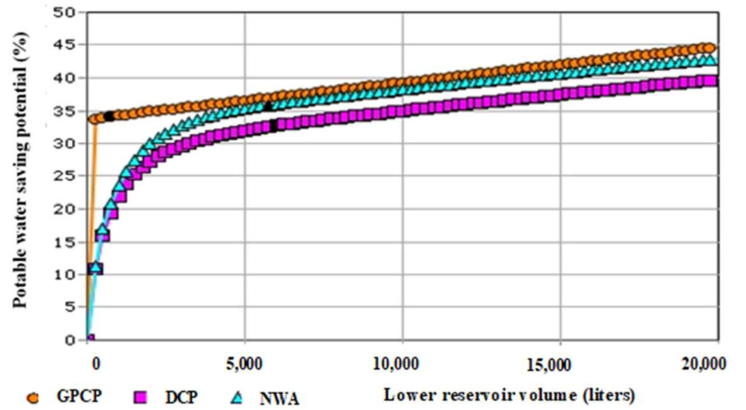

Figure 2: Potable water savingspotential as a function of the volume of the lower reservoir (liters), for the GPCP, DCP and NWA series in the period of 1998-2014.

For the test simulations, the following values are obtained for thesavingspotential: 45%, 40% and 44% for reservoirs with capacity of less than20,000 liters for GPCP, DCP and NWA, respectively. Considering the criterion of variation in the savings potential of less than 1.5%/m³, the values of the lower reservoir ideal volume are very different, being of 750 liters, 6,000 liters and 5,750 liters, allowing a savings potentialof 33.97%, 32.71% and 35.82%, respectively.

It is worth mentioning that the result for the indication of the ideal volume of a reservoir is based on the percentage variation of the savings potential, from a point where the savings potential does not vary more than a percentage. Since the savings potential curves as a function of the reservoir volume depend on several variables, the behavior of this result presents a non-linear variation, for the same pluviometric series.

This can be observed in Table 4, which presents a summary with the results of the lower reservoir ideal volume with its respective savings potentialfor each of the different precipitation series used in the simulations. Similar results to those obtained using the Netuno software, can be observed in the works of Campisano et al. (2012) and Martínez et al. (2014), who developed and implemented algorithms that apply behavioral methods to calculate the ideal volume of reservoirs for rainwater harvesting systems.

The initial behavior of the savings potentialas a function of the reservoir size is strongly influenced by the distribution of the daily rainfall of the series. As the distribution of the GPCP was uniform within each month and considering that the monthly value is divided by 30, the variable already reaches permanent regime value more quickly than the other series with observed daily data.

Table 4: Summary of the test simulations results with the precipitation series.

Series	Lower reservoir	Savings potential	Demand Attended		Not attended		Partial		Rainwater consumption
1998-2014	Liters	%	%	days	%	days	%	days	Liters/day
GPCP	20000	44.71	86.6	316.09	9.8	35.77	3.6	13.14	223.1
	750	34.11	58.9	214.98	29.5	107.67	11.6	42.34	170.2
DCP	20000	39.92	79.2	289.08	19.6	71.54	1.2	4.38	199.2
	6000	32.98	64.7	236.15	33.1	120.81	2.2	8.03	164.5
NWA	20000	43.14	85.4	311.71	13.1	47.81	1.5	5.47	215.3
	5750	36.09	70.6	257.69	26.4	9.36	3	10.95	180.05

Regarding the consumption of rainwater, all of the series tend to a value close to 200 liters/day, however the initial behavior, for lower reservoirs with smaller values than 2,000 liters, is distinct for the GPCP data series, what reflects in the indication of the ideal reservoir. For the GPCP series the result found was of 1,000 liters, enabling a daily consumption of rainwater of 170 liters.

For DCP and NWA, the daily consumption is of 160 liters and 170 liters, respectively, however the ideal reservoir was stipulated as over 5000 liters for both. About the percentage of the rainwaterattendance as a function of the lower reservoir volume, the GPCP tends to a percentage of complete attendance of 90% when considered a lower reservoir of 20,000 liters.

The unattended parcel is close to 10% and the partial attendance tends to zero. For the DCP series (NWA) the percentage of complete attendance reaches 80% (85%) considering a reservoir of 20,000 liters, while the unattended parcel approaches 20% (15%) and the partial attendance also tends to zero for both.

For the ideal reservoirs indicated through the variation of the savings potentialless than 1.5%/m^3 the percentage of total attendance is of 60% for GPCP, 63% for the DCP and 70% for the NWA, already the percentage of partialattendance is of 10%, 2% and 4% respectively. For the GPCP series, the percentage of non-attendance is close to 30% for lower reservoirs with volume of 1,000 liters, while for the series observed (NWA and DCP) this percentage of non-attendance for the ideal volume of the indicated lower reservoir is of 35% and 26% respectively.

The overflowed volume as a function of the lower reservoir capacity presents values of 120 liters for the GPCP series considering a lower reservoir of 20,000 liters, 80 liters for the DCP data in the same conditions and close to 100 liters for the NWA series. The highest discard in the series correspondent to the GPCP model indicates an overestimation of the rainfall volume, compared to the other series that contain observed data.

Thus, through the analysis of the results for the three different precipitation series for the city of Itajubá, it can be concluded that the corresponding series to the GPCP, besides overestimating the precipitation values, it is observed that, since it is a monthly rate, when used as a daily input data for the Netuno program, it makes the precipitation to be uniform in all of the days of the month, which directly impacts in the results.

Although the results for the observed DCP and NWA series present a very similar format, for the four variables analyzed, it is found that the NWA series is longer and more complete, with fewer failures.With this, it will be used for the simulations of the different scenarios in the Netuno software, varying now thesoftware input coefficients and keeping fixed the rain data series. Figure 3 shows the curves of potable water savings potentialas a function of the reservoir volume. They show an asymptotic behavior as the reservoir sizeincreases, for the eight scenarios used in this work. In Figure 3, it can be noted the asymptotic tendency of the savings potentialcurves as the reservoir volume increases.The points in it indicate the ideal volume for each of the scenarios, as presented numerically in Tables 5 and 6. Considering the tendency of the savings potential graphs, it can be noted that they will reach a limit due to the quantity of rainwater available along the months of the year, contradicting the idea that the larger is the chosen reservoir, the greater will be the savings potential obtained. Since the reservoir is the item that most impacts economically on a rainwaterharvesting system, minimizing this volume represents minimizing the cost of implementationof the system as a whole (RUPP et al., 2011).

It can be noted that this is possible because, as the curves show, in some cases practically there is no more positive variation in the savings potential by increasing the size of the reservoir. The tendency of stabilization of the savings potential curves as a function of the reservoir reflects directly in the indication of the reservoirs ideal volume numerically indicated in Tables 5 and 6, which show the results of the scenarios simulations used in this work.

Table 5 shows a summary of the results of the scenario simulations, for the conventional roof, with the following variables: surface runoff coefficient = 0.9; potable water demand = 166.3 liters/day; precipitation discard = 2 mm and replacement percentage = 50%. Table 6 also presents a summary of the results of the scenarios simulations with the same variables of Table 5, except for the surface runoff coefficient which is of 0.27 and for the discard of precipitation, which is of0 mm, since that, in this case, it is for the green roof. An interesting fact to be observed is that ifincreasing only the number of residentes and maintaining the other variables unchanged, the ideal reservoir volume tends to decrease, as it can be seen in Tables 5 and 6, indicating that the quantity of rainwater available is not sufficient to maintain a larger reservoir complete along the year, due to the increase in the consumption.

Table 5: Summary of the simulations results for the scenarios involving conventional roof.

Number of simulations	Catchment area(m²)	Number of residents	Lower reservoir. Ideal volume	Potable water savings potential
1	100	2	11250	45.29
2	100	4	5500	31.72
3	150	2	8750	46.14
4	150	4	6000	35.8

Table 6: Summary of the simulations results for the scenarios involving green roof.

Number of simulations	Catchment area(m²)	Number of residents	Lower reservoir. Ideal volume	Potable water savings potential
5	100	2	3500	25.65
6	100	4	2000	13.83
7	150	2	4000	32.16
8	150	4	3000	19.62

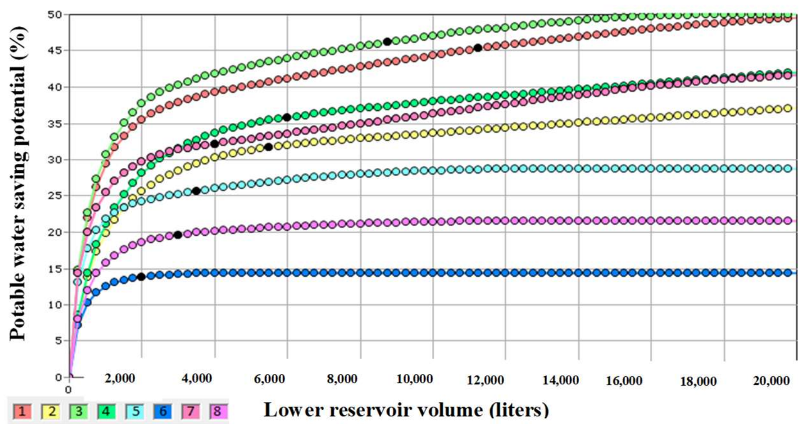

Figure 3: Potable water savings potential as a function of the lower reservoir volume (liters), for the eight scenarios used in this work.

The results previouslypresented consider the complete period of data availability for the execution of the simulations. However, it becomes interesting to analyze what results the software provides when anomalous of precipitation are considered, with rainfallabove and below the average, so that it can be verified how the reuse of this water will be in these extreme years.

Through analysis performed in the precipitation series, it can be noted that the extreme years of higher and lowerpluviometric density in the period of availability of the NWA data are, respectively, 1983 and 2014, with the accumulated annual rainfall values totalizing 2272.9 mm and 572.5 mm, respectively.

Using these conditions in a simulation in the Netuno software with the input data values corresponding to a typical residence, it is noted that the potable water savingspotential is strongly influenced by the quantity of rain available, as it can be observed in Figure 4 ,being that for the extreme of higherpluviometric density the demand for non-potable water is completely attendedthe whole year for lower reservoirs with capacity over 14,000 liters. Already for the extreme of lower pluviometric index, the savings potential stabilizes next to25% for lower reservoirs with capacity over 4,000 liters.

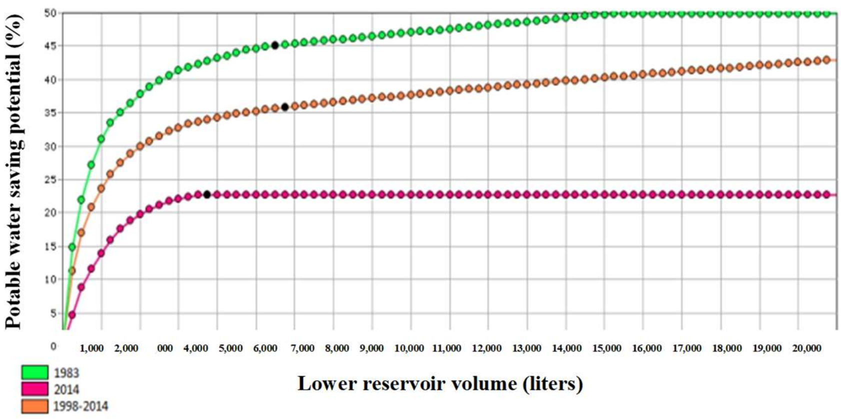

Figure 4: Potable water savings potential as a function of the volume of the lower reservoir (liters), for the extreme years of precipitation (1983 and 2014) and for the climatology from 1998 to 2014.

For the purpose of analysis and comparison, adopting a reservoir with a commercial volume of 10,000 liters in both cases, the savings potential would be of 47.57% (22.67%) for the year of 1983 (2014). This represents that, along the year, the demand of non-potable water of this residence would be completely attended in 346 (158) days, partially attended in 2 (15) days and not attended in 17 (192) days. In terms of average daily consumption, a 10,000 liter reservoir enables the replacement of 237.3 (113.12) liters/day of non-potable water. To the numerical summary that is presented in Table 7, a line was added with the values obtained using the climatology and being maintained fixed the other parameters.

Table 7: Summary of the simulations results for the scenarios involving green roof.

Year	Savings potential	Attended demand		Not attended demand		Partial demand		Rainwater consumption
	(%)	%	days	%	days	%	days	
1983	100	94.8	346	4.65	17	0.55	2	237.3
2014	150	43.29	158	52.6	192	4.11	15	113.2
1998-2014	150	75.18	274	22.4	82	2.41	8.8	190.8

CONCLUSIONS

Based on the study of the characteristics of the precipitation and rainwater harvesting for non-potable purposes in Itajubá - MG, it was possible to conclude that:

The corresponding series to the GPCP overestimated the precipitation values, when compared to the observed series and, as it has its presentation form with monthly values, which to be used in the Netuno program had to be transformed into daily values, resulted then, in a uniform rainfall distribution along the month, which does not correspond to the reality, impacting directly on the initial shape of the savings potential curve and underestimating the ideal reservoir value.

For the observed series, DCP and NWA, the results for this last showed better performance, in addition of this being longer and more complete, therefore being the one chosen for use in the scenarios. After defining the series used in the work, in this case, the NWA series, the other software input variables were characterized as demand, number of residents, percentage of potable water replacement, for conventional roofs and also green roofs.

With the variables characterized, the potable water savings potentialand the ideal reservoir capacity of were found through simulations. With regard to the most unfavorable scenario, there is the green roof, with the smallest catchment area (100 m^2) and the highest number of residents (4) with a replacement percentage of 50%, and, for a reservoir of 4000 liters, there is a savings potential of 14.38%. Although the use of rainwater harvesting is not better than in the conventional roof, there is an advantage with regard to the environmental aspect in the use of the green roof.

The increase in the catchment area causes a higher increase in the savings potential when compared to the increase of the reservoir volume. Thus, it is not justifiable to have a large reservoir if the catchment area does not have an adequate size. By opting between a larger reservoir or a larger catchment area, the larger catchment area must be choosen, which will provide for the same situation the greatest utilization and, consequently, the highest total cost savings.

For larger catchment areas, regardless of the reservoir volume, there is the greatest rainwater harvesting, indicating that the catchment area variable has higher influence in thecapacity of rainwater harvesting than the reservoir volume.

Therefore, this work contributes to the discussion referent to the preservation of existing water resources, highlighting that the rainwater harvesting system should be encouraged, considering that it is an important alternative measure for the preservation and management of these resources, benefiting the use of potable water in the future.

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REFERENCES

ABNT. Associação Brasileira de Normas Técnicas. **Nbr15.527**: Água de chuva: Aproveitamento de coberturas em áreas urbanas para fins não potáveis. Rio de Janeiro: ABNT, 2007.

CALHEIROS, H. C.; GOMES, M. R.; ESTRELLA, P. M. A.. Quality of meteoric water in the city of Itajubá, Minas Gerais, Brazil..**Ambiente e Água - An Interdisciplinary Journal of Applied Science**, Taubaté, v.9, n.2, p.336-346, 2014. **DOI:** http://doi.org/10.4136/ambi-agua.1329

CAMPISANO, A.; MODICA C.. Optimal sizing of storage tanks for domestic rain water harvesting in Sicily.**Resources, Conservation and Recycling**, v.63, p.9-16, 2012. **DOI:** http://doi.org/10.1016/j.resconrec.2012.03.007

CARVALHO, L. M. V.; JONES, C.; POSADAS, A. N. D.; QUIROZ, R.; BOOKHAGEN, B.; LIEBMANN, B.. Precipitation characteristics of the South American Monsoon System derived from multiple datasets. **Journal of Climate**, v.25, p.4600-4620, 2012.

COELHO, C. A. S.; CARDOSO, D. H. F.; FIRPO, M. A. F.. Precipitation diagnostics of an exceptionally dry event in São Paulo, Brazil. **Theoretical and Applied Climatology**, v.125, n.3, p.769-784, 2015. **DOI:** http://doi.org/10.1007/s00704-015-1540-9

DUARTE, J. M.; BLANCO, C. J. C.; CARDOSO, R. N. C.. Comparação de métodos para dimensionamento de reservatório de água da chuva: estudo de caso na Universidade Federal do Pará. In: SIMPÓSIO BRASILEIRO DE CAPTAÇÃO E MANEJO DE ÁGUA DE CHUVA, 10. **Anais.** Belém, 2010. p.1-6.

GARCIA, S. R.; KAYANO, M.T.. Determination of the onset dates of the rainy season in central Amazon with equatorially antisymmetric outgoing longwave radiation. **Theoretical and Applied Climatology**, v.97, p.361-372, 2009. **DOI:** http://doi.org/10.1007/s00704-008-0080-y

GARCIA, S. R.; KAYANO, M. T.. Moisture and heat budgets associated with the South American monsoon system and the Atlantic ITCZ. **International Journal of Climatology**, v.31, p.2154-2167, 2011. **DOI:** http://doi.org/10.1002/joc.2221

GARCIA, S. R.; KAYANO, M. T.. Some considerations on onset dates of the rainy season in Western-Central Brazil with antisymmetric outgoing longwave radiation relative to the equator. **International Journal of Climatology**, v.33, p.188-198, 2013. **DOI:** http://doi.org/10.1002/joc.3417

GARCIA, S. R.; KAYANO, M. T.. Multidecadal variability of moisture and heat budgets of the South American monsoon system. **TheorApplClimatol,** v.121, p.557-570, 2015. **DOI:** http://doi.org/10.1007/s00704-014-1265-1

GARCIA, S. R.; CALHEIROS, A. J. P.; KAYANO, M. T.. Revised method to detect the onset and demise dates of the rainy season in the South American Monsoon areas. **TheorApplClimatol,** v.126, p.481-491, 2016a. **DOI:** http://doi.org/10.1007/s00704-015-1599-3

GARCIA, S. R.; KAYANO, M. T.; CALHEIROS, A. J. P.; ANDREOLI, R. V.; SOUZA, R. A. F.. Moisture and heat budgets of the south American monsoon system: climatological aspects.. **TheorApplClimatol**, v.130, p.1-2, 2016b. **DOI:** http://doi.org/10.1007/s00704-015-1599-3

GHISI, E.; CORDOVA, M. M.; ROCHA, V. L.. **Netuno 4.0:** aproveitamento de água pluvial. Computer program, 2009.

GOMES, J.; WEBER, D. C.; DELONG, C. M.. Dimensionamento de Reservatórios de Armazenamento de Águas Pluviais, usando um Critério Financeiro.. **Revista Brasileira de Recursos Hídricos**, v.15, n.1, p.89-100, 2010.

KÖHLER, M.; SCHMIDT, M.; GRIMME, F. W.; LAAR, M.; GUSMÃO, F.. Technology ressource management & development - scientific contributions for sustainable development. In: IFLA (INTERNATIONAL FEDERATION OF LANDSCAPE ARCHITECTS) WORLD CONGRESS, 38. **Anais**. Singapore, 2001. p.151-162.

MARTÍNEZ, A. B.; ORTEGA, J. M. P.; RIVERA, F. N.; GONZÁLES, M. S.; MONTOYA, A. J. C.. Optimal design ofrainwatercollectin systems for domestic use into a residentialdevelopment. **Resources, Conservation and Recycling**, v.84, p.44-56, 2014. **DOI:** http://doi.org/10.1016/j.resconrec.2014.01.001

MAY, S.. “Prefácio”. In: TOMAZ, P.. **Aproveitamento de água de chuva**. São Paulo: Navegar Publisher, 2003. p.180.

MURÇA, M. C. R.; JULIO, M.; MORUZZI, R. B.. Metodologia de otimização para o dimensionamento de reservatórios de águas pluviais. **RBRH: Revista Brasileira de Recursos Hídricos,** v.19, n.2, p.29-40, 2014. **DOI:** http://doi.org/10.21168/rbrh.v19n2.p29-40

NETUNO. **Programa para Cálculo do Potencial de Economia de Água Tratada Utilizando Água de Chuva**. Energy Efficiency Laboratory (*LabEEE*). UFSC, 2004.

OHNUMA JUNIOR, A. A.; ALMEIDA NETO, P.; MEDIONDO, E. M.. Análise da Retenção Hídrica em Telhados Verdes a Partir da Eficiência do Coeficiente de Escoamento. **RBRH: Revista Brasileira de Recursos Hídricos**, v.19, n.2, p.41-52, 2014.

PORTO, R. L.; PORTO, M. F. A.; PALERMO, M.. A ressurreição do volume morto do Sistema Cantareira na Quaresma. **Revista DAE**, v.62, p.18-25, 2014.

ROCHA, V. L.. **Validação do algoritmo do Programa Netuno para a avaliação do potencial de economia de água potável e dimensionamento de reservatórios de sistemas de aproveitamento de água pluvial em edificações**. Dissertação (Mestrado em Engenharia Civil) - Universidade Federal de Santa Catarina, Florianópolis, 2009.

RUPP, R. F.; MUNARIM, U.; GHISI, E.. Comparação de métodos para dimensionamento de reservatórios de água pluvial. **Ambiente Construído**, Porto Alegre, v.11, n.4, p.47-64, 2011. **DOI:** http://doi.org/10.1590/S1678-86212011000400005

SANTOS, L.F.; GARCIA, S. R.. Início e Fim da Estação Chuvosa no estado de Minas Gerais: comparação de duas metodologias diferentes. **Revista Brasileira de Meteorologia**, v.31, p.92-104, 2016. **DOI:** http://doi.org/10.1590/0102-778620150017

TOMAZ, P.. **Aproveitamento de água de chuva para áreas urbanas e fins não potáveis**. 2 ed. São Paulo: Navegar Publisher, 2005.

TOMAZ, P.. **Aproveitamento de Água de Chuva:** para áreas urbanas e fins não potáveis. São Paulo: Navegar Publisher, 2009.

VERA, C.; HIGGINS, W.; AMADOR, J.; AMBRIZZI, T.;

GARREAUD, R.; GOCHIS, D.; LETTENMAIER, D. D.; MARENGO, J.; MECHOSO, C. R.; NOGUÉS-PAEGLE, J.; SILVA DIAS, P. L.; ZHANG, C.. Toward a unified view of the American Monsoon Systems. **Journal of Climate** - **Special Section**, v.19, n.20, p.4977-5000, 2006. **DOI:** http://doi.org/10.1175/JCLI3896.1

WILLES, J. A.. **Tecnologias em telhados verdes extensivos: meios de cultura, caracterização hidrológica e sustentabilidade do sistema**. Tese (Doutorado em Ciências) - Universidade de São Paulo, Piracicaba, 2014.

ZHOU, J. Y., LAU, K. M.. Does a monsoonclimateexist over South America? **J. Climate**, v.11, p.1020-1040 1998. **DOI**: http://doi.org/10.1175/1520-00442(1998)011<1020:DAMCEO>2.0.CO;2