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Rainfall and dew water harvesting for sanitary use on a metalurgy industry (Bom Jardim – RJ, Brazil)

Captação de água da chuva e orvalho para fins sanitários em uma indústria metalúrgica (Bom Jardim – RJ)

Aprovechamiento de agua de lluvia y rocío para fines sanitarios en una industria metalúrgica (Bom Jardim – RJ)

Elaide Dumingues
Engenheira Ambiental, Universidade Estácio de Sá, Brazil
evalledumingues@gmail.com

Anderson Mululo Sato
Professor Doutor UFF, Angra dos Reis
andersonsato@id.uff.br

Ricardo Finotti
Professor Doutor, Universidade Estácio de Sá
ricardo.leite@estacio.br

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RESUMO

Este estudo avalia um sistema de captação de água considerando seus aspectos sociais, econômicos e ecológicos. Para isso, construímos um protótipo que foi colocado no jardim da uma indústria metalúrgica, no município de Bom Jardim, estado do Rio de Janeiro, Brasil, que faz captação de água para fins sanitários. O protótipo possui as mesmas características do telhado industrial. A precipitação e o volume de escoamento foram medidos e a água também foi coletada em períodos em que não houve chuvas para avaliar a quantidade de condensação de água atmosférica coletada (água de orvalho). Um termo-higrômetro foi utilizado para registrar diariamente a umidade relativa do ar e a temperatura local. Realizamos um levantamento dos custos para construção de todo o sistema e aplicamos uma pesquisa aos funcionários do mesmo, para estimar a economia de água. Água da chuva foi coletada para analisar: turbidez, pH, nitrato, nitrito, ortofosfato, silicato, amônia, matéria orgânica, coliformes totais e *Escherichia coli*. A cobertura apresentou coeficiente de vazão médio de 88%, o que resultou para a área da cobertura (3.940m²) média de 28.354,04±44.674,86L. A captação de água por condensação atmosférica pode chegar a 2.469 litros por dia e está positivamente correlacionada com a temperatura mínima. O tempo de retorno dos investimentos em economia de água é de 10 anos. No entanto, dada a qualidade da água, este sistema poderia ser utilizado para outros fins, o que aumentaria a poupança de água e reduziria o tempo de retorno do investimento.

PALAVRAS-CHAVE: economia de água, condensação de orvalho, qualidade da água

SUMMARY

This study evaluates a Rain Water Harvesting (RWH) system considering its social, economic, and ecological aspects. We constructed a prototype at a metallurgical industry in Bom Jardim municipality, Rio de Janeiro state, Brazil, that uses rain water for sanitary purposes. The prototype has the same characteristics of the industry roof such as materials, positioning, and similar inclination. The rainfall and runoff volume were measured and water was also collected in periods when there was no rainfall to assess the amount of atmospheric water condensation collected (dew water). A thermo-hygrometer was used to note the local air relative humidity and temperature every day. We also conducted a survey on the costs to build the entire system and applied a survey to it employees, to estimate water savings. Collected rainwater was analyzed to the following parameters: turbidity, pH, nitrate, nitrite, orthophosphate, silicate, ammonia, organic matter, total coliform and E. coli. The roof had a mean flow coefficient of 88%, which resulted for the roof area (3,940m²) a mean of 28,354.04±44,674.86L. The uptake of water by atmospheric condensation can reach 2,469 liters on a day and it is positively correlated with the minimal temperature. The system payback time was estimated in 10 years. However, given the quality of the water, this system could be in use for other purposes, which would increase water savings and reduce the payback time.

KEYWORDS: water economy, dew condensation, water quality

RESUMEN

Este estudio evalúa un sistema de captación de agua considerando sus aspectos sociales, económicos y ecológicos. Para ello, construimos un prototipo que se colocó en el jardín de una industria metalúrgica, en el municipio de Bom Jardim, estado de Río de Janeiro, Brasil, que recolecta agua para fines sanitarios. El prototipo tiene las mismas características que la cubierta industrial. Se midieron las precipitaciones y el volumen de escorrentía y también se recogió agua en los periodos en los que no llovía para evaluar la cantidad de condensación de agua atmosférica recogida (agua de rocío). Se utilizó un termohigrómetro para registrar diariamente la humedad relativa del aire y la temperatura local. Realizamos una encuesta de los costos de construcción de todo el sistema y administramos una encuesta a los empleados para estimar el ahorro de agua. Se recolectó agua de lluvia para analizar: turbidez, pH, nitrato, nitrito, ortofosfato, silicato, amoníaco, materia orgánica, coliformes totales y Escherichia coli. La cobertura presentó un coeficiente de caudal promedio del 88%, lo que resultó en un promedio de 28.354,04±44.674,86L para el área de cobertura (3.940m²). La captación de agua por condensación atmosférica puede alcanzar los 2.469 litros diarios y se correlaciona positivamente con la temperatura mínima. El tiempo de recuperación de las inversiones en ahorro de agua es de 10 años. Sin embargo, dada la calidad del agua, este sistema podría utilizarse para otros fines, lo que aumentaría el ahorro de agua y reduciría el retorno de la inversión.

PALABRAS CLAVE: ahorro de agua, condensación de rocío, calidad del agua.

INTRODUCTION

Supply of good quality water is essential for economic development, the quality of life of human populations and the sustainability of cycles on the planet (Tundisi, 2003). Despite being a renewable one, cities face serious problems, critical environmental scenarios are expected by the year 2050 with water sources been severely impacted, mainly in undeveloped countries (IPCC 2022). This will further exacerbate the vulnerability of urban water services during extreme weather conditions related to scarcity caused by population expansion, waste, and polluting activities. The problem of decreasing water reserves has generated concern and encouraged rationing and the search for alternative solutions to scarcity (Furumai, 2008, Hagemann, 2009, Rodrigues et al., 2023).

Systems aimed to capture and store rainwater have been generally used since 3rd millennium BC in the Near East and the Mediterranean regions and ever since, rainwater-harvesting systems have evolved. Nowadays may still represents a valid technology to reduce the increasing demand for mains water supply (Mays, 2014; Zanin, 2019). Alternatives already used to reduce water use and waste like water-saving appliances, such as toilets, automatic closing taps, water control in showers, urinals, etc. These resources can be basins with an attached box, replacing discharge valves that have a higher consumption, in addition to requiring pipes with larger diameters. These are already in use in many industries, whose reservoir volume is much smaller, in addition to which there are basins with a 6-liter reservoir, which have 2 (two) buttons, one that empties 3 liters for liquids and the other that empties 6 liters for liquids. solids, according to the need for hygiene. Automatic (sensorized) taps, which only open when the user stands in front of it, used in hospital surgical centers, which contribute greatly to safety in terms of contagion, as there is no direct contact between the user and the tap, as well as valve-type taps, that is, hydro-mechanized with control over the opening time, all widely used in bathrooms in public areas, both contribute to saving water as they avoid waste, due to forgetting when closing, or using more than necessary to sanitize the hands. The objective of installing water-saving equipment is to reduce water consumption regardless of the user's action or willingness to change behavior to reduce water consumption (Stefanellli and Oliveira, 2009).

Beyond the alternatives to increase water supply being studied are the technologies of capture rainwater in built-up areas, the systems called Decentralized Rainwater Harvesting (DWH) and Grey Water Reuse (GWR), that can provide a fundamentally important contribution to urban water networks, including the potable, pluvial, and sewage systems (Rodrigues et al., 2023). Concerning DWH studies related with Rainwater Harvesting Systems (RHS) technologies are being applied and studied for its characteristics, vantages and problems. A RHS includes elements as a catchment surface; gutters and coarse filters to remove large solids (e.g. leaves and twigs); a storage tank, and a pump system from which water sent to be places to be used or to storage tanks that has overflows and level controllers (Zanni *et al.,* 2019). Rainwater for non-potable consumption is a system used in several countries and has been growing and placing emphasis on water conservation. In addition, it contributes to the prevention of floods caused by torrential rain in large cities, where the surface has become impermeable, preventing water infiltration (Group Raindrops, 2002; Tomaz 2003, Amorim and Pereira, 2008, Furumai, 2008, Zanni et al. 2019).

The non-potable water harvesting and demand is dependent on many factors as precipitation patterns, volume of the tanks and demand for non-drink water (Campisano *et al.*, 2017). The surfaces used for rainwater collection directly interfere with the natural characteristics of the water, since during dry periods the phenomenon of dry deposition of compounds present in the atmosphere occurs, due to gravitational sedimentation, the interception of particulate matter and/or the absorption of gases by surfaces (Gonçalves, 2006). Furthermore, differences in surface types can lead to the differences in water harvesting as dew water harvesting can be related to difference in materials on drop mobility and nucleation rate and to capacity of achieving temperatures below the dew point and harvest condensate water (Lee *et al.* 2012, Nioros *et al.,* 2021).

Studies about DWH systems are very common in either households or commercial buildings, including offices and educational facilities, while there are only few studies focused on industrial installations or agricultural infrastructure (Rodrigues et al., 2023). The analysis of the use of rainwater in condominiums and industries shows that it can supply from 40% to more than 60% of the demand in these environments (Ferreira, 2005). The study of the characteristics of the systems used for this purpose is extremely important for their evaluation and improvement. Furthermore, the assessment of the volume of water stored in relation to rainfall volumes and condensed atmospheric water in relation to the volumes used in toilets, as well as the quality of this water (Rocha et al., 2009), can provide important subsidies for the development of standards and guidelines so that rainwater harvesting technology can be disseminated and encouraged at a local level.

The objective of this article is to evaluate the volume variation produced and other aspects of a rainwater and dew harvesting system installed in a metallurgical industry for sanitary purposes. Aspects as rainwater collection capacity and water consumption by employees for hygienic purposes; water economy and the quality of collected water were analyzed.

MATERIAL AND METHODS

Study area

The study was conducted at Metalúrgica Bom Jardim (MBJ), a Stam Group company, was founded in April 2010 and began operations in May 2013. Installed in a 5,600 m² warehouse in the municipality of Bom Jardim/RJ (22º10´40´´ S / 42º24´15´´ W). at the mountain region of Rio de Janeiro State, Brazil. The metallurgy manufactures gas regulators, screws and padlocks.

Throughout the year, the temperature generally varies from 10 °C to 27 °C and is rarely lower than 7 °C or higher than 31 °C. In the coolest seasons (spring and winter), from April to September, maximum temperatures rise by 2°C, from 22°C to 24°C, rarely falling below 16°C or exceeding 29°C, but some nights could achieve temperatures below 0ºC (INMET 2022). The

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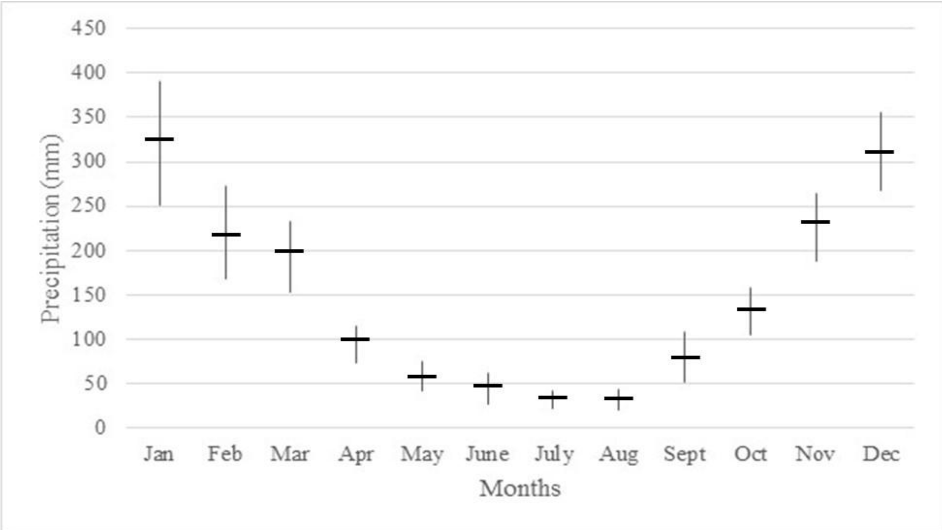
region has a wet and hottest period from October to March, and a dry and coolest period from April to September, what is typical pattern for Brazil Southeast Region. Water flow measures were done at the driest period, from April to August 2014, that was the coolest one also.

Figure 1 – Historical series from 1941-2005 of rainfall variation at Bom Jardim. Horizontal bars are means and vertical bars are standard deviations (SD).



Source: Bom Jardim rainfall station (Nº Hidroweb/ANA 02242021) (INMET 2015).

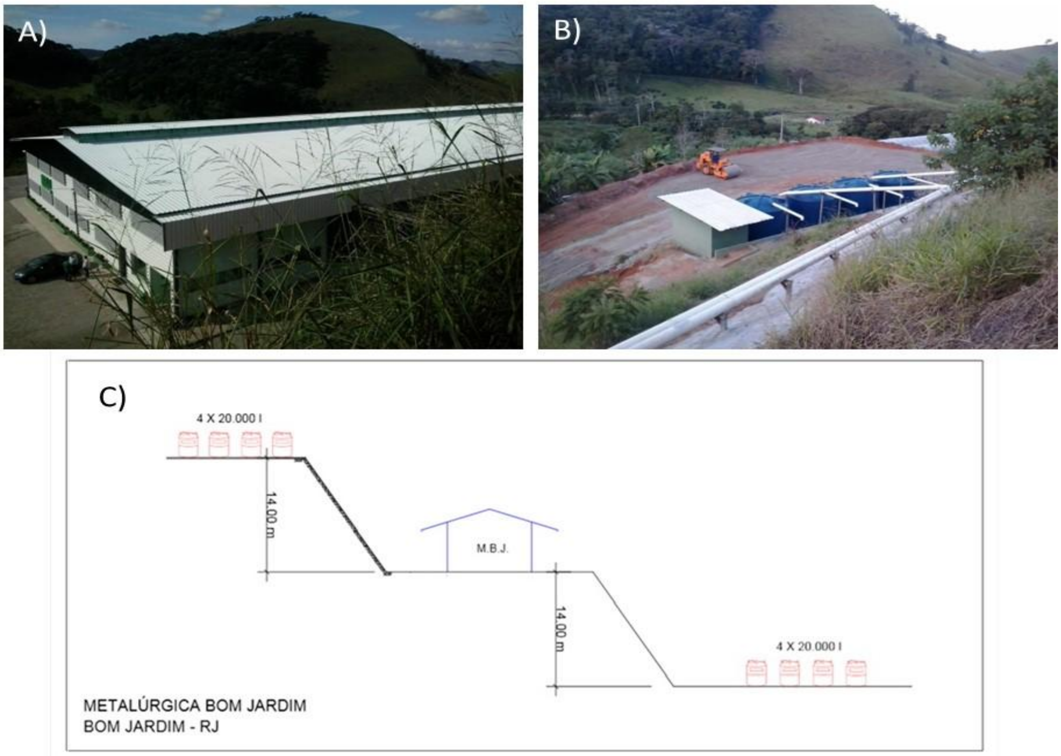
MBJ has two sources of water for its operation: water from the public water concessionaire (CEDAE) and rainwater collected from the roof. The size of the collecting water roof (3980 m²) and the reserve that should serve around 100 people daily, including employees and subcontractors, were considered. After sizing the system, the installation of reservoirs with large accumulation capacity began to also serve during dry periods. It is, therefore, a complementary supply system to that of the concessionaire, and this complement fully complies with user safety standards, in the sense of not there must be a cross connection that could mix rainwater with drinking water, all done by an automatic control system.

The roof was built with aluminum tiles, painted white for better light reflection, thus reducing the thermal sensation (Figure 2A). Rainwater is collected by two vertical PVC conductors (300mm), located half the length of the roof, starting from the metal gutter to the ground at sidewalk level. They are then connected to concrete shackles (300mm) to an inspection box that has two horizontal PVC conductors (200mm) inside, preceded by two metal mesh plates to retain leaves and coarse material.

From the inspection box the flow is directed by gravity to four reservoirs 20,000 liters each, totaling 80 m³. From each reservoir comes a PVC conductor (85 mm) connected that goes to the booster pump (10 hp) located in its own compartment. This pump launches water into a 20,000 liter reservoir, which is connected to 3 more reservoirs of 20,000 liters each, also totaling

80 m³, in the highest portion of the land from where the water serves the MBJ facilities by gravity (Figure 2B and 2C).

Figure 2 – A) Roof of aluminum tiles, B) Inferior 20,000 liters reservoirs, C) Schematic view of rainfall collector.



Source; the authors

ASSESSMENT OF WATER HARVESTING AND CONSUMPTION

Water harvesting

To evaluate the volumes of water harvesting, a reduced-scale roof model (1.07 m x 2.13 m = 2.28 m²) with a 1% slope was constructed in the company's yard with materials, positioning and inclination similar to the industry's metal roof. Initially, sketches were created on paper and in AutoCAD, inserting the diameter of the pipes and the dimensions and inclination of the roof (Figure 3). The model was built with the same materials of the warehouse and its execution was completed in March 2014.

The model is made of a pluviometer (rain gauge) made of PVC (300 mm in diameter by 250 mm in height) that drains into a 20 liter capacity reservoir; the roof prototype drains into two reservoirs of 200 L each connected in series. Below each drum was placed a record of ½” connected to a hose to collect water (Figure 3). Also, a thermo-hygrometer was installed at the company's entrance, whose temperature and humidity values are monitored daily.

Periódico Técnico e Científico Cidades Verdes
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ISSN 2317-8604 Suporte Online / *Online Support*

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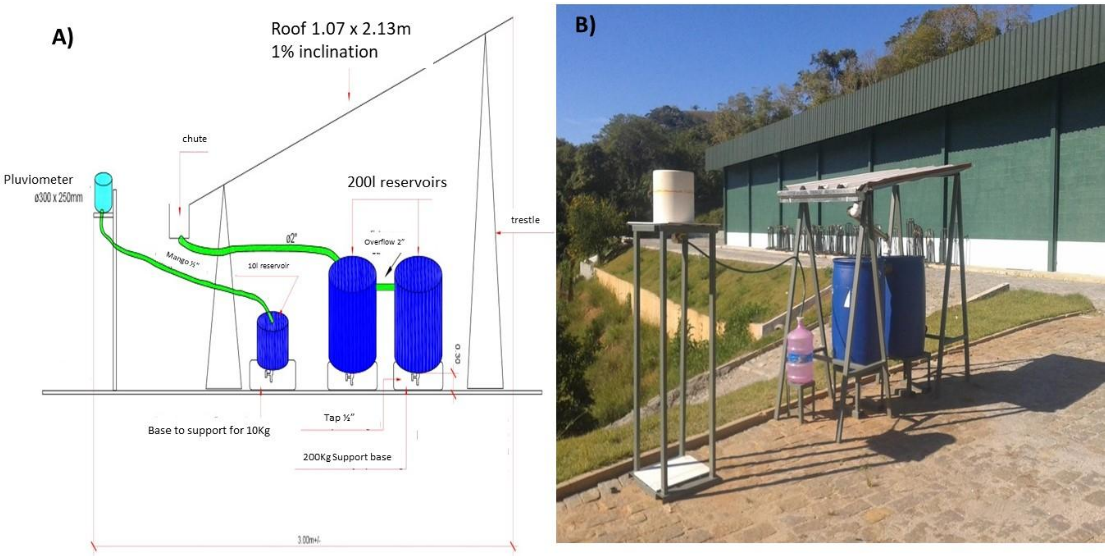
Figure 3- Prototype constructed at MBJ backyard.



Source: the authors

Volume measurements were made manually by the reserchers from May 2014 to August 2014, at least 10 days each month. In April 2014 only 4 four days on rainny days were collected because the model was being tested. So, these data will be used only for rain water volume collection. Water harvested measurements were made in 24 hours, in the previous day water was discarded at 8h a.m. and the water acumullated until 8h a.m. of the next day was collected. Measures were done at intervals that varied from daily to weekly, sometimes, following measures was taken during two, three or four days. Both measuring cylinders and graduated buckets were used, since the volumes drained over a single week sometimes reached more than a hundred liters of water, while in events where only dew condensation occurred volumes were sometimes less than 1liter. The values were recorded in a spreadsheet. Information on immediate, maximum and minimum temperature and humidity were recorded daily by the company's doormen.

Water quality analysis

Even if used for less noble purposes, that is, non-potable purposes, ABNT NBR 15527/2007 defines rainwater quality parameters for restrictive non-potable uses, which must be adopted in any system that aims to reuse water. The parameters analyzed went beyond those required by standard, namely: turbidity, pH, nitrates, nitrites, orthophosphate, silicate, ammonia, organic matter, total coliforms and *Escherichia coli*.

Water was collected from the roof model and from the bathroom taps for comparison. The analyzes of the physicochemical parameters were carried out at the UFRJ Hydrology Laboratory and the bacteriological analyzes were carried out at the L.A.C.A. laboratory in Nova Friburgo. The values of the quality parameters observed in the samples were compared to the

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limits suggested by the Brazilian Standard for the use of rainwater from roofs in urban areas for non-potable purposes - ABNT NBR 15527/2007 and by CONAMA (National Environmental Council) Resolution nº 357, of March 17, 2005.

Evaluation of the water storage and use

We made the comparison between the water volume used in the bathrooms and total water consumption. To estimate the water consumed by the MBJ employers in a month at toilets and urinals, information provided through the application of questionnaires was used. Calculations were done as follows:

For Male: $C♂ = N♂.F♂_U. V_U.WD + N♂.F♂_T.V_T.WD$, where:

C♂= Total consumption of water for males in a month

N♂= number of employers at a month

$F♂_U$ = Use frequency of urinals

V_U = urinals volume in a discharge (considered as 6L)

WD= number days of work

$F♂_t$ = Use frequency of toilets

Vt = toilet volume in a discharge (considered as 13,5L)

For Female: $C♀ = N♀.F♀_T.V_T.WD$, where:

C♀= Total consumption of water for females in a month

N♀= number of employers at a month

WD= number days of work

$F♀_t$ = Use frequency of toilets

Vt = toilet volume in a discharge (considered as 13,5L)

The estimate of the volume of water used and the water provided by the CEDAE and rainfall and dew water was based on the monthly water consumption in toilets and urinals, both by male and female employees. CEDAE water consumed was done using its bills. For the rain and dew water, a estimate was done using the volumes measured with the roof model and calculated for the original roof area. For this, calculations considered total water harvested at the roof model (2,28m²) divided by the number of the days collected for each month, so we achieved a mean for each day. After that, we estimate the water harvested for the roof (3980m²) and multiplied it by the number of the month days. So, a total water harvested by the roof for each month was obtained. Comparison of total water harvested and total sanitary water used was done graphically.

Stastical Analyzes

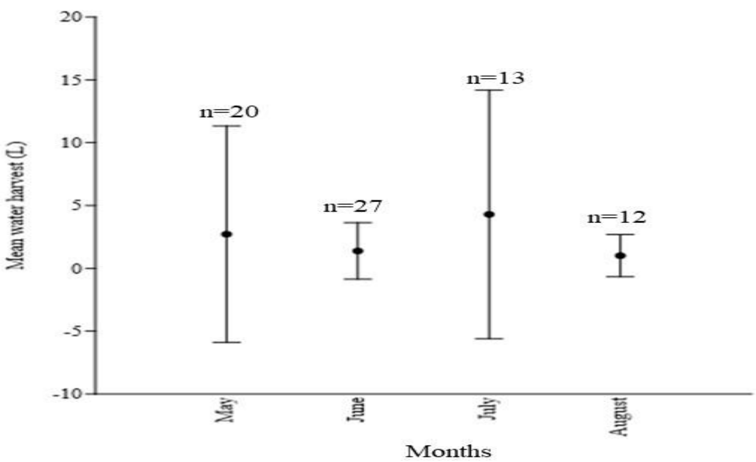
Means, standard deviations, minimal and maximal volumes were calculated for total water flow, rain water flow and dew water flow to evaluate the total and proportional contibution of each type. Pearson correlations (r) and Regression curves were done to establish the precipitation x water flow correlation for rainy days and between water flow and daily Minimal, maximal, mean temperature and humidity for dry days where only dew flow was observed.

RESULTS

Assessment of water capture and consumption

Mean rainwater and dew flow volume collected from the roof model was 4,74±15,3L and varied between 0,015L in August 16th to 115,75L on April 5th. Volume means didn't present significative differences between May to August 2014 (H=0,81, p=0,85) (Figure 4). Considering these values for the surface of MBJ roof, water and dew harvesting achieved values from 22,735 L in August to 163,320 L in July (mean of 80,549±63,708L).

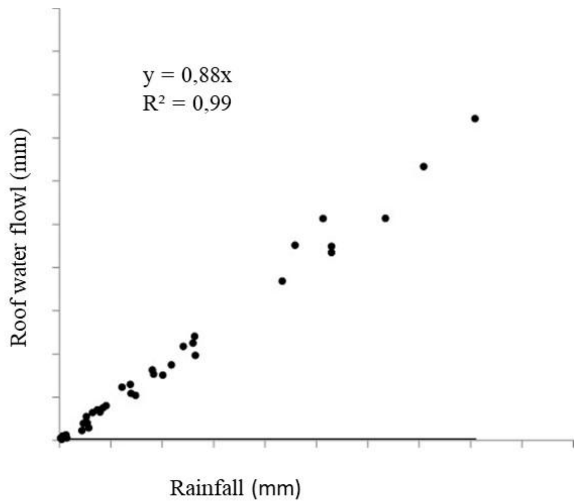
Figure 4- Monthly water flow volume means (in liters) and standard deviation (bars) of the water collected on the roof model. n= sample number.



Source: the authors

Considering only rainy days, there was a significative correlation between precipitation (mm) and water volume collected at the roof model (r^2=0.99, p=0.0001) (Figure 5). Mean water volume was 18.45±29.07L, with maximal water volume of 115.75L collected on April 5 and minimum water volume of 0,05L collected on May 20. Average runoff coefficient of the metallurgical roof was 88%. This value is higher than that found in roofs made of ceramic or fiber cement and is close to the coefficient indicated by other studies for metal roofs (ROCHA et al. 2009). This means that the MBJ roof is very efficient in transforming rain into runoff for capture by the rainwater harvesting system. Estimated mean values for the water harvested by the MBJ roof were 28,354±44,674 L.

Figure 5- Regression curve, inclination (y) and correlation coefficient (r²) between daily rainfall volume and water collected at the roof model.



Source: the authors

Water was collected even at days without rain when air water vapor condensation was harvested. Mean water volume in the roof prototype was 0.49±0.34 L with maximal volume of 1.8 L on July 18 and minimal volume of 0.05 L on June 4. Considering the total MBJ roof area this mean volume is equivalent to 753±522L and the maximal air water vapor production collection is equivalent to 2,469 liters. There was a negative weak but significant correlation between the dew flow volume and the minimal temperature of the day (r=-0.29, p=0.048) (Figure 6). A marginally significant correlation was found between mean temperature and dew water flow (r=0.24, p=0.09). All the others climate variables did not have significant correlations (Mean humidity: r=0.19, p=0.18; Maximal temperature: r=0.14, p=0.34; Maximal humidity: r=0.14, p=0.41; Minimal humidity: r=-0.21, p=0.16).

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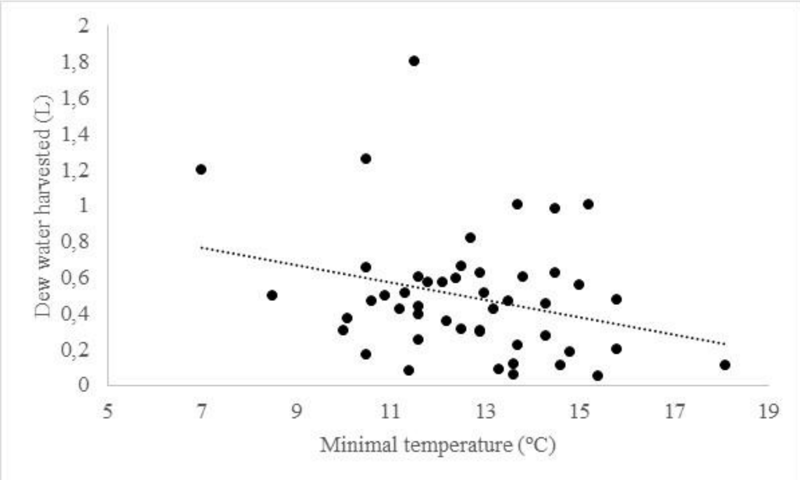
Figure 6- Correlation between Minimal Temperature (ºC) and Dew water harvested (L) on the roof model.



Source: the authors

Water quality analyzes

The analyzes of harvested water biological, physical and chemical parameters are in tables 1 to 3. The samples collected directly from the roof prototype show a high level of contamination in relation to total Coliforms and a small level of *E. coli*, also adequate values of turbidity and nitrite for classification in class I waters according to CONAMA resolution 357/2000 (Tables 1 and 2). The levels of orthophosphate and silicate also demonstrate low contamination by organic load that may come from fecal material or organic plant or animal material that may have been deposited on the roof (remains of leaves, twigs, small dead insects, etc.) (Table 3). The values of pH and nitrate higher values from the collection on 29/04/2015, leading to the suspicion of external contamination or even an abnormal organic load. The values obtained for the tap are in accordance with the standards analyzed here and, therefore, meet the requirements of current legislation. This indicates that a simple procedure such as adding chlorine periodically may be sufficient to make this water suitable for consumption. However, a greater number of samples is needed so that more solid conclusions regarding water quality can be drawn.

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Table 1 – Water analyzes results of Total Coliformes, *Escherichia coli* and organic matter of the water collected at the model roof on each day of water collection. L.Q= quantification limits, NMP= More probable number, mg=miligrams, ml=mililiters. (Source: L.A.C.A. laboratory).

			08/05/2015		
Paramete rs	**Meth od**	**.Q**	**value**	**Reference value**	**Unity**
Total Coliformes	multi ple	,1	> 8,0	ABSENCE/100 ml	**NMP/ 100 ml**
Escherichia coli		,1	2	ABSENCE/100 ml	
Organic Matter	Titri metric	1	N.D.	3,0 *	mg/l
			14/05/2015		
Paramete rs	**Meth od**	**.Q**	**value**	**VMP**	**Unity**
Total Coliformes	múlti plos	,1	> 8,0	ABSENCE/100 ml	**NMP/ 100 ml**
Escherichia coli		,1	> 8,0	ABSENCE/100 ml	
Organic Matter	Titrim etric	1	N.D.	3,0 *	mg/L
			30/04/2015		
Paramete rs	**Meth od**	**.Q**	**value**	**VMP**	**Unity**
Total Coliformes	múlti plos	,1	> 8,0	ABSENCE/100 ml	**NMP/ 100 ml**
Escherichia coli		,1	2	ABSENCE/100 ml	
Organic Matter	Titrim etric	1	2	3,0 *	mg/l

Source: the auhtors

Table 2 – Water analyzes results of Total Coliformes, *Escherichia coli* and organic matter of the water collected at taps bathroom on each day of water collection. L.Q= quantification limits, NMP= More probable number, mg=miligrams, ml=mililiters. (Source: L.A.C.A. laboratory).

Parameters	Me thod	.Q	value	VMP	Unida de
08/05/2015					
Total Coliformes	múl tiplos	,1	N.D.	ABSENCE/100 ml	**NMP/ 100 mL**
Escherichia coli		,1	N.D.	ABSENCE/100 ml	
Organic Matter	Titri metric		N.D.	3,0 *	mg/L
14/05/2015					
Parameters	**Me thod**	**.Q**	**value**	**VMP**	**Unida de**
Total Coliformes	múl tiplos	,1	N.D.	ABSENCE/100 ml	**NMP/ 100 ml**
Escherichia coli		,1	N.D.	ABSENCE/100 ml	
Organic Matter	Titri metric		N.D.	3,0 *	mg/l
30/04/2015					
Parameters	**Me thod**	**.Q**	**value**	**VMP**	**Unida de**
Total Coliformes	múl tiplos	,1	N.D.	ABSENCE/100 ml	**NMP/ 100 ml**
Escherichia coli		,1	N.D.	ABSENCE/100 ml	
Organic Matter	Titri metric		N.D.	3,0 *	mg/l

Source: the authors

Table 3– Water analyzes results of physical and chemical parameters of the water collected at the model roof and bathroom taps on each day of water collection. (Source: L.A.C.A. laboratory). L.Q= quantification limits, NMP= More probable number, mg=miligrams, ml=mililiters NTU= Nefelometric Turbidity Units. SD= Standard Deviation, CV= Coefficient of variation. References values: pH - between 6 and 9, Turbidity- until 100 NTU, Ortophosphate- until 0.15µM , Silicate- until 50µM, Ammonia- until 15µM, Nitrate- until 10µM, Nitrite – until 1µM.

		29/04/2015		13/05/2015	
		roof	tap	roof	tap
pH	Mean	4.25	6.00	4.40	5.89
Turbidity	NTU	9.66	2.01	4.63	2.20
Ortophosphate (µM)	Mean±SD	0.73±0.01	0.32±0.002	1.55±0.01	0.19±0.004
	CV%	1.659	0.670	0.822	1.827
Silicate (µM)	Mean ±SD	0.44±0.003	12.55±0.08	0.26±0.001	2.79±0.02
	CV%	0.636	0.637	0.550	0.709
Ammonia (µM)	Mean±SD	3.34±0.18	0.22±0.02	12.99±0.37	0.97±0.008
	CV%	5.440	2.990	2.837	0.805
Nitrite (µM)	Mean±SD	0.04±0.0	0.02±0.001	0.07±0.006	0.06±0.001
	CV%	0.000	4.562	9.428	1.230
Nitrate (µM)	Mean±SD	65.23±0.62	11.13±0.04	11.04±0.05	12.17±0.58
	CV%	0.954	0.381	0.461	4.765

Source: the auhtors

Evaluation of the water storage and use and economic savings

Based on the employees' questionnaires, per working day, men visit the bathrooms on average 3.66 times to use the urinal and 1.36 times to use the toilet. Women use the toilet on average 3.33 times per working day (Figure 7). Considering the cost of using urinals (13.5 liters) and toilet bowls (6 liters), each man uses almost 3 times more water (57.57 liters) than a woman (19.98 liters) per working day. Based on this consumption pattern between genders and the evolution of MBJ's staff (Figure 7A), the monthly water consumption in the bathrooms was determined.

Considering the 4 months, CEDAE water consumed by MBJ was 75,000±20,48L and estimated sanitary water consumption was 17,400±2,43L what means an economy about 19.6±5.35% in overall water consumption (Figura 7B). However, it is observed that not only the collection provided by the roof associated with the volume of the reservoirs (160 m³) fully meets the demands of the company's staff but also represents a surplus of 80,550±63,710L, which at

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Technical and Scientific Journal Green Cities
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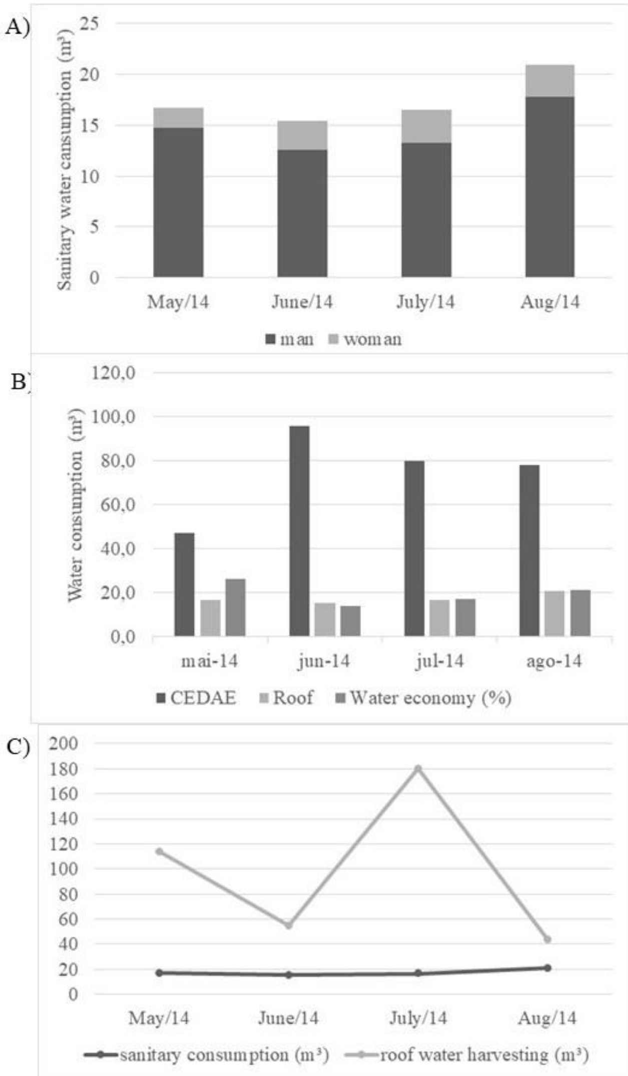
Edição em Português e Inglês / *Edition in Portuguese and English* - Vol. 12, N. 37, 2024

its peak reached the value of 163,320L in July 2014 (Figure 7C). This accumulated volume of water is enough to supply the consumption of 17,336 people in one day, considering the UN reference values of 110 liters/person/day (available at https://www.un.org/waterforlifedecade/pdf/human_right_to_water_and_sanitation_media_brief.pdf, accessed 15/01/2024).

The financial resources for the implementation of the RWH system was R$ 111,302.02, being distributed as R$ 77,042.02 in materials and R$ 34,260.00 in services. The financial savings with water calculated for the period from April 2013 to March 2015 was R$ 23,045.00, which represents an average saving of 49.1% in MBJ's water costs. If this economics savings is maintained, the financial return on investment will take approximately 10 years.

Figure 7- A) Sanitary water consumption for each month e for gender estimated from the questionnaire, B) Water consumption from CEDAE and total sanitary water consumption estimated from the questionnaire, C) Estimated water harvesting from the original roof (3980m²) and total sanitary water consumption for each month analyzed.



DISCUSSION

The values of rainwater use, and economics of this study are in accordance with already published for other Brazilian studies. Residential rainwater reuse in Brazilian residences can promote savings by the order of 12% to 79% in Southeast region (Ghisi, 2006; Ghisi and Mengotti de Oliveira, 2007). Run-off coefficient was also like other studies made at Brazil (Ghisi and Mengotti de Oliveira, 2007). However, water dew deposition and harvesting were not considered and, at our study, it was an important source of water harvesting, nearly 30% of water, at the dry weather period, was from it. This harvest capacity of collect dew water is probably influenced by the type of roofing material, as zinc could achieve lower temperatures and so is capable of condense a higher volume of water (Nioras *et al.*, 2021). Until we know, it is the first *in situ* measure of this type of water harvesting.

Values for water harvesting and economic savings made by it are very variable as it depends on the variables such tank size dimension, roof area in relation to water use (Zanni *et al.*, 2019). Volumes harvested by the MBJ system are above that needed for its sanitary purposes, in relation to the system harvest and storage capacity it is much above for sanitary use necessities. Its estimated payback period is very low when comparing to other studies in Brazil that generally are higher than 20 years, when considering familiar houses in Brazil (Ghisi, 2007). This considered, it is reasonable to suppose that further uses can be planned for the harvested water, what can increase economic savings derived from RWH system use. Maybe, as a metallurgy activity is reasonable to suppose that the water harvested could be used for this purpose.

However, the quality of water harvested is a question. Although water harvested seems to be of good quality, it is much necessary that is water would be constantly monitored. Rooftop surfaces are comparatively cleaner than parking lots, sidewalks and other, however can have substantial amounts of heavy metals and nutrients and, in areas characterized by high vehicle traffic volumes, high-density residential development and industry, collected rainwater could have low pH values related to the phenomenon of acid rain (Hamdan, 2009; Melidis *et al.*, 2007). Other problem is the high values of organic matter and microbial contamination, not only birds act as a major ,source of pathogens and organic matter but also possible elevated total suspended sediment (TSS) concentrations in rainwater caused by agricultural bush burning or linked to dry deposition include TSS, Pb (due industrial emissions), Cu, nitrates (due to agricultural fertilizer applications), nitrites, Zn, Al, Fe and Ca, can be an important contamination factor (Adeniyi and Olabanji, 2005; Morrow *et al.*, 2010; Mendez *et al.*, 2011). Other factor of contamination is the roofing materials and drainage systems, which contribute with dissolved and particulate matter to roof runoff in relation to weathering processes and chemical and physical reactions occurring between the rainwater and the materials (Zobrist *et al.*, 2000; Lee *et al.*, 2010; Akoto *et al.*, 2011). Several studies have shown that rough roofing surfaces, such as asphalt shingles, trap and retain particles and pollutants more so than smooth materials and can have a detrimental effect on harvested water quality \and more leaching materials, like copper or zinc should be avoided (Bradford and Denich, 2007; Farreny *et al.*, 2011). At MBJ this is not seems to be a rough problem as contamination levels are reasonable. However, MBJ is near the small cities and rounded by agricultural farms of diverse sizes. Low pH and high nitrates values, probably, could be a problem of dry deposition phenomena of both city and rural suspended matter. Nova Friburgo is a very important agricultural city, that produces for all Rio de Janeiro State, and also possess many important industries, so it is not possible to say precisely what is the major influence for water contamination.

CONCLUSION

It is concluded that metal roofs such as aluminum reduce runoff losses as it is a material that has lower porosity and roughness. These results can be even better in industries that use water in their production processes and where the water from RWH can be used as an input, with appropriate treatment and monitoring for this purpose.

It can be said that water collection by atmospheric condensation presents itself as an important source of savings, mainly because there is an increase in water collection with the reduction in temperature for the type of roof material analyzed, as they indicate a new possibility of collection of the same, mainly in the mountainous region of Rio de Janeiro, where precipitation and temperature decrease significantly in winter.

From an economic and environmental point of view, the results demonstrate the importance of this system in its ability to save water consumption from the concessionaire by approximately 50%, which resulted in a return on investment in 10 years. Payback period could be even smaller if other water uses were done.

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