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Demanda máxima y volumen sostenible de recogida de agua de lluvia RWH para su almacenamiento en edificios

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RESUMEN

En este artículo se determinan expresiones matemáticas alternativas que facilitan el procedimiento de cálculo a la hora de determinar las variables que se utilizarán para calcular el volumen de almacenamiento de recogida de agua de lluvia para las cubiertas. Así, este artículo se centra en determinar aquellas variables de oferta y demanda: superficie de la cubierta (*A*), número de habitantes por edificio (*n*) y demanda diaria que una persona podría satisfacer con agua de lluvia (*D*), a partir de los valores fijos de: el coeficiente de escorrentía del tipo de cubierta (C_e), la precipitación media diaria (*P*) de los doce meses y la precipitación anual (*PT*).

Finalmente, las soluciones o curvas de solución se correlacionaron en expresiones matemáticas resultantes de múltiples regresiones no lineales de (*A*, *n*, *D*, *PT*, *V*) que proporcionaron la demanda máxima diaria (*l/día*) por persona (D_{max}), y el volumen máximo sostenible volumen (m^3) sostenible para el edificio (V_{sost}) de agua de lluvia que, al equilibrarse con la demanda al final del periodo, dará un volumen acumulado cercano a cero.

Estas dos nuevas expresiones matemáticas son extremadamente fáciles de utilizar y sólo requieren datos del edificio, como la superficie del tejado, el número de habitantes y la de la ciudad, por lo que se evitan los cálculos repetitivos y largos, así como los resultados exagerados.

Palabras clave: Hidrología, RWH, Demanda diaria, Cambio climático, Volumen sostenible

Maximum demand and sustainable volume of rainwater harvesting RWH for storage in buildings

ABSTRACT

This article determines alternative mathematical expressions that facilitate the calculation procedure when determining the variables that will be used to calculate the volume of rainwater harvesting storage for the roofs. Therefore, this article focuses on determining those supply and demand variables: roof area (*A*), number of inhabitants per building (*n*) and daily demand that a person could satisfy with rainwater (*D*), based on the fixed values of: the roof type runoff coefficient (C_e), the average daily precipitation (P) of the twelve months and the annual precipitation (PT).

Finally, the solutions or solution curves were correlated in mathematical expressions resulting from multiple non-linear regressions of (A, n, D, PT, V) that provided the maximum daily demand (*l/day*) per person (D_{max}), and the maximum sustainable volume (m^3) for the building (V_{sost}) of rainwater that, when balanced with the demand at the end of the period, will give an accumulated volume close to zero.

These two new mathematical expressions are extremely easy to use and only require data from the building, such as roof area, number of inhabitants, and annual rainfall of the city, so we avoid repetitive and long calculations, as well as exaggerated results.

Keywords: Hydrology, RWH, Daily demand, Climate change, Sustainable volume

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INTRODUCTION

The world's freshwater resources are renewed through a continuous cycle of evaporation, rainfall and runoff - commonly known as the water cycle - that determines their distribution and availability over time and space (WWAP, 2016). Water does not stop its surface and underground movement, but there are innumerable variables that determine its presence in greater and lesser quantity. Since the water cycle is driven primarily by climate, the increase in variability in rainfall and evaporation patterns caused by climate change is expected to exacerbate spatial and temporal variations in water supply and demand (WWAP,2016).

Recent estimates suggest that climate change will be responsible for about 20% of the increase in global water scarcity (WWDR, 2003). It seems that the international agreements for the reduction of CO_2 emissions will not be fulfilled and a scenario with an invariable climate change is predicted.

Climate change exacerbates several of the threats to water availability and can increase the frequency, intensity and severity of extreme weather events. Scientists agree that climate change will alter the flow regimes of currents, deteriorate water quality and change spatial and temporal patterns of rainfall and water availability (IPCC, 2014).

Another aspect to take into account at this time, is that "the population will increase and with it its water demand, be it private or public, [...] the size of the world population will be between 8,5 and 8,6 billion in 2030, between 9,4 and 10,1 billion in 2050, and between 9,4 and 12,7 billion in 2100" UN (2019).

The decrease in the amount of water available will intensify competition for water among users, including agriculture, ecosystem maintenance, settlements, industry (includ- ing tourism) and energy production. This will affect water, energy and food security at the regional level, and eventually geopolitical security. Regions that have been identified as vulnerable to growing water scarcity include the Mediterranean and parts of South America, Western Australia, China and sub-Saharan Africa (WWAP, 2016).

As solutions all people must adapt to the present climate change. As immediate adaptation measures, the problem of inefficient use of water must be solved and work on the awareness of the population in saving water and energy. At the moment the population ignores the environmental recommendations because the problem is not yet felt, there is enough water, however, when the real problem is in the near future and we have to face water and energy rationing it may be too late to take action. There is much discussion about the identification of new sources of water for exploitation such as the case of groundwater, however, the answer is not to exploit new resources but to optimize the ones we are using and save the rest for when they really need them (Ramírez, 2008). Taking these aspects, in terms of the management of water resources in public and private buildings at urban level, today it is pursued to have better sanitary devices that optimize the use of drinking water in homes, as well as to raise awareness of the population on saving and efficient use of water. The importance of water is vital, so this resource must be used and protected. An easy measure to implement at the urban level is the so-called *rainwater harvesting* (RWH) of roofs of houses to be used to cover the demand of daily activities and thus reduce the use of drinking water.

The usual design methodology for domestic purposes in homes should follow a pro- cedure, which begins with the temporary distribution of very compressed rains (average monthly, quarterly or annual rainfall), meteorological information in many cases insuf- ficient, then the surface and type must be known of housing roof material, with which we obtain the supply of the environment in terms of rain to be collected, the demand for the home to be designed must also be known (number of habitants and appliances to be provided with water from rain), resulting in uncertainty regarding the size of the roof and the amount of drinking water to be replaced by harvesting rainwater RWH, so that the calculation would be compromised in terms of its final sensitivity and finally aggravate the problem, which is to determine the maximum storage volume that we could use, a process of trial and error must be carried out to determine the mass curve that best suits our needs and allows us to have a minimum excess of water in the driest months, this whole methodology takes time.

This article determines alternative mathematical expressions that correlate solutions or solution curves in multiple non-linear regression equations that provide the demand to be satisfied with rainwater (maximum demand) and the sustainable volume of the storage tank on demand required, facilitating the calculation procedure at the time of determining the variables that will be adjusted to obtain a representative mass or cumulative volume curve

MATERIALS AND METHODS

Rainwater harvesting - RWH

RWH is a technique used to harvest or collect, store and use rainwater. Rainwater is collected from various surfaces, such as roofs and other hard artificial roof surfaces. It is then stored and treated for final use in the building. RWH can be used for different purposes, such as garden irrigation, vehicle washing, household use with filtering, etc. It is drinkable and retains its purity even after the long storage period. Groundwater recharge can be carried out through rainwater collected also (Jadhav, 2016), as well as the decrease in stormwater runoff (Krishna et al., 2005) acting as a rain retarder in rain events.

Rainwater systems are normally installed in buildings as a complementary system along with a "normal" drinking water distribution system within the building. Therefore, the main problems are to allow both systems to coexist, guaranteeing a safe and continuous water supply and at the same time taking full advantage of non-main water. While the system may have been designed with the information provided that was up to date in the bidding stages, customer requirements may change, so the space and service routes within the building may change (Goodhew, 2016).

The RWH system on roofs (see Figure 1), in conceptual terms, is based on: a) the temporary supply of rain, b) the harvesting or catchment carried out on the roof, c) the demand or water requirement per home or building, and d) its storage for use in the dry period. Constructively, it must have: a filter, a storage tank, a pumping facility, a pipeline distribution facility within the building and an overflow unit. The size of the storage tank is by far the most important factor in the total cost of installation, therefore its optimization is essential in terms of the feasibility criteria (Matos et al., 2013). The methods for the design and operation of water supply reservoirs or dams are generally worked in time intervals of one month (Treiber and Schultz, 1976), this approximate time interval produces results of acceptable accuracy.

Storage volume

There are a number of different methods used to size the tanks. These methods vary in complexity and sophistication and can be seen from two perspectives: the demand side approach or the supply side approach (Rees and Ahmed, 1998). Each of these approaches varies from one manufacturer to another, from one country to another, from one region to another (Quadros, 2010).

Method 1: demand side approach

The first method is very simple, it is to calculate the highest storage request based on consumption rates and the occupation of the building (Rees and Ahmed, 1998) (Quadros,

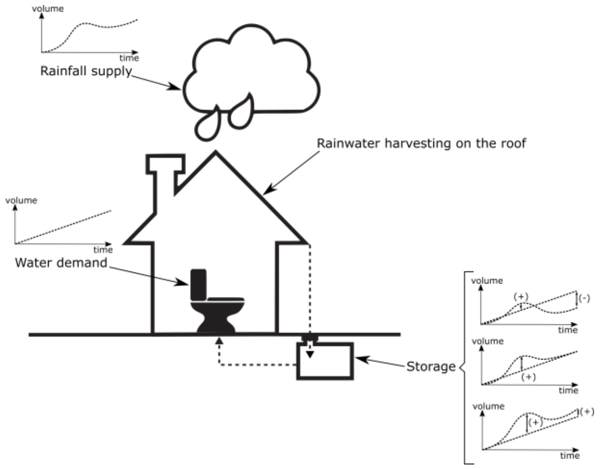

Figure 1: Roof rainwater harvesting RWH system

2010). This simple method assumes sufficient area of RWH, and is applicable in areas where this is the situation, that is in rural areas. It is a method to acquire approximate estimates of tank size (Rees and Ahmed, 1998) (Quadros, 2010).

Method 2: supply side approach

As Dai Rees and Shafieul Ahmed points out "in low rainfall areas or areas where the rainfall is of uneven distribution, more care has to be taken to size the storage properly. During some months of the year, there may be an excess of water, while at other times there will be a deficit. If there is enough water throughout the year to meet the demand, then sufficient storage will be required to bridge the periods of scarcity. As storage is expensive, this should be done carefully to avoid unnecessary expense. This is a common scenario in many developing countries where monsoon or single wet season climates prevail" Rees and Ahmed (1998).

From this method, several criteria are derived (Krishna et al., 2005) (Krygiel and Nies, 2008) (Matos et al., 2013): 1) System efficiency, which can vary between 80 to 90%, depending on the efficiency in the RWH (coefficient of runoff, lost from splashing on the roof and evaporation, lost from transport and driving, lost by diverters of first roof washing), the design of a sustainable building (Krygiel and Nies, 2008) uses 80%, the Texas Manual on harvesting of rainwater RWH (Krishna et al., 2005) uses 85%, other authors include it as a value of the general runoff coefficient, the study on the sizing of a rainwater storage tank of a commercial building (Matos et al., 2013) uses a coefficient of 80% for waterproof areas in general. 2) Use of rainfall data, which may vary in the use of the monthly average rainfall and use of the monthly median rainfall (Krishna et al., 2005), the first being the most used, and takes as a database the precipitation of the 10 or last 15 years (UNATSABAR, 2004). 3) Initial storage, which varies according to the criteria of the region, this volume should be stored at the beginning of the rainy season (Krishna et al., 2005), this initial storage being little used when increasing the calculated volume.

Storage volume calculation

As mentioned in the previous point, the most used method is the method based on the "supply side approach", which in its original form calculates the storage volume by the method of mass curves or method Rippl. (Matos et al., 2013) (Quadros, 2010) (VAPSB, 2011), being widely used in dams and reservoirs (Rippl, 1883), this Rippl method finds the required storage volume by using the mass curve of a time series of observed runoff from monthly values (Treiber and Schultz, 1976) (see Equation 1).

$$I(t) - O(t) = dS(t)/dt \quad (1)$$

Where, $I(t)$ = inflow to the reservoir or deposit, offer or temporary distribution of rainfalls, $O(t)$ = outflow to the reservoir or deposit, demand or water requirement of the building, $S(t)$ = reservoir or deposit volume, t = time.

This equation 1 is translated as the difference in the cumulative volume of RWH supply minus the cumulative volume of water demand of the building (see Figure 1, resulting in the volume of the storage.

Step 1 - Temporary rainfall offer or distribution

The procedure carried out in the present study, followed the scheme of the Figure 2 and the filling of the Table 2, beginning in step 1, with the potential for catchment or rainwater harvesting $I(t)$ on a roof or deck can be estimated based on local rainfall, according to the monthly, quarterly or annual formulation (VAPSB, 2011), “the monthly rainfall will cause us to have a mass curve with little sensitivity in the result, [...] which will lead to a severe underestimation of the required storage capacity” Van der Zaag (2000). “And [...] the influence of wide discretization times can be reduced by choosing daily time intervals instead of monthly values” Matos et al. (2013), so in this study daily values were used.

$$I(t) = \frac{P \cdot A \cdot C_e}{1000} \quad (2)$$

Where:

P =average daily monthly rainfall (in *mm/day*),

A = harvest area (in m^2),

C_e = runoff coefficient (dimensionless).

The calculation of the average monthly daily rainfall (see Figure 3) and annual rainfall (see Table 1), was obtained from the data of five meteorological stations in Bolivia of the National Meteorological Service and Hydrology (SENAMHI, 2019) with information of more than 40 years and different average annual rainfall: San Calixto (1917-2016), El Alto - Aeropuerto (1942-2017), Cochabamba - Aeropuerto (1942-2017) , Trompillo - Santa Cruz (1942-2017), and Cristal Mayu (1973-2017), subsequently, the values in the table were filled Table 2 - *Col*.3, obtaining the information on a daily basis for the twelve months of the year.

Table 1: Average monthly total rainfall - *PT*

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Station	**Total rainfall** (*mm/year*)
Cochabamba - Aeropuerto	469.90
San Calixto	574.20
Cristal Mayu	4236.67
El Alto - Aeropuerto	602.08
El Trompillo - Santa Cruz	1353.74

Table 2: Storage volume calculation - RWH

Col.1	*Col*.2	*Col*.3	*Col*.4	*Col*.5	*Col*.6	*Col*.7	*Col*.8	*Col*.9
Month	Days	Rainfall daily	Supply RWH of roof	Building water demand	Cumulat. Supply volume	Cumulat. demand volume	Cumulat. supply demand difference	Simple supply and difference
January February March . . . October November December	1,2...31							

Where:

Col.1 Period of the year in months: January, February . . . November, December; *Col*.2 Time in days of each month, some months only have 28, 29, 30, 31 days; *Col*.3 Average daily monthly rainfall Figure 3,

Col.4 Temporary supply of RWH rain on roofs, we use the Equation 2;

Col.5 Water demand for buildings for sanitary appliances, the Equation 3 is used;

Col.6 Cumulative data in *Col*.4 from January 1 to December 31,

Col.7 Cumulative data in *Col*.5 from January 1 to December 31,

Col.8 Difference between *Col*.6and *Col*.7.

Col.9 Difference between *Col*.4and *Col*.5.

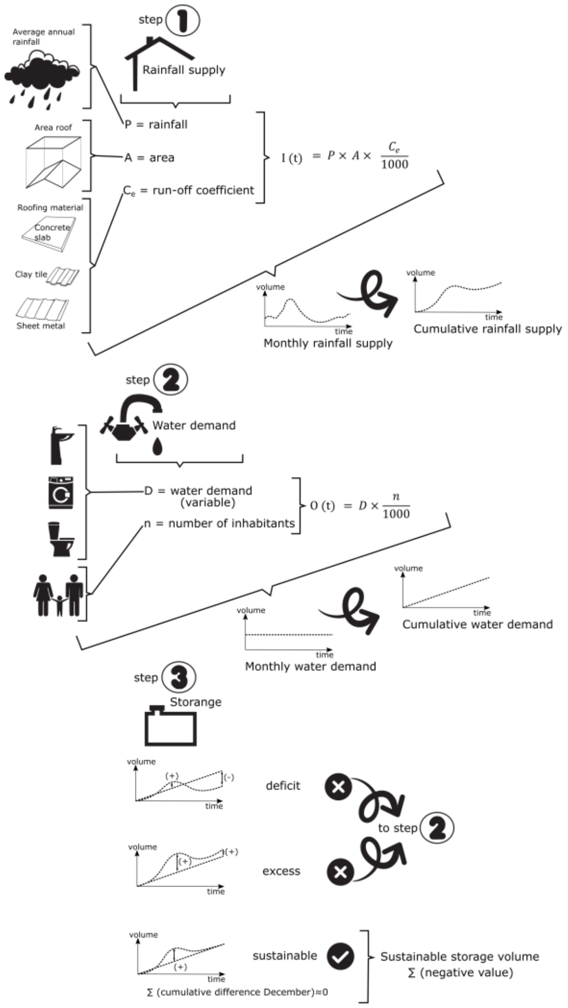

Figure 2: Calculation methodology

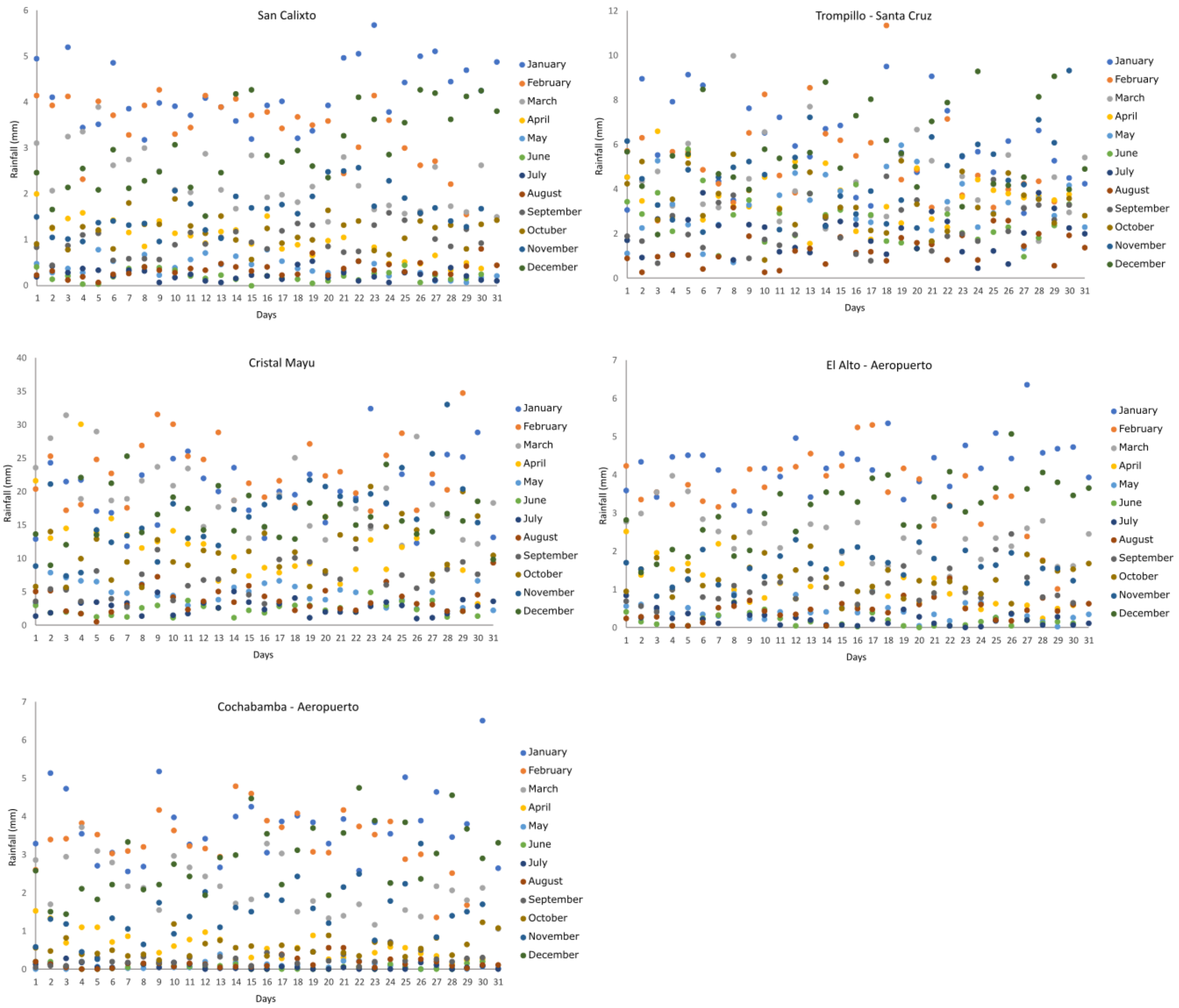

Figure 3: Average daily monthly rainfall per station

To determine the area of the roof of the building available for the RWH, the main types were identified according to the classification of the Bolivian Building Construction Guide (DGVU, 2015), See Table 3.

Since the areas of 100 m^2 and 200 m^2 could store enough water to meet other needs besides toilet washing and laundry (Lizárraga-Mendiola et al., 2015). Therefore, as an analysis variable, all the roofs areas of the Table 3 were used.

Table 3: Type of roof and its surface

Type	Area (m^2)
Of social interest, with low salaries	10
	20
	30
	40
	50
	60
	70
Simple with with average salaries	80
	90
	100
	150
	200
	250
	300

To determine the runoff coefficient, the roofs prevailing in Bolivia were identified, according to the National Statistics Institute of Bolivia (INE, 2012), Table 4, using these values in equation 2, for filling Table 2 - *Col*.4.

Table 4: Prevailing percentage of roof according to the type of material

Roof material	Corrugated metal	Clay tile	Concrete slab	Others
Percentage	83.32	5.60	9.36	1.72

Therefore, the types of roof with the highest prevalence in the construction of houses were used, and the C_e values recommended by the study "Roof selection for RWH: quantity and quality assessments in Spain" Farreny et al. (2011) were adopted, see Table 5.

Table 5: Runoff coefficient according to roofing material

Roof material	C_e
Clay tile	0.84
Metal	0.92
Concrete	0.90

Having very similar values, the value of C_e was averaged, obtaining for the present study the value of C_e = 0.89 for more usual roofs in Bolivia, using this value in the Equation 2, for filling Table 2 - *Col*.4.

Step 2 - Determination of the demand or water requirement per building

In step 2, the demand for water per building must be determined in function, first of the number of inhabitants of the building, this number is a function of the architectural project and is constant. Second of the consumption of sanitary devices by person or inhabitants of the building and that in our study is constant throughout the year, see Equation 3.

$$O(t) = \frac{D \cdot n}{1000} \quad (3)$$

Where:

D = consumption per person or habitant of the building of sanitary appliances (in *l/hab−day*),

n = number of inhabitants per household (in *hab*).

The variables D and n, in the present study were tested using ranges of values between 1 and 40 inhabitants in the case of n, and endowment ranges for artifacts between 1 to 100 (*l/hab-day*) for D, covering the demand for the most common artifacts sanitary such as: toilets with tanks, sinks, showers, dishwashers, washing machines. Using these values of n and D in the Equation 3, to fill the Table 2 - *Col*.5.

Step 3 - Sustainable storage volume and Rippl method

As a last step 3, two analyzes should be performed on the mass curve of cumulative volumes or Rippl method, that is, comparing the mass curve of $I(t)$ (in m^3 per t) and $O(t)$ (in m^3 per t), see Equation 4. First, as the study is conducted in a time frame that is daily, the 366 days (including leap years) must be completed. These daily differences are added and monthly values are obtained until the last month according to the analyzed period. This last difference of the cumulative volumes should be as close as possible to zero (0.01 - 0.10), with this it is known that the supply $O(t)$ and the demand $I(t)$ reached an equilibrium, which will be maintained in the following periods (5, 10, 100 years), this ensures sustainability. In Table 2 - *Col*.8 all the daily values were added, obtaining monthly values, and whose sum in the last month will be the one that approaches zero or in its absence should be iterated until this balance is achieved (*December Col*.8) 0, between supply and demand.

A daily water balance should be made to assess the reliability of domestic rainwater deposits when used as a partial supply of the demand for the family (O Brien, 2014) system. The cumulative volume of water storage is a function of the cumulative volume of water stored in the tank at the end of the time interval (V_t, in m^3).

$$V_t = V_{(t-1)} + I(t) - O(t) \tag{4}$$

Where:

V_t = the volume of water stored in the tank at the end of the time interval (in m^3),

$V_{(t-1)}$ = the volume of water stored in the tank at the end of the previous time interval (in m^3).

This process is iterative see Figure 2, if the final residue is greater than 0 as a value (+), there will be an excess at the end of the period and if the default is less than 0 as a value ( ) there will be a deficit at the end of the period, so you must return to step 2, varying the value of the number of users and the demand that satisfies and reach a balance.

Second, with the daily supply and demand data, the simple difference $I(t)$ $O(t)$ is made, of these values the sum is made, only of the data that is less than zero < 0.001, ensuring that only the negative values are added (results in deficit), since what matters is only to store what is missing each day. Table 2 - *Col*.9 subtracted all daily values of *Col*.4 and *Col*.5, obtaining daily difference values, and all negative (*negative values of Col*.9) = *V* values were added.

The result is the sustainable storage volume *V* for a data set of *A*, *n*, *D*, *P*, calculated, according to the proposed procedure.

Correlation and multiple nonlinear regression

There is a correlation between two or more variables when the values of one variable are in some way associated with the values of the other variable (Triola, 2018).

The study obtained several data such as: cover area (*A*), number of habitants (*n*), water demand per habitant (*D*), sustainable storage volume (*V*), and Average monthly total rainfall (*PT*) value that represents rainfall as a source of supply. So the statistics were applied to these data, to verify the existence of a correlation between the variables. Its multiple correlations were analyzed with the use of the adjusted R^2 value and the *P value* value as measures of how well the multiple regression equation fits the data obtained.

And finally, “the multiple regression equation [...] that expresses a linear or nonlinear relationship between a response variable and two or more predictor variables ($x1, x2, \ldots, xk$) is determined” Triola (2018). The general form of a multiple regression equation obtained from data obtained is Equation 5.

$$y = b_0 \cdot x_1^{b_1} + x_2^{b_2} + \cdots x_k^{b_k} \tag{5}$$

Where:

x = independent variable or predictors,

y = dependent variable,

k =number of predictor variables (also called independent variables or *x* variables).

With the equations obtained, a comparison is made with real values of storage volumes of tanks built in different countries, and that used the Rippl method criterion (Method 2). For this purpose, the measure of variation most commonly used in statistics (Triola, 2018), the standard deviation, was used (SD).

$$SD = \sqrt{\frac{\sum (x-\overline{x})^2}{n-1}} \qquad (6)$$

Where:

SD = standard deviation,

x = values,

$\overline{x}$ = average,

n = total number of values.

Results and discussion

From the data set (results obtained in spreadsheets) we have 6325 data divided into: area (A), number of inhabitants (n), demand (D), volume (V), and annual precipitation (TP); from these data we are interested in obtaining two expressions that correlate these variables, in this way the dependent variable in the first expression will be the demand (D) and in the second will be the volume (V).

As can be seen in Figure 4, the Pearson correlation test was carried out to see the association between these variables. What can be seen is that the demand variable (D) is related to variables (A), (n), (V) and (PT), and it can also be seen that the volume variable (V) is related to variables (A), (D) and (PT) and not to (n), (excluding it as part of the second expression).

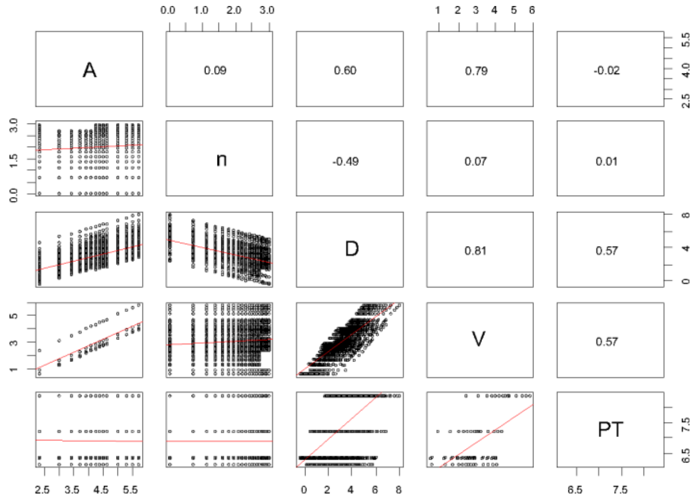

Figure 4: A plot of correlated variables *A, n, D, V, PT*

Table 6: Correlation values R, R^2 y $P - value$

Correlation	R	R^2	$P - value$
linear	0.7514	0.7506	2.20E-16
nonlinear	0.9961	0.9961	2.20E-16

The root of the information from which the variables start is also analyzed internally, so as not to introduce variables that are part of another variable internally. For the demand variable (D), (V) is excluded, since for several demands (D) in the same area (A), when equilibrium is reached, a single value of (V) is obtained (see Figure 5), in this figure extracted from the calculation as an example of the station San Calixto, you see the scenario $A = 250(m^2)$ and 20 habitants (value of n) comes into balance (after several iterations) with a demand $D = 16$, 594(*l/day*) and whose sustainable volume is $V = 43.00(m^3)$ and that is the same value for the scenario $A = 250(m^2)$ with $n = 5(hab)$ and $D = 66, 377(l/day)$ also in equilibrium.

But, as seen in Figure 2, "the storage will have a different result if a scenario of water demand not suitable for the system in equilibrium is taken, [...] which implies the need to simulate several scenarios to obtain the volume of storage that leads to an efficient and viable system" Matos et al. (2013).

For the volume variable (V), (D) is excluded, since when the system enters into equilibrium, the demand values have no relation for the definition of sustainable volume (V_{sost}), since the supply in equilibrium only depends on the contribution area (A) of RWH and the annual precipitation (PT).

Likewise, the variables correlation test was done, to know if they have a linear or non-linear coefficient, even though both correlations give similar *P- value*, see Table 6, but the highest values of R and R^2 are from the non-linear correlation, so the multiple non-linear regression must be done.

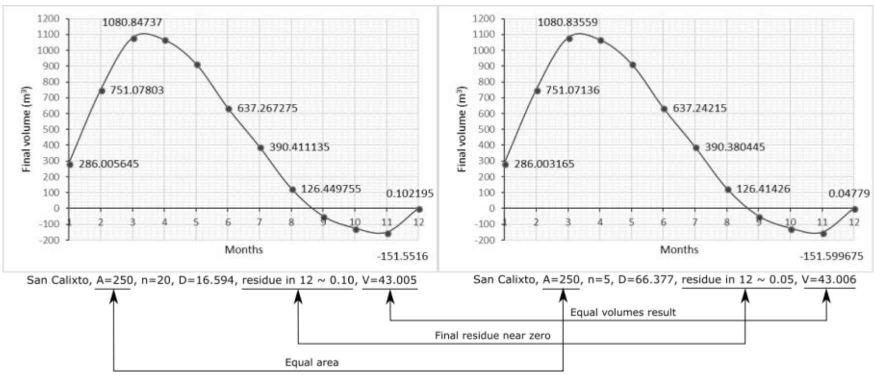

Figure 5: Example of balance calculation between demand and supply

From the results of the data set and the correlation analysis it is seen that the variable (D) has as predictive variables (A, n, PT), reaching a set of 5060 data, the variable (V) has as predictive variables a (A) and (PT), reaching a set of 3795 data. This data is what generates the coefficients of the multiple nonlinear regression for D_{max} and V_{sost}, see Table 7.

Table 7: Multiple nonlinear regression

Variable	Intercept	A	n	PT
D_{max}	-6.1997151	1.0000229	-0.9999862	1.0201194
V_{sost}	-7.0354355	1.0046684		0.8290742

Table 8: Comparison of real cases of RWH with values of the new equation

Cases, Location	**Annual rainfall (*mm/year*)**	**Roof area (m^2)**	**Storage V_1 - cases (m^3)**	**V_2 – eq. (m^3)**	**$V_1 - V_2$ (m^3)**
Eugene, Oregon, U.S	1067	95.1	30.28	27.71	2.57
Kleinmond, Western Cape, S. Africa	514	44.5	5.00	7.05	-2.05
Ruganzu, Biharamulo, Tanzania	1056	190.0	50.00	55.05	-5.05
Tegucigalpa, Honduras	700	100.0	28.00	20.54	7.46
Far Northeast H., Albuquerque, U.S	220	213.7	16.28	16.89	-0.61
Downtown, Albuquerque, U.S	220	153.3	6.25	12.10	-5.85
Northeast Heights, Albuquerque, U.S	220	157.9	6.25	12.46	-6.22
North Valley, Albuquerque, U.S	220	167.2	8.33	13.20	-4.87
Foothills, Albuquerque, U.S	220	92.9	4.16	7.31	-3.15
Mesa del Sol, Albuquerque, U.S	220	77.6	2.01	6.10	-4.10
Southwest, Albuquerque, U.S	220	97.5	2.01	7.68	-5.68
East Downtown, Albuquerque, U.S	220	113.8	3.79	8.97	-5.18
Southwest, Albuquerque, U.S	220	464.5	19.31	36.85	-17.54
Ghana, N.E.region, Africa	800	30.0	7.50	6.85	0.65
Swaziland, Lowveld, Africa	635	30.0	5.00	5.65	-0.65
Botswana Francistown, Africa	470	30.0	4.50	4.40	0.10
Java, Jakarta area, Indonesia	1800	30.0	7.80	13.41	-5.61
Madura, Indonesia	1500	30.0	5.00	11.53	-6.53
Khon Kaen area, Thailand	1300	60.0	11.50	20.54	-9.04
Khon Kaen area, Thailand	1300	30.0	5.80	10.24	-4.44
Sydney, Australia	1210	320.0	126.00	104.05	21.95
Sydney, Australia	1210	30.0	11.80	9.65	2.15
Griffith, New S. Wales, Australia	390	30.0	10.50	3.77	6.73
Area, Bermuda	1500	30.0	11.70	11.53	0.17

With the values of Table 7 the mathematical expressions that correlate the solutions in multiple non-linear regression equations are generated, see Equations 7 and 8.

$$D_{max} = 2.03 \times 10^{-3} \cdot A^{1.00} \cdot n^{-1.00} \cdot PT^{1.02} \quad (7)$$

$$V_{sost} = 8.80 \times 10^{-4} \cdot A^{1.00} \cdot PT^{0.83} \quad (8)$$

The standard deviation (*SD*) of the differences between V_1 V_2 of the 24 values extracted from real cases (see Table 8) of (Matt and Cohen, 2001; O Brien, 2014; Rees and Ahmed, 1998; Dos Anjos, 1998; Authors, 2010; UN-HABITAT, 2005), reached a value of 7.24, with an average of -1.87, and whose *non-significant* values of the variation reached 91.67%, and only 8.33% of the values were *significant* of the variation of the data set. In Figure 6 a 95% confidence interval is represented which will give a higher level of confidence reaching 22 data (92% of the calculated data); while for a smaller interval of 60%, which gives a more precise estimate in the results, which in the present study reaches 19 data (79% of the calculated data), being very satisfactory that the great majority of the data set is within these confidence intervals.

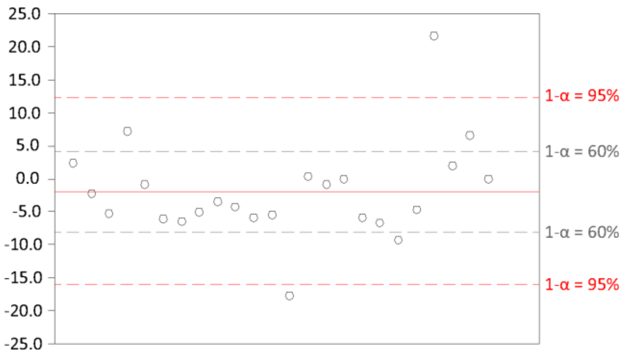

Figure 6: Confidence interval for 1-α = 95% and 60%

CONCLUSIONS

In this article, two alternative mathematical expressions to the usual methodology of design of the volume of storage of RWH in roofs were determined, obtaining firstly the expression that correlates the solutions or solution curves in a potential equation that provides the maximum daily demand (*l/day*) per person of rainwater (D_{max}), with the information of the daily distribution of rain immersed within the annual distribution of rain (PT), the roof surface of your building (A), and the number of inhabitants in your building (n), facilitating the calculation procedure when determining the variables that will be adjusted to obtain a representative mass curve or accumulated volumes and that the last month has a value close to zero, achieving a balance between the annual periods of supply and demand. And obtaining in the second expression, the maximum volume of sustainable storage (V_{sost}) of a potential equation, with the information of the annual precipitation of the city (PT) a value of easy obtaining in internet, the surface of the roof of its building (A) that also is easy to measure.

From this volume value (V_{sost}) that absorbs the variables of rainwater supply, demand, harvesting area, you can make the analysis of economic-financial sustainability and quality that depends on the quality of roofs and tanks, water purification according to final use and budget or costs to determine the volume to build, and proceed to quickly recalculate the daily demand (D_{max}) that this new system is able to balance.

Unlike the usual procedure (based on the supply with the Rippl method or mass curves) that induces us to determine volumes with excess or deficit at the end of the period, and that must be calculated several times until obtaining the volume in equilibrium, which demands time in its elaboration and information with more detail, or simple methods (based on the demand) that gives a very big volume. So with these two new mathematical expressions, we avoid repetitive calculations (trial and error process) and exaggerated overdimensioning.

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