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Sizing rainwater harvesting systems for animal watering in semi-arid regions

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Abstract

Brazilian semi-arid productive techniques use rainwater harvesting systems, which are a sustainable water management practice with a low environmental impact that have been adopted as an alternative to meet water demand worldwide. The aim of this study was to find an optimal sizing methodology for rainwater harvesting systems using local parameters allied to the lowest system cost. The analyses were based on a system supplying 95% of a 250 L/d demand for a goat herd in Feira de Santana, Bahia, Brazil. The area available for system implementation did not limit the analysis. The only limiting parameters were the quantity and quality of water required for the herd. The results indicated that, among the combinations of catchment area and water tank volume capable of meeting the defined demand, there is an optimal set, with minimum cost. This was a catchment covering 220 m^2 with a 21.1 m^3 water tank, equivalent to a 0.62 demand fraction (F_D). The variance influence of meeting service efficiency and demand, in the system's implementation and performance, was also analyzed.

Key words: goat breeding, livestock, optimization, rainwater systems, reservoir sizing

INTRODUCTION

The average annual precipitation in Brazil's semi-arid region is 750 mm, and the average annual evapotranspiration 2,500 mm (Montenegro & Montenegro 2012). In addition to irregular precipitation distribution through the year, the region is characterized by shallow soils with low infiltration capacity and scarce groundwater resources. These conditions lead to high water deficits, limiting the agricultural and livestock productivity of the region (Alves *et al.* 2016).

Goat husbandry stands out as an effective choice for Brazil's northeastern semi-arid region. Goat farming does not need large areas and, unlike other species, goats have low water loss, making them resistant to the high-temperature variance and water stress typical of the region (Kaliber *et al.* 2016).

Brazil's Northeast Region is home to approximately 9.1 million goats (Figure 1), about 93.0% of the Brazilian herd (IBGE 2016). However, the limited capacity of water support, associated with low water quality, affects goat farming negatively in the region (Mdletshe *et al.* 2017).

Worm infections are a serious sanitary problem in goat farming, and directly related to water supply quality. Infection affects the welfare of the animals and increases their stress levels, compromising production efficiency and quality (Palhares & Guidoni 2012; Mad-Ali *et al.* 2018).

In this type of scenario, rainwater harvesting and storage systems (RWHSs) are technically feasible alternatives. They are already used for both domestic purposes and animal production (Ayantunde *et al.* 2018; Vargas *et al.* 2019).

In the Northeast Region, the 'One Land Two Waters Program' (Programa Uma Terra Duas Águas – P1 + 2) has been the basis for implementing one RWHS each for domestic, farming and livestock use in each rural property (ASA 2019).

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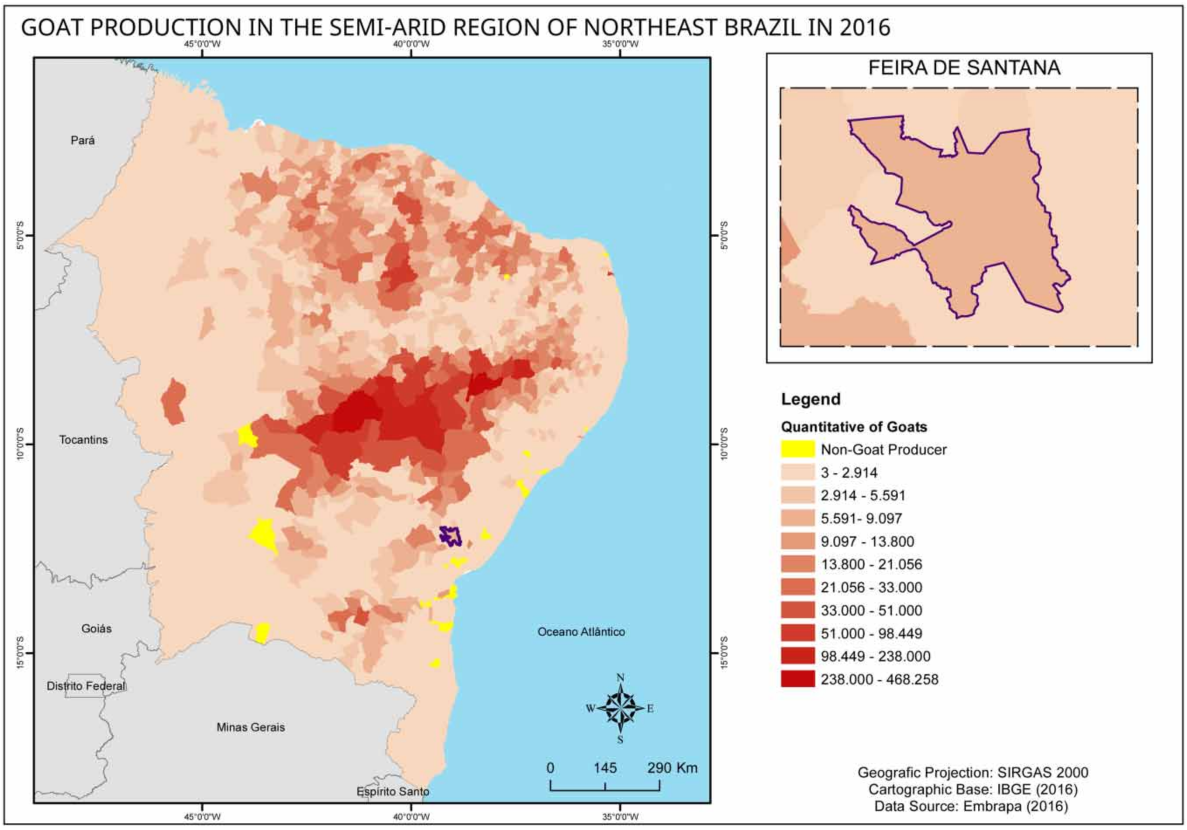

Figure 1 | Feira de Santana's location in Brazil's Northeast Region, with emphasis on the country's main goat farming areas.

International experience has shown successful use of RWHS in agricultural production (Rockström & Falkenmark 2015; Yosef & Asmamaw 2015) and animal production (Ayantunde *et al.* 2018; Londra *et al.* 2018). In Brazil, rainwater is used in poultry, pig and cattle husbandry (Palhares & Guidoni 2012; de Proença *et al.* 2015; Feitosa *et al.* 2018).

Despite the above, adequate system design methodologies have not been adopted, limiting the systems' potential. Suitable use of relevant parameters – for example, catchment area, and average annual precipitation and distribution – individualize the results for each region (Ghisi 2010; Araujo & Cohim 2016). Studies have shown that using uniform water tank volumes and/or catchment areas decreases system efficiency (Cohim & Orrico 2015; Gomes 2017).

An approach is needed that relates demand-meeting efficiency with an optimal RWHS, including tank capacity and catchment area in an integrated system approach, and allowing the greatest return on investment in the region's water infrastructure.

In this study, an optimal design method for RWHSs for goat husbandry is proposed in relation to the northeast region's semi-arid conditions, with a case study in Feira de Santana Bahia.

MATERIALS AND METHODS

Study area

Feira de Santana is in the central-north of Bahia, Brazil, between the Recôncavo Basin and the semi-arid region (Figure 1). The city's rainfall regime is well defined, with 43% precipitating from April to July. Precipitation data were extracted from the INMET platform (2018), for the Feira de Santana Station, code 83221, for the period 1 January 1998 to 31 December 2017 (20-year period). The annual average was 664 mm.

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Rainwater harvesting systems

The system design was based on the P1 + 2 model, which uses a surface covered with concrete slabs, known as boardwalks, as a catchment area. This is a low cost and widely used technology in Brazil's semi-arid region because of the One Land Two Waters Program (P1 + 2). The system has plate-type cisterns produced using concrete slabs and built *in situ* by a voluntary workforce from the region. The catchment area is constructed to incline at 2%. The system also includes a decanter for solids removal, improving the quality of the stored water. Figure 2 shows a typical layout (floor plan and section) of a catchment x cistern system.

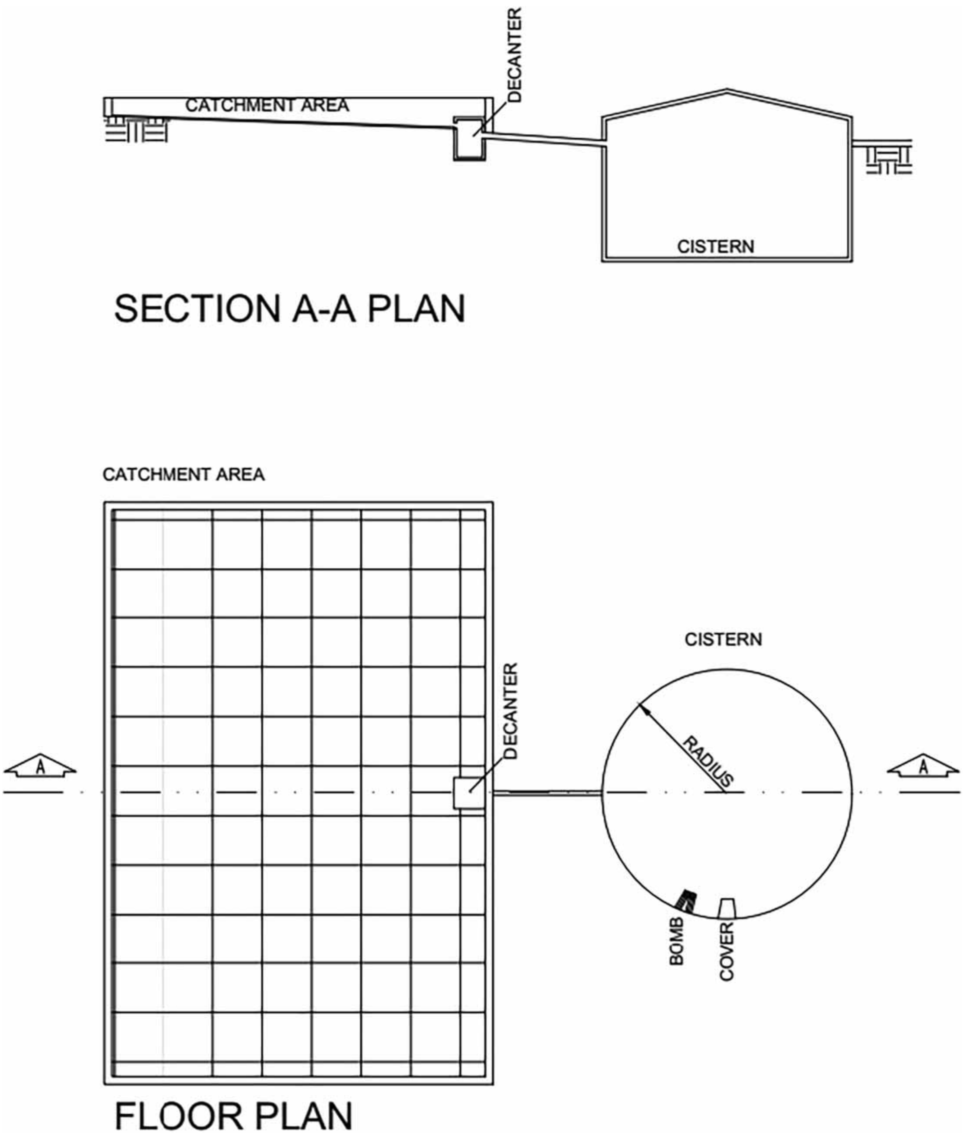

Figure 2 | Layout of the boardwalk and cistern system (floor plan and section).

Calculation criteria

To calculate the daily demand, a herd of 50 goats was considered – the average size in the region (IBGE 2012), (Table 1) with average water consumption per goat of 5 L/d. Total water consumption was thus 250 L/d.

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Table 1 | Goat headcounts in agricultural establishments

	Goat headcount							
Region herd size	**1–4**	**5–9**	**10–19**	**20–49**	**50–99**	**100–199**	**200–499**	**>500**
Semi-arid Brazil	3.7%	8.1%	16.9%	31.9%	18.5%	10.4%	8.2%	2.3%
Semi-arid Bahia	1.9%	5.5%	14.8%	33.1%	21.1%	11.2%	9.4%	3.0%

System behavior was modeled on the basis of serial water balances at daily intervals (Fewkes 2000) – Equations (1)–(4):

$$Q_{(t)} = P_{(t)} x A x C \tag{1}$$

$$Y_{(t)} = min\left\{ \begin{array}{c} D_{(t)} \\ V_{(t-1)} + \theta Q_{(t)} \end{array} \right\} \tag{2}$$

$$V_{(t)} = min\left\{ \begin{array}{c} (V_{(t-1)} + Q_{(t)} - \theta Y_{(t)}) - (1-\theta) Y_{(t)} \\ R - (1-\theta) Y_{(t)} \end{array} \right\} \tag{3}$$

where $Q_{(t)}$ (L) is the volume of water flowing in interval t (day), $P_{(t)}$ precipitation (mm), A the catchment area (m²), and C the flow coefficient, which is taken as 0.8. The coefficient θ varies between 0 and 1. When $\theta = 0$, it describes the condition where consumption of daily demand is complete before the rainwater runoff in the time interval is added to the tank, when $\theta = 1$ it was made afterwards. In this study, θ was taken as 0.6. $Q_{(t)}$ (L) is the water demand in time interval t, $V_{(t)}$ the water volume stored in the same interval (L), R the cistern's reserve capacity (L), and $Y_{(t)}$ (L) the yield of what is stored in interval t.

Equation (4) was used to verify the service efficiency of the RWHS in meeting the demand:

$$E_A(\%) = \frac{\sum Y_{(t)}}{\sum D} \times 100 \tag{4}$$

where $\sum Y_{(t)}$ and $\sum D$ correspond to the sum of the rainwater volume used and the demand, respectively, during the period concerned.

The tank volumes and related catchment areas were calculated assuming an E_A – Equation (4) – equal to 95%. E_A reflects the overall system performance for the simulated period. Thus, system performance for each year of the series was analyzed, taking into account the rainfall anomaly index (RAI) and the precipitation concentration degree (PCD).

The RAI characterizes dry and rainy year severity on the basis of annual precipitation volume (Pereira *et al.* 2017), and is calculated for each year using Equations (5) and (6).

For positive anomalies:

$$RAI = 3\left[\frac{(N - \bar{N})}{(M - \bar{N})}\right] \tag{5}$$

For negative anomalies:

$$RAI = 3\left[\frac{(N - \bar{N})}{(\bar{X} - \bar{N})}\right] \tag{6}$$

where, N is the annual precipitation (mm), $\bar{N}$ (mm) the historic series annual average, $\bar{X}$ (mm) the average of the seven lowest annual precipitations in the series, and M the average of the seven highest annual precipitations.

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To calculate PCD, the year, based on the trigonometric circle, is divided into 12 parts (months) at an angle of 30°. R_i corresponds to the annual precipitation, and R_{xi} and R_{yi} correspond to the annual precipitations from the x- and y- axes, respectively. r_{ij} is the monthly precipitation, in which i and j represent the year and month, respectively. PCD was calculated using Equations (7)–(10) (Li *et al.* 2011) and varies from 0 to 1. Values close to 0 represent well-distributed rainfall through the year, while values close to 1 indicate the concentration of rains in a shorter period (Araujo & Cohim 2016).

$$R_i = \sum r_{ij} \tag{7}$$

$$R_{xi} = \sum r_{ij} sin\theta_{ij} \tag{8}$$

$$R_{yi} = \sum r_{ij} cos\theta_{ij} \tag{9}$$

$$PCD = \frac{\sqrt{R_{xi}^2 + R_{yi}^2}}{R_i} \tag{10}$$

The model was tested for the highest catchment area costs and a catchment area already available, and finally, for demand values that could supply herds of between 30 and 500 goats.

Some analyses were based on the dimensionless standard parameter F_D (demand fraction), depending on the quantity and variety of parameters used for the simulation. F_D expresses the relationship between annual demand, D (L), and the product of the catchment area, A (m^2), and average annual precipitation, P (mm) (Fewkes 2000) – Equation (11).

$$F_D = \frac{D}{A^*P} \tag{11}$$

Costs

The systems' costs were calculated on the basis of the materials and workforce required for construction, etc. Operating and maintenance costs were not considered.

Budgets were made for cisterns with capacities of between 5 and 100 m^3, allowing interpolation to obtain the costs of cisterns of any capacity in that interval. For the catchment area, the average unit cost was budgeted, allowing calculation of the total cost (TC) of a catchment area.

RESULTS AND DISCUSSION

The cost curves obtained for the catchment system components are shown in Figure 3.

Curves for five capture areas of different sizes – 163, 180, 200, 250 and 300 m^2 – are shown in Figure 4. Tank capacities above 45,000 L were omitted to make the figure clearer. Figure 4 shows that, for $E_A = 95\%$, the 250 L/d demand could only be met satisfactorily with a catchment area of about or exceeding 180 m^2. As can be seen, there is a volume that satisfies the demand with the desired efficiency, for each catchment area, and for a catchment area of 163 m^2, the tank volume is over 90,000 L (Table 2), which makes RWHS deployment uneconomic. It is noted that, for the same service (E_A) and demand levels, larger catchment areas need relatively smaller cisterns.

Technically, all catchment area and cistern combinations have the same service efficiency, which is characteristic of a mathematical indeterminacy. However, as Table 2 shows, the TC is different for each combination.

TC is the sum of two plots whose tendencies are inverse. As the catchment area increases, its cost increases while that of the cistern decreases. Thus there must be a minimum TC value, which is the optimum sought – see Table 2.

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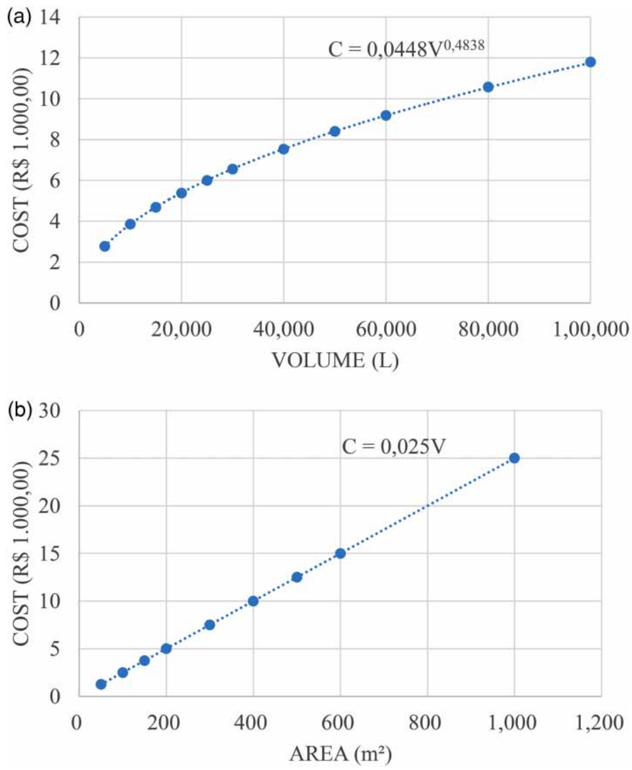

Figure 3 | Cost of constructing cisterns (a), and catchment areas (b).

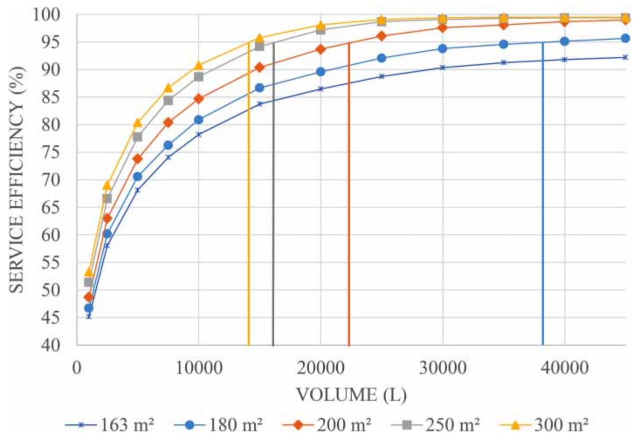

Figure 4 | Cistern volume × service efficiency for different catchment areas.

Table 2 | Comparison of RWHS cost to meet demand of 250 L/d, with various combinations of catchment area and cistern capacity

Catchment area (m²)	Cistern volume (m³)	Catchment area cost	Cistern cost	Total cost
163	94.9	R$ 4,080.00	R$ 11,460.00	R$ 15,540.00
180	38.8	R$ 4,500.00	R$ 7,432.09	R$ 11,932.09
200	25.5	R$ 5,000.00	R$ 6,067.66	R$ 11,067.66
250	17.0	R$ 6,250.00	R$ 4,987.97	R$ 11,237.97
300	14.6	R$ 7,500.00	R$ 4,634.25	R$ 12,134.25

Note – R$ 1 is roughly US$ 0.25.

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The TC curve for a 95% E_A demand (Figure 5) was obtained by applying the cost equations (Figure 3) to a range of catchment areas and their respective volumes. The equation for the TC curve provided a good fit to the data points, with $R^2 = 0.99$. The minimum value is obtained by equating the equation's first derivative to zero and solving it for variable A (catchment area). For 250 L/d demand and 95% E_A, the optimal solution is A = 220 m² and V = 21.1 m³, at TC = R$11,029.25 (Figure 5).

As there is considerable variation in the catchment area materials and surfaces – for example, ceramics, metal and paving – the sensitivity of the model to their cost variations was evaluated. The results are presented in Figure 6.

Increasing the catchment area cost leads to a smaller optimal area, which is reflected in the total system cost. The area, volume, and cost values are shown in Table 3.

If a usable catchment area already exists, the related costs decrease but the optimal area does not change (Figure 7). This is because the catchment area cost curve behavior maintains the same angular coefficient with a smaller intercept value as the area available increases.

Table 4 shows the results of a year-by-year analysis of the system's reliability for the criterion E_A = 95%. The data indicate that in 17 of the 20 years in the study, reliability is equal to or exceeds 90%, thus justifying use of the E_A = 95% criterion adopted.

On the basis of the RAI and local standards, there was a predominance of wet periods in the series during the period studied. The three years in which E_A was below 90% were precisely those classified as extremely dry. The results are not as consistent, however, for the other years. For example, the years classified as 'dry' between 2001 and 2011 have reliability of 100%, while those between 2004 and

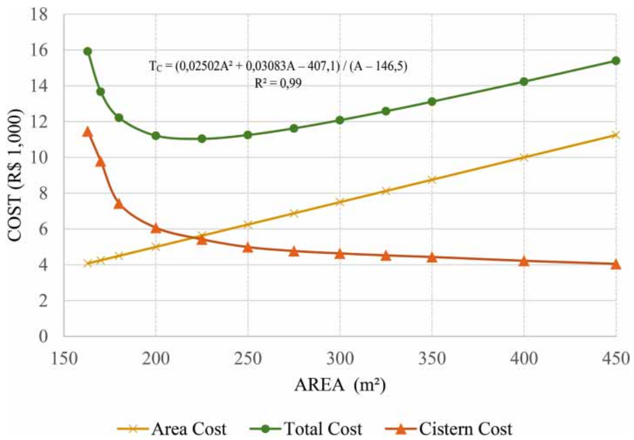

Figure 5 | System component costs and total cost for D = 250 L/d and E_A = 95%.

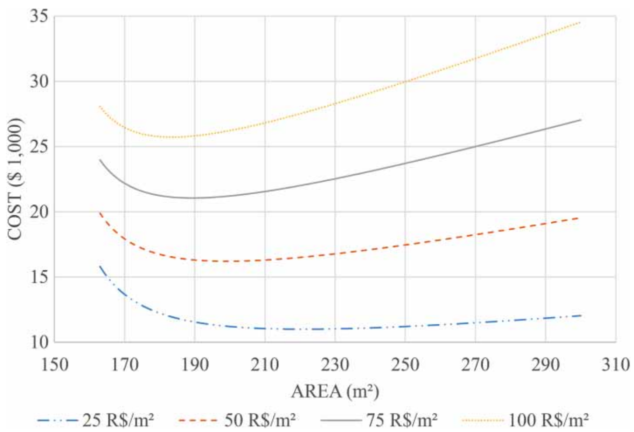

Figure 6 | System cost variation with catchment area cost.

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Table 3 | Comparison of system cost sensitivity to catchment area cost

Area cost/m²	Optimal area/m²	Volume/m³	Cost
R$ 25.00	220	21.1	R$ 11,001.61
R$ 50.00	199	25.6	R$ 16,210.22
R$ 75.00	189	29.0	R$ 21,057.70
R$ 100.00	184	33.8	R$ 25,727.03

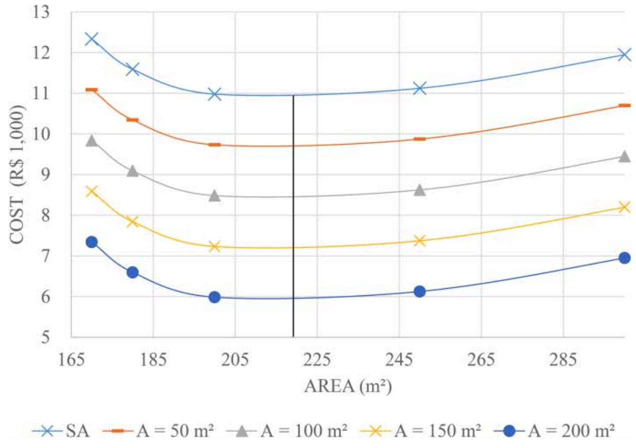

Figure 7 | System cost vs. variation in existing catchment area.

Table 4 | Precipitation, reliability, RAI and PCD in the period 1998 to 2017.

Year	P (mm/a)	Reliability (d)	Reliability	PCD	Intensity class (RAI)
2013	372	236	65%	0.26	Extremely dry
2012	375	237	65%	0.25	
2017	425	275	75%	0.26	
2009	582	331	91%	0.39	Dry
1998	586	327	90%	0.39	
2011	604	365	100%	0.11	
2001	619	365	100%	0.15	
2002	644	365	100%	0.15	
2016	670	330	90%	0.39	Wet
2015	670	365	100%	0.18	
1999	689	365	100%	0.25	
2014	714	365	100%	0.07	
2006	716	345	95%	0.35	
2007	766	335	92%	0.38	Very wet
2004	774	353	97%	0.35	
2005	783	365	100%	0.14	
2003	785	365	100%	0.29	
2008	792	365	100%	0.13	
2010	850	365	100%	0.27	Extremely wet
2000	864	365	100%	0.04	

The table is organized in order of increasing depth of precipitation in the year.

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Table 5 | Comparison between system costs for $F_{Doptimal}$ and F_D average

Demand (L/d)	$F_{D\ optimal}$	Cost ($F_{D\ optimal}$ R$)	Cost (F_D Average R$)	Variation
150	0.60	R$ 7.566.78	R$ 7.747.58	2%
250	0.62	R$ 10.915.52	R$ 11.110.32	2%
350	0.64	R$ 14.018.85	R$ 14.181.39	1%
450	0.66	R$ 16.951.31	R$ 17.138.95	1%
550	0.67	R$ 19.752.36	R$ 19.973.19	1%
650	0.68	R$ 22.504.25	R$ 22.763.68	1%
1,000	0.70	R$ 31.645.70	R$ 32.138.90	2%
1,500	0.72	R$ 43.946.00	R$ 44.883.98	2%
2,000	0.73	R$ 55.759.00	R$ 57.025.61	2%
2,500	0.74	R$ 67.178.00	R$ 69.328.84	3%

2007, classified as very wet, do not achieve that level – that is, maximum reliability. This is explained by the PCD, which is influenced by precipitation distribution through the year (Li *et al.* 2011).

It is noted that E_A is 100% in years with below-average precipitation – for example, 2011 with 604 mm – while in 2007, with 766 mm, the E_A achieved is 92%.

As shown in Table 4, in all years with PCD exceeding 0.3 the E_A reached 100%, which proves the PCD's importance. That, in turn, confirms that basing the RWHS design solely on the guaranteed annual precipitation yields inadequate results. For example, Zhu *et al.* (2015) recommend that RWHS design for animal watering is based on rainfall equal to or exceeding 70%, corresponding approximately to a 1.5 year return period.

In order to generalize application of the methodology, the sensitivity of $F_{Doptimal}$ to other demand values were analyzed. Demands from 150 to 2,500 L/d· were tested, corresponding to the demands of 90% of the goat herds in Brazil's northeast Region – see $F_{Doptimal}$ values (in Table 5, column 3. The variation is sufficiently small (SD = 0.01), however, in view of the inherent uncertainties in the rainfall data, to justify use of the average F_D value = 0.67. Adopting this value to calculate the area and tank volume, TC values are obtained that differ by no more than 3% from the specific values of each demand (Table 5).

CONCLUSIONS

Definition of the catchment area and tank capacity to meet a given demand and service efficiency is a mathematically indeterminate problem. The solution can be obtained by minimizing the TC of the rainwater harvesting system, which comprises the sum of the catchment area and cistern costs.

As several combinations of catchment area and cistern volume can meet the required service efficiency, this methodology has shown that the installation cost is an adequate system choice criterion. For any given combination of demand level and service efficiency, the higher the catchment area's unit cost, the smaller the area yielding the lowest TC.

The availability of a suitable catchment area does not change the value of $F_{Doptimal}$, although it does reduce the total system cost.

A 95% service efficiency in animal watering was adequate in Feira de Santana, where 100% was achieved in 11 of the 20 years and more than 90% in 17 of them.

The year by year performance of the system, measured by service efficiency, is influenced by the RAI and the PCD.

An increase in demand of more than 1,600% causes an increase of less than 25% in the value of $F_{Doptimal}$. Use of the average $F_{Doptimal}$ for demand range tested in the RWHS design in Feira de

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Santana yields a maximum difference of 3% in total system cost compared to that calculated with the actual $F_{Doptimal}$.

REFERENCES

Alves, D. V., Nunes, J. S. & Faria, L. P. P. 2016 Aplicabilidade do aproveitamento de águas pluviais em grandes centros urbanos: estudo de caso aplicado a uma residência de Belo Horizonte (MG). (Applicability of rainwater harvesting in large urban centers: a case study applied to a residence in Belo Horizonte (MG)). *Revista Petra* **2**(2), 174–189.

Araujo, J. F. & Cohim, E. 2016 A influência da variação sazonal das chuvas no volume de cisternas de água no estado da bahia (The influence of seasonal rainfall variation in the volume of water tanks in Bahia state). *Anais Seminário de Iniciação Científica* **4**(21), 1–4.

ASA 2019 *Articulação do semiárido Brasileiro (Brazilian Semi-Arid Articulation)*. Available from: http://www.asabrasil.org.br/Portal/Informacoes.asp?COD_MENU=1558&WORDKEY.

Ayantunde, A. A., Cofie, O. & Barron, J. 2018 Multiple uses of small reservoirs in crop-livestock agro-ecosystems of Volta basin: implications for livestock management. *Agricultural Water Management* **204**, 81–90.

Cohim, E. & Orrico, S. R. M. 2015 A confiabilidade do volume das cisternas da zona rural para reservar água de chuva.(The reliability of cistern volumes in rural areas to reserve rain water). *Revista Gesta* **1**(d), 91–99.

de Proença, G. G., Schmidt, C. A. P. & dos Santos, J. A. A. 2015 Dimensionamento de cisterna para aproveitamento de água da chuva para granjas de suínos. (Sizing cisterns for rainwater use on pig farms). *Revista Técnico-Científica* **1**(3), 1–7.

Feitosa, E. R., Yada, M. M. & Soares, N. M. 2018 Uso de cisternas na captação da água da chuva para uso animal (Use of tanks in the ratio water capture for animal use). *Revista Interface Tecnológica* **15**(1), 305–314.

Fewkes, A. 2000 Modelling the performance of rainwater collection systems: towards a generalised approach. *Urban Water* **1**(4), 323–333.

Ghisi, E. 2010 Parameters influencing the sizing of rainwater tanks for use in houses. *Water Resources Management* **24**(10), 2381–2403.

Gomes, L. S. 2017 *Avaliação da eficiência de cisternas utilizadas no P1MC frente aos diferentes regimes pluviais do Rio Grande do Norte. (Evaluation of the Efficiency of Cisterns Used in P1MC Against the Different Rainfall Regimes of Rio Grande do Norte)*. Bachelor's thesis, Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Brazil.

IBGE 2012 *Censo Agrícola (Agricultural Census)*. Available from: https://ww2.ibge.gov.br/home/estatistica/economia/ppm/2012/.

IBGE 2016 *Efetivos da pecuária (Livestock Effects)*. Available from: https://brasilemsintese.ibge.gov.br/agropecuaria/efetivos-da-pecuaria.html.

INMET 2018 *Estações convencionais (Conventional Stations)*. Available from: http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesConvencionais.

Kaliber, M., Koluman, N. & Silanikove, N. 2016 Physiological and behavioral basis for the successful adaptation of goats to severe water restriction under hot environmental conditions. *Animal* **10**(1), 82–88.

Li, X., Jiang, F., Li, L. & Wang, G. 2011 Spatial and temporal variability of precipitation concentration index, concentration degree and concentration period in Xinjiang, China. *International Journal of Climatology* **31**(11), 1679–1693.

Londra, P. A., Theocharis, A. T., Baltas, E. & Tsihrintzis, V. A. 2018 Assessment of rainwater harvesting tank size for livestock use. *Water Science and Technology: Water Supply* **18**(2), 555–566.

Mad-Ali, S., Masniyom, P. & Benjakul, S. 2018 Characteristics and properties of goat meat gels as affected by setting temperatures. *Food Chemistry* **268**, 257–263.

Mdletshe, Z. M., Chimonyo, M., Marufu, M. C. & Nsahlai, I. V. 2017 Effects of saline water consumption on physiological responses in Nguni goats. *Small Ruminant Research* **153**, 209–211.

Montenegro, A. A. & Montenegro, S. M. G. L. 2012 Olhares sobre as políticas públicas de recursos hídricos para o semiárido.(Review of public water resources policies for semi-arid areas). *Recursos hídricos em regiões semiáridas: Estudos e aplicações.* **1**, 282.

Palhares, J. C. P. & Guidoni, A. L. 2012 Qualidade da água de chuva armazenada em cisterna utilizada na dessedentação de suínos e bovinos de corte. (Quality of rainwater stored in cisterns used in the digestion of swine and beef cattle). *Embrapa Pecuária Sudeste-Artigo em periódico indexado (ALICE)* **7**(1), 244–254.

Pereira, M. L. T., Soares, M. P. A., Silva, E. A., de Assunção Montenegro, A. A. & de Souza, W. M. 2017 Variabilidade climática no Agreste de Pernambuco e os desastres decorrentes dos extremos climáticos. (Climatic variability in the pernambuco agreste and the disasters arising from climatic extremes). *Journal of Environmental Analysis and Progress* **2**(4), 394–402.

Rockström, J. & Falkenmark, M. 2015 Agriculture: increase water harvesting in Africa. *Nature News* **519**(7543), 283–285.

Vargas, D., Dominguez, I., Ward, S. & Oviedo-Ocana, E. R. 2019 Assisting global rainwater harvesting practitioners: a decision support tool for tank sizing method selection under uncertainty. *Environmental Science: Water Research & Technology* **5**(3), 506–520.

Yosef, B. A. & Asmamaw, D. K. 2015 Rainwater harvesting: an option for dry land agriculture in arid and semi-arid Ethiopia. *International Journal of Water Resources and Environmental Engineering* **7**(2), 17–28.

Zhu, Q., Gould, J., Li, Y. & Ma, C. 2015 *Rainwater Harvesting for Agriculture and Water Supply*. Science Press. Gansu Research Institute for Water Conservancy. Lanzhou, China.