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Potential for potable water savings by using rainwater: An analysis over 62 cities in southern Brazil

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Abstract

Water availability has been a matter of concern all over the world. This paper describes the water availability scenario in the state of Santa Catarina, southern Brazil, and evaluates the potential for potable water savings estimated for the residential sector of 62 cities in the state. Water availability in Santa Catarina amounts to about 10,000 m^3 per capita per year, but it is predicted to be lower than 2000 m^3 per capita per year from 2100 onwards. As for the potential for potable water savings by using rainwater, it is shown that it ranges from 34% to 92% depending on the potable water demand verified in the 62 cities, with an average potential for potable water savings of 69%. Results demonstrate that if there were a government programme to promote potable water savings by rainwater usage, there would be significant potable water savings and a consequent preservation of water resources in the state of Santa Catarina.

Keywords: Water availability; Potable water savings; Rainwater usage in southern Brazil

1. Introduction

It has been reported that rainwater usage can promote significant potable water savings in residences in different countries. In Germany, a study performed by Herrmann and Schmida [1] showed that the potential for potable water savings in a house might vary from 30% to 60%, depending on demand and roof area. In Australia, Coombes et al. [2] analysed 27 houses in Newcastle and concluded that rainwater usage would promote potable water savings of 60%. In the UK, Fewkes [3] monitored the performance of a rainwater collector installed in a house in Nottingham and concluded that an average water saving efficiency of about 57% would be obtained. In Brazil, a study performed by Marinoski et al. [4] evaluated a multi-storey residential building composed of six blocks located in Florianópolis. Although the specific roof area per person in multi-storey buildings is low, a potential for potable water savings of about 40% was observed. Other studies on rainwater have also been performed in Singapore [5], Zambia [6], and China [7] to quote just a few.

Rainwater is abundant in most parts of Brazil. In the south region, which is composed of three states, average rainfall is 1615 mm per year [8]. A study performed over the three states of the southern region of Brazil showed a potential for potable water savings of 82% on average when there is rainwater usage in the residential sector [9]. Fig. 1 shows rainfall data for four cities located in the state of Santa Catarina for the period 1961–1990. Such data indicate that there is plenty of rainwater in the state of Santa Catarina. However, there is no government programme to promote rainwater harvesting. Nonetheless there are some people that are starting to collect rainwater in their homes in order to save potable water and to contribute to a sustainable world. These

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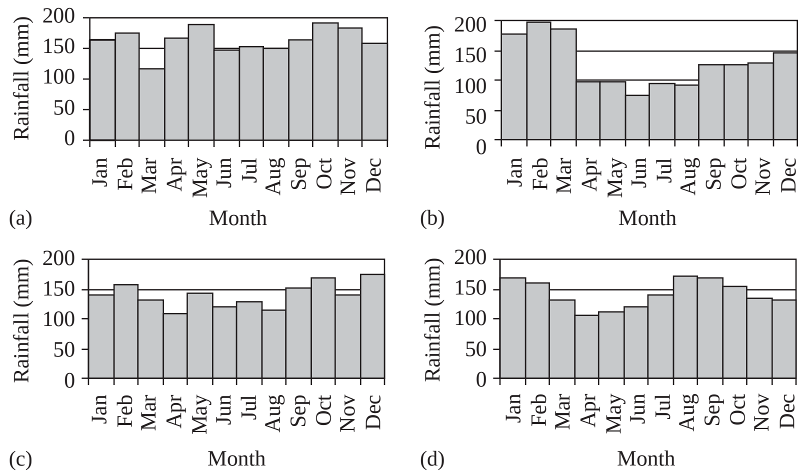

Fig. 1. Average rainfall for four cities in Santa Catarina over the period 1961–1990: (a) Chapecó—1954 mm per year; (b) Florianópolis—1544 mm per year; (c) Porto União—1678 mm per year; (d) São Joaquim—1693 mm per year.

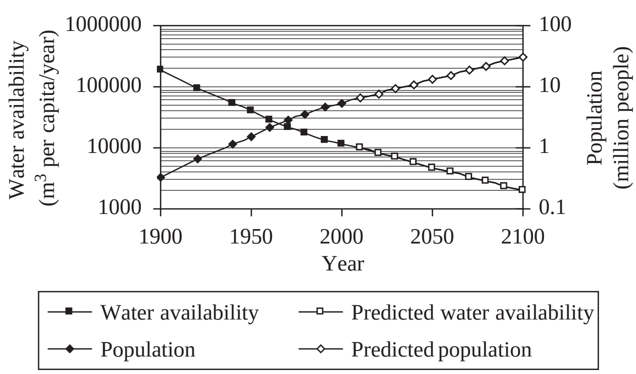

Fig. 2. Population and water availability in Santa Catarina from 1900 to 2100. *Source*: based on IBGE [11] and ANA [12].

people may not be aware but they are also contributing to ease a major problem of water availability that may surface in Santa Catarina in the near future.

Fig. 2 shows the population of Santa Catarina for the period 1900–2000 and the predicted population for the period 2000–2100 considering the growth rate observed between 1991 and 2000. There are about 6 million people in Santa Catarina at the moment, but the predictions indicate that there will be about 27 million people in the year 2100. Therefore, water availability, which is about 10,000 m^3 per capita per year at the moment, will be reduced to about 2000 m^3 per capita per year in the year 2100 (Fig. 2). According to UNEP's classification [10], Santa Catarina will have a medium water availability (5000–10,000 m^3 per capita per year) up to the year 2050; the water availability will be low from 2050 to 2100 and very low from about 2100 onwards as the water availability will be lower than 2000 m^3 per capita per year.

2. Objective

The main objective of this paper is to evaluate the potential for potable water savings by using rainwater in the residential sector of 62 cities located in the state of Santa Catarina, southern Brazil. Prediction of water availability as well as correlation between the potential for potable water savings and either water demand or rainfall are also investigated.

3. Methodology

To accomplish the objective specified above it was necessary to obtain rainfall data, potable water consumption, population and number of dwellings in each city included in the analysis. It was intended to consider all of the cities in the state of Santa Catarina. However, a full set of data was obtained for 62 cities only, representing about 33% of the land area of the state and 41% of the population. Fig. 3 shows a map of Brazil indicating the location of the state of Santa Catarina and also the location of the 62 cities in the state of Santa Catarina.

The total volume of potable water consumed per month as well as the number of people supplied with potable water in each city was obtained from the local water utility. Data on population and number of dwellings were needed to calculate the number of people per dwelling in each city. It was necessary to perform such a calculation as some dwellings in certain cities do not require the services of the water utility. Therefore, based on data available at the Brazilian Institute for Geography and Statistics—IBGE [11] the number of people per dwelling was calculated for each city. Then, having the number of people per dwelling and the

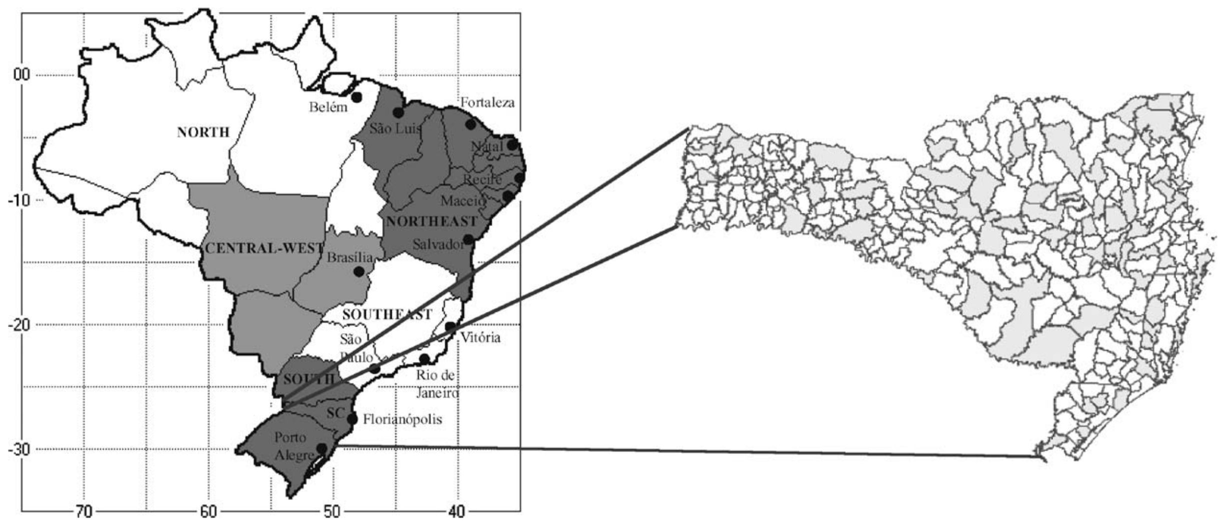

Fig. 3. Map of Brazil with location of the state of Santa Catarina (SC) and map of Santa Catarina with location of the 62 cities (grey colour) included in the analysis.

number of people supplied by the water utility in each city, it was possible to estimate the number of dwellings supplied by the water utility in each city. This was needed in order to estimate the total roof area and the volume of rainwater that could be harvested in each city. Then, to obtain the potential for potable water savings, the monthly water demand was compared to the volume of rainwater that could be harvested in each city.

3.1. Rainfall data

Daily rainfall data were obtained from EPAGRI (the Santa Catarina agency for research on agriculture). The available data did not cover the same period for all the cities and in some cases they were not complete. According to EPAGRI, this happens due to either interruption for maintenance or lack of funding to keep all climatic stations in operation. The data were processed in order to obtain the average monthly rainfall for each city.

3.2. Volume of rainwater

The volume of rainwater that could be harvested in each of the 62 cities was calculated as follows.

3.2.1. Population supplied with potable water

The number of people supplied monthly with potable water in each city was given by the water utility for the period 2000–2002. An arithmetic average was performed to determine the number of people supplied with potable water per month.

3.2.2. Number of people per dwelling

The number of people living in each city and the number of dwellings were obtained from IBGE [11]. Thus the specific number of people per dwelling was estimated by using Eq. (1).

$$PD = \frac{PC}{NDC}, \qquad (1)$$

where PD is the number of people per dwelling, PC is the number of people living in the city, and NDC is the number of dwellings in the city.

3.2.3. Number of dwellings supplied with potable water

The number of people supplied with potable water was obtained from the water utility. The number of dwellings supplied with potable water by the water utility was then estimated by using Eq. (2).

$$ND = \frac{NP}{PD}, \qquad (2)$$

where ND is the number of dwellings supplied with potable water, NP is the number of people supplied with potable water per month (as given by the water utility), and PD is the number of people per dwelling.

3.2.4. Total roof area

From all dwellings located in the state of Santa Catarina, 91.1% on average are houses and 8.6% are flats located in multi-storey residential buildings [11] where the specific roof area per person is low. Therefore, as there are no official data on roof areas, an area of 85.00 m^2 was assumed for houses and 3.75 m^2 per person for flats (this gives approximately 15.00 m^2 of roof area per flat, as used in Ghisi [9]). A weighted average roof area per dwelling was then determined by using Eq. (3).

$$RA = H \times 85.00 + F \times PD \times 3.75, \quad (3)$$

where RA is the weighted average roof area per dwelling in each city (m^2), H is the percentage of houses in each city (non-dimensional), F is the percentage of flats in each city (non-dimensional), PD is the number of people per dwelling in each city.

The total roof area in each city was obtained considering only the population supplied with potable water. It was determined by using Eq. (4).

$$TRA = RA \times ND, \quad (4)$$

where TRA is the total roof area in each city (m^2), RA is the weighted average roof area per dwelling in each city (m^2), and ND is the number of dwellings supplied with potable water.

3.2.5. Volume of rainwater

The monthly volume of rainwater that could be harvested in each city was determined considering monthly rainfall data, the total roof area, and a runoff coefficient of 0.80. Such a runoff coefficient indicates a loss of 20% of the rainwater that is discarded for roof cleaning and evaporation. Thus, the volume of rainwater that could be harvested in each city was determined by using Eq. (5).

$$VR = \frac{R \times TRA \times R_c}{1000}, \quad (5)$$

where VR is the monthly volume of rainwater that could be harvested in each city (m^3/month), R is the monthly rainfall in each city (mm/month), TRA is the total roof area in each city (m^2), R_c is the runoff coefficient (non-dimensional), and 1000 is the conversion factor from litres to m^3.

3.3. Potable water demand

The monthly potable water demand considered in the analysis was determined as a function of the data obtained from the water utility for the period 2000–2002.

3.4. Potential for potable water savings

The monthly potential for potable water savings was determined for each of the 62 cities by using Eq. (6).

$$PPWS = 100\,\frac{VR}{PWD}, \quad (6)$$

where $PPWS$ is the potential for potable water savings in each city (%), VR is the monthly volume of rainwater that could be harvested in each city (m^3/month), and PWD is the monthly potable water demand in each city (m^3/month).

4. Results

4.1. Number of people per dwelling

The number of people per dwelling ranged between 3.30 and 4.19 over the 62 cities, with an average of 3.69 people per dwelling. Such a figure is close to the average for southern Brazil, which is 3.42 people per dwelling according to IBGE [11].

4.2. Roof area

In order to determine an adequate roof area per dwelling, the percentage of houses and flats in multi-storey residential buildings was obtained for the 62 cities. Such a distinction was deemed appropriate as the specific roof area per person is lower in multi-storey buildings. Fig. 4 shows the results. The average for the 62 cities indicates that 96% of all the dwellings are composed of houses and 4% of flats in multi-storey residential buildings. There is just one city in which the percentage of flats is as high as 31% (Florianópolis—first bar in Fig. 4) and three cities in which such percentage ranges from 10% to 12% implying in lower specific roof area per person.

By applying Eq. (3), the average roof area obtained for the 62 cities was 81.84 m^2 ranging from 75.10 to 84.80 m^2 amongst all cities (as also indicated in Fig. 4). An exception was verified in Florianópolis, where an average roof area as low as 60.00 m^2 was obtained due to the high percentage of flats in that city. In order to facilitate the analysis, an average roof area of 80 m^2 per dwelling was assumed for all the 62 cities.

4.3. Potable water demand

The average potable water demand obtained for the 62 cities was 118 litres per capita per day. Such a figure is very close to the average observed for the three states that are located in the south region of Brazil, which is 117 litres per capita per day [9]. Fig. 5 shows the maximum, average and minimum potable water demand obtained for the 62 cities. It ranged from 59 to 240 litres per capita per day.

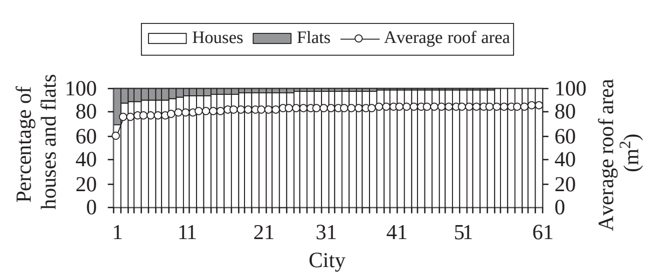

Fig. 4. Percentage of houses and flats in multi-storey residential buildings and average roof area in the 62 cities.

4.4. Volume of rainwater

The monthly volume of rainwater that could be harvested in each one of the 62 cities was calculated through the procedure described in the methodology. Table 1 presents an example for the city of Florianópolis, the capital of Santa Catarina.

4.5. Potential for potable water savings

The potential for potable water savings was estimated for the 62 cities and it ranged from 23% to 100%. Table 1 shows the results for Florianópolis where a potential ranging from 27% in June to 73% in February was observed.

Fig. 6 shows the results for the two cities with the minimum and maximum potential for potable water savings observed for the twelve months. The average potential for potable water savings observed in Armazém was 34% and in Curitibanos, 95%.

Fig. 7 presents the maximum, average and minimum potential for potable water savings observed for all of the 62 cities. On average, such a potential ranges from 55% in April to 87% in October. The overall average observed was 71%.

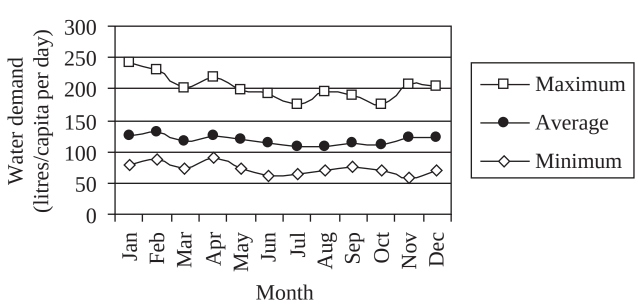

Fig. 5. Maximum, average and minimum potable water demand for the 62 cities.

4.6. Correlations

Fig. 8 shows the correlation between the average potential for potable water savings and water demand over 60 cities. Two cities were not considered in this analysis as their rainfall was too high and their exclusion increased the R^2 from 0.5112 to 0.7454. It can be observed that there is a good correlation between the average potential for potable water savings and average water demand. Therefore, the potential for potable

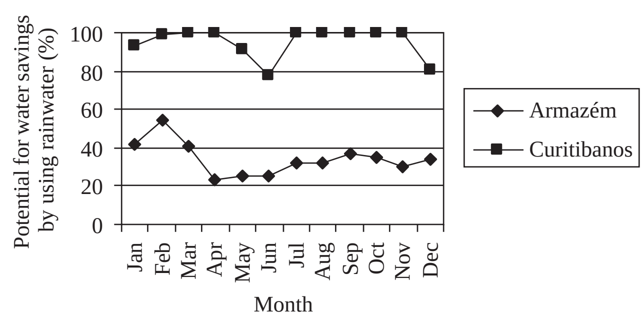

Fig. 6. City with maximum and city with minimum potential for potable water savings by using rainwater.

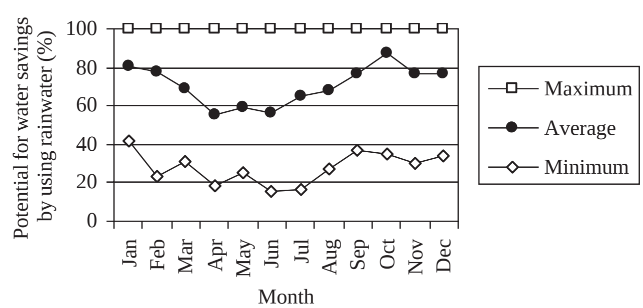

Fig. 7. Maximum, average and minimum potential for potable water savings by using rainwater over the 62 cities.

Table 1
Results for Florianópolis

Month	Average roof area per dwelling (m^2)	Number of dwellings supplied with potable water	Total roof area (m^2)	Volume of rainwater (m^3/month)	Water demand (m^3/month)	Potential for potable water savings (%)
January	80	64,928	5,194,271	732,184	1,135,326	64
February	80	65,169	5,213,519	824,570	1,132,058	73
March	80	65,297	5,223,741	778,546	1,171,927	66
April	80	65,423	5,233,834	404,471	1,193,158	34
May	80	65,707	5,256,549	407,488	1,181,492	34
June	80	65,905	5,272,372	317,186	1,179,262	27
July	80	65,926	5,274,077	399,142	1,098,445	36
August	80	65,905	5,272,420	390,159	1,135,580	34
September	80	66,132	5,290,554	536,674	1,162,905	46
October	80	66,239	5,299,160	534,155	1,094,367	49
November	80	66,456	5,316,509	549,089	1,237,191	44
December	80	66,660	5,332,824	623,727	1,260,527	49

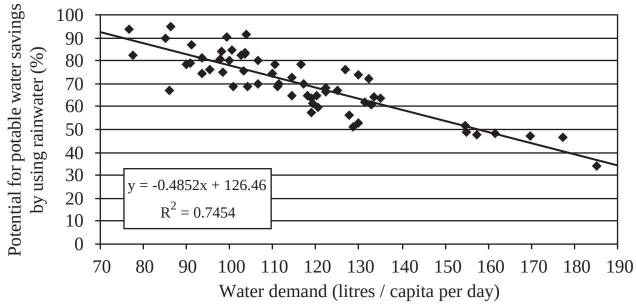

Fig. 8. Correlation between the potential for potable water savings and water demand over 60 cities.

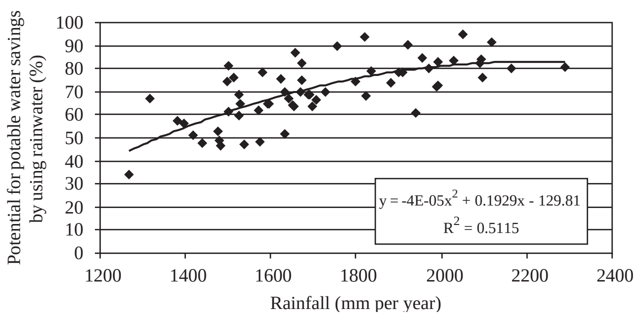

Fig. 9. Correlation between the potential for potable water savings and rainfall over 60 cities.

water savings in cities located in the state of Santa Catarina could be estimated as a function of the average water demand by using the equation shown in Fig. 8. Such an equation can be applied for water demand ranging from 70 to 190 litres per capita per day. Thus, potable water savings raging from 34% to 92% would be achieved in Santa Catarina depending on the water demand. Considering the average water demand of 118 litres per capita per day, an average potential for water savings of 69% can be obtained, which is very close to the potential of 71% shown previously.

As for the correlation between the potential for potable water savings and rainfall, it was observed that a linear trendline gives a correlation with R^2 of 0.4733 while a second-order polynomial trendline (Fig. 9) gives a better correlation (R^2 of 0.5115). However, such a correlation is weaker than the previous one and therefore not recommended to be used to estimate the potential for potable water savings.

All the correlations presented above were also investigated on a monthly basis but they were weaker and therefore not taken into account. Such correlations were weaker because the potential for potable water savings reaches 100% in the months with high rainfall.

4.7. Water availability prediction

As suggested in Ghisi [9], the contribution of rainwater usage on the water availability indicator was investigated. Fig. 10 shows the prediction of water availability for Santa Catarina over the period 2000–2100 considering both no rainwater usage and rainwater usage. The benefits of rainwater usage on the water availability are shown for three situations: considering the potential for potable water savings of 34%, 69% and 92% as demonstrated previously. It can be observed that on average (potential for potable water savings of 69%) water availability will be about 5000 m^3 per capita per year in 2100 against 2000 m^3 per capita per year if there is no rainwater usage. This indicates that rainwater usage would be a solution to ease water availability problems in Santa Catarina. Other solutions would be the reduction of potable water usage by avoiding waste of water and using low water consumption equipment, but these are not in the scope of this paper.

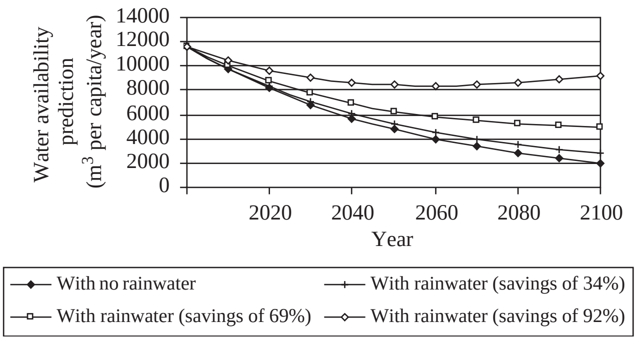

Fig. 10. Predictions of water availability in Santa Catarina.

5. Conclusions

The water availability problem and the potential for potable water savings by using rainwater in the state of Santa Catarina, southern Brazil, have been assessed. Results show that the water availability will be lower than 2000 m^3 per capita per year from 2100 onwards, which is considered very low by United Nations Environment Programme. This indicates that the state of Santa Catarina may face water availability problems in the future unless there are government programmes to promote water conservation and rainwater harvesting.

Results of the research performed over 62 cities located in Santa Catarina indicate that water demand in the residential sector is about 118 litres per capita per day and that there is an average rainfall of about 1700 mm per year. The average potential for potable water savings is 69% ranging from 34% to 92% depending on the potable water demand. Such a potential is very significant as rainwater could be used for both potable and non-potable purposes. It must be highlighted though that rainwater should go through proper treatment in order to be used for potable purposes. This and also rainwater storage tank sizing are subjects for future research as they may affect the potential for potable water savings as presented in this paper.

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