CEVE 101: Project 03

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First, we instantiate the folllowing packages.

using Revise  
using RainwaterHarvesting

Line 1

Revise allows us to update code without restarting Julia.

Line 2

We load the RainwaterHarvesting package that contains our simulation tools.

### Setting the file path

Next, we specify the rainfall data file for the Aurora station.

filepath = "data/18.txt"  
rainfall\_data = RainfallData(filepath)

Line 1

This is the path to the rainfall data file for the station of interest.

Line 2

This creates a RainfallData object containing the rainfall data for the specified station.

RainfallData for station: AURORA  
 Location: -6.9425833333333, -38.968444444444  
 Years of data: 50  
 Total days: 18259

### Plotting the Data

The following is a plot of all 50 years of rainfall data for the Aurora station.

plot(rainfall\_data)

Line 1

This plot function is defined in [viz.jl](./RainwaterHarvesting/src/viz.jl) and is a thin wrapper around the Plots.jl package.

### Discussion

Each month from January 1974 until October 2024 has complete rainfall data. There are no years or months that have to be removed because of insufficient data which makes the complete 50-year data set great for meaningful risk assessment.

## Historical Droughts

According to a study at the Federal University of Brazil, Drought Impacts and Policy Responses in Brazil: The Case of the Northeast Region, there have been droughts in Caerá, the northeast part of Brazil where the station is found, in the following years: 1979-83, 1987, 1992-93, 1997-98, 2002-03, 2010, and 2012-2018. There are noticeable dips in rainfall in the station’s graph following these droughts. The years that have the most obvious dips are 2002-2003 and the 2012-1018 area. Despite the droughts, all the data during these years is complete which is not the case for other stations in Caerá. The Aurora station is located in the middle of a well-developed city which makes sense for its consistent data and started in the early year of 1974.

## Understanding the Theoretical Model

The model contains limiting assumptions and approximations. First, an assumption is made that the household only begins using water from the cistern after the 150th day of the year. This is because the rainy season lasts for about the first 150 days of the year and it is assumed that a household does not use water from the tank during those months. The second assumption is that each household consumes 74.1 liters per day during the dry season.

One limitation of this model rests on the calculations of the consumption equation. The model assumes that the tank is not in use for the rainy season, which is not necessarily accurate to real life. Depending on the size of the family, their daily water needs, and the amount of rain in a particular year, the tank may need to be used before the 150 days. Additionally, water consumption changes from day to day for families. The consumption model, however, assumes a household is using 74.1 liters per day. This does not take into account the daily fluctuations in water consumption for families and the human element that would lead families to use less water when they are running low.

There are also approximations for the Inflow calculations. For example, the first flush volume would fluctuate depending on how recently it has rained and how dirty the roof is. It is possible the first flush need not be discarded if the roof is not dirty because it has recently rained. Perhaps the problem could be the other way around and the first flush is abnormally large because of birds pooping on the roof. The runoff coefficient of .85 is used because of the prevalence of ceramic roofs in the area. This coefficient is an approximation and may not accurately reflect the actual runoff from evaporation and spilling for a particular roof.

I would relax these assumptions by allowing for water consumption in the first 150 days of the year. Following data analysis of water consumption during the first part of the year, I would find a value, k, which approximates the water consumption for the first 150 days. The consumption equations would change to look something like this.

### Defining the Model Parameters

For rain area of 45 and water tank volume of 16000, there were three years out of 50 which failed. The years were 1976, 1998, and 2016.

param1 = ModelParameters(  
 runoff\_coefficient=0.85,  
 roof\_area\_m2=45.0,  
 first\_flush\_mm=2.0,  
 tank\_capacity\_L=16000.0  
)

Line 1

This creates a ModelParameters object with the specified parameters.

Line 2

The runoff coefficient () is a measure of how much of the rain that falls on the roof ends up in the tank.

Line 3

The roof area () is the area of the roof that the rain falls on.

Line 4

The first flush volume () is the volume of rain that is discarded because it is dirty.

Line 5

The tank capacity () is the maximum volume of the tank.

### Running the Simulation for One Year

Let’s run the model for the year 1998.

rainfall\_1998 = rainfall\_data.annual\_data[1998]  
results\_1998 = run\_timesteps(rainfall\_1998, param1)  
p1 = plot(results\_1998)

I changed the model perameters to increase the realiability of the cistern.

param2 = ModelParameters(  
 runoff\_coefficient=0.85,  
 roof\_area\_m2=55.0,  
 first\_flush\_mm=2.0,  
 tank\_capacity\_L=16000.0  
)

However, changing the rain area of the roof to 55 lowers that number to only 1 year of failure, 1976. These years of failure occured during dry years when the rainfall into the tank was not enough to last through the dry months. Changing the rain area to 55 allows for the tank to fill up faster during the dry months.

rainfall2\_1998 = rainfall\_data.annual\_data[1998]  
results2\_1998 = run\_timesteps(rainfall2\_1998, param2)  
p1 = plot(results2\_1998)

Line 1

We select the annual rainfall data for the year 1981.

Line 2

We run the simulation for the year 1981.

Line 3

We plot the results, again using a plot function defined in [viz.jl](./RainwaterHarvesting/src/viz.jl).

To compare rainfall and tank volume:

p2 = plot(rainfall2\_1998)  
plot(p2, p1, layout=(2, 1), size=(1000, 700), link=:x)

Changing the rain area to 55 would also allow for the use of the tank during the rainy season. During the year modeled, there is overflow in the tank for about the period of about two months in the rainy season. With the larger area of roof, the tank fills faster and would allow more use of water during the rainy season if necessary and if that parameter and usage of water was taken into account.

### Reliability Analysis

all\_years = sort(collect(keys(rainfall\_data.annual\_data)))  
all\_results = [run\_timesteps(rainfall\_data.annual\_data[year], param2) for year in all\_years]  
any\_failures = [!isempty(result.failure\_dates) for result in all\_results]  
println("Number of years with failures: ", sum(any\_failures), " out of ", length(all\_years))

Number of years with failures: 1 out of 50

The reliability of the system is (50-49)/50 which amounts to a 98% reliability. This reliability is the largest probability without drastically changing the parameters. to make the cistern reliability 100%, either the rain area would have had to be increased significantly more or the tank capacity would have had to be increased to 17000L. I thought it would be unreasonable to increase the cistern to 17000L as they are not custom made and most are made to carry 16000L

There are gaps in the model when faced with the assumptions of no consumption over the rainy months and the assumption of daily 74L consumption during the dry months. To address this gap, we could collect data on water consumption for families using cisterns during the dry season to better understand how their water consumption fluctuates daily. This would enhance the analysis because it would provide a more accurate result of the tank levels throughout the wet season rather than a linear decline in the tank levels.