Relation Between Basin Surface Runoff and Deforestation

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Introduction

The Paquequer Basin is in the municipality of Teresópolis, Rio de Janeiro, Brazil. It is inside a geomorphological context of high degree slopes and heights, in the mountainous region of Rio de Janeiro State. The main river, named Paquequer, starts inside the Serra dos Órgãos National Park and then crosses the city center, playing a major role in how the city developed over the years.

This basin often suffers from landslides, having a tremendous impact on the inhabitants of this area. Not only the geology-geomorphological features are the main drivers for these events, but also rainfall/surface runoff intensity. Runoff, as described by Society (2011), it all the water prevenient from rainfall that doesn`t infiltrate the soil and ended up running off over the surface. Such process is influenced by many factors, such as land use, soil humidity, rainfall intensity, topography.

In the last 4 decades, Teresopolis city grew and saw a change in your agriculture and pasture zones. This impacts directly on the surface runoff. Another important feature is the forests. Occasionally, a new area is significantly deforested, leading to urban areas or agriculture-pasture zones, changing the runoff and water absorption processes.

Having all these concepts in mind, this paper tries to measure whether there was an increase in deforesting from 1985 to 2021, whether these land class changes interfere in the surface runoff within Paquequer Basin, besides understanding how the hydrological years of 1985 was and 2021.

Methodology

To develop this research, two main steps were fundamental for the application of concepts: data collection and data processing - with the selection of all parameters and modelling.

Data Collection

Running a surface runoff analysis is quite a complex task. To have a good model, it is necessary to have several data (Table 1).

Table 1: Data types and data sources used in this research.

Data	Data Source
Land Use & Land Class	MapBiomas
Soil Classification	IBGE
Fluviometric & Pluviometric Data	ANA/HydroBR
Digital Elevation Model	TOPODATA - INPE

Fluviometric and Pluviometric data were collected using Python HidroBR library. With this information, it is feasible to understand the stream flow and the rainfall behavior through the years. The data is available from 1916 to 2022. Another required data is land class and land use. For that, timeseries data was extracted from MapBiomas plataform – which is an independent organization that with the aid of remote sensing monitors the evolution of forests, water surface and urban growth. Finally, the last crucial data is soil data and digital elevation model from Instituto Brasileiro de Geografia (IBGE) and Topodata INPE. With such information it will be possible to model how is going to be the soil bearing after the period of rain and where the water will flow, besides making it possible to determine the basins and sub-basins. All data and tools are explained in a schema in Figure 1.

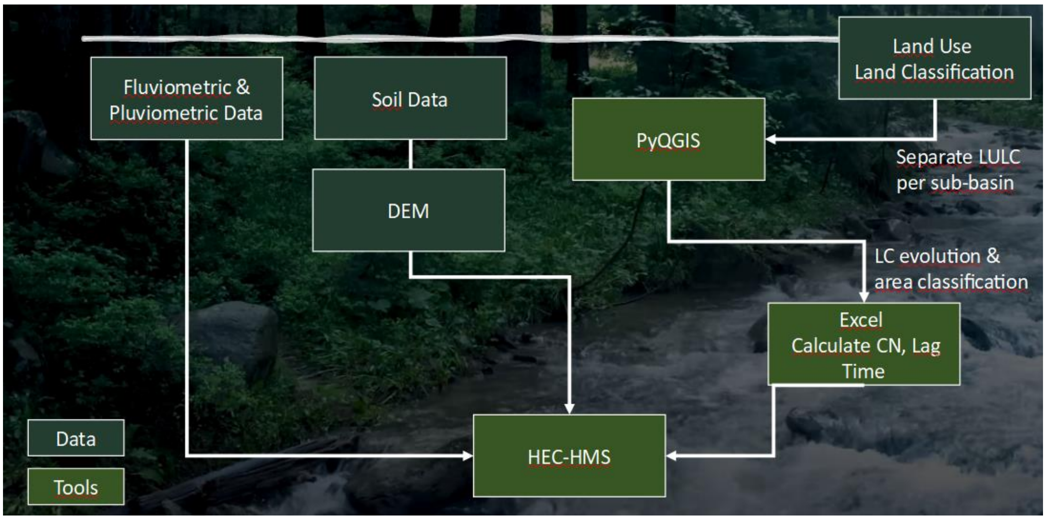


Figure 1: Research workflow.

Data Processing

For data processing, was used PyQGIS, Python and Excel. Python and PyQGIS were used in order to perform automatizations, since was necessary to process the same data for the same area but in different years. The output from these tools was a table with information of the percentage area for each in every sub-basin, plus the chosen curve number (CN). Proceeding to the next step, Excel was an important tool since all results and calculations for curve number, lag time and other sub-variables were saved in this environment. Once all variables were finally calculated, they were inputted in HEC-HMS, making executable the model.

Setting Parameters

To conduct the research, a rainfall-runoff empirical model Soil Conservation Service – Curve Number (SCS-CN) was used within the Hydrologic Modeling System (HEC-HMS) software. The model has a bright side of requiring very few parameters, making data-driven models easy (Sitterson et al. 2018). On the other hand, this type of algorithm has no connection to the catchment. The SCS-CN, as an empirical model, is good for a simple implementation, is fast in computational terms, besides being cost effective (Dawson e Wilby, 2001).

According to Mishra e Singh (2003), the SCS-CN method relies on the water balance equation and two fundamental assumptions. The initial assumption establishes an equivalence between the proportion of actual direct surface runoff (Q) to the total rainfall (P) (or maximum potential surface runoff) and the proportion of actual infiltration (F) to the potential maximum retention (S). The second assumption establishes a relationship between the initial abstraction (Ia) and the potential maximum retention. Hence, the SCS-CN method comprises the following components:

(a) Water balance equation: $P = Ia + F + Q$
(b) Proportional equality hypothesis: $Q / (P – Ia) = F/S$
(c) Ia – S hypothesis: $Ia = YS$

Where P = total rainfall; Ia = initial abstraction; F = cumulative infiltration excluding Ia; Q = direct runoff; and S = potential maximum retention or infiltration.

The parameter S of the SCS-CN method depends on the soil type, land use, hydrologic condition and antecedent moisture condition (AMC) (Mishra e Singh 2003). The initial abstraction accounts for the short-term losses, such as infiltration and surface storage. The Y parameter depends on climatic and geological factors, and the method assumes Y to be equal to 0.2 for practical applications (Bosznay 1989; Mishra e Singh 2003, Ramasastri and Seth 1985). For the study area, and aiming simplification, the selected AMC class was II; the soil type was set as Group C which presents moderately fine to fie texture as clay loams, shallow sandy loam and soils low in organic content, and has slow water transmission; the period of the year chosen was from January 15th to February 15th, where the region shows significant levels of rainfall during the summer.

As parameter S can span from 0 to infinite, it is transformed into a dimensionless curve number (CN), ranging from 0 to 100, which is more visually appealing, as the equation $S = (1000 / CN) – 10$ (Table 2). Once all parameters for soil type and moisture were set, the next step is to find the runoff curve number for hydrologic cover complexes according to the land use provided in Mishra & Singh (2003). The following step was calculating the S parameter for each basin using the Weighted-CN Method, where the CN-value is multiplied with the percentage of the area and divided by 1000. This weighting methodology was chosen because it requires less computational effort than others.

Table 2: Curve number used for each class within Paquequer Basin.

Land Class	**Curve Number**
Forest	73
Planted Forest	73
Pasture	79
Non-forested wetland	73
Agriculture	90
Semi Perennial Agriculture	90
Urban Area	94
Non-Vegetation **Area**	94
Water Bodies	99
Rock Outcrop	94
Mining Area	79

Results and Discussion

Analyzing the land use and land classification between 1985 and 2021 (Table 3), there were some expected but also surprising results. The mean of forest land use increased 7.2%, followed by urban area. While there was more area being reforested, the pasture and agriculture fields dropped by 7%, indicating an urbanization process – which can also be confirmed by Datapedia information, having an 86% population increase from the 80's to 2020. Other classes had minor changes, as shown in Figure 2 shows these changes visually.

Table 3: Land class difference in percentage when comparing 2021 to 1985.

Class % from the whole basin	Mean 2021	Mean 1985	Diff (%)
Forest	56,48	49,25	7,223639
Planted Forest	0,14	0,00	0,142547
Pasture & Agriculture	11,86	18,86	-6,9963
Non-forested Wetland	0,01	0,00	0,010707
Urban Area	3,90	0,74	3,159916
Non Vegetation Area	0,13	0,36	-0,2304
Water Bodies	0,12	0,18	-0,0544
Rock outcrop	3,03	2,97	0,059085
Mining Area	0,03	0,01	0,025486

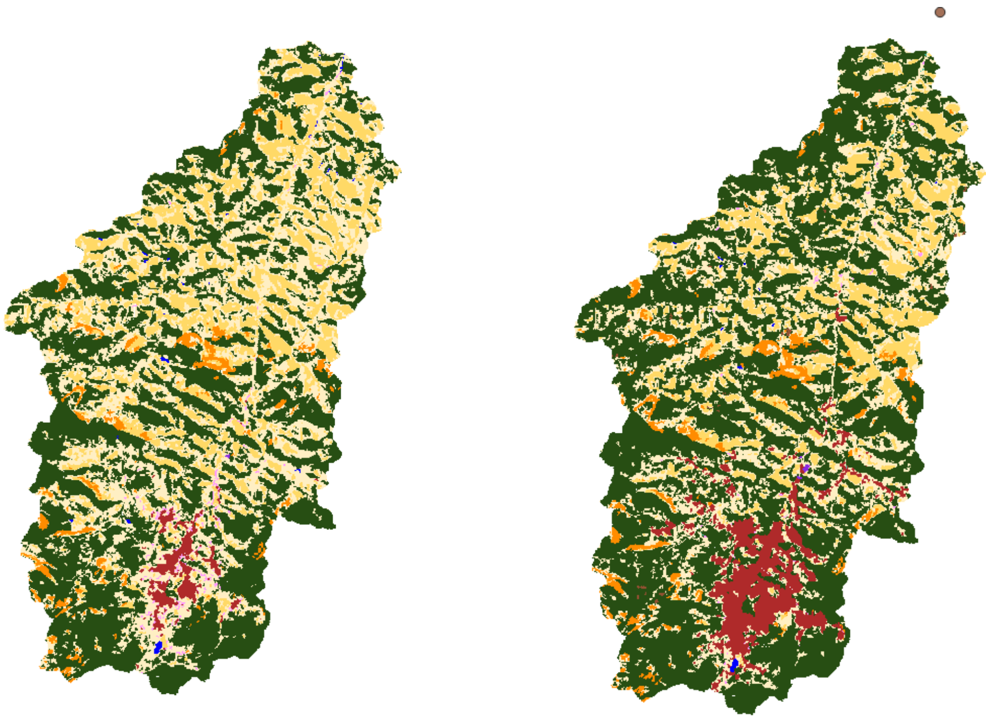
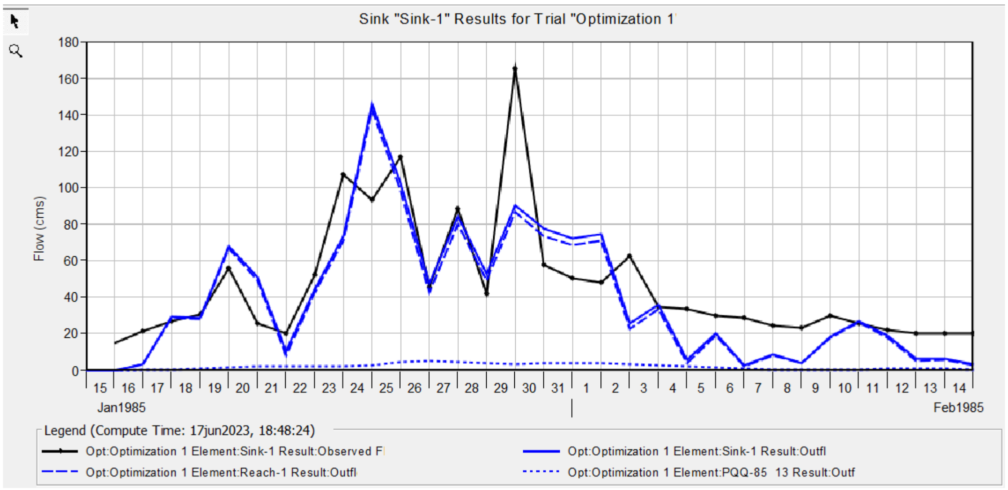


Figure 2: Land class evolution. 1985 (left) versus 2021 (right). Urban area in red, vegetation in green, agriculture in orange, agriculture and pasture in dark yellow and light yellow.

The modelling for 1985 had a Nash-Sutcliffe accuracy measurement of 0.520, being slightly fair for a model, where it is necessary at least 0.7. The simulation showed a volume of 106 967.5 m^3, meanwhile an observed of 122 737.9m^3, a total difference of -12.8%. The peak flow observed was 165m^3/s on January 30th, 1985, a 11.7% error when compared with the simulated one on January 26th, 1985, with a peak flow of 145.6m^3/s. Figure 3A displays how fit was the model (blue line) when comparing observed data (black line). When looking at Figure 3B, it is visible how streamflow and rainfall match with each other in most of the cases, exhibiting an increase in the flow as it rains. Nonetheless it is important to point out that not every time the peaks are having the same response, and one hypothesis is this happens probably due to how scattered are the pluviometric stations, and not near-by the fluviometric station.



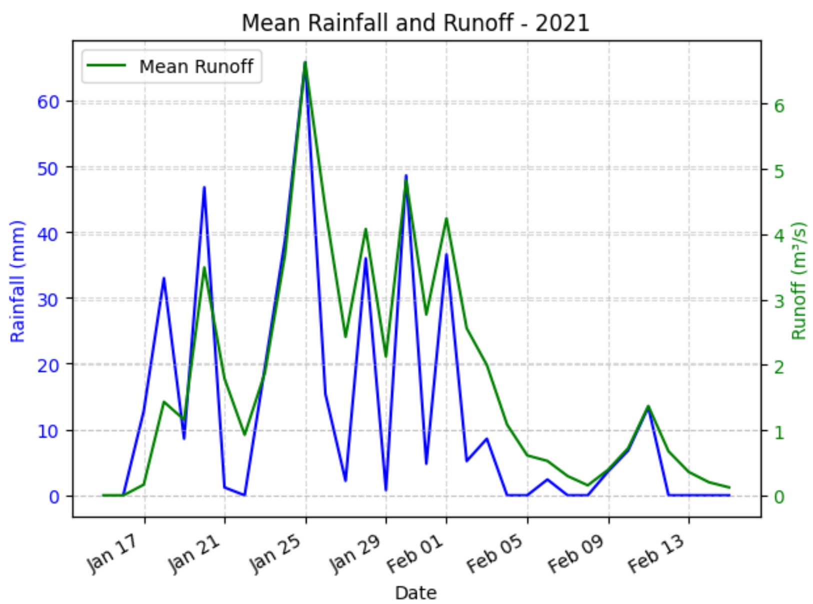
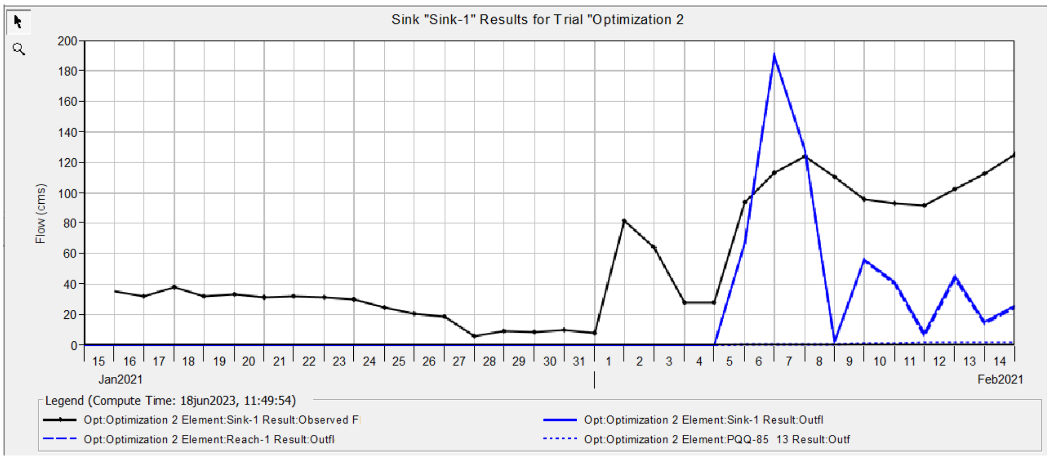


Figure 3: Model for 1985. A) Model result indicating the observed (black line) and the output (blue line). B) Mean rainfall and runoff for 1985.

Meanwhile the model for 1985 had a slightly fair performance, the model for 2021 was not good enough. With the Nash-Sutcliffe accuracy measurement of -0.55. There was a -64.2% difference in the simulated and observed water volume. The percentage difference for peak flow volume between simulated and observed was 51.3%, showing a very discrepant result. When looking at the charts (Figure 4A), there is no fit between observed and simulated, like the ones seemed in the 1985 model. In order to better understand, the Figure 4B indicates a dry period from January 15th to February 4th, being an anormal event considering that these months are summer and rainy months. Also, after a higher volume of rain on February 5th, the peak of streamflow doesn't match rain, indicating rains in local places, a lot of soil absorption or problem in registering the streamflow volume.



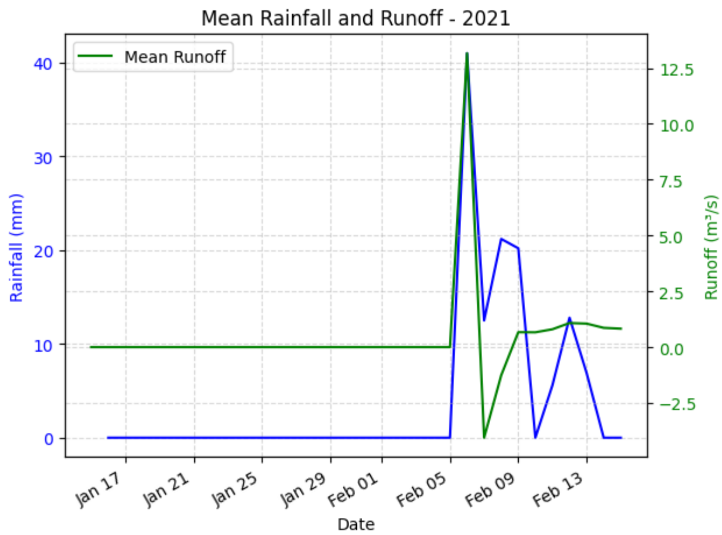


Figure 4: Model for 2021. A) Model result indicating the observed (black line) and the output (blue line). B) Mean rainfall and runoff for 2021.

Conclusion

After conducting the modeling, the results were inconclusive due to the low value of the model measurement evaluation. A Nash-Sutcliffe model evaluation number of at least 0.7 is required to obtain meaningful results. The model performed relatively better for the year 1985; however, significant disparities between rainfall and streamflow data hindered accurate determination. Surprisingly, no apparent relationship was observed between the data for the year 2021, despite an anticipated positive correlation.

As a result of these model evaluation measurements, the estimation of runoff for the Paquequer Basin cannot be determined reliably. Possible factors contributing to this outcome include inappropriate parameter selection and issues with the available data. A longer timeseries is required to comprehensively evaluate the water cycle of the basin.

Nevertheless, an analysis revealed a nearly 7% increase in the mean forest land use throughout the entire basin between the two years. The urban area experienced the second most substantial change, with an average increase of 3%.

For future research, it would be valuable to utilize a more extensive timeseries for modeling instead of relying on a single month of data. Additionally, investigating the influence of climate change on the region, including abnormal precipitation patterns, would enable proper data preparation and analysis.

References

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