Case study detailing precipitation and evaporation rate information for the lagoon area of a wastewater treatment plant

https://doi.org/10.56238/Connexpemultidisdevolpfut-086

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ABSTRACT
This article presents a detailed case study on the evaporation and water level of the lagoons at the Cooperativa Agrícola Mixta São Roque Ltda Wastewater Treatment Plant located in Salvador das Missões, Rio Grande do Sul, Brazil. The objective of the study was to quantify the evaporative losses at the Wastewater Treatment Plant and understand the behavior of the reservoirs in the region. To achieve this, information on precipitation and evaporation rates for the area of the lagoons was collected. The evaporation of water from open-air reservoirs is a factor that affects various sectors such as human water supply, energy production, livestock, agriculture, and industries. The northeastern region of Brazil, in particular, has climatic characteristics that result in approximately 70,000 open-air reservoirs due to the semi-arid climate and erratic rainfall. The Jensen-Haise method, which has proven to be efficient in arid and semi-arid regions, was used to calculate the daily evaporation rates for each month of the study period. The main factors that affect evaporation are temperature, wind, air pressure, humidity, and radiation. The results showed that the average daily value of evaporated effluent is justified and in line with the calculated values of water evaporation for the region. Additionally, data on the volume of captured rainfall and the increase in the lagoons' water level due to rainfall were presented.

Keywords: Water evaporation, Evaporation rate, Lagoons, Wastewater treatment plant, Precipitation.

1 INTRODUCTION

The evaporation of water from artificial reservoirs, mainly open-air reservoirs, affects not only the reliability of human supply, but also energy production, livestock , agriculture and industries where litigation depends on water, which is a major concern for society.

There are approximately 70,000 open-air reservoirs in the northeast region (SUASSUNA, 2002), a number justified by the climatic characteristics of the region, such as semi-arid climate and erratic rainfall. This rainfall irregularity also occurs quantitatively, with annual rainfall ranging from 300 to 800 mm (CRISPIM et al., 2016). It is also poorly distributed throughout the year, with rainfall concentrated in the first month of the year. In addition, due to several factors such as the high evapotranspiration of about 2000 mm per year (SUASSUNA, 2002), it is recommended to use this water and energy system to increase availability and increase demand when there is a shortage of water and energy.

Rio Grande do Sul, identically to what happens with most of the states of the Northeast, has been presenting long periods of drought in recent years (EMPARN, 2017). The last dry season lasted two years with below-average rainfall.With this scenario, the main hydrographic basins of RS present a critical situation. Therefore, the efficient management of water resources is extremely important to ensure water supply and preserve the environment. In this context, the detailed study of precipitation information and evaporation rate in an effluent treatment plant is fundamental to understand and optimize water use (IGARN, 2017).

Given the high evaporation of water in the Missions region and the scarcity of water resources in Rio Grande do Sul, it is important to understand the behavior of the state's reservoirs. Given these facts, this work aims to quantify evaporative losses in the Effluent Treatment Station of COOPEROQUE, located in the municipality of Salvador das Missões, in the interior of Rio Grande do Sul.

2 THEORETICAL CONTRIBUTION

Springs are reservoirs of water or sources of human food, and the quantity, quality and availability of water must be ensured according to the purpose of supply. According to the "Manual of Hygiene" of the National Sanitation Foundation – FUNASA (2016), the sources are categorized as follows:

- Surface springs: These include streams, streams, rivers, lakes, artificial reservoirs such as reservoirs and reservoirs. Seawater is also a potential source of surface water, as desalination technologies suitable for seawater supply are being developed around the world.
- Underground springs: These are where water originates from underground sources such as natural springs, wells, groundwater, deep aquifers (leaf), and is drawn through shallow or deep wells, drilled or tubular wells, infiltration ditches, underground dams.

The most common surface source in Rio Grande do Sul is the weir. Dam is the set consisting of dam or dam of a watercourse and the respective reservoir or lake formed (SEMARH / SE, 2017). The construction of dams alters the flow of natural rivers to create a lentic environment and create reservoirs and groundwater. According to Hoestra and Mekonen (2012), these changes caused by artificial reservoirs increase evaporation rates, consuming a significant fraction of the accumulated water.

2.1 EVAPORATION

Evaporation is a physical process in which a liquid slowly and gradually changes to a gaseous state under constant pressure. "Evaporation loss is the amount of water evaporated per unit horizontal area during a given time interval..." (PINTO et al., 2008). This amount is measured in millimeters or meters by the height of the evaporated water evenly distributed over the reservoir area. The evaporation intensity is the rate at which evaporative loss is processed and has units of mm.day-1 or mm.year-1. The main factors affecting evaporation are:

- **Temperature:** This change is endothermic. That is, the higher the temperature, the faster the liquid will evaporate.
- **Wind:** The more aeration on the liquid, the less saturated the air, the more energy transferred to the surface particles and the greater the evaporation.
- **Air pressure:** The higher the pressure, the more difficult it is for molecules to escape from the liquid phase into the atmosphere, resulting in less evaporation.
- **Humidity:** Higher humidity levels indicate more water vapor, making it difficult to evaporate.
- **Radiation:** Gives energy to liquid substances to promote evaporation. Because the sun is the main source of radiation, evaporation is greatest in outdoor artificial reservoirs exposed to direct sunlight.

Leo (et al., 2013) explains that evaporation can be estimated by a combination of models based on mass transport, energy balance, water balance methods and empirical formulas such as those derived from the Pennant equation. Another method of calculation is an estimate based on the data collected by the evaporators. This is the most used class A tank in Brazil.

2.1.1 Jensen-Haise Method

The central objective of this work, the calculation of evaporation, was developed in 1963 by the American researchers Jensen and Heise. In the study that developed the method, two researchers used more than 3,000 observations of evapotranspiration variation determined from statistically related data collected over 35 years in the western United States.

This model has produced important results in several studies, such as that of Majidi (et. al., 2015), in which the Jensen-Haise method provided the most accurate evaporation estimates, despite limitations in the input data. The study also shows that despite its simplicity, the method provides more reliable evaporation estimates than some of the more complex and expensive methods. The simplicity of this method lies in the number of parameters used in the calculation. Some empirical methods for calculating evaporation require a lot of information, but the formula used in the Jensen-

Haise method requires only two parameters to perform the calculation: temperature and local insolation.

A study entitled Estimation of Baseline Evapotranspiration in the Semi-Arid Region of Pernambuco argued that the Jensen-Haise method had the best performance in estimating evapotranspiration (DA SILVA; DE SOUZA, 2011, p. 18).

The method chosen in this study to calculate evaporation presents good results when applied in arid and semi-arid regions similar to those where the studied reservoirs are located (MEDEIROS, 2008). Therefore, the equation defined by Jensen and Haise (1963) and used in this methodology is:

$$\mathbf{E = 0.03523.\ Rs.\ (0.014.\ Ta - 0.37)} \qquad (1)$$

Being:

E - daily evaporation rate (mm/day)

Rs – solar radiation (W.m-2)

Ta - air temperature (Fº)

3 MATERIALS AND METHODS

3.1 CHARACTERIZATION OF THE STUDY AREA

The Effluent Treatment Station (ETE) of the Milk Cooling Station of the Mixta São Roque Agricultural Cooperative Ltda is located in the municipality of Salvador das Missões, northwest of the state of Rio Grande do Sul.

Figure 1: Location of the WWTP of COOPEROQUE in the Municipality of Salvador das Missões-RS

Source: Cooperoque, 2021.

3.2 EVAPORATION

The initial information used to calculate evaporation was the monitoring data of the water level, volume of effluent released into the WWTP, volume of rainfall and the volume of the reservoir, provided by COOPEROQUE.

To calculate the evaporation, it was necessary to obtain the data, according to the Jensen-Haise method equation:

- Solar radiation, in (W.m-2);
- Air temperature, in °F.

The temperature data used were those of the climatological station of COOPEROQUE. The temperatures in question were harvested in degrees Celsius, being converted into Fahrenheit by the following equation, in order to fit the evaporation calculation equation.

The solar radiation could also be taken from the same climatological station and was compared with the solar radiation of the Solarimetric Atlas of Brazil.

With the averages of temperature and radiation of each month, evaporation was calculated by the Jensen-Haise method (equation 1), resulting in a daily evaporation in millimeters. The evaporation was then converted into meters per day and multiplied by the time period, i.e. the date of the subsequent measurement minus the date of the previous measurement. This evaporation in the period between measurements, when multiplied by the average of the reservoir area (average between the areas between measurements) resulted in the loss of evaporation of the reservoir, in cubic meters, in the period.

4 RESULTS AND DISCUSSIONS

The present study details the information of precipitation and evaporation rate by the area of the lagoons of the Effluent Treatment Station (ETE) of the Milk Station of COOPERQUE as requested in the official nº 1576/2023 FEPAM.

The total area of the lagoons of the COOPEROQUE WWTP comprises 3014 square meters.

Considering the lowering of 1m (100 cm) at the level of the WWTP ponds, the corresponding volume of these can be calculated.

$$\text{Volume} = \text{Area x height} = 3014 \text{ m } 2^{\text{x 1 m} = 3014 \text{ m3}}$$

Considering the correlation:

$$1\text{m (100 cm) ------ } 3014 \text{ m}^3$$

One can calculate the lowering of the level of the ponds corresponding to 13 cubic meters of evaporated effluent.

100 cm ------ 3014 m3

X ------ 13 m3

X = 0.43 cm/day or **4.3 mm/day**

We can infer that the evaporation of 13 cubic meters of water corresponds to the lowering of 4.3 mm/day from the level of the lagoons of the COOPEROQUE WWTP.

4.1 CALCULATION OF EVAPORATION BY THE JENSEN-HAISE METHOD

The Jensen-Haise method has generated significant results in several studies, such as that of Majidi et. al, 2015 and produced the most accurate evaporation estimates, even though it had limitations in its input data. The research further points out that despite its simplicity, the method has provided more reliable evaporation estimates than several more complex and expensive methods.

The Jensen-Haise method chosen to calculate evaporation in this study presents good results that are similar to those found in the ponds of the COOPEROQUE WWTP. Thus, the equation defined by Jensen and Haise (1963) and used in this methodology was:

$$E = 0.03523. Rs (0.014. Ta – 0.37)$$

Being:

E - daily evaporation rate (mm/day)

Rs – solar radiation (W.m-2)

Ta - air temperature (F°)

Considering the data of the average air temperature and the solar radiation of Salvador das Missões obtained.

Table 1. Average air temperature and solar radiation of Salvador das Missões obtained.

Month	January	February	March	April	May
Temperature (°C)	29,2	24,6	27,0	21,5	17,5
Temperature (°F)	84,6	76,3	80,6	70,7	63,5
Solar radiation ($W.m^{-2}$)	267	253	233,6	170	143

Source: Cooperoque weather station.

Temperature data were obtained from the weather station of COOPEROQUE. The solar radiation was obtained by the same weather station and compared with data from the Brazilian Atlas of Solar Energy developed by the National Institute for Space Research (INPE). Access to the data can be done through an interactive map and obtained in Wh.m-2/day and converted to W.m-2 as required by the Jensen-Haise method equation. The material is organized by states and municipalities. The user has access to tables with monthly irradiation levels for all 5,570 Brazilian cities (LABREN - Brazilian Atlas of Solar Energy (inpe.br)).

- **Evaporation calculation for the month of January 2023**

  E = 0.03523. Rs (0.014. Ta – 0.37)

  E = 0.03523. 267 (0.014. 84.6 – 0.37) = **7.68 mm/day**

- **Evaporation calculation for the month of February 2023**

  E = 0.03523. Rs (0.014. Ta – 0.37)

  E = 0.03523. 253 (0.014. 76.3 – 0.37) = 6.24 **mm/day**

- **Evaporation calculation for the month of March 2023**

  E = 0.03523. Rs (0.014. Ta – 0.37)

  E = 0.03523. 233.6 (0.014. 80.6 – 0.37) = 6.22 **mm/day**

- **Evaporation calculation for the month of April 2023**

  E = 0.03523. Rs (0.014. Ta – 0.37)

  E = 0.03523. 170 (0.014. 70.7 – 0.37) = 3.71 **mm/day**

- **Evaporation calculation for the month of May 2023**

  E = 0.03523. Rs (0.014. Ta – 0.37)

  E = 0.03523. 143 (0.014. 63.5 – 0.37) = 2.61 **mm/day**

Considering that 13 cubic meters of water correspond to the lowering of 4.3 mm/day of the level of the ponds of the WWTP of COOPEROQUE and according to the calculations of water evaporation of the months of January and February 2023 (average value of 6.96 mm/day), it can be concluded that the average daily value of effluent evaporated in the WWTP of the Milk Station of COOPEROQUE is adequate, lower and is justified by comparing with the mean value of the average of the calculated values of water evaporation for Salvador das Missões using the Jensen-Haise Method for the corresponding months.

In the elaboration of the present study, the use of water is considered from the volume recorded in the hydrometer allocated between the artesian well and the water tank, the volume of effluent registered in the hydrometer that was installed in the truck washing sector and the volume of effluent registered in the hydrometer that was installed in the outlet pipe of the last maturation pond of the Effluent Treatment Station (ETE) of the Cooling Station of Milk from COOPEROQUE. The volumes of these effluents and the data from the hydrometer register were made available by COOPEROQUE through tables in the form of spreadsheets. It can be inferred that the Milk Cooling Station has two types of effluents: effluent from the cooling of milk from the Milk Station and the washing of trucks.

Table 3 (attached) shows the rainfall recorded at the meteorological station of the COOPEROQUE Milk Station.

TABLE 3. Rainfall rates recorded at the meteorological station of the Milk Station of COOPEROQUE.

Month/2023	Rainfall index
January	107.4 mm
February	15.4mm
March	110.4mm
April	121.3mm
May	233.7 mm

Source: Cooperoque weather station.

From the rainfall indexes recorded at the meteorological station of the Milk Station of COOPEROQUE and considering the total area of the ponds of the WWTP of 3014 ^{m2}, it is possible to calculate the estimate of the volume of rainwater of these lagoons considering that 1 meter (100 cm) corresponds to 3014 m3.

100 cm --------------------- 3014 m3

10.74 cm --------------------- x

x = 323.7 m3

In table 4 we can see the volume of rainwater captured (m3/day), the average volume of rainwater captured (**m3**/day), as well as the increase in the level of the ponds by rainwater (mm/day) calculated from the correlation above (mm/day).

Table 4. Volume of rainwater captured and the increase in the level of the ponds by rainwater.

Month	**Rain (mm)**	**Volume of rainwater collected in the lagoons of the WWTP (m3/month**	**Average rainfall volume captured in the WWTP lagoons (m3/day)**	**Increase in the level of the lagoons by rainwater (mm/day)**
January	107,4	323,7	10	3,31
February	15,4	46,4	1,6	0,53
March	110,4	332,7	10,7	3,55
April	121,3	365,6	12,2	4,04
May	233,7	704,4	22,7	7,54

Source: The author.

According to the data from the water balance report previously sent to FEPAM, it can be inferred that 13 cubic meters of water are evaporated in the ponds of the effluent treatment plant. Considering the total area of the ponds of the WWTP of 3014 m2, it is possible to calculate the estimate of lowering of the daily water level of these ponds considering that 1 meter (100 cm) corresponds to 3014 m3.

100 cm --------------------- 3014 m3

X --------------------- 13 m^3

x = 0.43 cm /day or 4.3 mm/day

Considering that 13 cubic meters of water are evaporated per day in the ponds of the effluent treatment plant, it can be inferred that the water level of these ponds decreased by 4.3 mm/day.

Table 6 shows the lowering of the pond level considering the amount of water from the well and rain by subtracting the amount of effluent infiltrated into the soil.

Table 5. Lowering the level of the ponds considering the amount of water from the well and rain subtracting the amount of effluent infiltrated in the soil.

Month/year	Well Water (m3/day)	Estimated rainwater (m3/day)	Infiltrated effluent (m3/day)	Difference of Water (Well + Rain) and infiltrated effluent (m3/day)	Lowering of the level of the ponds considering the evaporation of effluent (mm/day)
January/2023	41,9	10	31,3	20,6	6,83
February/2023	43,2	1,6	32,1	12,7	4,21
March/2023	39,5	10,7	38,2	12	3,98
April/2023	39,9	12,2	44,2	7,9	2,62
May/2023	39,9	22,7	55,1	7,5	2,49

Source: The author.

From table 6 it can be observed that in the month of January 2023 we had a considerable volume of evaporated water, resulting in a considerable lowering of the surface level of the ponds (6.83 mm/day). In February the amount of rain was very low (daily average of 1.6 m3/day) which resulted in a lower lowering (4.21 mm) of the lagoons compared to the month of January. In the month of March the lowering of the lagoons (3.98 mm) remained identical to the month of February 2023, however we have to consider an increase in the amount of rainfall, but a decrease in solar incidence compared to the month of January. The peak of evaporation in the months of January to March is justified to the detriment of the incidence of higher values of insolation, temperature and wind speed, associated with low precipitation (VIEIRA, 2015). It can be observed that in the month of March the amount of rain was similar to the surplus of evaporated water.

In the month of April there was an increase in the amount of rainfall compared to the month of March and there was an infiltration of a greater volume of effluent, which resulted in a small difference in the volume of water (well and rain) and the volume of effluent infiltrated causing a lower lowering in the level of the ponds (2.62 mm), lower than that calculated by the Jensen-Haise Method (3.71 mm) according to table 7. In the month of May we also had an increase in the amount of rainfall and an infiltration of a greater volume of effluent compared to the previous month, resulting in a small difference in the volume of water (well and rain) and the volume of effluent infiltrated, causing a lower lowering in the level of the ponds (2.49 mm).

In table 6 we can compare the evaporation calculated by the Jensen-Haise Method with the effluent evaporation values of the ponds of the COOPEROQUE WWTP.

Table 6. Evaporation calculated by the Jensen-Haise Method with the effluent evaporation values of the COOPEROQUE WWTP ponds

Month/Year	Effluent evaporation volume (m3/day)	Lowering of the level of the ponds by evaporation of effluent (mm/day)	Lowering of the level considering the effluent evaporation calculated by the Jensen-Haise Method (mm/day)
January/2023	20,6	6,83	7,68
February/2023	12,7	4,21	6,24
March /2023	12,0	3,98	6,22
April /2023	7,9	2,62	3,71
May/2023	6,9	2,49	2,61

Source: The author.

The results of the evaporation of the ponds calculated by the Jensen-Haise Method are slightly higher and justify the evaporation values found in the ponds of the WWTP of COOPEROQUE. In the month of January 2023 we had a considerable volume of evaporated water, resulting in a considerable lowering of the surface level of the ponds (6.83 mm/day) and the one calculated by the Jensen-Haise Method was 7.68 mm/day. In February the amount of rain was very low (daily average of 1.6 m^3/day) which resulted in a lower lowering of 4.21 mm/day and the one calculated by the Jensen-Haise Method was 6.24 mm/day. In March, the lowering of the ponds was 3.98 mm/day and the Jensen-Haise Method was 6.22 mm/day. In April, the lowering of the level of the lagoons was 2.62 mm/day and the Jensen-Haise Method was 3.71 mm/day. In the month of May, the lowering of the level of the lagoons was 2.49 mm/day and the one calculated by the Jensen-Haise Method was 2.61 mm/day.

Table 8 shows the volumes of rainwater collected and effluent infiltrated, as well as the subtraction of this volume with that of the infiltrated effluent. It is also presented the estimate of evaporation of water from the effluent and monthly evaporation rates. From the month of March it is observed that there was an increase in precipitation values and from April a reduction in monthly evaporation rates.

Table 7. Volumes of water (well and rain), infiltrated effluent and evaporation rates.

Month/year	Well Water (m3/day)	Estimated rainwater (m3/day)	Infiltrated effluent (m3/day)	Subtraction of Water (Well + Rain) and infiltrated effluent (m3/day)	EVAPORATION of Water (%)
January/2023	41,9	10,0	31,3	20,6	39,7
February/2023	41,3	1,6	31,5	12,7	29,6
March/2023	39,5	10,7	38,9	12,0	23,9
April/2023	39,9	12,2	50,2	7,9	15,2
May/2023	39,9	22,7	55,1	7,5	12,0

Source: The author.

In a study of evaporation and energy balance for a lake in Tibet-Himalaya, YU et al. (2011) found that decreases in insolation, temperature and wind speed led to a reduction in the rate of evaporation, corroborating the results previously presented.

The number of molecules that leave the surface is related to the surface temperature of the water (Finch, 2008), that is, the degree of agitation of the molecules increases with the increase in temperature. Evaporation varies from one location to the next, due to climatic differences (air temperature, wind speed, solar radiation, relative humidity, precipitation), characteristics and management practices of water use (Benzaghta, 2014). According to Hostetler and Bartlein (1990) evaporation occurs whenever there is a deficit of water vapor pressure between the surface of the water and the atmosphere above this surface, and the availability of energy necessary for the process.

Martínez-Alvarez et al. (2008) observed that in the Segura River basin, southeastern Spain, evaporation water losses (58.5 x 106 m3 $^{\text{year-1}}$) correspond to 8.3% of all water derived for irrigation in this region. Craig et al. (2005) observed that in some places in Australia, 50% of the water stored in the reservoirs is lost by evaporation. Less than 20% of the available water is destined to meet the demand of the population, while 60% is lost by evaporation in Africa (Fowe et al., 2015).

5 FINAL CONSIDERATIONS

However, it can be concluded that the evaporation values found in the ponds of the WWTP of COOPEROQUE are justified with the values calculated by the Jensen-Haise Method and the other references corroborate the results presented in this detailed study of the information of precipitation and evaporation rate by the area of the lagoons of the WWTP of COOPEROQUE.

The study showed that evaporation rates were influenced by factors such as temperature, wind and precipitation. The results also indicated that evaporation rates were highest in the months of January to March, which can be attributed to higher solar radiation and temperature. However, evaporation rates decreased in the following months due to increased precipitation and lower solar radiation. The findings of this study have important implications for water management in the region. By understanding evaporation rates and changes in water level in ponds, it is possible to optimize water use and mitigate water scarcity problems. This information can be used to improve the design and operation of wastewater treatment plants, ensuring that evaporation losses are taken into account in the overall water balance. In addition, the study highlights the importance of using appropriate methods to estimate evaporation rates. The Jensen-Haise method, used in this study, has been shown to be effective in estimating evaporation in arid and semi-arid regions. Despite its simplicity, this method has been shown to be efficient in estimating evaporation rates and can be a valuable tool for the management of water resources. It is worth mentioning that the study focused on the

COOPEROQUE Effluent Treatment Station in Salvador das Missões, Rio Grande do Sul, Brazil. However, the findings and methodology may be applicable to other regions.

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