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Feasibility and sustainability of evaporation ponds as final basins for industrial wastewater: statistical evaluation of gross parameters

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ABSTRACT

Many industrial sites use evaporation ponds as their final discharge location for wastewater. Many environmental impacts and aspect studies have recommended this type of solution to avoid industrial wastewater discharge into superficial water to avoid water pollution. However, this solution may pose a serious environmental and ecological issue. Based on a practical study for an industrial site located in the Eastern Region of Morocco that used evaporation ponds for its wastewater, we assessed the evolution of wastewater physico-chemical parameters between the evaporation ponds and the effluent system (wastewater before discharge into evaporation pond) for a period of one year. The results of a study of wastewater stored in evaporation ponds to see how evaporation affects industrial effluent show a significant increase in physico-chemical parameters. As a result, there will be an increase in water contamination. The strongly correlated and interrelated wastewater parameters in the evaporation pond were identified using correlation coefficients. For highly linked wastewater characteristics, regression models linking these identified and correlated parameters were developed. This water pollution poses a significant environmental concern in the case of an unintended leak, and it might have a significant impact on biodiversity because the water draws a wide range of bird and animal species. In certain cases, wastewater reuse/recycling is offered as a control mechanism to reduce potential environmental and ecological risks.

Keywords: Evaporation ponds; Environment; Wastewater; Physico-chemical parameters; Correlation and regression analysis

1. Introduction

The irreversible depletion of natural resources, particularly water, and the degradation of their quality continue to be major challenges in the twenty-first century.

Morocco's water resources are primarily conventional. Water desalination, reuse, and recycling of treated wastewater are examples of non-conventional water resources that have recently been developed to reduce natural resource withdrawals and protect the environment. In the case of an unintentional leak, this water pollution poses a substantial environmental risk, and it might have a significant impact on biodiversity because the water attracts a diverse range of bird and animal species [1].

Evaporation ponds are lined earthen ponds in which the concentrate evaporates naturally as a result of solar irradiation. As the freshwater evaporates from the ponds, the minerals in the concentrate precipitate into salt crystals, which are harvested and disposed of off-site on a regular basis [2].

Evaporation ponds have been used to remove water from saline solutions for decades. The usage of evaporation ponds to dispose of waste saltwater provides a number of benefits.

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They argue that evaporation ponds are easier to construct, require less maintenance, and require less operator attention than mechanical systems.

The need for enormous tracts of land when the evaporation rate is low or the disposal rate is high, as well as the necessity for vast tracts of land when the evaporation rate is low or the disposal rate is high, are some of the downsides [3].

Evaporation ponds can be an effective industrial waste disposal alternative, especially in countries with dry and warm weather, high evaporation rates, and low-cost land. To reduce the risk of groundwater contamination, evaporation ponds can be sealed [2].

Evaporation ponds, according to Alameddine and El-Fadel [4] are ideally suited to fairly warm and dry environments with high evaporation rates, level topography, and cheap land costs.

Evaporation ponds are used to concentrate effluents. As a result, they use evaporation to reduce effluent volume, which may result in the formation of salt [2].

Martin et al. [5] created a rating system to evaluate disposal basins based on basin size, input volume to evaporative capacity ratio, groundwater leakage possibility, ownership and monitoring frequency, re-use, and other factors.

Ahmed et al. [2] used these criteria to examine evaporation basins in New South Wales, Australia. They wanted to know what the exact risk of using evaporation basins was. Both publications offer information that can be used to identify disposal basins that are likely to be hazardous to the environment.

Evaporation ponds are a solution for industrial effluent that is put into large ponds and slowly evaporates with the help of direct sunlight. They are a common form of saline water management in many countries across the world [6].

Evaporation ponds, despite their advantages, may pose a number of environmental and ecological risks. Any wastewater overflow from the evaporation ponds, for example, may have a severe negative impact on the ecosystem (soil, and groundwater contamination). Furthermore, because evaporation ponds are open water surfaces, they attract birds and animals, potentially increasing the mortality of those species if the effluent quality is bad and exceeds the limits.

By analyzing the wastewater of an industrial site in Morocco, we will demonstrate the inconvenience for all industrial sites that used to discharge their wastewater into evaporation ponds. This investigation included a physico-chemical analysis of the presence of water contaminants. To correlate the physico-chemical properties, statistical processing was used to define the most typical characteristics.

2. Materials and methods

2.1. Description of the study area

During the 2020/2021 period, an industrial site with an internal water treatment plant in Morocco's Eastern Area was chosen to collect wastewater samples from the effluent and three evaporation ponds to cover the entire year.

2.1.1. Climatic framework

Morocco's Eastern Area has a dry climate with continental tendencies, which is typical of the country. Both the Saharan and the south-western Atlantic air masses have an impact, with the former having the upper hand. The Atlas Mountains limit the ocean's influence [7].

2.1.1.1. Precipitation

Low rainfall is a feature of the area. The annual rainfall is around 150 mm.

The interannual distribution of the rainfall regime is exceedingly variable. In the region, there have been several dry years with precipitation as low as 30 mm/y and wetter years with averages of up to 268 mm.

The region has a low amount of thunderstorm days, about two per year on average, and a very minor number of hail days. Snow is not prevalent at the project site or in the immediate vicinity.

2.1.1.2. Temperatures

The average temperature in the region is around 23.0°C. July is the hottest month, with an average temperature of 32.0°C, while January is the coldest, with an average temperature of 8.0°C.

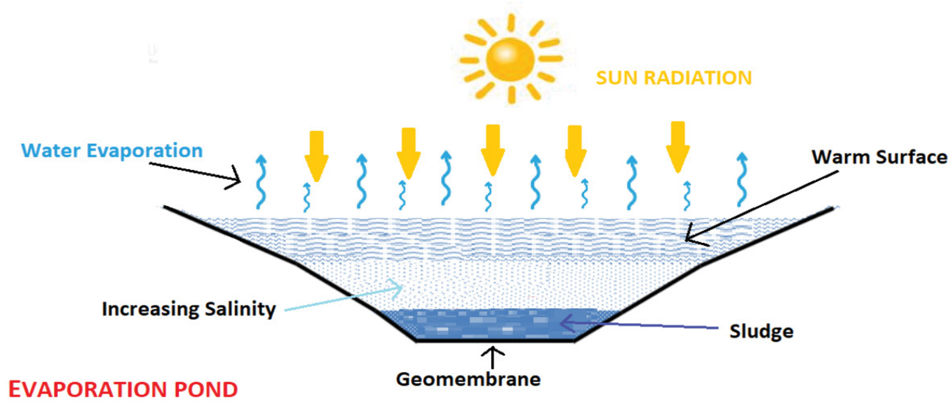

Fig. 1. Evaporation pond illustration.

In the winter, temperatures range from 0.6°C to 23.0°C. Temperatures in the summer range from 32.0°C to 41.0°C. Only a few days a year do temperatures fall below 0.0°C.

In 1983, the area's maximum temperature was 43.0°C and its lowest temperature was –11.0°C (Table 1 and Fig. 2).

2.1.1.3. Wind

The wind regime is generally weak in the region, with the west to north-west sector dominating, followed by the south and south-east sector.

Wind speeds range from 1 to 12 km/h, with medium winds ranging from 13 to 28 km/h and occurring occasionally. Winds above 29 km/h are rare. There is calm weather (5 km/h) around 11% of the time (Fig. 3).

2.1.1.4. Humidity

The relative humidity drops as the temperature rises. According to data collected in the region between 1985 and 2011, relative humidity fluctuates from 32% in July to 57% in December, depending on the month (Fig. 4).

The potential evaporation rate, which exceeds 2 m/y, is among the highest in Morocco, with the highest concentration of evaporation happening from May to September (50%) and a maximum in July.

2.2. Sampling and physico-chemical analysis

The sampling took place between September 2020 and September 2021, and it was done with a certified automatic sampler, the SIGMA type 940P.

The effluent was physico-chemically analyzed using established methods in our Laboratory of Biotechnology, Materials, and Environment.

Because oil traces were found in the effluent from the evaporation ponds, samples were taken in specific containers (glass materials).

The samples were taken from the industrial site and tested the same day.

Table 1
Climatic characteristics of the region

	Jan-20	Feb-20	Mar-20	Apr-20	May-20	June-20	July-20	Aug-20	Sept-20	Oct-20	Nov-20	Dec-20
Average temp. (°C)	10.2	12.3	15.6	19.6	22.3	27.2	30.1	30.5	26.3	20.3	15.5	10.2
Temp. min. average (°C)	2.0	4.2	7.4	10.2	13.2	17.3	20.6	21.4	16.5	11.5	8.0	3.4
Temp. max. (°C)	19.0	20.1	23.6	28.2	32.4	35.9	39.0	40.1	36.2	28.3	22.4	17.5
Precipitations (mm)	17.0	13.0	12.0	12.0	11.0	4.0	2.0	6.0	13.0	25.0	26.0	18

Table 2
The sampling method used for wastewater analysis

Parameter	Analysis device
Temperature (T)	HACH CDC641T Conductivity Cell with temperature sensor
Potential of hydrogen (pH)	HACH HQ2200 Portable Multi-Meter pH, conductivity, TDS, salinity, dissolved oxygen (DO), and oxidation–reduction potential (ORP), w/o electrodes
Electrical conductivity (EC)	HACH HQ2200 Portable Multi-Meter pH, conductivity, TDS, salinity, dissolved oxygen (DO), and oxidation–reduction potential (ORP), w/o electrodes
Total suspended solids (TSS)	HACH Solitax ts-line Suspended Solids (0.001–50 g/L) immersion probe, stainless steel
Chemical oxygen demand (COD)	HACH Z7000 Chemical Oxygen Demand Analyzer
Biochemical oxygen demand (BOD_5)	TRAK II Manometric – HACH
Iron (Fe^{+++})	HACH EZ2308 Total Iron Analyzer, 1 stream, MODBUS RS485
Sodium (Na^+)	HACH Polymetron 9240 Sodium Analyzer
Aluminium (Al^{+++})	HACH EZ2300 Total Aluminium Analyzer
Sodium adsorption ratio (SAR)	Calculation: SAR = $Na^+/\sqrt{(½(Ca + Mg)}$
Nitrate (NO_3^-)	HACH EZ1029 Nitrate Analyzer
Bicarbonate (HCO_3^-)	HACH Alkalinity Test Kit AL-AP, 5–100/20–400 mg/L $CaCO_3$ 100 pcs
Total dissolved solids (TDS)	HACH HQ2200 Portable Multi-Meter pH, conductivity, TDS, salinity, dissolved oxygen (DO), and oxidation–reduction potential (ORP), w/o electrodes
Sulfates (SO_4^{--})	HACH EZ4039 Sulphate Analyzer

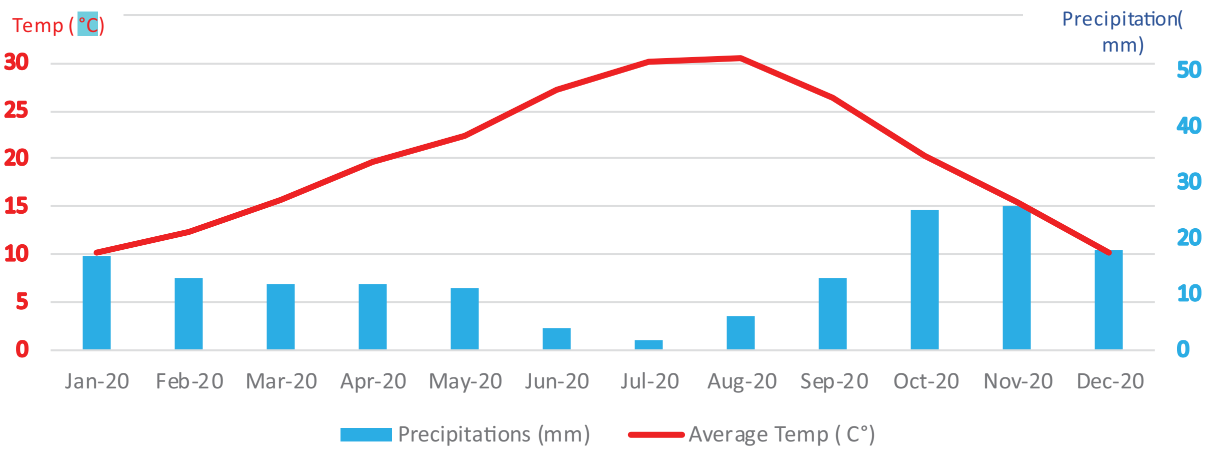

Fig. 2. Umbro thermal and precipitation diagram of the Eastern Region of Morocco.

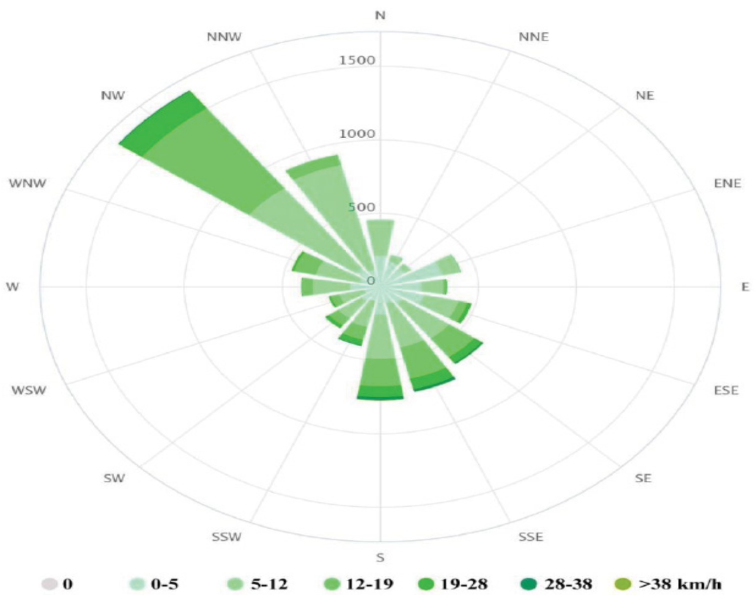

Fig. 3. The Wind Rose Diagram of the Eastern Region of Morocco humidity.

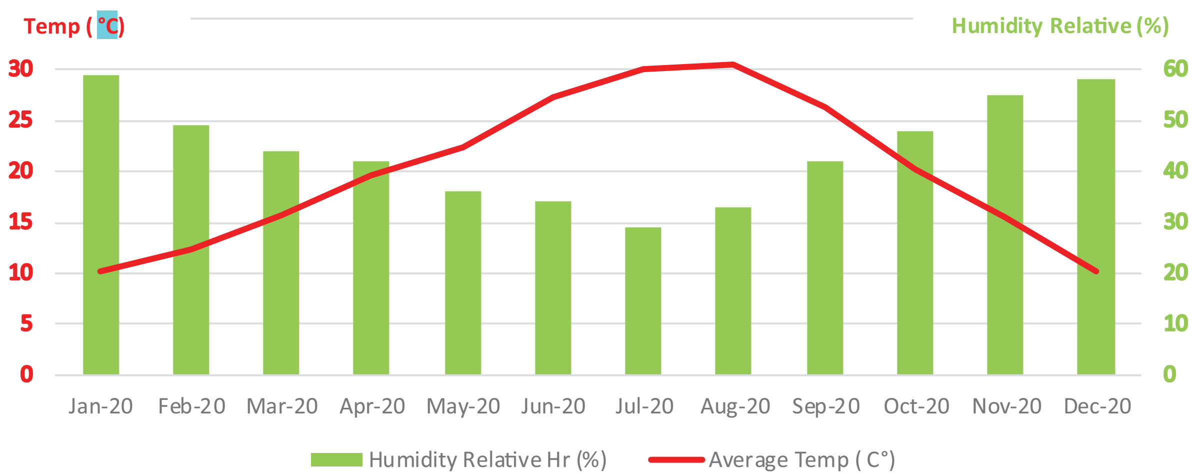

Fig. 4. Average temperature and relative air humidity in the Eastern Region of Morocco.

Standard methods for the examination of wastewater were employed, which are detailed in the Standard Methods for the Examination of Wastewater [8].

The following physico-chemical analysis was measured as follows:

3. Statistical analysis

3.1. Correlation

For assessing wastewater quality in the evaporation pond, correlation and regression analysis are helpful. Correlation and regression analyses were carried out by using statistical tools. The Pearson correlation type was used to calculate the correlation coefficient (r) for industrial wastewater physico-chemical parameters in this study. The most popular types of correlations used in statistics are Pearson, Spearman, Point-Biserial, and Kendall rank correlations. Pearson correlation, on the other hand, is the most often used method for determining the degree of linearly connected variables' association. According to Eq. (1), the Pearson coefficient (r) correlation is determined [9]:

$$r = \frac{N\sum xy - \sum x \sum y}{\sqrt{\left[N\sum x^2 - \left(\sum x\right)^2\right]\left[N\sum y^2 - \left(\sum y\right)^2\right]}} \quad (1)$$

where r = correlation coefficient of Pearson; N = value in each data set number; $\sum x$ = x scores' sum; $\sum y$ = y scores' sum; $\sum x^2$ = x squared scores' sum; $\sum xy$ = sum of paired scores' products; $\sum y^2$ = y squared scores' sum.

The purpose of this statistical analysis is to determine how physico-chemical characteristics in wastewater are related to each other. Correlation is a bivariate study that evaluates the degree of correlation between two variables as well as the direction of the relationship [9].

For the purpose of calculating correlation coefficients, the correlation matrix was formed by calculating the coefficients of different pairs of those parameters.

A correlation coefficient (r) of –1 or +1 indicates the largest negative or positive association between two variables; when this value is near to 1, the degree of relationship between the two variables is highly significant. If the correlation coefficient value approaches 0, the relationship between those two variables will become less significant [10]. The p-value was then used to determine the correlation's significance [11]. Thus, if p is less than 0.05 or less than 0.01, the correlation is significant in this case. The correlation is non-significant if the value of p is greater than 0.05. The significance is determined at the 0.01 and 0.05 levels of significance (2-tailed analysis).

3.2. Regression

Least-squares regression is a statistical technique for forecasting the evolution of dependent variables. The least-squares approach illustrates why the line of greatest fit should be included among the data points. Regression analysis can reveal the relationship between dependent and many independent variables [12]. The model for this relationship has been developed, and parameter values have been approximated and utilized to construct a regression equation based on Eq. (2) [13]:

$$y = ax + b \quad (2)$$

where y = dependent; x = independent; a = intercept; b = constant.

4. Results and discussion

4.1. Results of wastewater physico-chemical analysis

Table A1 shows the findings of a one-year physico-chemical investigation of industrial effluent.

The graphs (appendix) presented the results of the physico-chemical study of the effluent and evaporation pond (averaged over one year).

Table A1 shows that eleven wastewater parameters increased significantly between the effluent and the evaporation pond. Three parameters, however, were reduced: T, nitrate (NO_3^-) and bicarbonate (HCO_3^-).

The graphs (appendix) demonstrate the evolution of the physico-chemical parameters in the effluent and evaporation ponds throughout the duration of the year.

According to the results of the evaporation pond's wastewater physico-chemical investigation, the following parameters exceed Moroccan Regulations for wastewater discharge into surface or subsurface waters [14]:

- The electrical conductivity (EC) has an average value of 30.5 mS/cm exceeding the limit value of 2.7 mS/cm.
- The biochemical oxygen demand (BOD_5) has an average value of 160.86 mg O_2/L exceeding the limit value of 100 mg O_2/L.
- The chemical oxygen demand (COD) has an average value of 502.3 mg O_2/L exceeding the limit value of 500 mg O_2/L.
- The sodium (Na^+) has an average value of 3,378.5 mg/L is extremely high.
- The sodium adsorption ratio (SAR) has an average value of 17.14 is very high.
- The total dissolved solids (TDS) has an average value of 18,045.7 mg/L exceeding the recommended irrigation limit value of 7,680 mg/L.
- The sulfates ($SO_4^{-\,-}$) has an average value of 17,921.4 mS/cm exceeding the limit value of 600 mg/L.

Furthermore, the findings indicate that the parameters of industrial wastewater discharge changed while storage in evaporation ponds, namely:

- A slight increase of pH at 25° (the average value in the effluent is 7.7 while the average value in the evaporation ponds is 8.78).
- In the evaporation ponds, the EC increased from 5.5 mS/cm in the effluent to 30.5 mS/cm.
- Increase of the total suspended solids (TSS) from 29.3 mg/L in the effluent to 58.6 mg/L in the evaporation ponds.
- Increase of the COD from 38.3 mg O_2/L in the effluent to 502.3 mg O_2/L in the evaporation ponds.

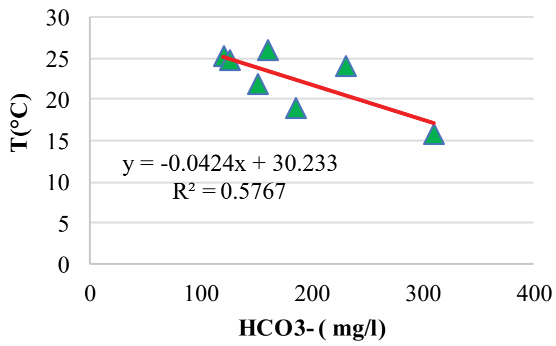

Fig. 5. Linear plot between T and HCO_3^-.

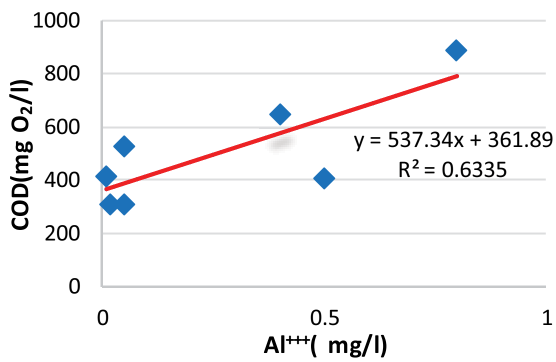

Fig. 6. Linear plot between COD and Al^{+++}.

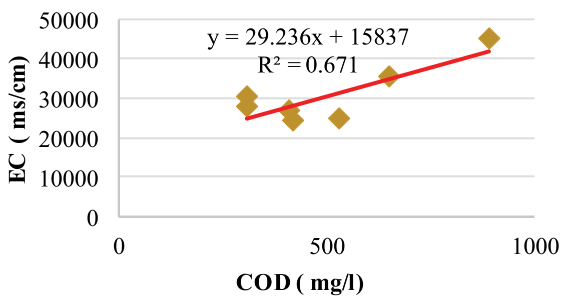

Fig. 7. Linear plot between EC and COD.

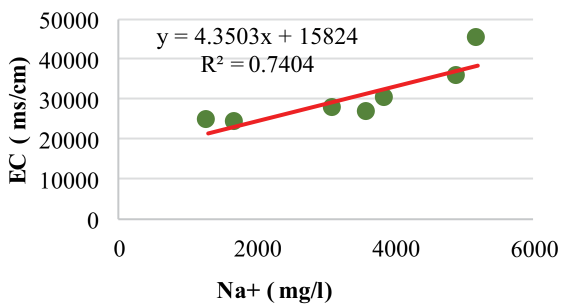

Fig. 8. Linear plot between EC and Na^+.

- Increase of BOD_5 from 8.7 mg O_2/L in the effluent to 160.86 mg O_2/L in the evaporation ponds.
- Increase of Na^+ from 532.7 mg/L in the effluent to 3,378.5 mg/L in the evaporation ponds.

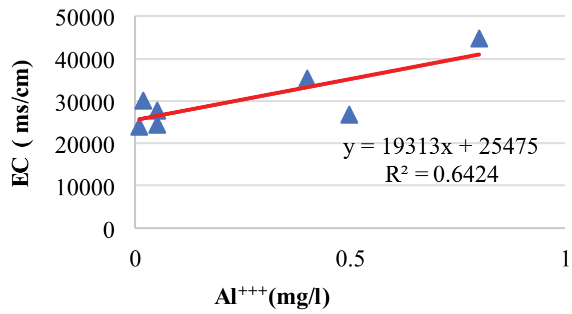

Fig. 9. Linear plot between EC and Al^{+++}.

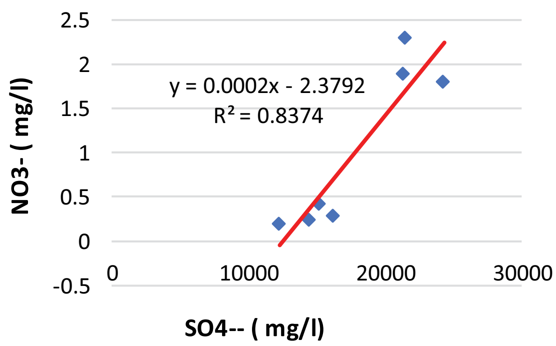

Fig. 10. Linear plot between NO_3^- and SO_4^{--}.

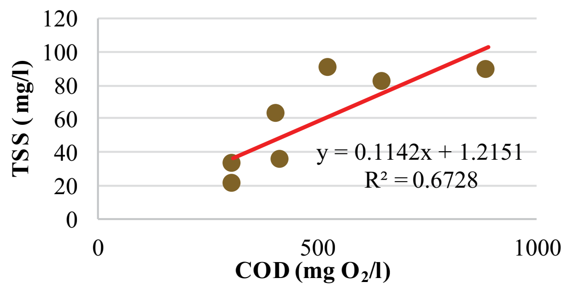

Fig. 11. Linear plot between TSS and COD.

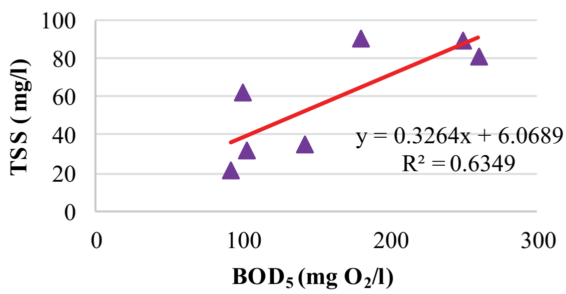

Fig. 12. Linear plot between TSS and BOD_5.

- Increase of SAR from 4.17 mg/L in the effluent to 17.14 mg/L in the evaporation ponds.
- Decrease of NO_3^- from 11.63 mg/L in the effluent to 1.02 mg/L in the evaporation ponds.
- Decrease of HCO_3^- from 270.4 mg/L in the effluent to 183.6 mg/L in the evaporation ponds.

- Increase of TDS from 3,326.4 mg/L in the effluent to 18,045.7 mg/L in the evaporation ponds.
- Increase of SO_4^{--} from 3,139.3 mg/L in the effluents to 17,921.4 mg/L in the evaporation ponds.

4.2. Correlation results

Table A2 summarizes the results of the correlations over the period of the year (including winter and summer seasons):

4.2.1. Temperature

The statistical analytical results are shown in Table A2, which reveal that wastewater temperature has a negative correlation with pH, EC, NO_3^-, TDS, SO_4^{--} and positive correlation with Fe^{+++} and SAR, however, the T has a weak correlation with TSS, COD, BOD_5, Al^{+++}, Na^+.

T has a significant effect on the release of Fe^{+++} and SAR in wastewater, but not on TSS, COD, or BOD_5. This could be explained by evaporation effects in wastewater, which raise the water concentration and salinity.

4.2.2. pH

pH has a weak positive correlation with COD, Fe^{+++}, NO_3^-, Al^{+++}, and HCO_3^-, and a weak negative correlation with EC, BOD_5, Na^+, SAR, TDS, and SO_4^{--}.

The impact of pH revealed that when the wastewater condition is alkaline, the release of Fe^{+++}, NO_3^-, Al^{+++}, and HCO_3^- increases.

4.2.3. Electrical conductivity

EC has a positive correlation with TSS, BOD_5, NO_3^-, HCO_3^-, SO_4^{--} and TDS, and a negative correlation with SAR and Fe^{+++}.

The high EC value, which is proportional to the increase in TSS, BOD_5, NO_3^-, HCO_3^-, SO_4^{--} and TDS could be explained by the decomposition of organic matter in the evaporation pond wastewater, EC is increased when there is a lot of organic contamination.

4.2.4. Total suspended solids

TSS has a positive correlation with Al^{+++} and a negative correlation with SAR; TSS shows its weak correlation with Fe^{+++}, Na^+, NO_3^-, HCO_3^-, TDS, and SO_4^{--}.

TSS levels in the evaporation pond can rise due to the oxidation of Fe^{+++} complexes with ambient oxygen.

4.2.5. Chemical oxygen demand

COD has a positive correlation with Na^+, and shows its weak correlation with Fe^{+++}, NO_3^-, HCO_3^-, TDS, and SO_4^{--}.

The presence of oxidative resilience of organic matter, mostly in the effluent of the evaporation pond, and the presence of Na^+ could explain the high COD readings [15].

4.2.6. Biochemical oxygen demand

BOD_5 has a positive correlation with Na^+, Al^{+++}, and a negative correlation with SAR, however, BOD_5 has a very weak correlation with Fe^{+++}, NO_3^-, HCO_3^-, TDS, and SO_4^{--}.

This association could be interpreted as the BOD_5 result being under-evaluated if the wastewater is lacking in nutrients. Nitrification happens if the nutrient concentration is too high, and the BOD_5 is overestimated.

Because some organic molecules are small or non-biodegradable, bacteria will need to adapt for a long period before they can modify the organic compounds.

4.2.7. Iron

Fe^{+++} has a negative correlation with Na^+, NO_3^-, HCO_3^-, TDS, SO_4^{--}.and a very weak correlation with Al^{+++} and SAR.

The decrease in Fe^{+++} in the evaporation pond could be explained by the presence of an oxidant in the form of chlorine [6].

4.2.8. Sodium

Na^+ has a positive correlation with Al^{+++}, NO_3^-, HCO_3^-, TDS, SO_4^{--}, and a weak negative correlation with SAR; this is evidence of freshwater-saltwater interaction.

4.2.9. Aluminium

Al^{+++} has a positive correlation with HCO_3^-, and a negative correlation with SAR, however Al^{+++}, shows its weak correlation with NO_3^- and SO_4^{--}.

The answer to preventing the corrosion of Al^{+++} and its mechanisms in wastewater was discovered by the presence of HCO_3^- [16].

4.2.10. Sodium adsorption ratio

SAR has a negative correlation with HCO_3^- and a very weak correlation with NO_3^-, TDS and SO_4^{--}.

This could be explained that high HCO_3^- levels in wastewater can lead to calcium and magnesium deposition, as well as an increase in the relative Na^+ concentration that means an increase of SAR.

4.2.11. Bicarbonate

HCO_3^- has a positive correlation with TDS and SO_4^{--}.

The presence of a strong association between HCO_3^- and SO_4^{--} could indicate considerable weathering [17].

The statistical analysis revealed the following significant correlations between wastewater parameters:

The T revealed a significant negative correlation with HCO_3^- ($r = -0.759$, $p < 0.05$). The EC revealed a significant positive correlation with COD ($r = 0.819$, $p < 0.05$), Na^+ ($r = 0.860$, $p < 0.05$), Al^{+++} ($r = 0.802$, $p < 0.05$).The TSS revealed a significant positive correlation with COD ($r = 0.820$, $p < 0.05$) and BOD_5 ($r = 0.797$, $p < 0.05$) a decrease of BOD_5 could be explained by the TSS accumulation in the evaporation pond. The COD revealed a significant positive correlation with BOD_5 ($r = 0.912$, $p < 0.01$) As a result, the high COD/BOD_5 ratios imply that the non-biodegradable fraction of total organic contaminants is presently growing in the evaporation pond [15], Al^{+++} ($r = 0.796$, $p < 0.05$) and a significant negative correlation with SAR ($r = -0.868$, $p < 0.05$). The NO_3^- revealed the most significant positive correlations

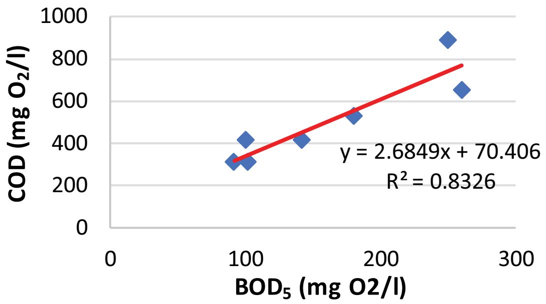

Fig. 13. Linear plot between COD and BOD_5.

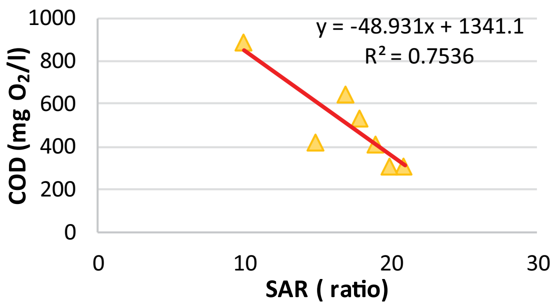

Fig. 14. Linear plot between COD and SAR.

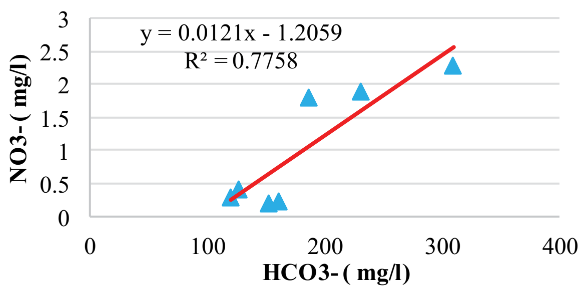

Fig. 15. Linear plot between NO_3^- and HCO_3^-.

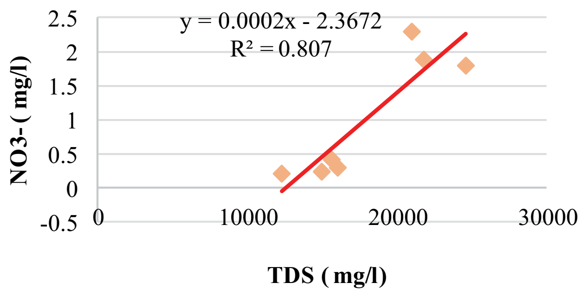

Fig. 16. Linear plot between NO_3^- and TDS.

with HCO_3^- (r = 0.881, p < 0.01) and TDS (r = 0.898, p < 0.01) and SO_4^{--} (r = 0.915, p < 0.01).The TDS revealed a significant positive correlation with SO_4^{--} (r = 0.997, p < 0.01) highlighting evaporation-induced salinization.

The statistical analytical results of the possible association between wastewater physico-chemical characteristics and regional climate are shown in Table 3, which reveal that the ambient temperature of the region has a negative

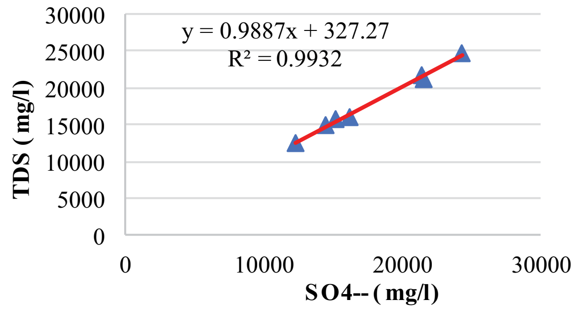

Fig. 17. Linear plot between TDS and SO_4^{--}.

Table 3
Correlation matrices for wastewater parameters and region climate for 1 y

Pearson correlation	Ambient temperature	Humidity	Precipitation
T	–0.727	0.621	0.569
pH	0.215	–0.287	–0.016
EC	0.121	0.214	0.064
TSS	–0.596	0.557	0.381
COD	–0.239	0.350	0.203
BOD_5	–0.427	0.424	0.111
Fe^{+++}	–0.505	0.400	0.577
Na^+	0.021	0.410	0.266
Al^{+++}	–0.184	0.493	0.517
SAR	–0.010	–0.072	–0.114
NO_3^-	0.814*	–0.512	–0.502
HCO_3^-	0.695	–0.332	–0.177
TDS	0.728	–0.484	–0.572
SO_4^{--}	0.725	–0.476	–0.577
Ambient temperature	1	–0.868*	–0.686
Humidity		1	0.863*
Precipitation			1

correlation with T, TSS, Fe^{+++}, and a positive correlation HCO_3^-, SO_4^{--} and TDS; in parallel, this temperature has a weak correlation with pH, EC, COD, BOD_5, Na^+, Al^{+++}, SAR.

The region's humidity has a positive correlation with T and TSS, and a negative correlation with NO_3^-, however, it has a weak correlation with pH, EC, COD, BOD_5, Fe^{+++}, Na^+, Al^{+++}, SAR, HCO_3^-, TDS, and SO_4^{--}. Precipitation has a positive correlation with T, Al^{+++} and Fe^{+++}, a negative correlation with NO_3^-, TDS, SO_4^{--}, and ambient temperature, precipitation has a weak correlation with pH, EC, TSS, COD, BOD_5, Na^+, SAR, HCO_3^-.

The significative correlation has shown between ambient temperature and NO_3^- (r = 0.814, p < 0.05), between humidity and ambient temperature (r = –0.868, p < 0.05), and between humidity and precipitation (r = 0.863, p < 0.05).

4.3. Regression results

The regression analysis of wastewater parameters was performed using statistical software.

The last square of the regression equation based on wastewater parameters with significant association is summarized in Table A3 [18].

4.3.1. Graphs

The linear plots between wastewater physico-chemical parameters are shown in the graphs below:

The plots revealed that EC has a direct linear and positive association with COD, Na^+, and Al^{+++}. Linear regression was used to get the regression coefficient (R) and (R^2) values for those associations.

The graph demonstrates that, COD, Na^+ and Al^{+++} are discovered to be reliant on the EC, an increase of EC leads to an increase of COD, Na^+ and Al^{+++}.

Also, the TSS with COD and BOD_5 have a direct linear and positive relationship, as a result, COD and BOD_5 are discovered to be reliant on the TSS, an increase of TSS leads to an increase of COD and BOD_5.

TDS and SO_4^{--} have also a direct linear and positive relationship, an increase of TDS leads to an increase of SO_4^{--}.

NO_3^- with HCO_3^-, SO_4^{--} and TDS have a direct linear and positive relationship, an increase of NO_3^- leads to an increase of HCO_3^-, SO_4^{--} and TDS.

COD with BOD_5 and Al^{+++} have a direct linear and positive relationship, an increase of COD leads to an increase of BOD_5 and Al^{+++}.

The T with HCO_3^- have a direct linear and negative relationship, an increase of HCO_3^- leads to an increase of T.

SAR and COD have also a direct linear and negative relationship, an increase of SAR leads to an increase of COD.

Fig. 18 shows that 72.8% of the information is represented by the first two axes FC1and FC2.

The variables (EC, Na^+, HCO_3^-, COD, Al^{+++} and NO_3^-) have a strong positive contribution on the FC1 axis, and the variable (SO_4^{--}, TDS and NO_3^-) have a strong negative contribution on the FC2 axis. These variables are characteristic of wastewater pollution in the evaporation pond.

The following properties can be distinguished by projecting the EC on the FC1 and FC2 axes:

The EC's position in the cloud, which corresponds to variables with a strong positive contribution to FC2, leads to the conclusion that the organic compounds degraded in the evaporation pond's effluent.

4.4. Discussion

The results of analyzing the physico-chemical characteristics of wastewater deposited into the evaporation pond demonstrate that evaporation has a negative impact on such industrial effluents, as evidenced by a large increase in various wastewater parameters. This phenomenon has the potential to have significant environmental and ecological consequences.

The significant influence of T on Fe^{+++} and SAR production in wastewater can be explained by evaporation effects in the wastewater, which raise the water concentration and saline.

The high value of EC, which is related to the increase of several physico-chemical parameters; EC is increased when there is a lot of organic pollution, could be explained by biodegradation in the evaporation pond effluent.

Increased TSS in the evaporation pond can also be caused by the oxidizing of Fe^{+++} ions with ambient oxygen.

The existence of oxidative robustness of organic compounds, particularly in the effluent, and the presence of Na^+ could explain the high COD readings because some organic molecules are small or non-biodegradable, bacteria will need to adapt for a long period before they can modify the organic compounds [15].

The occurrence of HCO_3^- was determined to be the key to reducing Al^{+++}' corrosion and its mechanisms in wastewater [16].

A significant amount of HCO_3^- in wastewater can cause calcium and magnesium deposition, as well as a rise in the comparative Na^+ concentration, which causes an increase in SAR.

The association between wastewater parameters and the climate in the region implies that wastewater parameters are influenced by a dry and sunny environment.

Finally, we advocate repurposing the wastewater collected in the evaporation pond using greenhouse techniques, particularly in dry and sunny places, based on our findings.

5. Conclusions

The results of analyzing the physico-chemical parameters of the wastewater discharged into the evaporation pond show that evaporation has a negative effect on this

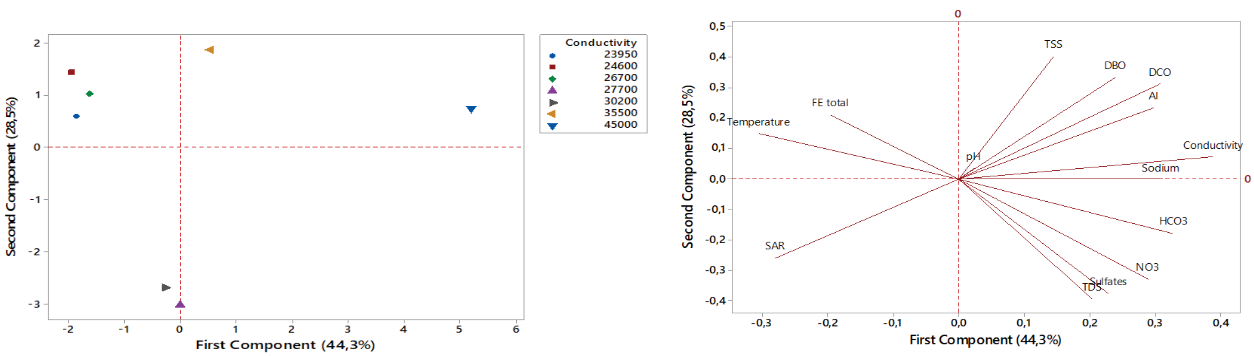

Fig. 18. Principal component analysis (PCA) of wastewater physico-chemical parameters.

industrial wastewater, and that the evaporation phenomenon causes a significant increase in several physico-chemical parameters, including EC, SO_4^{--}, Na^+, TSS, and COD, etc, As a result, we're talking about an increase in water contamination, which is attributable to a variety of external environmental causes (dust, the concentration of water under the effect of the sun, the biodiversity, the organic waste of the fowls, etc).

According to the results of the correlation analysis, the EC of the wastewater collected in the evaporation pond shows a substantial correlation with most of the other waste metrics. The wastewater, on the other hand, exhibits the strongest link between COD and BOD_5, and between NO_3^- and HCO_3^-. As a consequence, regression models relating wastewater characteristics with substantial correlation were developed and are presented in Table A3.

According to this study, all the physico-chemical properties of industrial wastewater collected in an evaporation pond are associated in some way. However, EC, BOD_5, COD, Na^+, SAR, TDS, and SO_4^{--} are the values that exceed the permissible limits for wastewater quality attributes in the research area. In order to prevent potential environmental and ecological concerns, wastewater reuse or recycling using various technical procedures is offered as a control mechanism.

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Appendix

Table A1
Results of wastewater physico-chemical analysis of the effluent and evaporation pond

Parameter	Unit	Sampling	Sep-20	Nov-20	Jan-21	Mar-21	May-21	Jul-21	Sep-21
T	°C	Evap. pond	15.9	26	25.3	24.9	22	19	24.1
		Effluent	17	27	26.1	25.3	18.2	23.4	25.3
pH	pH unit	Evap. pond	8.9	9	8.6	8.6	9	9	8.4
		Effluent	8.9	7	7.9	8	7.45	7.63	7.02
EC	mS/cm	Evap. pond	45	26.70	35.50	24.60	23.95	27.70	30.20
		Effluent	6.46	6.52	3.62	4.20	5.26	5.40	6.89
TSS	mg/L	Evap. pond	89	62	81	90	35	32	21
		Effluent	55	19	36	24	30	22	19
COD	mg O_2/L	Evap. pond	890	410	650	530	418	310	308
		Effluent	28	21	30	29	65	54	41
COD	mg O_2/L	Evap. pond	250	100	260	180	142	102	92
		Effluent	9	8	10	11	8	8	7
Fe^{+++}	mg/L	Evap. pond	0.01	0.2	0.01	0.18	0.01	0.01	0.01
		Effluent	0.01	0.12	0.01	0.05	0.01	0.01	0.01
Na^+	mg/L	Evap. pond	5,200	3,600	4,900	1,300	1,700	3,100	3,850
		Effluent	210	580	310	450	680	710	789
Al^{+++}	mg/L	Evap. pond	0.8	0.5	0.4	0.05	0.01	0.05	0.019
		Effluent	0.1	0.06	0.07	0.05	0.042	0.052	0.035
SAR	ratio	Evap. pond	10	19	17	18	15	21	20
		Effluent	2.36	3.78	4	3.15	5	4.92	5.98
NO_3^-	mg/L	Evap. pond	2.3	0.25	0.3	0.42	0.2	1.8	1.9
		Effluent	10	10.36	9.36	9.5	12.3	21.3	8.6
HCO_3^-	mg/L	Evap. pond	310	160	120	126	152	186	231
		Effluent	318	460	175	252	156	182	350
TDS	mg/L	Evap. pond	21,000	15,000	16,000	15,600	12,320	24,600	21,800
		Effluent	3,200	1,500	1,425	1,200	5,240	5,600	5,120
SO_4^{--}	mg/L	Evap. pond	21,500	14,500	16,200	15,200	12,300	24,350	21,400
		Effluent	3,100	2,100	1,800	1,650	4,200	4,125	5,000

Graphs: Difference between wastewater physico-chemical analysis of the effluent and evaporation pond.

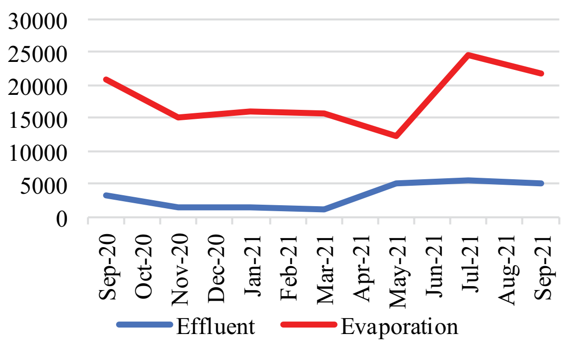

Fig. A1. TDS (mg/L) analysis results.

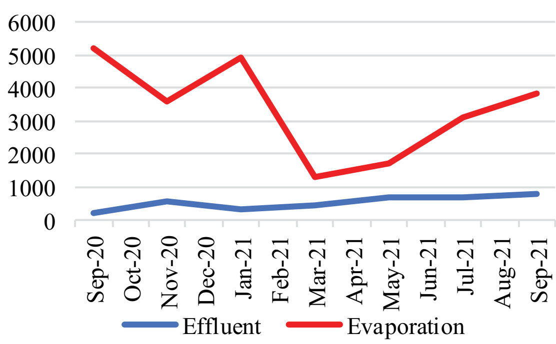

Fig. A2. Na^+ (mg/L) analysis results.

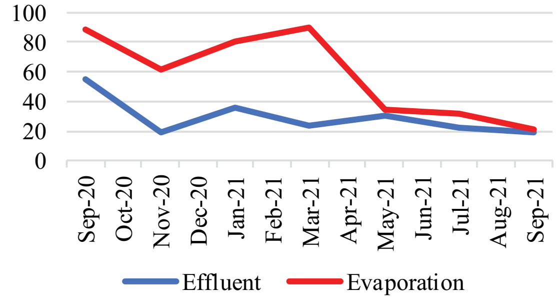

Fig. A3. TSS (mg/L) analysis results.

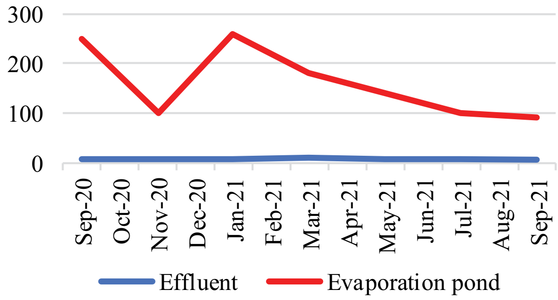

Fig. A4. BOD_5 (mg O_2/L) analysis results.

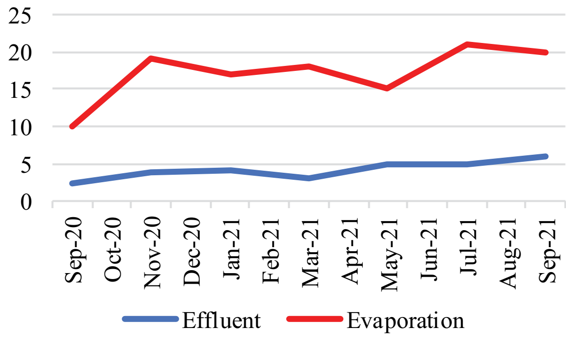

Fig. A5. SAR (ratio) analysis results.

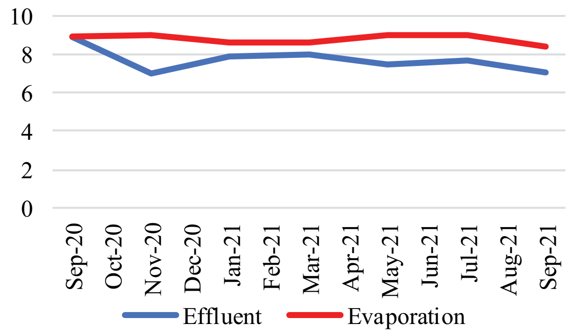

Fig. A6. pH at 25°C analysis results.

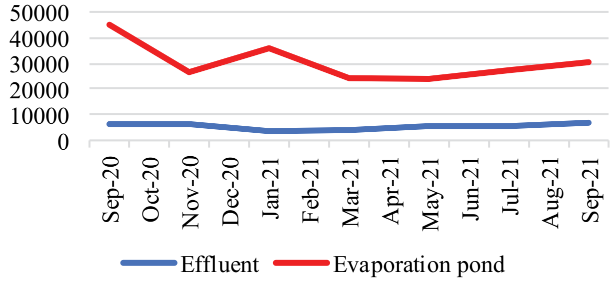

Fig. A7. EC (us/cm) analysis results.

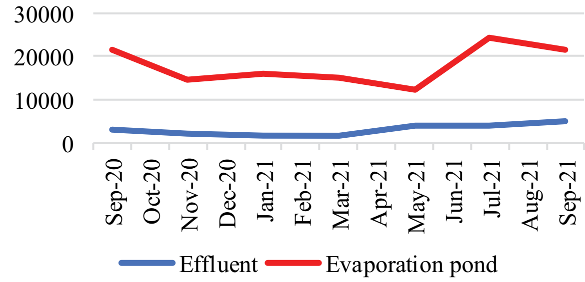

Fig. A8. SO_4^{--} (mg/L) analysis results.

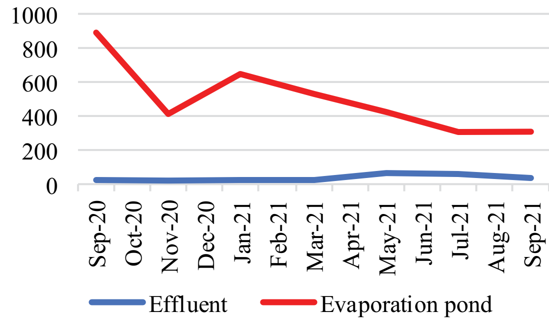

Fig. A9. COD (mg O_2/L) analysis results.

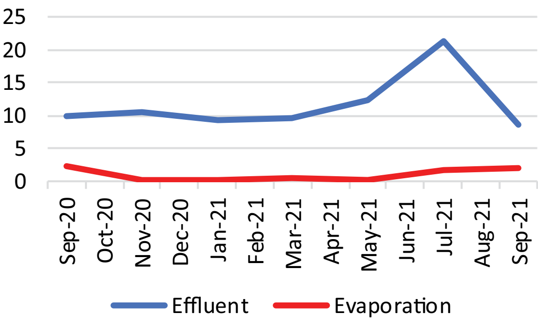

Fig. A10. NO_3^- (mg/L) analysis results.

Table A2
Correlation matrices for wastewater parameters during winter and summer seasons

		T	pH	EC	TSS	COD	BOD_5	Fe^{+++}	Na^{+}	Al^{+++}	SAR	NO_3^{-}	HCO_3^{-}	TDS	SO_4^{--}
T	Pearson correlation	1	–0.438	–0.574	–0.009	–0.424	–0.232	0.549	–0.283	–0.338	0.567	–0.743	–0.759*	–0.559	–0.607
	Sig. (2-tailed)		0.326	0.178	0.985	0.344	0.616	0.202	0.539	0.458	0.184	0.056	0.048	0.192	0.148
pH	Pearson correlation		1	–0.079	–0.047	0.024	–0.141	0.070	–0.110	0.261	–0.233	–0.088	0.074	–0.114	–0.100
	Sig. (2-tailed)			0.866	0.920	0.958	0.763	0.882	0.814	0.571	0.616	0.851	0.875	0.808	0.830
EC	Pearson correlation			1	0.455	0.819*	0.694	–0.439	0.860*	0.802*	–0.684	0.585	0.706	0.385	0.449
	Sig. (2-tailed)				0.305	0.024	0.084	0.325	0.013	0.030	0.090	0.168	0.076	0.393	0.312
TSS	Pearson correlation				1	0.820*	0.797*	0.389	0.210	0.632	–0.533	–0.204	–0.049	–0.288	–0.251
	Sig. (2-tailed)					0.024	0.032	0.388	0.652	0.128	0.218	0.660	0.918	0.531	0.588
COD	Pearson correlation					1	0.912**	–0.116	0.515	0.796*	–0.868*	0.165	0.393	–0.081	–0.012
	Sig. (2-tailed)						0.004	0.805	0.237	0.032	0.011	0.724	0.384	0.863	0.980
BOD_5	Pearson correlation						1	–0.221	0.436	0.581	–0.712	–0.033	0.087	–0.178	–0.109
	Sig. (2-tailed)							0.634	0.328	0.171	0.072	0.945	0.854	0.703	0.817
Fe^{+++}	Pearson correlation							1	–0.399	0.058	0.254	–0.510	–0.402	–0.425	–0.471
	Sig. (2-tailed)								0.376	0.902	0.583	0.242	0.372	0.342	0.286
Na^{+}	Pearson correlation								1	0.745	–0.325	0.472	0.541	0.413	0.456
	Sig. (2-tailed)									0.055	0.476	0.285	0.210	0.358	0.304
Al^{+++}	Pearson correlation									1	–0.661	0.209	0.493	0.029	0.079
	Sig. (2-tailed)										0.106	0.653	0.261	0.950	0.866
SAR	Pearson correlation										1	–0.179	–0.516	0.199	0.128
	Sig. (2-tailed)											0.701	0.235	0.668	0.784
NO_3^{-}	Pearson correlation											1	0.881**	0.898**	0.915**
	Sig. (2-tailed)												0.009	0.006	0.004
HCO_3^{-}	Pearson correlation												1	0.609	0.641
	Sig. (2-tailed)													0.146	0.120
TDS	Pearson correlation													1	0.997**
	Sig. (2-tailed)														0.000
SO_4^{--}	Pearson correlation														1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Table A3
Least square of the regression relation considering physico-chemical parameters that are substantially correlated

Y: Dependent	*X*: Independent	Correlation (*r*)	R^2	*a*	*B* (constant)	Regression equation ($Y = ax + b$)
T	HCO_3^-	–0.759	0.576	–0.042	30.23	$T = -0.042HCO_3^- + 30.23$
EC	COD	0.819	0.671	29.236	15,837	EC = 29.236COD + 15,837
EC	Na^+	0.860	0.740	4.350	15,824	$EC = 4.350Na^+ + 15{,}824$
EC	Al^{+++}	0.802	0.642	19313	25,475	$EC = 19{,}313Al^{+++} + 25{,}475$
TSS	COD	0.820	0.672	0.1142	1.215	TSS = 0.1142COD + 1.215
TSS	BOD_5	0.797	0.635	0.326	6.069	$TSS = 0.326BOD_5 + 6.069$
COD	BOD_5	0.912	0.833	2.685	70.406	$COD = 2.685BOD_5 + 70.406$
COD	SAR	–0.868	0.753	–48.931	1,341.1	COD = –48.931SAR + 1,341.1
COD	Al^{+++}	0.796	0.633	537.34	361.886	$COD = 537.34Al^{+++} + 361.886$
NO_3^-	SO_4^{--}	0.915	0.837	0.0002	–2.379	$NO_3^- = 0.0002SO_4^{--} - 2.379$
NO_3^-	HCO_3^-	0.881	0.7758	0.0121	–1.206	$NO_3^- = 0.012HCO_3^- - 1.206$
NO_3^-	TDS	0.898	0.807	0.0002	–2.367	$NO_3^- = 0.0002TDS - 2.367$
TDS	SO_4^{--}	0.997	0.9932	0.988	327.27	$TDS = 0.988SO_4^{--} + 327.27$

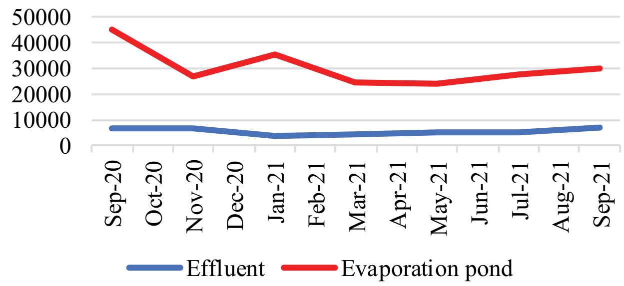

Fig. A11. HCO_3^- (mg/L) analysis results.