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# Identification of the most correlated input and output physicochemical parameters in domestic wastewater at experimental treatment facilities in Nouakchott (Mauritania)

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## ABSTRACT

The study was conducted on domestic wastewater collected at the National Sanitation Office monitoring station and treated using three experimental cylindrical filters (200 L) with a filtering medium 0.70 m high. The treatment achieved average removal efficiencies of 41.42% for biochemical oxygen demand ($BOD_5$), 39.11% for chemical oxygen demand (COD), and 23.30% for total suspended solids (TSS), all within acceptable ranges. Average removal rates of 40.50% and 57.64% were obtained for nitrogen and orthophosphate, respectively, along with a significant improvement in hydrogen potential (pH). The links between correlated variables were investigated using multivariate statistical methods, including principal component analysis and hierarchical clustering. The results show a significant reduction in pollutant loads after treatment, particularly in $BOD_5$, COD, TSS, nitrogen, orthophosphate, and hydrogen potential. PCA highlights the principal axes of variability, and hierarchical classification distinguishes groups of parameters with similar water quality.

**Keywords:** Input and output parameters, experimental devices, principal component analysis, hierarchical classification.

## INTRODUCTION

Sustainable urban wastewater management is a significant challenge for cities in developing countries, where population pressure and rapid urbanization are compromising water resources and public health (Pireh et al., 2023). Nouakchott, the capital of Mauritania, faces a growing wastewater pollution problem due to the lack of a structured, collective sanitation network, leading to wastewater being discharged directly into the environment without adequate treatment. This discharge, rich in organic and inorganic pollutants, contributes to the degradation of aquatic environments, the salinization of groundwater, and the transmission of waterborne diseases (Sharif et al., 2025).

Plant-based filtration systems rely on three key components: microorganisms, filter material, and vegetation. Plants play a central role by promoting the formation of aerobic microzones around their roots and by directly absorbing nutrients, thereby improving pollutant removal (Sandoval Herazo et al., 2023).

It is now feasible to compare treatment site performance, better understand the spatiotemporal variability in the physicochemical characteristics of wastewater, and determine the most critical parameters for pollution assessment using multivariate statistical techniques such as principal component analysis (PCA) and hierarchical classification (Elharbili et al., 2024).

The objective of this study is to characterize raw and treated urban wastewater collected at the National Sanitation Office monitoring station and treated using three experimental cylindrical filters with a capacity of 200 L and a filtering medium 0.70 m high. The study aims to analyze the main physicochemical parameters, including $BOD_5$, COD, TSS, total nitrogen, phosphates ($PO_4^{3-}$), and pH, and to explore the relationships among these variables using principal component analysis (PCA) to identify the main axes of variability.

## MATERIALS AND METHODS

### Study environment

Nouakchott is located in the sub-Canarian zone, which acts as a buffer between the Saharan climate in the north and the Sahelian climate in the south. The summertime rainfall is minimal and highly erratic, and the temperature is typically dry throughout the year. The most excellent temperature range is 28.4 °C to 36.4 °C, while the lowest temperature range is 14.6 °C to 25.7 °C. The alternation of maritime trade winds and monsoons affects humidity, which is high in all seasons (influenced by sea breezes). Rainfall is low (averaging 110 mm/year) and concentrated over a short period of two to three months in the summer.

### Study site

For this study, the sampling site was the National Sanitation Office's monitoring station, which collects domestic wastewater to obtain a representative measure of all wastewater discharged by neighborhoods connected to the sewer system. Three cylindrical barrels, each with a capacity of 200 L, a diameter of 0.54 m, and a height of 0.90 m, make up the experimental apparatus (Figure 1). Every filter has a bottom pipe, which is preceded by a valve to control discharge flow. The material was dispersed to a height of 0.7 m thanks to the filters' 0.9 m height.

### Analysis methods

For five months in 2024, a monthly sample of urban wastewater was collected for analysis. chemical oxygen demand (COD), biological oxygen demand ($BOD_5$), TSS, orthophosphate ($PO_4^{3-}$), hydrogen potential (pH), and Kjeldahl nitrogen (NTK) were all examined. Potassium dichromate oxidation in an acidic medium is used to measure COD. Spectrometry is used to determine absorbance. TSS is acquired by vacuum filtration via a GF/C glass microfiber filter, and $BOD_5$ is calculated using the manometric method with Oxitop manometers. A spectrophotometer is used to measure phosphorus concentration. After organic matter mineralizes in an acidic environment with a catalyst present, Kjel-Dahl nitrogen is measured. A pH meter was used to directly measure the pH.

### Methodology for PCA

To analyze the relationships among the physicochemical parameters of the water ($BOD_5$, COD, TSS, total nitrogen, orthophosphate, and pH), a PCA was performed using R version 4.4.3. The data were standardized (centered and scaled) to put all variables on the same scale and prevent any variable from dominating the analysis due to its unit or variance. The eigenvalues of each axis and the percentage of variance explained were calculated, and the axes retained were selected based on Kaiser's criterion (>1) and the inspection of the scree plot. Although the sample size is limited, PCA remains appropriate as it allows visualization of the correlations among variables and provides a graphical synthesis of the data, facilitating interpretation even with a small number of observations.

## RESULTS

### Physicochemical characterization of wastewater before and after treatment

The results presented in Table 1 show that the average concentrations of all measured parameters, such as $BOD_5$ (149.8 mg/L), COD (239.1 mg/L), TSS (280.3 mg/L), nitrogen (167.5 mg/L), orthophosphate (67.8 mg/L), and pH (7.6). These data indicate that raw wastewater is highly polluted, with significant variation in values depending on the samples taken for the input parameters (E). The results are similar to those reported by Kong et al. (2022). N'diaye et al., (2013) analyzed the physicochemical parameters of effluents from the wastewater treatment plant used for vegetable cultivation in Sebkha Nouakchott, Mauritania. They reported a wastewater

**Figure 1.** Experimental area for the experimental devices

temperature of 28.7 °C, a pH of 7.4–7.9, and salinity assessed by electrical conductivity and chloride concentration, with maximum values of 3290 µS/cm and 1262.1 mg/L, respectively.

After treatment, the values measured in Table 1 still show averages for all output parameters ($BOD_5$ 55.7 mg/L, COD 118.0 mg/L, TSS 88.5 mg/L, nitrogen 65.5 mg/L, orthophosphate 34.7 mg/L, and pH 7.7). The measured values show significant reductions across all output parameters, demonstrating the effectiveness of the implemented phytopurification treatment processes.

## Principal component analysis PCA

PCA is a technique used in data analysis and, more broadly, in multivariate statistics that creates new, correlated variables from related variables (referred to as "correlated" in statistics). We refer to these new variables as "principal components" or axes. It enables practitioners to condense the data into fewer components than the original number of variables (Rodes et al., 2010).

This is both a geometric approach (representing variables in a new geometric space along the directions of maximum inertia) and a statistical approach (searching for independent axes that best explain the data's variability and variance).

Based on the idea of twofold projection on factorial axes, PCA aims to graphically display as much information as possible from a data table (Maliki, 2000, Lagarde, 1995). Data processing by principal component analysis, using $BOD_5$, COD, MES, nitrogen, orthophosphate, and pH as variables, and the six months of sampling as individuals.

## Correlations between the various physicochemical parameters

### *Correlation of input parameters*

The correlation of $BOD_5$ with COD, TSS, nitrogen, orthophosphate, and pH is, respectively, (0.054204, 0.53097, 0.50428, and 0.14484). The correlation between COD and $BOD_5$, TSS, nitrogen, $PO_4^{3-}$, and pH are (0.87152, 0.58869, 0.58691, 0.25896, and 0.10238), respectively. The correlation of TSS with $BOD_5$, COD, nitrogen, $PO_4^{3-}$, and pH is (-0.37755, -0.32908, 0.50603, 0.72993, and 0.71824), respectively.

**Table 1.** Physicochemical characteristics of the input parameter (E) and output parameter (S)

| Parameters | Input parameters (E) | | | | | | Output parameters (S) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $BOD_5$ mg/l (E) | COD mg/l (E) | TSS mg/l (E) | Nitrogen mg/l (E) | $PO_4^{3-}$ mg/l (E) | pH (E) | $BOD_5$ mg/l (S) | COD mg/l (S) | TSS mg/l (S) | Nitrogen mg/l (S) | $PO_4^{3-}$ mg/l (S) | pH (S) |
| February | 227 | 309 | 286 | 496 | 94 | 7.8 | 33 | 48.5 | 33 | 116 | 34 | 7.8 |
| March | 219.5 | 283 | 190 | 132.5 | 76 | 7.5 | 26 | 35 | 30.5 | 49 | 48 | 7.9 |
| April | 108.5 | 186 | 157.5 | 86 | 150 | 7.66 | 63 | 89 | 24 | 39.5 | 35.5 | 7.7 |
| May | 74 | 194.5 | 472 | 73 | 24 | 7.5 | 36.5 | 60 | 67 | 33 | 22 | 7.6 |
| June | 120 | 223 | 296 | 98 | 68 | 7.5 | 88 | 198 | 176 | 50 | 50 | 7.6 |
| Min | 74.0 | 186.0 | 157.5 | 50.0 | 31.5 | 7.5 | 26.0 | 35.0 | 33.0 | 39.5 | 24.0 | 7.5 |
| Maximum | 227.0 | 309.0 | 472.0 | 496.0 | 94.0 | 7.8 | 120.0 | 223.0 | 176.0 | 116.0 | 48.5 | 7.9 |
| Average | 149.8 | 239.1 | 280.3 | 167.5 | 67.8 | 7.6 | 55.7 | 118.0 | 88.5 | 65.5 | 34.7 | 7.7 |
| Standard deviation | 69.2 | 54.5 | 122.7 | 186.1 | 25.0 | 0.1 | 38.6 | 85.8 | 63.2 | 30.8 | 8.9 | 0.2 |
| Variance | 4789.3 | 2970.3 | 15065.5 | 34629.0 | 624.8 | 0.0 | 1488.5 | 7359.4 | 3,995.8 | 948.8 | 79.1 | 0.0 |
| Imbalance | 0.3 | 0.5 | 1.0 | 2.1 | -0.6 | 0.7 | 1.6 | 0.4 | 0.8 | 1.5 | 0.8 | -0.8 |
| Kurtosis | -2.8 | -2.4 | 1.1 | 4.5 | -0.4 | -1.9 | 2.3 | -2.8 | -1.9 | 1.9 | 1.9 | 0.3 |

The correlation of Nitrogen with $BOD_5$, COD, TSS, $PO_4^{3-}$, and pH is respectively (-0.40031, -0.33057, -0.39881, 0.86381, and 0.43367). The correlation of $PO_4^{3-}$ with $BOD_5$, COD, TSS, nitrogen, and pH are (-0.61329, -0.62564, -0.21375, 0.10717, and 0.032511), respectively. The correlation of pH with $BOD_5$, COD, TSS, nitrogen, and $PO_4^{3-}$are (-0.74935, - 0.80224, -0.22316, 0.46177, and 0.90898), respectively, as shown in Table 2

Component (1) $BOD_5$, COD, nitrogen, $PO_4^{3-}$, and pH in the positive direction of the element on the one hand. And suspended solids in the negative direction of the same component, on the other hand (Figure 2 and Tables 1 and 2).

Figure 3 shows $BOD_5$, COD, pH, and $PO_4^{3-}$ at component (1) in the positive direction, and suspended solids and nitrogen in the negative direction of component (3).

Figure 4 shows the dendrogram illustrating how the months (February, March, April, May) are grouped according to the similarity of their physicochemical characteristics of raw wastewater.

### *Correlation of output parameters*

The correlation between COD and $BOD_5$ is 0.96, while the correlations between TSS and BOD5 and between TSS and COD are -0.46 and -0.22, respectively. The correlation between nitrogen and $BOD_5$, COD, and TSS is (0.72, 0.79, 0.79, and -0.05), respectively. The correlation between $PO_4^{3-}$ and $BOD_5$, COD, TSS, and nitrogen is (0.76, 0.67, 0.79, and 0.81), respectively. The correlation of pH with $BOD_5$, COD, TSS, nitrogen, and $PO_4^{3-}$ is respectively (0.39, 0.40, -0.27, 0.79, and 0.85) as shown in Table 3.

The physicochemical parameters of the effluent wastewater (S) are represented in Figure 5 by vectors (TSS, COD, $BOD_5$, $PO_4^{3-}$, pH, nitrogen). The component 1 and component 2 axes summarize most of the data variability.

Each month has a distinct physicochemical profile, with February being rich in nitrogen and high in nitrogen pollution. May has the highest TSS levels. March, April, and June have lower TSS and nitrogen levels. Two parameters dominate the variability of treated wastewater: TSS (vertical axis) and nitrogen (horizontal axis). The other parameters (pH, $PO_4^{3-}$, COD, $BOD_5$) have a weaker influence but evolve together.

Figure 6 illustrates the hierarchical classification dendrogram of treated wastewater parameters based on their degree of similarity in correlations and temporal behavior. The vertical similarity scale indicates the level of resemblance: values (0.96–1.00) indicate very high similarity, values (0.64–0.80) indicate medium similarity, and values < 0.50 indicate a very isolated parameter with different behavior.

## General discussion

Monthly removal efficiencies for the analyzed parameters vary with season and initial concentrations. For $BOD_5$, efficiencies range from 26.7% in June to 88.2% in March. For COD, they range from 11.2% in June to 87.6% in March. TSS is removed more consistently, with removal rates ranging from 40.5% to 88.5%. Nitrogen is reduced by 49.0% to 76.6%, while orthophosphates ($PO_4^{3-}$) show more variable removal rates, ranging from 8.3% in May to 76.3% in April. These variations reflect the effectiveness of constructed wetland treatment, which depends on climatic conditions, pollutant load, and season. The results found can be explained by the fact that plant roots absorb nutrients and pollutants, whether organic or inorganic. In addition, microorganisms in the root zone break down specific contaminants (Mirzaee et al., 2021). The $BOD_5$ results are lower than those reported by Zahui et al. (2021), which ranged from 95.2 to 98.5%. For TSS, the observed values are also lower than those reported

**Table 2.** Correlation matrix between the physicochemical variables of the influent wastewater (E)

| Variables | $BOD_5$ (E) | COD (E) | TSS (E) | Nitrogen (E) | $PO_4^{3-}$ (E) | pH (E) |
|---|---|---|---|---|---|---|
| $BOD_5$ (E) | 1 | 0.054204 | 0.53097 | 0.50428 | 0.27131 | 0.14484 |
| COD (E) | 0.87152 | 1 | 0.58869 | 0.58691 | 0.25896 | 0.10238 |
| MES (E) | -0.37755 | -0.32908 | 1 | 0.50603 | 0.72993 | 0.71824 |
| Nitrogen (E) | -0.40031 | -0.33057 | -0.39881 | 1 | 0.86381 | 0.43367 |
| $PO_4^{3-}$ (E) | -0.61329 | -0.62564 | -0.21375 | 0.10717 | 1 | 0.032511 |
| pH (E) | -0.74935 | -0.80224 | -0.22316 | 0.46177 | 0.90898 | 1 |

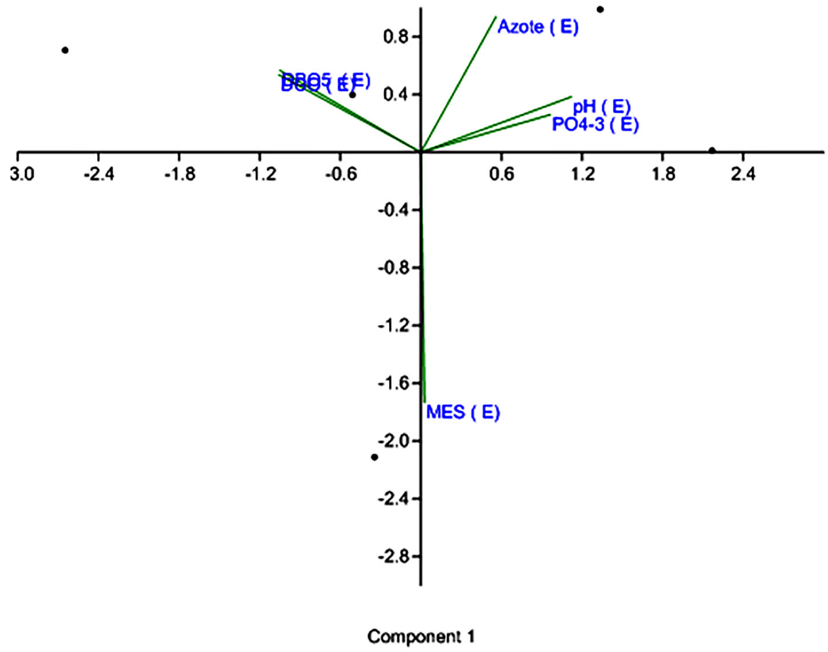


**Figure 2.** F1xF2 vector space (input parameters

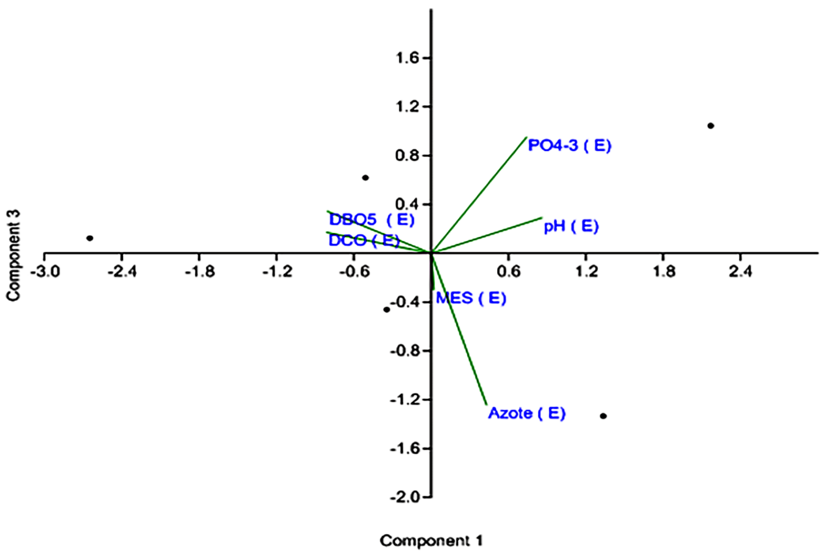


**Figure 3.** F1xF3 vector space (input parameters)

by Bouchaala et al. (2025; TSS: 194.25 ± 110.38). The reduction in total nitrogen is lower than the 76–84% reported by Zahui et al. (2021). For orthophosphates ($PO_4^{3-}$), the results for May and June are similar to those of Zahui et al. (2021), ranging from 77.4 to 96.9%. Finally, the hydrogen potential (pH) remains close to neutrality (7.6 to 7.8), which is similar to the values of 7.61 ± 0.31 observed by Bouchaala et al. (2025). Regarding phosphate removal, this study achieved efficiencies ranging from 49.0% to 76.6%, which are higher than the 40% reported by Bouchaala et al. (2025). The sharp deterioration in water quality at site S2 was followed by a significant improvement at site S3, with removal efficiencies of 68.5% for fecal coliforms and 92.3% for fecal streptococci, as well as a notable increase in dissolved oxygen, confirming the effectiveness of phytoremediation using Phragmites australis as a sustainable and environmentally friendly solution for improving surface water quality. The treatment results in a significant reduction in $BOD_5$ (WHO limit ≤ 30 mg/L), COD (≤ 90 mg/L), and TSS (≤ 20 mg/L), but values remain above WHO limits for TSS, total nitrogen (≤ 40 mg/L), and phosphates ($PO_4^{3-}$ ≤ 2 mg/L) in several months.

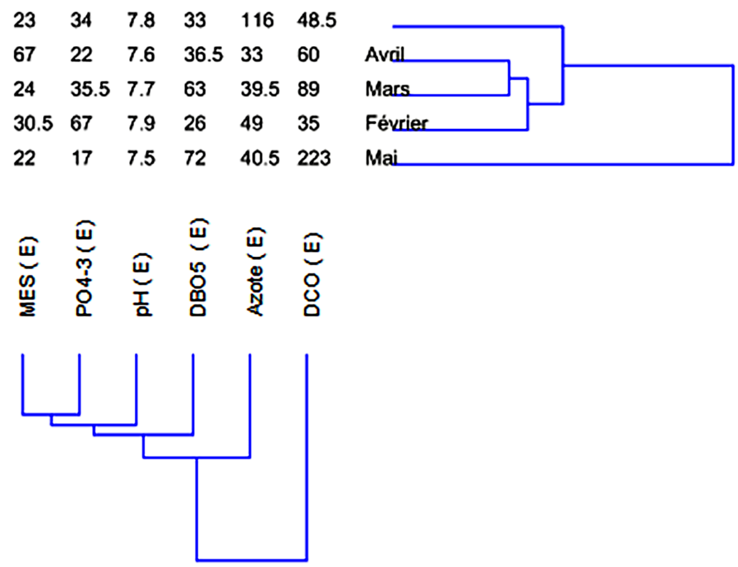


**Figure 4.** Hierarchical classification of input parameters and relationship with time

**Table 3.** Correlation matrix between the physicochemical variables of wastewater effluent

| Variables | $BOD_5$ (S) | COD (S) | MES (S) | Nitrogen (S) | $PO_4^{3-}$ (S) | pH (S) |
|---|---|---|---|---|---|---|
| BOD5 (S) | 1 | | | | | |
| COD (S) | 0.96 | 1 | | | | |
| MES (S) | -0.46 | -0.22 | 1 | | | |
| Nitrogen (S) | 0.72 | 0.79 | -0.05 | 1 | | |
| $PO_4^{3-}$ (S) | 0.76 | 0.67 | 0.79 | 0.81 | 1 | |

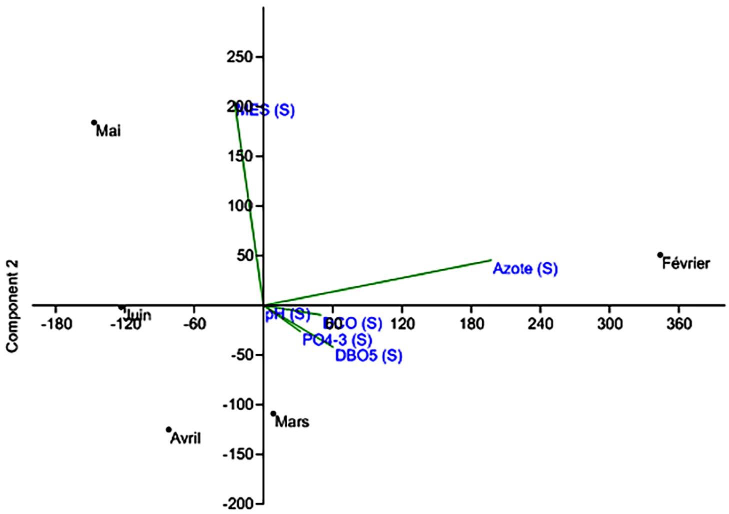


**Figure 5.** Projection of output parameters on the F1xF2 factorial plane

The pH (WHO limit: 6.5–8.5) remains within the acceptable range.

## Application of PCA using the physicochemical input and output parameters

Analysis of the results showed that most of the information is explained by the factorial axes. Examination of the correlation matrix (Tables 1

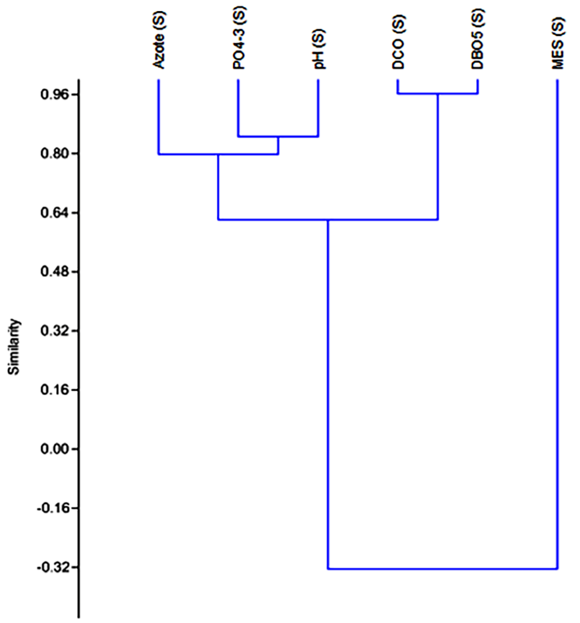


**Figure 6.** Hierarchical classification of output parameters

and 2) reveals a first set of strongly correlated variables. PCA, which allows data to be interpreted based on cumulative variance and factor loadings, identifies relationships and collinearity between variables. When a few components explain most of the variability, variables can be selected to simplify the model (Wang et al., 2022). The results show that $BOD_5$ (E) and COD (E) exhibit a strong positive correlation (0.871), but they are negatively correlated with TSS, nitrogen, $PO_4^{3-}$, and pH, indicating inverse relationships with these variables.

Sharif et al. (2025) also showed that $BOD_5$ and COD are closely correlated, as both measure the amount of organic matter in water. TSS is negatively correlated with $BOD_5$ and COD, but positively correlated with nitrogen, $PO_4^{3-}$, and pH, suggesting that these parameters change together. Nitrogen (E) is negatively correlated with $BOD_5$ and COD, and moderately positively correlated with TSS, $PO_4^{3-}$, and pH. $PO_4^{3-}$ (E) is weakly negatively correlated with $BOD_5$ and COD, but strongly positively correlated with pH. Finally, pH (E) shows negative correlations with $BOD_5$ and COD, and strong positive correlations with $PO_4^{3-}$ and TSS.

For output parameters (S), no correlation was observed between $BOD_5$(S) and other parameters (COD, TSS, nitrogen, $PO_4^{3-}$, and pH), while COD(S) showed a strong correlation only with $BOD_5$. Suspended solids (SS) show a negative correlation with $BOD_5$ and COD. Nitrogen (S) is positively correlated with $BOD_5$ and COD, but shows a weak negative correlation with SS. $PO_4^{3-}$ (S) is strongly positively correlated with $BOD_5$, COD, TSS, and nitrogen. At the same time, pH (S) is the only parameter strongly positively correlated with most other output parameters, except TSS, with which it shows a negative correlation. These results are consistent with several international studies. Sandoval-Herazo et al. (2023) showed a strong correlation between ammoniacal nitrogen ($NH_4^+$-N) and BOD, indicating that $NH_4^+$-N is mainly linked to the degradation of biodegradable organic matter. Moderate correlations with COD (CODMn and CODCr) confirm this organic origin. A strong correlation was also observed between $NH_4^+$-N and total phosphorus (TP), suggesting familiar sources and a shared role in eutrophication. The significant relationships between BOD, COD, and TP indicate that phosphorus is mainly in organic form. In addition, data from the Sfax wastewater treatment plant (southeastern Tunisia), covering 12 years (1984–1996), were analyzed using PCA to assess changes in wastewater quality. The study, based on six physicochemical and biological parameters, revealed strong correlations among $BOD_i$, $COD_i$, and $TSS_i$, as well as among $BOD_o$, $COD_o$, and $TSS_o$. At the same time, no significant relationship was observed between water temperature and $TSS_o$ (Ouali et al., 2009). Mirzaee et al. (2021) reported a strong relationship among TSS, BOD, COD, N, P, and $NH_3$ in wastewater discharged from the former DAF facilities at the fish processing plant. This relationship among the parameters could indicate the presence of solids, organic matter, proteins, oils, nutrients, and bacteria in this wastewater.

## CONCLUSIONS

The quality and quantity of urban wastewater depend mainly on the amount of water consumed (daily per capita allocation), the percentage of this amount that ends up in the sewer system, which depends on climatic conditions, the standard of living of the population connected to the sewerage network, social habits, and the type of housing.

Overall, monitoring of the physicochemical quality of raw wastewater discharged into the pumping station indicated pollution, as evidenced by high nitrogen and $BOD_5$ levels.

The data collected during our study enabled us to draw up a picture of the physical and chemical quality of the incoming and outgoing wastewater. Applying principal component analysis to these results shows that, overall, the physical and chemical parameters of the incoming and outgoing wastewater are well correlated.

The results reveal variable performance: some show good overall efficiency, while others retain significant pollutant loads, particularly nitrogen and $BOD_5$. This indicates differences in the operation or efficiency of the experimental planted treatment systems.

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