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Operational efficiency of wastewater treatment in semi-arid region: Performance and environmental compliance

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ABSTRACT

As part of environmental preservation and sustainable water resource management actions, particularly in a semi-arid region, an annual monitoring program was carried out in 2024 to assess the treatment performance and environmental compliance of the Djelfa city wastewater treatment plant. This approach aimed to assess the effectiveness of the biological treatment and to identify possible optimization needs, in accordance with national regulatory requirements and WHO recommendations. The study focused on the main physicochemical parameters, including pH, temperature, electrical conductivity, turbidity, suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonium (NH_4^+), nitrates (NO_3^-) and phosphates (PO_4^{3-}), in order to evaluate the removal efficiencies and quality of the treated effluents. The results obtained highlight generally satisfactory performance, with yields of 91 to 92% for suspended solids and BOD_5, 83 to 84% for COD and 55 to 66% for phosphates. Regarding nitrogen, ammonium was reduced by 57 to 61%, while nitrates recorded a marked increase (200 to 236%), demonstrating the effectiveness of the nitrification process. Overall, the quality of the treated effluents complies with Algerian discharge standards and international recommendations. However, the fluctuations observed in nitrogen and phosphorus nutrient concentrations reflect certain limitations in the nitrification/denitrification and phosphorus removal processes, suggesting the need for operational adjustments to enhance the stability and efficiency of the biological treatment.

Keywords: wastewater treatment, treatment performance, discharge standards, environmental compliance, semi-arid region.

INTRODUCTION

Water is a very limited natural resource in semi-arid regions. It is in great demand and necessary for all socio-economic activities (Zella, 2007). Its scarcity is a prominent concern for Algeria due to its arid to semi-arid Mediterranean climate. A worry which negatively affects the well-being of citizens and threatens of future generations (Karef, 2017).

Once water is utilized, it undergoes degradation and pollution. Wastewater thus is an extremely complex environment, altered by human activities following domestic, industrial, artisanal, agricultural, or other uses. It is considered polluted and must therefore be treated before any reuse or injection into the natural receiving environments (Touafek et al., 2025). Discharges from domestic and industrial water uses carry numerous substances, both in solid and dissolved forms, along with various pathogenic microorganisms. These pollutants pose a significant threat to the overall quality of the environment (Tamrabet, 2011). Discharge of these effluents untreated into the receiving environment can reduce dissolved oxygen levels, lead to aquatic eutrophication, negatively affect biological life (Boughou et al., 2024; Ozturk and Yilmaz, 2019), and pose a significant threat to human health (Boughou et al., 2024; Wei et al., 2011). The surface and shallow groundwater in developing countries around urban areas are often polluted by domestic wastewater containing these microbes and nutrients (Rezagui et al., 2024).

However, a prior treatment of wastewater not only reduces its environmental impact, but also promotes its recovery, particularly in agriculture (Karef et al., 2014). In this study, we aim to assess the quality of the treated water as well as the treatment performance of the wastewater treatment plant (WWTP) of the city of Djelfa. This will allow us to compare the quality of this water with the available Algerian and international standards and to deduce the necessary operational improvements.

MATERIALS AND METHODS

Commissioned in 1986, and later rehabilitated and expanded in 2014, the wastewater treatment plant located north of the city of Djelfa is designed to treat urban wastewater conveyed by gravity through a single collector, as the sewerage system is unitary. This plant treats wastewater generated by a population equivalent of 270,000 inhabitants, with a nominal daily flow of 27,800 m³/day.

The plant operates under a medium mass load and comprises two treatment lines: an existing line and a new line, as illustrated in Figure 1. Both lines share a single raw water inlet and each have primary treatment, biological treatment, and a chlorination unit. At the outlet, they share common thickening and dewatering sludge.

For the purpose of this study, we monitored and controlled various physicochemical parameters of the wastewater at both the inlet and outlet of the wastewater treatment plant in the city of Djelfa throughout 2024.

The water analyses were made at the laboratory of WWTP. The different measured parameters, the used methods and equipment are given in Table 1.

RESULTS AND DISCUSSION

The physicochemical analyzes of this wastewater are conducted in 2024. The average values and results of these analyses are discussed in relation to national standards and various national and international legislations, adopted and available in the literature. The average values and results of the analyses conducted during 2024 are provided in Table 2.

Physical parameters

Temperature

At the treatment plant level, the average temperature values (Figure 2) indicate a slight increase from the input of 13 °C to the outputs of 14 °C (output 1) and 12 °C (output 2).

The analysis of this parameter is very important, because it conditions many parameters, such as electrical conductivity, dissolved oxygen and pH, as well as degradation and mineralization reactions of organic matter (Karef et al., 2017).

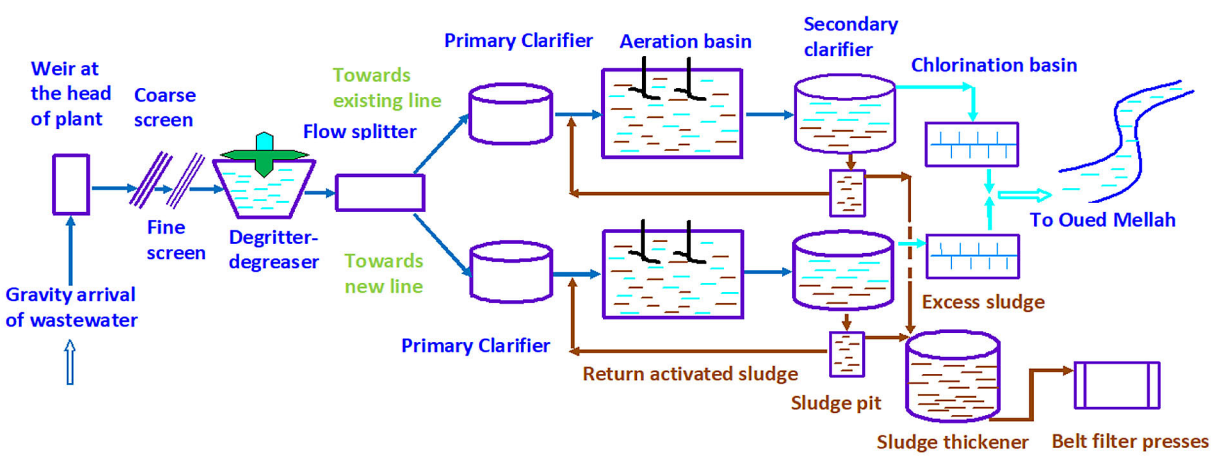

Figure 1. Schematic representation of the WWTP of Djelfa

Table 1. Material and analytical methods

Parameter	Analysis method	Material used
Temperature	Direct measurement	Thermal probe / pH meter
pH	Direct measurement	pH meter WTW 3310
Electrical conductivity (EC)	Direct measurement	Conductimeter WTW Cond 3310
Turbidity	Direct measurement	Turbidimeter HACH
Total suspended solids (TSS)	Gravimetric	GF/C filters,105 °C oven, balance
Chemical oxygen demand (COD)	Colorimetric	Spectrophotometer HACH, Reactor COD LCK 514
Biochemical oxygen demand (BOD_5)	Incubation 5 days	BOD meter (incubator 20 °C)
Ammoniacal nitrogen (NH_4^+)	Colorimetric	Spectrophotometer HACH, LCK 304 Kit
Nitrates (NO_3^-)	Colorimetric	Spectrophotometer HACH, LCK 339 Kit
Total phosphorus (TP)	Colorimetric	Spectrophotometer HACH, Reactor LCK 350

Table 2. Results of the physicochemical analyses of the wastewater at the inlet and outlet of the Djelfa WWTP

Parameters	Plant inlet	Outlet (1)	Outlet (2)
TSS (mg/l)	407	33	38
COD (mg/l)	654	106	112
BOD_5 (mg/l)	270	22	24
NO_3^- (mg/l)	1.1	3.3	3.7
NH_4^+ (mg/l)	0.74	0.28	0.32
TP (mg/l)	8.6	2.9	3.8
T (ºC)	13	14	12
EC (µS/cm)	326	289	296
pH	7.9	8	8.1
Turbidity (FTU)	339	28.7	82.5

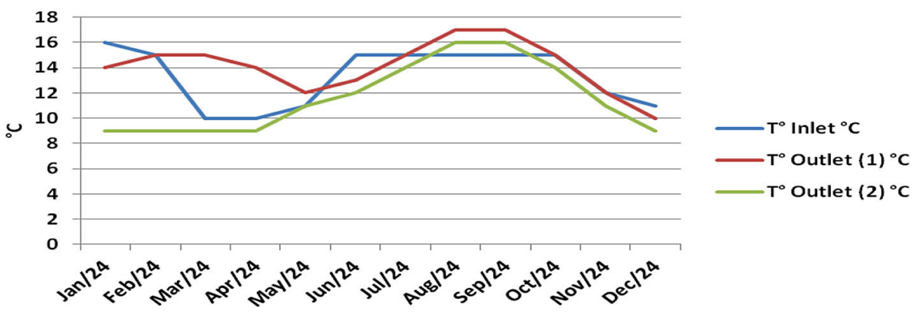

Figure 2. Variation of the temperature (T°) from inlet to outlet of the WWTP

The rise in temperature is always accompanied by a modification of the properties of the water, the density and the viscosity which promote self -purification and increases the speed of sedimentation, which can have an interest in the treatment plants (Gromaire-Mertz, 2000). According to (Degrémont, 1989), at treatment plants, the temperature of wastewater significantly impacts the efficiency of the treatment process. For instance, decantation is more effective at higher temperatures. Furthermore, biological activity during treatment decreases in colder conditions, with nitrification slowing significantly below 10 °C.

pH

The pH values indicate an increase from 7.9 at the inlet to 8 at the outlet (1), and to 8.1 at the outlet (2) of the treatment plant. Wastewater exhibits alkaline properties, mainly stemming from domestic sources such as soapy water, feces, urine, and garbage (Mercoiret, 2010). In our case, the pH of the treated wastewater at the treatment plant is acceptable on the environmental plan (OJ, 2006; WHO, 2006).

Electrical conductivity (EC)

The electrical conductivity values recorded within the treatment plant vary from 326 µS/cm at the inlet to an average of 289 µS/cm at the outlet (1), and 296 µS/cm at the outlet (2) (Figure 3). These values are significantly lower than the average value of 1076.67 µS/cm found by Shehab and Alsultani (2025) in his study.

In our case, the EC of the wastewater of the treatment plant is acceptable for water undergoing treatment (OJ, 2006; WHO, 2006).

Turbidity

The water turbidity values are confined within a range of 339 FTU at the inlet and 28.7 FTU at the outlet (1), and 82.5 FTU at the outlet (2), at the sewage treatment plant level.

Considering the elevated values observed at the station's entrance and the subsequent decrease in water turbidity post-treatment at the outlet, it can be concluded that the treatment process appears to be highly effective.

Chemical parameters

Total suspended solids

The total suspended solids (TSS) analysis indicates (Figure 4) a notable decrease from the input concentration of 407 mg/l to 33 mg/l at output (1) and 38 mg/l at output (2) of the treatment plant, representing substantial reductions of 92% and 91% respectively. These contents are comparable to the average value of 23.45 found by Karef et al. (2025).

The value recorded at the inlet of the wastewater treatment plant is evidently high due to the urban origin of the wastewater. The subsequent decrease observed at the outlet is attributed to the treatment processes undergone by the wastewater. This reduction is notably significant, as only 8% of the initial TSS remain in output (1) and 9% in output (2). These figures underscore the effectiveness of the treatment, especially since they are close to the value of TSS in treated wastewater, which is 30 mg/l (JO, 2006; WHO, 2006).

Chemical oxygen demand

The chemical oxygen demand (COD) values recorded at the wastewater treatment plant show a significant reduction in organic matter, from 654 mg/l at the inlet to 106 mg/l at outlet 1 and 112 mg/l at outlet 2. These results correspond to removal efficiencies of 84% and 83%, respectively, reflecting proper operation of the treatment system. While Karef et al (2025) in his study found a COD value of 56.19 mg/l. The significant reduction in COD between the influent and the treated effluent highlights the effective degradation of oxidizable organic matter by the processes implemented within the plant (Metcalf and Eddy et al., 2014).

Furthermore, the residual concentrations observed at the outlet remain below the limit value of 125 mg/l, in accordance with current discharge standards (OJ, 2006; Metcalf and Eddy et al., 2014). These performances confirm the environmental compliance of the discharge and attest to the proper control of the treatment applied to the wastewater.

Biochemical oxygen demand

The biochemical oxygen demand (BOD_5) values recorded at the treatment plant (Figure 5) vary between 270 mg/l at the plant inlet and 22 mg/l at outlet (1), and 24 mg/l at outlet (2). These values are both significantly lower than the average BOD_5 value of 51.47 mg/l reported in a study conducted by Shehab and Alsultani (2025) and higher than that found of 14.13 mg/l by Karef et

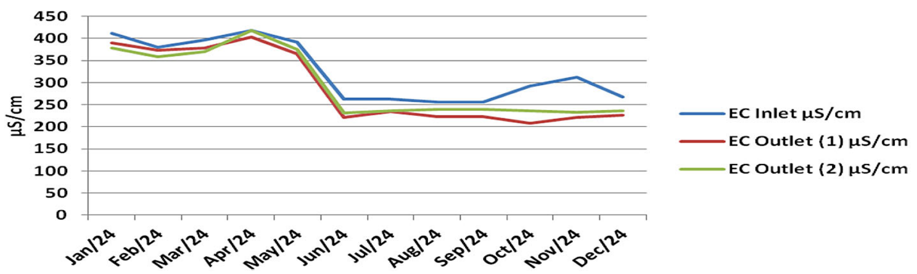

Figure 3. Variation of the Electrical conductivity (EC) from the Inlet to the outlet of the WWTP

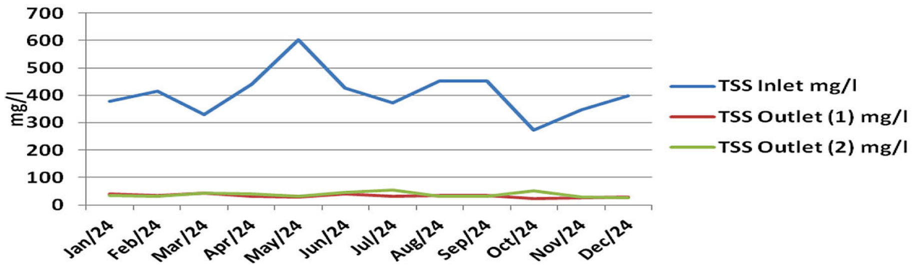

Figure 4. Variation of total suspended solids from the Inlet to the outlet of the WWTP

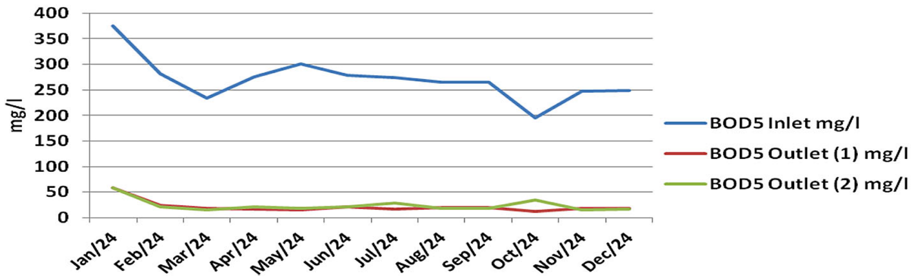

Figure 5. Variation of BOD_5 from the Inlet to the outlet of the WWTP

al. (2025). The significant reductions, with respective values of 92% and 91%, reflect the proper functioning of the WWTP.

The minimum value recorded at the outlet of the treatment plant indicates that the biological treatment applied to the wastewater is highly satisfactory, particularly when considering that the standard requires a BOD_5 level of less than 30 mg/l (OJ, 2006; WHO, 2006).

The biodegradability of wastewater entering the WWTP

According to the COD and BOD_5 values, we observe that the ratio of these two parameters (COD/BOD_5) is equal to 2.42. This result clearly indicates that the wastewater entering the WWTP of Djelfa is biodegradable (Płuciennik-Koropczuk and Myszograj, 2019). This suggests that the nature of the wastewater entering the WWTP is primarily domestic. Additionally, it implies that industrial effluents discharged into the city's sewerage networks are minimal (Metcalf and Eddy et al., 2014).

Nitrogen

Two elements present in water are particularly crucial as they are essential for the synthesis of microorganisms and plants in aquatic environments. These elements are nitrogen (N) and phosphorus (P), typically assimilated by plants in the form of nitrate (NO_3^-) and phosphate (PO_4^{3-}) (Deronzier et al., 2001).

Ammoniacal nitrogen

At the treatment plant level, it is observed that the concentration of ammoniacal nitrogen (NH_4^+) decreases from 0.74 mg/l at the inlet to 0.28 mg/l at the outlet (1) and 0.32 mg/l at the outlet (2). These inlet values are lower than those typically found in urban wastewater (Choubert, 2002). For treated wastewater, regulatory standards require that the ammoniacal nitrogen content of less than 3 mg/l (Choubert, 2002) and 5 mg/l according to (Ayers and Westcot, 1985; WHO, 2006). Therefore, the water leaving the WWTP has no negative effects on the environment.

The reduction in NH_4^+ content at the wastewater treatment plant, from inlet to outlet, results from the biological treatment by activated sludge, based on an autotrophic nitrification process. This nitrification is of significant importance, since the nitric form is much less toxic than the ammoniacal and nitrous forms (Deronzier et al., 2001).

Nitrates

Nitrates (NO_3^-) represent the final stage of nitrogen oxidation and constitute the most highly oxidized form of nitrogen found in water. Their concentrations in natural waters typically range between 1 and 10 mg/l (Karef et al., 2017).

For the Djelfa WWTP, we observed a low value of 1.1 mg/l for the incoming water. In the outgoing water at outlet (1), the content was 3.3 mg/l, and at outlet (2), it was 3.7 mg/l (Figure 6). This increase (200% to 236%) is attributed to nitrification, which converts ammoniacal nitrogen to nitric nitrogen from the inlet to the outlet (Metcalf and Eddy et al., 2014). In case of reuse in irrigation, these values are clearly lower than the limit value cited in (Ayers and Westcot, 1985; WHO, 2006).

Total phosphorus

The highest concentration of total phosphorus (TP) is observed at the inlet of the treatment plant, at 8.60 mg/l, which decreases towards the outlets: 2.90 mg/l at outlet (1) and 3.80 mg/l at outlet (2), a decrease of 56% to 66% (Figure 7).

In wastewater, human discharges account for only 30 to 50% of total phosphorus (ranging between 5 and 20 mg/l), with the remainder coming from cleaning products (Armel, 2001). This accounts for the high concentrations observed in wastewater. Total phosphorus levels measured in treated wastewater are higher than the limit value of 2 mg/l, cited in (Ayers and Westcot, 1985; WHO, 2006).

CRITICAL ANALYSIS

This work is part of a rigorous environmental monitoring approach for the Djelfa WWTP, in a semi-arid context where water resources are scarce and precious. The study covers a full year (2024), ensuring temporal representativeness and consideration of seasonal variations. It is based on reliable physicochemical analyses conducted in the laboratory, in accordance with national and international standards.

Overall process performance

The process adopted is the medium-load activated sludge process, recognized for its robustness and efficiency in urban wastewater treatment.

The results confirm excellent treatment efficiency, as shown in Table 3.

To visualize the different treatment efficiencies operated on the different pollution parameters, we have drawn the graph presented in Figure 8.

It is clear that the removal efficiency of nitrates (NO_3^-) is significantly higher than that of ammonium (NH_4^+). This reflects an inverse proportionality between nitrates and ammonia from the inlet to the outlet of the treatment plant. This results from the nitrification process, during which the progressive oxidation of ammoniacal nitrogen leads to the formation of nitrates.

The treatment system implemented at the Djelfa treatment plant is operationally efficient and stable, with a discharge quality in accordance with Algerian regulations and WHO recommendations. Młyńska et al. (2017) confirmed that biological treatment processes are more effective if the raw wastewater flowing into the treatment plant has an appropriate composition. This means that the wastewater from the city of Djelfa has a composition typical of domestic and urban effluents and does not exhibit any abnormalities.

Qualitative diagnosis of discharges

The physicochemical characteristics of the treated water generally reflect satisfactory operation of the treatment system, confirming the performance of the biological activated sludge process implemented:

- pH, slightly alkaline (≈ 8–8.1): It remains compatible with environmental standards and is favorable to aquatic life as well as agricultural reuse.

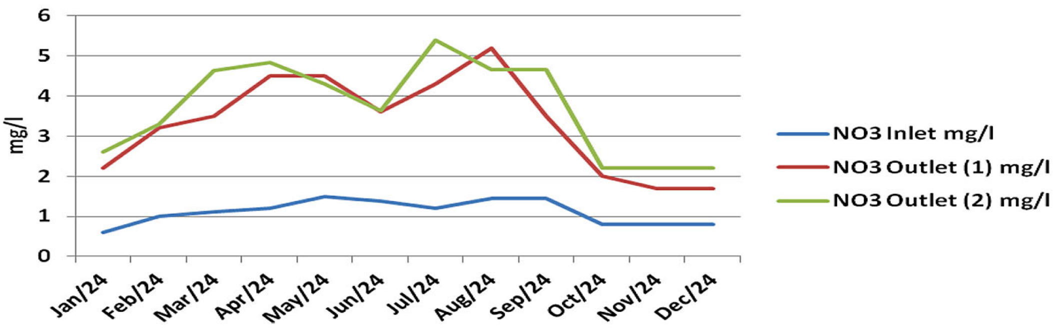

Figure 6. Variation of the nitrates from the inlet to the outlet of the WWTP

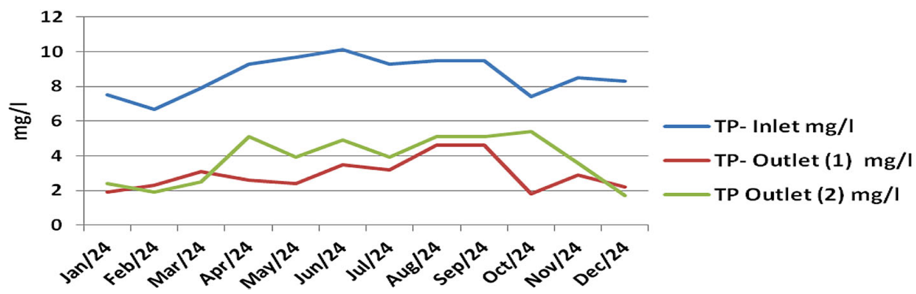

Figure 7. Variation of the total phosphorus from the inlet to the outlet of the WWTP

Table 3. Treatment performance and compliance

Parameter	Removal efficiency	Compliance	Interpretation
TSS	91–92%	Yes	Very good physical and biological treatment
BOD_5	91–92%	Yes	High biodegradation of organic matter
COD	83–84%	Yes	Good mineralization of the organic load
NH_4^+	57–61%	Yes	Good nitrification, stable biological activity
NO_3^-	+200 à 236%	Yes (Nitrification observed)	Evidence of a complete nitrogen conversion process
TP	55–66%	Partially compliant	Need for optimization on dephosphatation
Turbidity	Reduction >75%	Yes	Good particle reduction

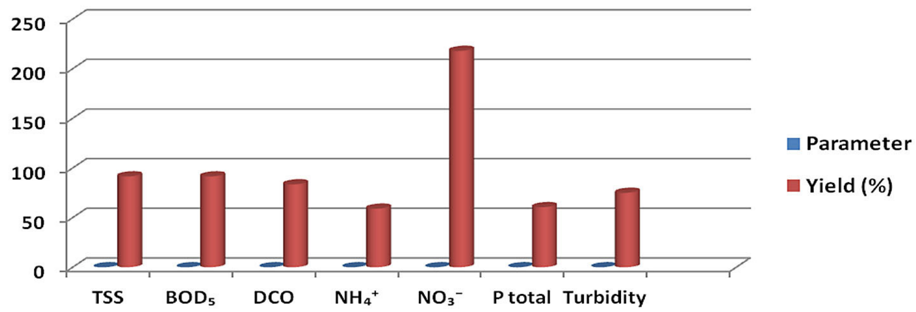

Figure 8. Removal rate of different pollution parameters

- Electrical conductivity, moderate (≈ 290 µS/cm): It indicates low salinity and limited mineralization, characteristics of water suitable for reuse for irrigation.
- Nitrates (inlet = 1.10 mg/l; outlet 1 = 3.30 mg/l; outlet 2 = 3.70 mg/l): The increase observed between the inlet and outlet of the Djelfa plant reflects an effective nitrification process. This result confirms the good activity of the biological activated sludge treatment. However, this complete oxidation ideally requires an additional denitrification step to avoid enrichment of the receiving environment with oxidized nitrogen.
- Total phosphorus (inlet = 8.60 mg/l; outlet 1 = 2.90 mg/l; outlet 2 = 3.80 mg/l): The observed decrease reflects a partial elimination of phosphorus by the activated sludge process, linked to its biological assimilation. However, the absence of specific phosphorus removal limits this performance.
- Pollution parameters (MES, COD and BOD_5): Their outlet values, significantly lower than those measured at the inlet, reflect a good capacity of the system to eliminate the organic load and suspended matter, in accordance with the expected performance for this type of process.

Biodegradability and nature of effluent

The COD/BOD_5 ratio of 2.42 confirms a biodegradability characteristic of mainly domestic water, with low industrial contribution. This justifies the choice of the biological process and the stable operation observed throughout the year.

Regulatory and environmental aspects

- The quality of the treated effluent generally complies with Algerian standards (OJ, 2006) and WHO guidelines (WHO, 2006).
- The study shows that the Djelfa WWTP achieves its design objectives, effectively protecting the receiving environment.
- The potential for agricultural reuse is real, subject to additional microbiological control.

ENVIRONMENTAL RECOMMENDATIONS

Analysis of the operation of the Djelfa treatment plant highlights an overall efficient treatment, but with some room for improvement to optimize the quality of the discharge and the sustainability of the system.

Strengthen monitoring and control

- Integrate microbiological indicators (coliforms, *E. coli*) to assess agricultural reuse.
- Expand the campaign to include emerging parameters (heavy metals, microplastics, micropollutants).

Optimizing nitrogen treatment

- Consider adding an anoxic zone or implementing a nitrification-denitrification process to reduce nitrates to nitrogen gas (N_2).
- Adjust residence time and sludge recirculation to promote denitrifying bacteria.

Improving phosphorus removal

- Consider incorporating additional physicochemical treatment (coagulation-flocculation) in the event of persistent non-compliance.

Recovery and reuse

- Promote the controlled reuse of treated water for irrigation of green spaces or non-food crops, in accordance with WHO guidelines.
- Recover stabilized sludge after treatment (composting, agriculture), subject to safety analyses (heavy metals, pathogens).

At the end of this discussion, the study highlighted a high-performance, well-designed, and controlled plant that meets regulatory and environmental requirements. However, for sustainable and exemplary management, it is necessary to integrate a denitrification stage, optimize phosphorus reduction, and strengthen continuous monitoring and traceability of performance. The Djelfa WWTP thus represents a regional model of urban treatment and a strategic lever for the reuse of wastewater in semi-arid areas.

CONCLUSIONS

This study, devoted to the evaluation of the Djelfa wastewater treatment plant, is part of an integrated and sustainable water resource management approach in a semi-arid context marked by water scarcity and growing environmental protection challenges. Through rigorous analytical monitoring carried out over a year 2024, it provided an objective assessment of the treatment performance, the regulatory compliance of the treated effluent, and the potential for reuse of the treated wastewater.

The results obtained clearly demonstrate the satisfactory overall efficiency of the medium-load activated sludge biological process, with high reduction efficiencies for the essential parameters (MES, BOD_5, COD). The reduction rate of over 90% of organic matter and suspended particles demonstrates stable and controlled operation. Furthermore, analysis of nitrogen forms reveals successful nitrification, confirming the vitality of the biomass and good oxygenation of the system. However, the study also highlighted certain technical limitations, including the absence of complete denitrification and partial phosphorus removal, justifying the need for optimization of the biological treatment or the addition of a complementary physicochemical process. Similarly, the absence of regular microbiological data constitutes an obstacle to the evaluation of the real potential for agricultural reuse, although the physicochemical parameters remain largely in line with national and international standards.

In light of these findings, several technical and strategic recommendations were made:

- The integration of an anoxic zone to ensure complete denitrification,
- The strengthening of analytical monitoring by adding microbiological and emerging indicators,
- The improvement of phosphorus removal through operational or chemical adjustments,

- The sustainable recovery of effluents in controlled irrigation and stabilized sludge in agriculture.

In conclusion, the Djelfa wastewater treatment plant stands out for its good technical mastery, proven purification efficiency and overall environmental compliance, making it a regional model for urban wastewater management. However, achieving sustainable environmental excellence requires the adoption of targeted optimization measures, the strengthening of environmental monitoring, and the promotion of an integrated approach combining technical performance, resource development and compliance with ecological requirements. Thus, the Djelfa WWTP is fully in line with a logic of sustainable development, contributing to the preservation of water resources, the protection of the natural environment and the environmental security of the region.

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