JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(6), 134–149
https://doi.org/10.12911/22998993/202234
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.02.05
Accepted: 2025.04.07
Published: 2025.04.15

Long-term effects of olive mill wastewater on the physicochemical properties of a wastewater treatment plant in central Morocco – Wastewater quality index approach

Maria El Ouazzani[1,2*], Mustapha Afdali[3], Naaila Ouazzani[2], Abdelmajid Haddioui[1]

[1] Laboratory of Agro-Industrial and Medical Biotechnology, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco
[2] Laboratory of Water Sciences, Microbial Biotechnologies and Natural Resources Sustainability, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh, Morocco
[3] Water Treatment Department, National Office of Drinking Water, Beni Mellal, Morocco
* Corresponding author's e-mail: m.elouazzani.age@gmail.com

ABSTRACT

During the olive oil extraction season, a huge amount of olive mill wastewater (OMW) is produced in a short period. The uncontrolled disposal of this liquid by-product into water bodies poses significant environmental challenges in Morocco, due to its complex compositions and low biodegradability. This study evaluates the long-term effects of OMW disposal on the physicochemical properties of the wastewater treatment plant by a natural lagoon (WWTP-NL), in Zaouit Cheikh City in central Morocco. The OMW's effect was investigated based on physicochemical analysis data of raw and treated wastewater conducted monthly over eight years. To reach this aim, two wastewater quality indices (WWQI) namely, the Canadian Council of Ministers of the Environment water quality index (CCME-WQI), and the weighted arithmetic water quality index (WA-WQI), were applied to summarize large amounts of data into a single numerical value, that is easily manageable for environmental managers. The proposed indices highlight the persistent effects of OMW on the physicochemical properties before, during, and after the harvesting season, by evaluating the effluent's compliance with Moroccan standards for domestic discharge. According to the statistical analysis, and the WWQI scale classification, the CCME-WQI values for raw influent were 47.49 (marginal quality) before, 30.51 (poor quality) during, and 46.24 (marginal quality) after the olive harvesting season (OHS). For treated effluent, the CCME-WQI values were 55.66 (marginal quality) before, 33.61 (poor quality) during, and 55.94 (marginal quality) after OHS. For the WA-WQI, the calculated rates for raw influent range from 98.13 (bad quality), 104.60 (very bad quality), and 98.66 (bad quality) before, during, and after OHS. For treated effluent, the WA-WQI ranged from 91.58 before, 93.47 during, and 88.30 after OHS, consistently indicating bad quality across all three periods. The findings of this research indicate significant seasonal variations during OHS, marked by increased BOD_5, COD, and TSS, along with decreased pH, DO, and biodegradability, with a considerable persistence of OMW pollutants after OHS compared to their levels before OHS, as confirmed by the WWQI classification. This study shows that the CCME-WQI and WA-WQI methods are effective tools for evaluating the long-term effects of OMW disposal on the WWTP-NL and providing useful information to optimize wastewater management.

Keywords: wastewater treatment plant, olive mill wastewater, physicochemical parameters, water quality index, CCME-WQI, WA-WQI.

INTRODUCTION

Water resource management is undoubtedly one of the paramount challenges in the Mediterranean basin, particularly the southern countries with arid and semi-arid climates (Burak and Margat, 2016; Cramer et al., 2018), including Morocco (MdEnv, 2016), where per capita water availability is expected to decrease by half by 2050 (The World Bank, 2007), falling significantly below the global water poverty limit outlined by the World Health Organization (Meddi and Eslamian, 2021). Furthermore, the increase in demand for agricultural water withdrawal by up to 87% in 2020 (FAO, 2016), combined with the substantial decrease in annual average precipitation ranging from 10% to 35% by 2030 according to the World Bank (The World Bank, 2018) puts significant strain on natural water bodies. Additionally, it is crucial to consider the deterioration of water resource quality due to untreated wastewater discharges, i.e. domestic and industrial wastewater (Dahan, 2017). In this context, and to ensure the sustainability of the limited hydraulic potential, the Moroccan authorities specifically the National Office of Water and Electricity (ONEE) and the regional water agencies (Alhamed et al., 2018; MdEnv, 2016), are supporting the implementation of a stronger policy for managing non-conventional water resources, particularly the reuse of treated wastewater (Dahan, 2017; Meddi and Eslamian, 2021). One of the crucial measures implemented is the National Shared Liquid Sanitation Program (PNAM), which aims to achieve the target of reusing 573 million m3 of wastewater annually by 2040, with a significant focus on rural regions (Mateo-Sagasta et al., 2022; ONEE, 2022). Among the measures performed are constructing several wastewater treatment plants by natural lagoons (WWTPs-NL) in rural communities and reusing treated wastewater, particularly for irrigating landscapes and green spaces (Mateo-Sagasta et al., 2022).

For over a decade, Morocco has opted for the lagooning system as the optimum natural solution and cost-effective method for treating domestic wastewater (Fernandez-Cassi et al., 2016), in small and medium towns (Benaddi et al., 2023; Osmane et al., 2023), taking into account the spatial characteristics and climatic conditions of these areas. Despite the progress achieved by the (PNAM), several factors affect the purification performance of the WWTPs, and subsequently the quality of the treated wastewater. In central Morocco, the main factor that can affect the WWTPs-NL is the intrusion of parasitic water, i.e. extraneous waters generated by agro-industrial activities, specifically olive oil extraction (Hassen et al., 2023) as the predominant industrial practice in these regions, where huge quantities of untreated olive mill wastewater (OMW) are discharged seasonally into the sewage network in a short-lasting period, i.e. October to January (Hassen et al., 2023). This liquid by-product is the main harmful effluent of the olive oil industry, with annual production of OMW in Morocco exceeding 250.000 m^3, particularly from the traditional milling processes, due to its high toxicity related to the predominance of non-biodegradable fractions, particularly phenolic compounds (Rharrabti and Yamani, 2019; Benaddi et al., 2023; Hassen et al., 2023).

Several studies have highlighted the pollutant potential of OMW and its harmful effect on soil, air, and water ecosystems (Comegna et al., 2022; Hassen et al., 2023), due to its unstable and heterogeneous composition, rich in organic compounds and nutrients which are major contributors to water bodies eutrophication (Souilem et al., 2017; Fleyfel et al., 2022). Consequently, the impact of 1 m^3 of OMW is equivalent to a range of 100 to 200 m^3 of domestic wastewater (Hassen et al., 2023). Moreover, the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations range from 12.000 to 100.000 mg/L and 80.000 to 200.000 mg/L respectively, explaining its high pollution index (Souilem et al., 2017). These alterations significantly impact the microbial communities in conventional treatment systems, reducing the overall efficiency of urban wastewater plants (Souilem et al., 2017; Fleyfel et al., 2022). In the Mediterranean Basin, conventional physicochemical and biological treatments are often ineffective (Manama and Albahnasavi, 2024). To address these limitations, advanced chemical remediation strategies, such as ozonation, photocatalysis, Fenton's reagent, electrochemical, and solar-driven processes (Ochando-Pulido et al., 2017), provide more effective pollutant degradation and reduction of toxicity.

To the best of our knowledge, there is hardly any literature reporting or evaluating the impact of uncontrolled OMW disposal on the WWTP-NL, particularly the fluctuation in the wastewater quality indicators on a large scale. However, a recent study by (Manama and Albahnasavi, 2024) explored the impact of uncontrolled OMW disposal on WWTPs using activated sludge. The study showed a significant increase in influent pollutant levels, with the highest recorded levels of BOD, COD, and TSS. Several studies in central Morocco have investigated, on a laboratory scale, the physicochemical characteristics of a mixture of OMW and urban wastewater collected from a WWTP by activated sludge (Ahmali et al., 2020; El Ghadraoui et al., 2021). Also, a study by (TURAN, 2004) in Zeytinli, Turkey, evaluated the effects of OMW on municipal WWTP by activated sludge, and tested pretreatment methods like acid cracking and Fenton oxidation.

This highlights the importance of assessing the impact of OMW on wastewater treatment processes. In the field of WWTP management, frequent laboratory analysis of its influent and effluent are important tools to maintain treatment efficiency (Abbas et al., 2022; Redha et al., 2024) and ensure conformity with environmental standards. Although all the analysis data are collected, managers still face challenges in extracting information and making decisions that accurately reflect the complex relationships between all the parameters (Jamshidzadeh and Barzi, 2020; Arabzadeh et al., 2023; Redha et al., 2024). To facilitate the interpretation of complex data, the wastewater quality indices (WWQI) could be the most appropriate approach to summarize a large set of wastewater quality data and to express the seasonal variations in the effluent quality into a single numerical value, which could be beneficial for and environmental specialists (Dinu et al., 2020; Ayoub and El-morsy, 2021; Arabzadeh et al., 2023).

This approach is based on the WQI, which was initially developed by Horton in the United States in 1965 (Horton, 1965; Tasneem and Abbasi, 2012). The most commonly utilized WQIs in wastewater quality assessment are the Canadian Council of Ministers of the Environment water quality index (CCME-WQI) as the most applied and trusted method for assessing wastewater quality (Abbas et al., 2022; Aboulfotoh and Heikal, 2022), and the weighted arithmetic water quality index (WA-WQI), based on selecting key wastewater quality parameters, i.e. COD, BOD, TSS, and DO, and comparing them with the standards for effluent discharge into water bodies (Khudair et al., 2018; Rahmat et al., 2022). Additionally, this approach is widely applied to evaluate the quality of industrial wastewater. According to the study conducted by (Ramya and Vasudevan, 2019), the CCME-WQI has some limitations when applied to industrial wastewater due to its sensitivity to parameter selection and exclusion criteria. In the study, only 14 parameters were used for the influent and 8 for the effluent, due to the low concentration or non-detection of certain parameters like cyanide, heavy metals, and pesticides. This can lead to an incomplete assessment and underestimation of risks from undetected or low-concentration contaminants. Furthermore, (Chidiac et al., 2023) notes that a single outlier value in the WA-WQI can distort the overall water quality evaluation, emphasizing the need for careful parameter selection.

To achieve this, the current study aims to investigate the long-term effect of OMW disposal on the physicochemical parameters of raw and treated wastewater at Zaouiat Cheikh WWTP-NL. The focus on this urban area, a major olive-growing region in central Morocco with distinct environmental challenges, enhances the study's specificity and significance. To numerically express this significant effect, a comparative study was performed between two WWQIs, namely the CCME-WQI and WA-WQI based on larger historical datasets, of key wastewater quality indicators over eight consecutive years. The findings were then compared to the Moroccan standards for domestic wastewater discharge into aquatic environments.

MATERIALS AND METHODS

Study area and wastewater treatment plant description

Zaouiat Cheikh is located 80 km northeast of Beni-Mellal city in central Morocco, characterized by mountainous relief, limited by the Oum Er-Rbia River and the Middle Atlas Mountains under a semi-arid climate, with an average yearly rainfall of approximately 477 mm and a mean annual temperature of 13.8 °C. This region represents one of the most significant olive-growing regions in central Morocco, with around 36 traditional units using a continuous (three-phase) extraction system, with crushing capacity ranging from 0.8 to 10 tons/unit/day. This intensive olive processing activity produces a significant amount of OMW, estimated at 2552.7 m^3/year.

The selected plant, constructed in 2013, is located approximately 2.25 km to the northwest of the city at an altitude of 780 m above mean sea level and 300 meters from the Oum Er-Rbia River (Fig. 1). The plant is designed to treat domestic wastewater using a natural lagoon as an extensive process, with a 28.000 population equivalents capacity and a treatment flow of 1354 m^3/day. The wastewater treatment process uses a natural system of a series of ponds where wastewater flows successively from one to the next by gravity. The WWTP includes grit removal and screening units designed for pretreatment. The subsequent phases consist of three anaerobic ponds for preliminary treatment

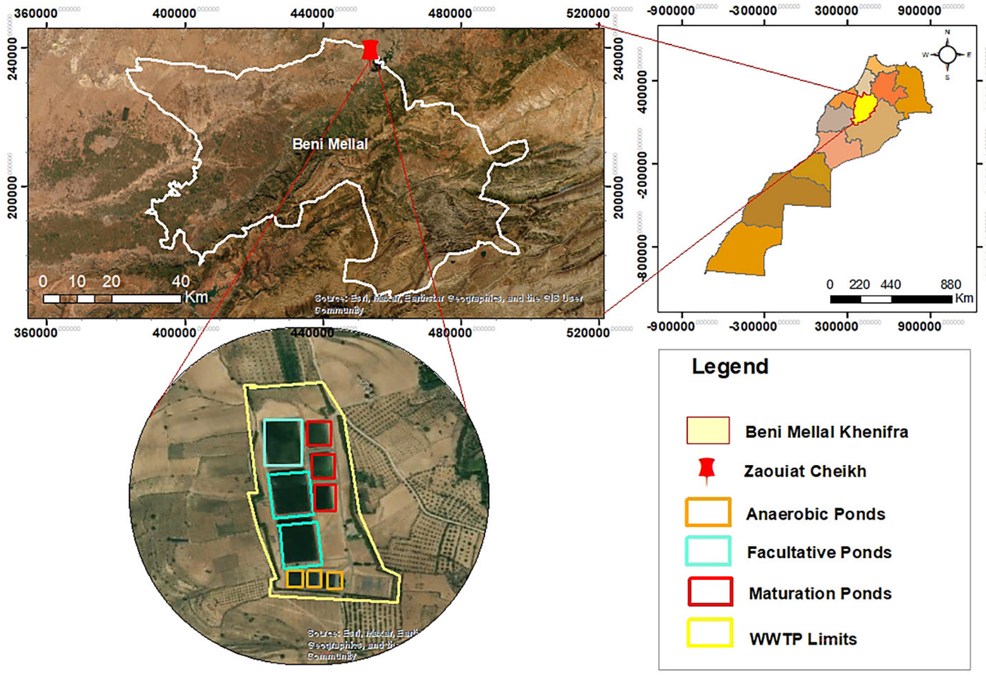

Figure 1. Study area location in Morocco and general view of the Zaouiat Cheikh WWTP-NL

with a retention time of 4.4 days, followed by three facultative ponds for secondary treatment with a retention time of 17.38 days, and three maturation ponds for tertiary treatment with a retention time of 6.4 days. All these ponds are systematically arranged and operated in series for 28 days of treatment. The treated wastewater is reused for irrigation (green spaces) or discharged into the Oum Er-Rbia River.

Data sources

The basic data used in this study was obtained directly from the WWTP operator (ONEP) through monthly reports of the wastewater quality investigation within an eight-year monitoring period from March 2015 to June 2022. The reported data of the raw influent (RI) and treated effluent (TE), are measured monthly on an average sample of 24 hours. The selection of parameters was typically based on data availability and accessibility, expert judgment, and environmental importance. The WQI approach was applied to the RI data by monitoring six physicochemical parameters: Daily flow, water temperature, pH, biochemical oxygen demand (BOD_5), COD, and total suspended solids (TSS). To provide a more comprehensive assessment, two ratios were calculated: the biodegradability index R_1 = (COD/BOD_5) and the production index of excess sludge R_2 = (TSS/BOD_5). Additionally, for TE six physicochemical parameters were treated: temperature, pH, TSS, BOD5, COD, and dissolved oxygen (DO). The parameter selection is based on the research objectives and the environmental characteristics of the WWTP-NL. These parameters which characterize the overall wastewater quality are also the key monitoring indicators that align with the main criteria outlined in Morocco's specific limits for domestic discharge, which are mentioned in the official bulletin N°. 5448 of 17 August 2006 (Water Quality Division, 2014). It is crucial to consider the missing data due to the COVID-19 pandemic, as well as the fluctuations in physicochemical parameters, due to anthropic factors and natural phenomena such as atmospheric, climatic, and hydrological influences.

Data treatment and statistical analysis

To evaluate the impact of OMW disposal on WWTP-NL, the raw data were systematically filtered, digitized, and categorized into three distinct four-month periods: before the olive harvesting season "BOHS" (June, July, August, September), during the olive harvesting season "DOHS" (October, November, December, January), and after the olive harvesting season "AOHS" (February, March, April, May). This temporal segmentation provides a comprehensive assessment of the seasonal fluctuations in wastewater quality, focusing

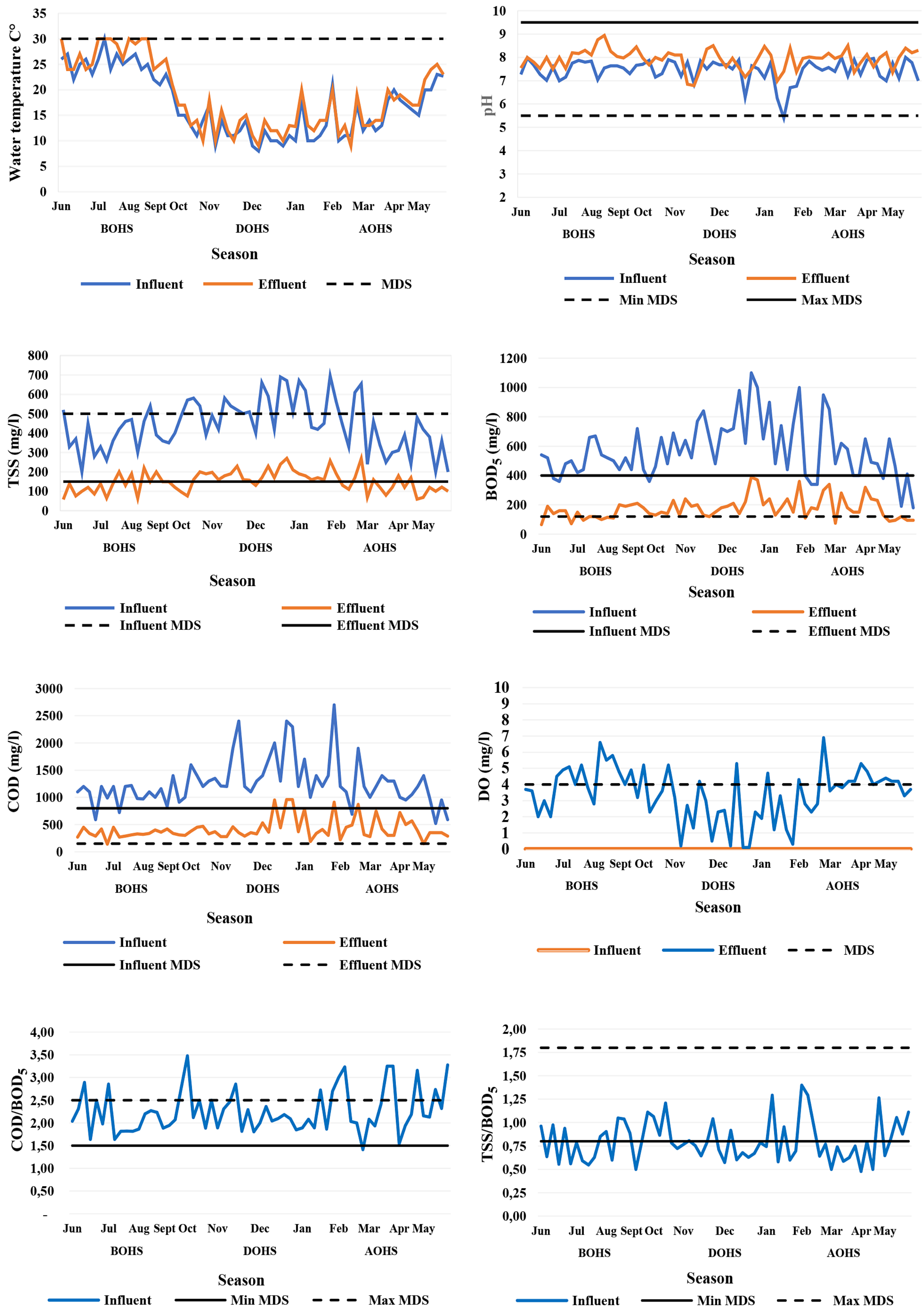

Figure 2. Dataset of raw influent and treated effluent parameters before, during, and after the olive harvesting season

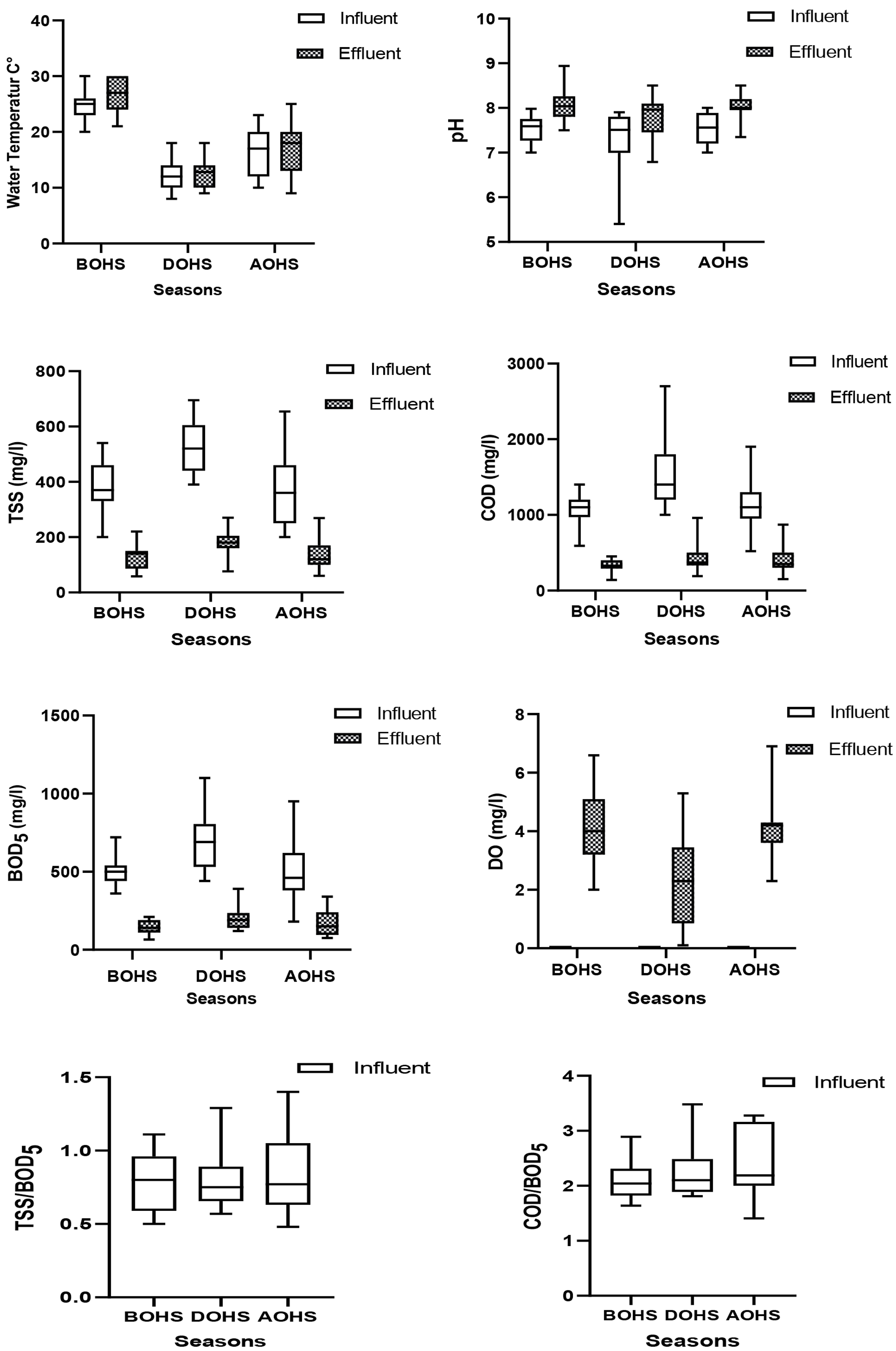

Figure 3. Comparative box plots of the raw influent and treated effluent parameters before, during, and after the olive harvesting season

on the impact of the olive harvesting season on the WWTP's treatment efficiency. Descriptive statistics for the eight physicochemical parameters of the RI and the TE were analyzed using GraphPad Prism (version 8.3.0). Figures 2 and 3 illustrate these statistics for the WWTP-NL under study before, during, and after the olive harvesting season.

Application of the wastewater quality indices (WWQI)

WWQI is an effective and flexible approach used recently by decision-makers to evaluate the pollution levels generated by human activities and the treatment effectiveness of WWTPs (Vijayan et al., 2016; Pirvu et al., 2019; Bessedik et al., 2021; Rahmat et al., 2022;). Based on mathematical expression, the WWQI summarizes a huge water quality dataset into a single number by rating wastewater quality on a scale of 0 to 100 (Arabzadeh et al., 2023; Shrivastava and Mategaonkar, 2024). Thus, The WWQI can be identified as a flexible method for various combinations of specific parameters, excluding the importance of the critical factor of sampling frequency (Aljanabi et al., 2021; Restrepo et al., 2022). The higher values indicate the treated effluent's compliance with design objectives and efficient performance of the WWTP, whereas raw influent often has low WWQI values (Ebrahimi et al., 2017). This study used two WWQI methods to verify if the WWTP-NL is impacted by the OMW disposal, based on the physicochemical characteristics compared with the Moroccan standards for domestic discharge to the water stream.

Canadian Council of Ministers of the Environment water quality index method (CCME-WQI)

In light of the objectives mentioned above, the WWQI was applied to the physicochemical parameters of the RI and the TE, based on WQI analytics methods developed by the Canadian Council of Ministers of the Environment that can be applied to various water in accordance with specific guidelines of each country (Tyagi et al., 2013; CCME, 2017). The CCME-WQI is a flexible method adaptable to specific sites and treatment conditions. Its low sensitivity to missing data makes it suitable for evaluating water quality in areas affected by persistent pollution sources. (Akhtar et al., 2021; Rahmat et al., 2022; Restrepo et al., 2022). Moreover, it focuses on assessing the monitoring data based on the combination of three factors (F1, F2, F3) using the calculation formulas (1) to (7):

- F1 (scope): measures the percentage of variables that fail to meet wastewater quality guidelines. At least once during the monitored period.

$$F1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100 \tag{1}$$

- F2 (frequency): measures the percentage of tests that fail to meet wastewater quality guidelines.

$$F2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \tag{2}$$

- F3 (Amplitude): measures the amount by which failed tests do not meet their guidelines. F3 is calculated in three steps:

1) The number of times an individual concentration exceeds or falls below the guideline, the objective is termed an "excursion".

$$Excurions_i = \frac{Failed\ test\ value_i}{Objective_j} - 1 \tag{3}$$

2) When the test value must not exceed the guideline.

$$Excurions_i = \frac{Objective_j}{Failed\ test\ value_i} - 1 \tag{4}$$

3) The normalized sum of excursions (nse) quantifies the collective amount by which individual tests are out of compliance.

Table 1. Wastewater quality scale and categories based on CCME-WQI (CCME, 2017)

Quality categories	Range of values	Water quality description
Excellent	95–100	Virtually natural or pristine, all measurements consistently reach the recommended guidelines
Good	80–94	Protected with minimal threat, conditions usually deviate from normal levels
Fair	65–79	Normally preserved but is occasionally threatened or impaired, with conditions sometimes deviating from natural or desirable levels
Marginal	45–64	Regularly threatened or impaired, with conditions often deviating from natural or desirable levels
Poor	0–44	Consistently threatened or impaired, conditions usually deviate from desirable levels

$$nse = \frac{\sum_{i=1}^{n} excurions_i}{Objective_j} \quad (5)$$

The F3 is then calculated by an asymptotic function that scales the normalized sum of excursions (nse) from 0 to 100.

$$F3 = \frac{nse}{0.01nse+0.01} \quad (6)$$

The *CCME-WQI* is calculated by summing the squares of the three factors, with a divisor of 1.732 used to normalize the index scale (CCME, 2017).

$$CCMEWQI = 100 - \frac{\sqrt{F1^2+F2^2+F3^2}}{1.732} \quad (7)$$

Once the *CCME-WQI* is determined, the wastewater quality is classified into five categories based on the index score as shown in Table 1.

Weighted arithmetic water quality index method (WA-WQI)

Based on Brown's model (Brown et al., 1972), the WA-WQI is one of the common rating methods used for converting complex wastewater quality data into comprehensible value (Ibrahim, 2019; Ayoub and El-morsy, 2021; Abualhaija, 2023). On the same dataset, the WA-WQI is computed using the following formulas (8) to (11), with a scale ranging from 0 (excellent wastewater quality) to 100 (worst wastewater quality), as described in Table 2.

Quality rating scale (*Qn*):

$$Q_n = 100(V_n - V_0|S_n - V_0) \quad (8)$$

where: *Vn* – estimated concentration of the nth parameter, *Sn* – the recommended standard value of the nth parameter, *V*0 – ideal value of the nth parameter in pure water, *V*0 = 0 (i.e., the ideal value for pH =7 and DO = 14 mg/l).

Unit weight (Wn):

$$W_n = {}^{K}/_{S_n} \quad (9)$$

Table 2. Wastewater quality rating using the WA-WQI method

Rating of wastewater quality	Range of values
Excellent	0–25
Good	26–50
Poor	51–75
Bad	76–100
Very bad	> 100

where:

$$K = \frac{1}{\sum(1/S_n)} \quad (10)$$

where: *Sn* – standard value for nth parameter, *K* – constant for proportionality.

The *WA-WQI* – aggregation of the quality rating with the unit weight.

$$WAWQI = \sum Q_n W_n / \sum W_n \quad (11)$$

RESULTS AND DISCUSSIONS

Seasonal evolution of raw influent and treated effluent qualities

Based on monthly average values, the descriptive statistics of the physicochemical parameters before, during, and after the olive harvesting season (OHS) over the eight-year monitoring period, as shown in Figures 2 and 3, indicate that all variables showed a significant seasonal variation during the three seasons for both RI and TE. After evaluating the seasonal results, the TE showed lower water temperatures than the RI across all seasons. In contrast, low values (8 °C and 20 °C) were recorded during OHS (October, November, December, and January), corresponding to the wet season. In contrast, higher temperatures ranged between 21 °C and 30 °C after OHS and 10 °C and 25 °C before OHS respectively, which corresponds to the dry season. This variation could be generally attributed to the atmospheric temperature, seasonal fluctuations typical of semi-arid climates, and differences in retention times within the WWTP-NL ponds. These values, however, fall within the permissible Moroccan discharge standards. The data shows that daily influent is the highest and most variable during OHS, ranging from 1060 to 1900 m^3/d, due to increased OMW disposal and parasitic water (rainy season). Before OHS, flows fluctuate between 1032 and 1530 m^3/d. After OHS, flows decrease to values ranging from 915 to 1821 m^3/d, partly due to increased freshwater consumption during the dry season. The pH values of RI are lower than those of TE across all seasons. Before OHS the pH ranges from 7 to 7.98 for RI and 7.50 to 8.94 for TE. During OHS it falls to 5.40–8.80 for RI and 6.79–8.50 for TE. While after OHS, the pH ranges from 7 to 8 for RI and 7.35 to 8.50 for TE. The minimum pH values for RI during and after OHS were within the accepted standards (5.5–9.5). These lower values can be attributed to the OMW disposal into the WWTP-NP. Generally, the acidic nature of the OMW ranges from a pH of 4.8 to 5.7 (Souilem et al., 2017), while in the Moroccan traditional system, the pH varies from 4.4 to 4.9 (Fleyfel et al., 2022), due to its high load of organic matter and the extended storage time (Hassen et al., 2023). Furthermore, the pH variation in wastewater is influenced by algal activity. The respiration and photosynthetic processes are linked to algae consumption of dissolved CO_2, leading to water alkalinization (Osmane et al., 2023). However, the disposal of OMW, rich in organic acids and phenolic compounds, disrupts this balance by lowering the pH and reducing microbial activity. In comparison with the study by (Ahmali et al., 2020), which observed a pH of 7.26 for a mixture of 1% OMW and 99% urban wastewater at a lab scale. It becomes clear that low concentrations of OMW do not significantly affect the pH levels. Conversely, in our case, the significant disposal of OMW decreases the wastewater pH to a minimum of 5.4.

The total suspended solid (TSS) values are higher during the OHS for both RI (320 to 695 mg/l) and TE (76 to 670 mg/l), compared to before OHS (RI: 200 to 540 mg/l; TE: 58 to 220 mg/l), and after OHS (RI: 200 to 654 mg/l; TE: 60 to 269 mg/l). A recent study by (Fleyfel et al., 2022) reported that in the Moroccan traditional system, the TSS levels range between 6820 and 71000 mg/l, reflecting the high organic load in OMW. Similarly, (El Ghadraoui et al., 2021) observed TSS values of 577.78 mg/l for a mixture of a 90% organic load of OMW and 10% of municipal wastewater, aligning with our findings and confirming the elevated suspended solids in OMW. As a key indicator of biodegradable organic content during self-purification processes. the biological oxygen demand (BOD_5) measures the oxygen required by microorganisms to decompose organic matter in the effluent. According to Fig. 3, the BOD_5 values recorded before the OHS ranged from 360 to 720 mg/l for RI, and 65 to 210 mg/l for TE. During the OHS, the BOD_5 values were significantly higher, ranging from 440 to 1100 mg/l for RI, and 120 to 380 mg/l for TE. After the OHS, the values were 180 to 950 mg/l for RI and 75 to 340 mg/l for TE. For instance, the BOD_5 values of OMW vary from 350.00 to 110.000 mg/l (Hassen et al., 2023), reflecting significant fluctuations in organic content that can impact the microbial degradation process. The chemical oxygen demand (COD) measures the oxygen demand to oxidize all organic and inorganic substances in the effluent. the obtained COD values during OHS were higher compared to the other seasons, ranging from 1100 to 2700 mg/l for RI, and from 190 to 960 mg/l for TE, compared to before OHS (RI: 590 to 1400 mg/l; TE: 140 to 450 mg/l), and after OHS (RI: 520 to 1900 mg/l; TE: 150 to 870 mg/l), respectively. Although, the OMW is characterized by its high COD content, ranging from 40.000 to 220.000 mg/l (Hassen et al., 2023). these results are similar to those of (Ahmali et al., 2020; El Ghadraoui et al., 2020) who reported that the COD of a mixture of OMW and urban wastewater (1–99%) is around 6100 mg/l. This increase is attributed to dissolved salts in the OMW, which contribute to higher soluble COD levels (Lazrak et al., 2018). As a result, the COD and BOD values in OMW are 200 to 400 times higher than those found in domestic wastewater (Souilem et al., 2017), reflecting the heavy organic load compared to standard domestic limits.

The biodegradability index ($BI=R_1$), determined by the COD/BOD_5 ratio, is a crucial indicator of biological treatment efficiency, reflecting the presence of poorly or non-biodegradable compounds. BI below 3 indicates an easily biodegradable effluent, while a BI between 3 and 5 suggests partial biodegradability. In contrast, a BI greater than 5 indicates a hardly biodegradable effluent, generally associated with toxic industrial substances that inhibit biological activity (Rodier et al., 2009). In this study, the obtained values of R_1 ranged from 1.64 to 2.29 before OHS, from 1.81 to 3.48 during OHS, and from 1.41 to 3.28 after OHS. In general, OMW is known for its poor biodegradability (Souilem et al., 2017) expressed by a high BI ranging from 2 to 5 (Khdair and Abu-Rumman, 2020) in contrast to the BI of domestic wastewater, which falls between 1.25 and 2.5 (Karef et al., 2017). Similarly, (Hassen et al., 2023) reported a BI value of 4.31 for OMW from a traditional system. In our case, the BI during OHS is between 3 and 5 which is partially biodegradable. Thus, while OMW has a high organic load, it becomes partially biodegradable when diluted with domestic wastewater.

The excess sludge production index ($R_2=TSS/BOD_5$), reflects sludge generation from the TSS naturally present in the raw wastewater. However, the observed values of R_2 for the RI ranged from 0.50 to 1.11 before OHS, 0.52 to 1.29 during OHS, and from 0.48 to 1.40 after OHS. According to (Bessedik et al., 2021; Karef et al., 2017), the R_2 value for domestic wastewater is typically between 0.8 and 1.2. Also (Allaoui et al., 2019) reported an R_2 value below 0.9 during the wet season in a WWTP by a natural lagoon. By comparing our results with those in the literature, it is evident that the higher value (1.29) recorded during OHS correlates with the high organic load and suspended solids present in OMW (Hassen et al., 2023), leading to increased sludge generation and accumulation in the treatment system.

DO is essential for natural auto-purification in lagoon basins. The observed values for the RI ranged from 2 to 6.60 mg/l before OHS, 0.10 to 5.30 mg/l during OHS, and 2.30 to 6.90 mg/l after OHS. However, the lower DO levels during OHS were due to the reduced DO concentrations in the OMW (Souilem et al., 2017). DO is crucial for the aerobic degradation of organic matter, and a decrease in oxygen levels can destabilize the biological balance in the system. Additionally, the previously cited study by (El Ghadraoui et al., 2020) showed that DO is around 1.18 mg/l which falls within the range of our observed values.

According to the study by (Manama and Albahnasavi, 2024), the Khan Younis WWTP which uses activated sludge systems and receives direct discharges from 11 olive mills, recorded maximum COD, BOD, and TSS concentrations of 2200 mg/L, 680 mg/L, and 1825 mg/L, respectively. The same study reported that the Central Gaza WWTP, also using activated sludge and receiving OMW discharges from 17 olive mills, recorded peak COD, BOD, and TSS levels of 3040 mg/L, 1382 mg/L, and 1810 mg/L, respectively. In comparison, our findings on the Zaouiat Cheikh WWTP, which operates with a natural lagoon system and receives OMW discharges from 36 olive mills, show maximum COD, BOD, and TSS levels of 2700 mg/L, 1100 mg/L, and 695 mg/L, respectively. Our results show lower COD and BOD levels than those recorded at the Central Gaza WWTP but higher than those at the Khan Younis WWTP, while TSS concentrations are significantly lower in Zaouiat Cheikh than in both plants. This reduction in pollutant levels can be attributed to rainwater intrusion during the OHS, which partially dilutes the raw wastewater.

To summarize, all these factors make it possible to assess the significant seasonal variations observed during OHS, characterized by increased concentrations of BOD_5, COD, and TSS, along with decreased pH, DO, and biodegradability levels, for both raw influent and treated effluent. However, these parameters showed a significant persistence of residual pollutants from OMW after OHS compared to the levels recorded before OHS. This study provides a better understanding of the long-term effects of uncontrolled OMW disposal on Zaouiat Cheikh WWTP-NL, an issue that has not been widely examined in large-scale assessments of this area. As a result, these findings clearly reflect the effects of OMW discharge on the natural processes of the lagooning system, reducing the treatment efficiency, even though the plant receives diluted wastewater, i.e. parasite water, during the OHS (rainy season). Furthermore, it is essential to consider the lack of precise data on the volume of OMW discharged into the WWTP-NP, combined with the significant annual variability in olive production. It is also important to note that the OMW properties depend on the olive cultivar, stage of maturity, storage conditions, production systems, and use of pesticides and fertilizers (Khdair and Abu-Rumman, 2020; Souilem et al., 2017).

Wastewater quality assessment using the CCME-WQI index

Following the WWQI methodology described previously, the CCME-WQI calculations with the quality range for RI and TE during the study period, are presented in Tables 3 and 4. The CCME-WQI evaluates three key factors: the number, frequency, and amount of variables whose objectives are not met based on the quality standards (Ebrahimi et al., 2017). As expected, the CCME-WQI during OHS is classified as poor quality for RI and TE with values of 30.51 and 33.61, respectively.

This indicates that most of the physicochemical parameters were higher during OHS coinciding with the peak of OMW discharge. Before and after OHS the CCME-WQI is classified as marginal quality with values of 47.49 and 46.24, respectively. After treatment, the CCME-WQI is classified also as marginal with values of 55.66 and 55.94, before and after OHS, respectively. This aligns with the findings of (Pirvu et al., 2019), who demonstrated that the WWQI from a wastewater treatment plant in a rural area is on marginal designation. Also, the RI value after the OHS showed a continued decline in wastewater

Table 3. CCME-WQI calculations for raw influent quality before, during, and after the olive harvesting season

Parameter	BOHS	DOHS	AOHS
Number of failed variables	4	5	4
Total number of variables	6	6	6
Total number of tests	114	143	109
Total number of failed tests	41	79	41
F1	66.67	83.33	66.67
F2	35.96	55.24	37.61
F3	50.35	66.24	53.02
nse	1.01	2.03	1.13
CCME -WQI	47.49	30.51	46.24
Quality range	Marginal	Poor	Marginal

Table 4. CCME-WQI calculations for treated effluent quality before, during, and after the olive harvesting season

Parameter	BOHS	DOHS	AOHS
Number of failed variables	4	5	4
Total number of variables	6	6	6
Total number of tests	114	150	126
Total number of failed tests	41	90	41
F1	66.67	83.33	66.67
F2	35.96	60	32.54
F3	12.64	51.77	17.85
nse	0.14	1.07	0.22
CCME -WQI	55.66	33.61	55.94
Quality range	Marginal	Poor	Marginal

quality, indicating a significant persistence of residual pollutants from OMW after OHS compared to the levels recorded before OHS. In contrast, after OHS some parameters for the TE are significantly close to exceeding acceptable limits. These results are comparable with (Ebrahimi et al., 2017), who reported that the higher WWQI values signify that the WWTP operates efficiently and that its effluents conform to design objectives. In contrast, raw influents usually have lower WWQI values, reflecting their nature as untreated wastewater. After treatment, effluents should achieve higher WWQI values, confirming their safety for discharge into the water stream (Aboulfotoh and Heikal, 2022).

Wastewater quality assessment using weighted arithmetic water quality index

The WA-WQI of the present investigation for RI and TE before, during, and after OHS was calculated using the standard values, quality rating scale, and unit weight for each wastewater quality parameter. These formed the basis for the final results, presented in Tables 5 and 6 for all the seasons. During OHS, all the observed mean for the seven parameters used for WA-WQI were within permissible limits except the water temperature and the pH values which exceeded acceptable levels compared to before and after OHS. For the raw influent, the WA-WQI values ranged from 98.13 before OHS (bad quality), to 104.60 during OHS (very bad quality), and 98.66 after OHS (bad quality). On the other hand, the treated effluent WA-WQI values ranged from 91.58 before OHS, to during OHS 93.47, and 88.30 after OHS, representing bad quality across all seasons. Nevertheless, a decrease in the WA-WQI values is detected after treatment indicating the effectiveness of the process in reducing pollutants and improving water quality.

According to the graphic representations in Figure 4, the CCME-WQI quality range (Tables 3 and 4) varied from marginal to poor for the RI, and from fair to poor category for TE. On the other hand, the WA-WQI for the same dataset (Tables

Table 5. WA-WQI calculation for raw influent quality before, during, and after the olive harvesting season

Parameter		BOHS				DOHS				AOHS			
Designation	Sn	Vn	Qn	Wn	WnQn	Vn	Qn	Wn	WnQn	Vn	Qn	Wn	WnQn
Daily flow	1350	1306.10	108.13	0.004	0.41	1459.76	108.13	0.004	0.46	1330.35	98.54	0.004	0.42
Water temperature	30	24.56	45.38	0.19	15.91	13.61	45.38	0.19	8.77	16.42	54.74	0.19	10.58
pH	5.5–9.5	7.51	118.40	0.77	83.52	7.59	118.40	0.77	91.56	7.57	109.20	0.77	84.45
TSS	500	385.52	104.47	0.01	0.89	522.34	104.47	0.01	1.21	390.95	78.19	0.01	0.91
BOD5	400	498.58	174.02	0.01	1.81	696.08	174.02	0.01	2.52	475.95	118.99	0.01	1.73
COD	800	1084.13	181.19	0.01	0.98	1449.52	192.71	0.01	1.397	1099	137.38	0.01	1.00
WA-WQI		98.13				104.60				98.66			
Quality range		Bad				Very bad				Bad			

Note: Sn – standards, Vn – observed mean, Qn – quality rating, Wn – unit weight.

Table 6. WA-WQI calculation for treated effluent quality before, during, and after the olive harvesting season

Parameter		BOHS				DOHS				AOHS			
Designation	Sn	Vn	Qn	Wn	WnQn	Vn	Qn	Wn	WnQn	Vn	Qn	Wn	WnQn
Water temperature	30	29.42	98.06	0.08	7.78	14.34	47.80	0.08	3.79	17.35	57.83	0.08	4.59
pH	5.5–9.5	8.32	74	0.28	20.73	7.82	54.46	0.28	15.26	8,29	66.30	0.28	18.57
TSS	150	135.60	90.40	0.02	1.44	190.68	127.12	0.02	2.02	124.48	79.65	0.02	1.26
BOD5	120	146.10	121.75	0.02	2.42	197.81	164.84	0.02	3.27	178.90	149.08	0.02	2.96
COD	250	336.41	134.56	0.01	1.28	469.29	187.71	0.01	139.18	429.88	171.95	0.01	1.64
DO	4	4.28	97.33	0.60	57.94	2.98	113.13	0.60	67.34	4.08	99.59	0.60	59.28
WA-WQI		91.58				93.47				88.30			
Quality range		Bad				Bad				Bad			

Note: Sn – standards, Vn – observed mean, Qn – quality rating, Wn – unit weight.

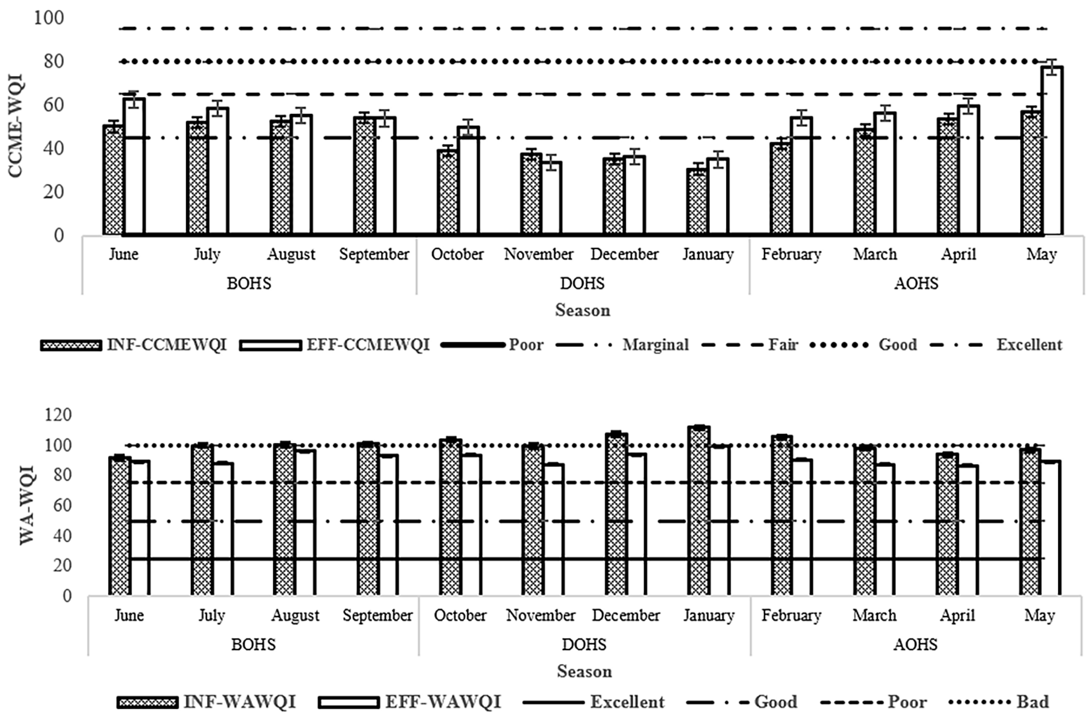

Figure 4. Comparative analysis of CCME-WQI and the WA-WQI according to the wastewater quality scales

5 and 6) ranges from poor to bad quality for both RI and TE. This indicates that while wastewater quality improves after treatment, it remains insufficient, showing that more improvements are needed to achieve better quality standards. Furthermore, this also shows a strong correlation between the raw influent and treated effluent of the WWTP-NL. By comparing the WWQI approaches, it can be noticed that the CCME-WQI and the WA-WQI produce similar results across all the study seasons according to the wastewater quality scale and categories. However, (Bessedik et al., 2021) applied both indices in a WWTP in northern Algeria and found that the two methodologies generated similar results, showing no significant differences between them.

CONCLUSIONS

In this paper, we presented a comprehensive approach by studying and analyzing the seasonal variations of seven measured parameters, and two calculated ratios for the raw influent and treated effluent over an eight-year monitoring period from March 2015 to June 2022. This study provides a better understanding of the long-term effects of uncontrolled OMW disposal on the physicochemical properties of Zaouiat Cheikh WWTP-NL, a largely unexamined issue in this area. A statistical analysis was conducted to determine the average, minimum, and maximum values of the physicochemical parameters, biodegradability index, and production index of excess sludge, as the key monitoring indicators that characterize the overall wastewater quality. On the same dataset, two wastewater quality indices were applied to numerically express the significant effect of OMW disposal. According to the WWQI scale classification, the CCME-WQI value during OHS was classified as "poor" for both raw influent and treated effluent, which means that wastewater quality is consistently threatened or impaired, and conditions usually deviate from desirable levels, before and after OHS, the CCME-WQI values were classified as "marginal" for both raw influent and treated effluent. This indicates that the wastewater quality is regularly threatened or impaired, with conditions often deviating from natural or desirable levels. Furthermore, the WA-WQI value during OHS was categorized as very bad for RI, bad for TE, and bad quality for the other study seasons, indicating that the effluent is unsuitable for any purpose. As a matter of fact, the seasonal discharge of the OMW significantly affects the WWTP-NL treatment process, leading to persistent effects on the physicochemical properties of the effluent during and after the olive production season, which complicates the management of receiving water bodies. These findings highlight the need for further research on the long-term impact of OMW discharge on the microbial community dynamics of WWTP-NL systems, focusing on the microbiological parameters, to improve wastewater management and promote sustainable water resource management.

Acknowledgements

The authors would like to express their sincere gratitude to the National Office of Water and Electricity "ONEE" in Beni Mellal for supporting this research. Special thanks are extended to Mr. Brahim AZMY, director of the Zaouit Cheikh Wastewater Treatment Plant, and his team for their valuable cooperation and assistance in data acquisition, their contribution was essential to the success of this work. The authors also wish to thank the editors and reviewers for their helpful feedback, during the review process of this study.

REFERENCES

1. Abbas, A., Yousif, Y. T., & Almutter, H. (2022). Evaluation of Al-Thagher wastewater treatment plant. *Periodica Polytechnica Civil Engineering, 66*(1), 112–126. https://doi.org/10.3311/PPci.18513
2. Aboulfotoh, A., & Heikal, G. (2022). Estimation of per capita loading and treated wastewater quality index in Sharkia governorate, Egypt. *Journal of Ecological Engineering, 23*(5), 73–80. https://doi.org/10.12911/22998993/146767
3. Abualhaija, M. (2023). Applying the quality and pollution indices for evaluating the wastewater effluent quality of Kufranja wastewater treatment plant, Jordan. *Water Conservation and Management, 7*(1), 6–11. https://doi.org/10.26480/wcm.01.2023.06.11
4. Ahmali, A., Mandi, L., Lout, K., El Ghadraoui, A., El Mansour, T. E., El Kerroumi, A., Hejjaj, A., Del Bubba, M., & Ouazzani, N. (2020). Agro-physiological responses of Koroneiki olive trees (*Olea europaea* L.) irrigated by crude and treated mixture of olive mill and urban wastewaters. *Scientia Horticulturae, 263*(109101). https://doi.org/10.1016/j.scienta.2019.109101

5. Akhtar, N., Ishak, I. S. M., Ahmad, M. I., Umar, K., Md Yusuff, M. S., Anees, M. T., Qadir, A., & Almanasir, Y. K. A. (2021). Modification of the water quality index (Wqi) process for simple calculation using the multi-criteria decision-making (mcdm) method: A review. *Water (Switzerland), 13*(7). https://doi.org/10.3390/w13070905
6. Alhamed, H., Biad, M., Saad, S., & Masaki, M. (2018). *Business Opportunities Report for Reuse of Wastewater in Morocco.* file:///C:/Users/asus/Downloads/business-opportunities-report-for-reuse-of-wastewater-in-morocco (1).pdf
7. Aljanabi, Z. Z., M. Jawad Al-Obaidy, A.-H., & M. Hassan, F. (2021). A brief review of water quality indices and their applications. *IOP Conference Series: Earth and Environmental Science,* 012088, 779. https://doi.org/10.1088/1755-1315/779/1/012088
8. Allaoui, M., Mohati, E. L. H., Saadallah, M., & El Harfi, A. (2019). Purifying Performance of the STEP of Mrirt (Natural lagoon). *Moroccan Journal of Chemistry, 1*(7), 49–60. https://doi.org/10.48317/IMIST.PRSM/morjchem-v7i1.9606
9. Amaral, C., Lucas, M. S., Sampaio, A., Peres, J. A., Dias, A. A., Peixoto, F., Anjos, M. do R., & Pais, C. (2012). Biodegradation of olive mill wastewaters by a wild isolate of *Candida oleophila. International Biodeterioration and Biodegradation, 68*, 45–50. https://doi.org/10.1016/j.ibiod.2011.09.013
10. Arabzadeh, M., Eslamidoost, Z., Rajabi, S., Hashemi, H., Aboulfotoh, A., Rosti, F., Nazari, F., Pouladi Borj, B., & Hajivand, M. (2023). Wastewater quality index (WWQI) as an indicator for the assessment of sanitary effluents from the oil and gas industries for reliable and sustainable water reuse. *Groundwater for Sustainable Development, 23*, 101015. https://doi.org/10.1016/j.gsd.2023.101015
11. Ayoub, M., & El-morsy, A. (2021). Applying the wastewater quality index for assessing the effluent quality of recently upgraded Meet Abo El-koum Wastewater treatment plant. *Journal of Ecological Engineering, 22*(2), 128–133. https://doi.org/10.12911/22998993/130893
12. Benaddi, R., Osmane, A., Zidan, K., Harfi, K. El, & Ouazzani, N. (2023). A Review on processes for olive mill waste water treatment. *Ecological Engineering & Environmental Technology Ecological, 24*(7), 196–207. https://doi.org/10.12912/27197050/169876
13. Bessedik, M., Abdelbaki, C., Badr, N., Tiar, S. M., & Megnounif, A. (2021). Application of water quality indices for assessment of influent and effluent wastewater from wastewater treatment plant of Oran City, Algeria. *Desalination and Water Treatment, 236*, 306–317. https://doi.org/10.5004/dwt.2021.27682
14. Brown, R., Mccleiland, N., Deiniger, R., & O'Connor, M. (1972). A Water Quality Index—Crossing the Psychological Barrier. *Proceedings of the International Conference on Water Pollution Research, Jerusalem,* 787–797.
15. Burak, S., & Margat, J. (2016). Water Management in the Mediterranean Region: Concepts and Policies. *Water Resources Management, 30*(15), 5779–5797. https://doi.org/10.1007/s11269-016-1389-4
16. CCME. (2017). Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME water quality index user's manual 2017 update. https://ccme.ca/en/res/wqimanualen.pdf
17. Chidiac, S., El Najjar, P., Ouaini, N., El Rayess, Y., & El Azzi, D. (2023). A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives. *Reviews in Environmental Science and Biotechnology, 22*(2), 349–395. https://doi.org/10.1007/s11157-023-09650-7
18. Comegna, A., Dragonetti, G., Kodesova, R., & Coppola, A. (2022). Impact of olive mill wastewater (OMW) on the soil hydraulic and solute transport properties. *International Journal of Environmental Science and Technology, 19*(8), 7079–7092. https://doi.org/10.1007/s13762-021-03630-6
19. Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J. P., Iglesias, A., A.Lange, M., Lionello, P., Llasat, M. C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., N.Tsimplis, M., & Xoplaki, E. (2018). *Climate change and interconnected risks to sustainable development in the Mediterranean.* In Nature Climate Change 8(11), 972–980. Springer US. https://doi.org/10.1038/s41558-018-0299-2
20. Dahan Stephane. (2017). *Managing Urban Water Scarcity in Morocco*. In Managing Urban Water Scarcity in Morocco. World Bank. https://doi.org/10.1596/29190
21. Dinu, C., Scutariu, R. E., Geanina Vasile, G., Tenea, A. G., Petre, J., & Valeria Cruceru, L. (2020). Evaluation of wastewater quality using water quality index. *Romanian Journal of Ecology & Environmental Chemistry, 2*(2), 99–108. https://doi.org/10.21698/rjeec.2020.213
22. Ebrahimi, M., L Gerber, E., & D Rockaway, T. (2017). Temporal performance assessment of wastewater treatment plants by using multivariate statistical analysis. *Journal of Environmental Management, 193*, 234–246. https://doi.org/10.1016/j.jenvman.2017.02.027
23. El Ghadraoui, A., Ouazzani, N., Ahmali, A., El Mansour, T. E. H., Aziz, F., Hejjaj, A., Del Bubba, M., & Mandi, L. (2020). Treatment of olive mill and municipal wastewater mixture by pilot scale vertical flow constructed wetland. 198(September 2018), 126–139. https://doi.org/10.5004/dwt.2020.26009
24. El Ghadraoui, A., Ouazzani, N., Saf, C., Ahmali, A., Hejjaj, A., Aziz, F., Del Bubba, M., & Mandi, L. (2021). Behaviour of physicochemical and

microbiological characteristics of vertical flow constructed wetland substrate after treating a mixture of urban and olive mill wastewaters. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-14874-7

25. FAO. (2016). Food and Agriculture Organization of the United Nations-FAOSTAT Data Set. http://www.fao.org/faostat/en/#data
26. Fernandez-Cassi, X., Silvera, C., Cervero-Aragó, S., Rusiñol, M., Latif-Eugeni, F., Bruguera-Casamada, C., Civit, S., Araujo, R. M., Figueras, M. J., Girones, R., & Bofill-Mas, S. (2016). Evaluation of the microbiological quality of reclaimed water produced from a lagooning system. *Environmental Science and Pollution Research, 23*(16), 16816–16833. https://doi.org/10.1007/s11356-016-6812-0
27. Fleyfel, L. M., Vel Leitner, N. K., Deborde, M., Matta, J., & Hamdi El Najjar, N. (2022). Olive oil liquid wastes – characteristics and treatments: A literature review. *Process Safety and Environmental Protection, 168*, 1031–1048. https://doi.org/10.1016/j.psep.2022.10.035
28. Hassen, W., Hassen, B., Werhani, R., Hidri, Y., & Hassen, N. J. A. (2023). *Processes of Valorization and Management of Olive By-Products: The Pomace and Olive Mill Wastewater.* In: S. Souabi & A. Anouzla (Eds.), Wastewater from Olive Oil Production 17–41. Springer Water. Springer. https://doi.org/10.1007/978-3-031-23449-1
29. Ibrahim, M. N. (2019). Effluent quality assessment of selected wastewater treatment plant in jordan for irrigation purposes: Water quality index approach. *J. Ecol. Eng., 20*(10), 206–216. https://doi.org/10.12911/22998993/112491
30. Jail, A., Boukhoubza, F., Nejmeddine, A., Sayadi, S., & Hassani, L. (2010). Co-treatment of olive-mill and urban wastewaters by experimental stabilization ponds. *Journal of Hazardous Materials, 176*, 893–900. https://doi.org/10.1016/j.jhazmat.2009.11.120
31. Jamshidzadeh, Z., & Barzi, M. T. (2020). Wastewater quality index (WWQI) as an assessment tool of treated wastewater quality for agriculture : a case of North wastewater treatment plant effluent of Isfahan. *Environ Sci Pollut Res, 27*, 7366–7378. https://doi.org/10.1007/s11356-019-07090-x
32. Karef, S., Kettab, A., Loudyi, D., Bruzzoniti, M. C., Del, M., Ait, F., Boujelben, N., & Mandi, L. (2017). Pollution parameters and identification of performance indicators for wastewater treatment plant of Medea (Algeria). *Desalination and Water Treatment, 65*, 192–198. https://doi.org/10.5004/dwt.2017.20290
33. Khdair, A., & Abu-Rumman, G. (2020). Sustainable environmental management and valorization options for olive mill byproducts in the Middle East and North Africa (MENA) Region. *Processes, 8*(671), 1–22. https://doi.org/10.3390/pr8060671
34. Khudair, B. H., AL-Sulaimen, A. M., & Rehab, K. J. (2018). Effluent quality assessment of al-diwaniyah sewage treatment plant based on wastewater quality index. *International Journal of Civil Engineering and Technology (IJCIET), 9*(10), 22–31. http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=10
35. Lazrak, A., Mandi, L., N.Djeni, T., Neffa, M., & Ouazzani, N. (2018). Assessing biomass diversity and performance of an activated sludge process treating saline table olive processing wastewater. *Environmental Technology*, 1–22. https://doi.org/10.1080/09593330.2018.1447603
36. Manama, A. Al, & Albahnasavi, A. (2024). Olive mills wastewater effect on domestic wastewater treatment plants : Gaza strip case study. *Environmental Monitoring and Assessment,* 1–17. https://doi.org/10.21203/rs.3.rs-4574549/v1
37. Mateo-Sagasta, J., Al-Hamdi, M., & AbuZeid, K. (2022). *Water reuse in the Middle East and North Africa: a sourcebook*. Colombo, Sri: Lanka International Water Management Institute (IWMI). https://doi.org/10.5337/2022.225
38. MdEnv. (2016). *Third national communication of Morocco to the United Nations Framework Convention on Climate Change.* Ministry delegated to the Minister of Energy, Mines, Water and the Environment in charge of the environment. https://unfccc.int/resource/docs/natc/marnc3.pdf
39. Meddi, M., & Eslamian, S. (2021). Uncertainties in rainfall and water resources in Maghreb countries under climate change. In African handbook of climate change adaptation (pp. 1967–2003). Springer, Cham. https://doi.org/10.1007/978-3-030-45106-6_114
40. Ochando-Pulido, J. M., Pimentel-Moral, S., Verardo, V., & Martinez-Ferez, A. (2017). A focus on advanced physico-chemical processes for olive mill wastewater treatment. *Separation and Purification Technology, 179*, 161–174. https://doi.org/10.1016/j.seppur.2017.02.004
41. ONEE. (2022). ONEE, a major player in the development of the drinking water and liquid sanitation sectors in Morocco. http://www.onep.ma/plaquettes/Plaquette-institutionnelle-2022-FR-FINAL.pdf
42. Osmane, A., Zidan, K., Benaddi, R., Sebah, I., Elmouraille, N., Ali, M. A., & Belmouden, M. (2023). Study the effectiveness of the natural lagoons for removal of organic matter, nutrients and fecal coliform from urban domestic wastewater under arid climate (Morocco). *Journal of Ecological Engineering, 24*(2), 196–207. https://doi.org/10.12911/22998993/156518
43. Pirvu, F., Cruceru, L., Niculescu, M., Petre, J., Iancu, V., Pascu, F., & Galaon, T. (2019). New tools for assessment of wastewater quality. Case study, one rural region from Romania. *International Symposium*

"The Environment and the Industry", SIMI 2019, 302–309. https://doi.org/10.21698/simi.2019.fp38

44. R. K. Horton. (1965). An index number system for rating water quality. *Journal of the Water Pollution Control Federation, 37*(3), 300–306.
45. Rahmat, S., Altowayti, W. A. H., Othman, N., Asharuddin, S. M., Saeed, F., Basurra, S., Eisa, T. A. E., & Shahir, S. (2022). Prediction of wastewater treatment plant performance using multivariate statistical analysis: A case study of a regional sewage treatment plant in Melaka, Malaysia. *Water, 14*(3297). https://doi.org/10.3390/w14203297
46. Ramya, K., & Vasudevan, N. (2019). Performance evaluation of ETP from pesticide manufacturing industry by using WWQI and multivariate statistical analysis. *Environmental Science and Pollution Research, 26*(20), 20595–20609. https://doi.org/10.1007/s11356-019-05034-z
47. Redha, Z. M., Bu-Ali, Q., Janahi, A. Y., AlQahtani, M. M. B., & Anas, R. (2024). Development of wastewater quality index as an assessment tool of treated wastewater quality for sea discharge. *Water and Environment Journal, 38*(3). https://doi.org/10.1111/wej.12940
48. Restrepo, J. L. A., Diaz, Y. J. R., & Barraza, H. C. O. (2022). Water quality indices (WQI) and contamination indices (WPI) a bibliographic review Índices. *Tecnura, 22*(77), 1–20. https://doi.org/10.14483/22487638.20052
49. Rharrabti, Y., & Mohamed EI Yamani. (2019). *Olive Mill Wastewater: Treatment and Valorization*. In: C. M. Hussain (Ed.), Handbook of Environmental Materials Management 1659–1686. Springer, Cham. https://doi.org/10.1007/978-3-319-58538-3_91-1
50. Rodier, J., Legube, B., Merlet, N., & Coll. (2009). *Wastewater.* In Dunod (Ed.), Water Analysis (9th ed., p. 997).
51. Shrivastava, P., & Mategaonkar, M. (2024). Case study on water quality index for wastewater treatment in Mumbai. *Water Practice & Technology, 19*(4), 1177–1184. https://doi.org/10.2166/wpt.2024.081
52. Souilem, S., El-Abbassi, A., Kiai, H., Abdellatif Hafidi, Sayadi, S., & Galanakis, C. M. (2017). *Olive oil production sector: environmental effects and sustainability challenges*. In: C. M. Galanakis (Ed.), Olive mill waste: recent advances for sustainable managment 18–302. Nikki Levy. https://doi.org/10.1016/B978-0-12-805314-0.00001-7
53. Abbasi, T. & Abbasi, S. A. (2012). Water quality indices based predominantly on physico- chemical characteristics. In Elsevier (Ed.), Water quality indice, 16–375. https://doi.org/10.1016/B978-0-444-54304-2.00001-4
54. The World Bank. (2007). Factors inside and outside the water sector drive MENA's water outcomes. In *Making the most of scarcity 22*(2). https://doi.org/10.1596/978-0-8213-6925-8
55. The World Bank. (2018). Beyond Scarcity: Water Security in the Middle East and North Africa. MENA Development Report. World Bank, DC: Washington. https://doi.org/10.1596/978-1-4648-1144-9
56. Turan, İ. (2004). *Effect of Olive Mill Wastewater Discharge on the Municipal Wastewater Treatment and Feasibility of Various Pretreatment Methods* [Graduate School of Natural and Applied Sciences of Dokuz Eylül University]. https://fbe.deu.edu.tr/ALL_FILES/Tez_Arsivi/2004/YL_t1742.pdf
57. Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources, 1*(3), 34–38. https://doi.org/10.12691/ajwr-1-3-3
58. Vijayan, G., Saravanane, R., & Sundararajan, T. (2016). Wastewater quality index – A tool for categorization of the wastewater and its influence on the performance of sequencing batch reactor. *International Journal of Environmental Engineering and Management, 7*(1), 69–88.
59. Water Quality Division. (2014). Preservation of water resource quality and pollution control,Limit values for effluent discharge (Moroccan pollution standards).