

EVALUATING THE PURIFICATION EFFICIENCY OF MOROCCAN WASTE STABILIZATION PONDS' SYSTEMS: CHALLENGES AND FUTURE PROSPECTS

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ABSTRACT

Lagoon wastewater treatment systems, introduced in 1970, have become a preferred economic solution in Morocco due to favourable climatic and economic conditions. However, these facilities often face performance problems, particularly related to excessive hydraulic and pollutant loads, resulting in treatment efficiencies below regulatory standards for urban discharges. Waste stabilization ponds in Morocco show average reduction rates of 70 % for chemical oxygen demand, 65 % for biochemical oxygen demand during 5 days, and 62 % for suspended solids. This study aims to evaluate the performance of seven lagoon treatment plants in different regions of the country and identify solutions to ensure compliance with discharge standards. The Moroccan experience in biological lagoon treatment is valuable for improving purification efficiency, with observed reductions of chemical oxygen demand, biochemical oxygen demand during 5 days, and suspended solids of 65 %, 54 %, and 62 % respectively, proposing strategies to optimize these processes and ensure adherence to specific norms.

Keywords: *wastewater, purification, chemical oxygen demand, biochemical oxygen demand, suspended solids*

INTRODUCTION

Rapid global population growth is putting significant pressure on freshwater resources [1]. United Nations projections show that the world population could reach 8.1 billion by 2025 and 9.6 billion by 2050 [2]. This population growth increases the demand for water for domestic, agricultural, and industrial

purposes, particularly affecting arid and semi-arid regions. In addition, the degradation of water quality has emerged as a critical issue, with human activities contributing to the rise of "Emerging Contaminants" (ECs) that threaten water quality worldwide [3]. Industrial growth has further degraded water sources, introducing organic and inorganic pollutants that threaten public health and

ecosystems. According to the Food and Agriculture Organization (FAO), more than 80 % of global wastewater is discharged untreated, contaminating freshwater and marine ecosystems and endangering biodiversity and food safety [4]. This situation highlights the urgent need for innovative and sustainable strategies to protect water resources. In Morocco, urban wastewater discharges reach 550 million cubic meters per year. Currently, there are 156 wastewater stabilization ponds (WSPs) operating with a treatment capacity of approximately 2.5 million cubic meters per day, handling an organic load of 450,000 kg of biochemical oxygen demand (BOD₅) per day. This represents significant progress since 2006, when only 1 million cubic meters per day (80,000 kg of BOD₅) were treated, thanks to the National Sanitation Program (PNA). This program, launched by the National Office of Electricity and Drinking Water (ONEE-BO), has greatly improved sanitation capacity and adapted treatment technologies to meet Morocco's specific needs [5].

This study aims to evaluate the efficiency of the most widely used wastewater treatment processes in Morocco, using operational data from seven wastewater treatment plants in different regions. It will focus on the characterization of the wastewater entering and leaving the treatment plants to propose recommendations for improving the design and operational parameters.

MATERIALS AND METHODS

Presentation of the studied cases

The selected WSPs for this study are located in various regions in the northern part of the country. They are designed for wastewater treatment from small to medium-sized communities, with a population not exceeding 50,000 inhabitants (Figure 1).

The treatment capacity of the plants varies from 12,600 to 35,000 equivalent inhabitants, with daily wastewater volumes ranging from 610 to 2,800 m³/day and daily BOD₅ loads

ranging from 376 to 1,216 kg/day. The characteristics of the raw wastewater and the treated water from the 7 WSPs are shown in Table 1 to provide a general overview of the average pollutant load as well as the efficiency of the treatment process.

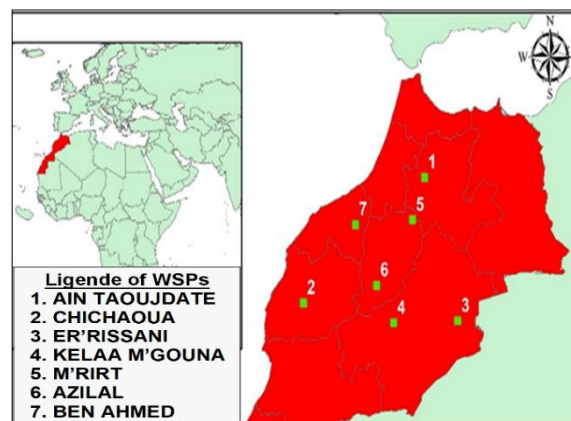


Figure 1. Geographical location of the studied WSPs

Sample collection procedure

To assess the effectiveness of the lagoon-type WSP, samples for analysis were collected at the inlet and outlet of each of the studied WSPs throughout the year, and the sampling frequency was once a month, in accordance with the guidelines of the Moroccan standard, decree N° 1607-06 of 29 Joumada II 1427, July 25th, 2006. The volume of wastewater samples taken at each point was one liter. Samples were stored in polyethylene bottles. The 24-hour composite sampling method based on the flowrate was used. The analysis of physicochemical and parasitological parameters was performed. For bacteriological parameters, a regular sampling method was used. The samples were then transported to the central laboratory of ONEE-BO under standard conditions at 4 °C, where subsequent analyses were carried out to determine biochemical oxygen demand during 5 days (BOD₅), chemical oxygen demand (COD), and suspended solids (SS), which are crucial indicators of wastewater pollution, according to the Moroccan standards: NM ISO 5815-1 and NM ISO 5815-2 (2012) for BOD₅, NM 03.7.54 - 2013 for COD, and NM EN 872 (2013) for SS [6].

Table 1. Data and characteristics of the studied WSPs

Cities	AIN TAOUJDATE	CHICHAOUA	ER'RISSANI	KELAA M'GOUNA	M'RIRT	AZILAL	BEN AHMED
Commissioning date	2004	2009	2004	2004	2003	2012	2004
Total area of the WSP [ha]	10.86	7	10.04	6.07	2.95	18.5	8.66
Nominal flow rate [m ³ /day]	1,500	1,500	1,180	620	1,800	2,800	1,830
Average flow rate [l/s]	17.7	17.4	13.6	7.1	20.9	27.5	21.2
Dry weather peak flow rate [l/s]	37	36.5	36	19	40	113	49
Pollution load [kg BOD ₅ /day]	600	580	747	376	1216	924	862
Number of anaerobic lagoons in parallel	4	3	2	2	4	3	2
Number of facultative lagoons in parallel	2	2	3	2	4	3	2
Geographic coordinate	33°58'15.1"N	31°33'47.71"N	31°15'59.35"N	31°14'0.83"N	33°10'11.05"N	31°56'9.62"N	33° 4'14.50"N
	5°13'33.18"W	8°43'56.60"W	4°16'18.47"W	6° 7'14.62"W	5°35'10.05"W	6°37'9.73"W	7°15'30.89"W
Altitude (m)	405	333	759	1420	1105	1218	550
Arrangement of the inputs and outputs of the "Anaerobic pools"							
Arrangement of the entrances and exits of the "Optional pools"							

On the other hand, the assessment of bacteriological contamination was carried out in a lactose medium at an incubation temperature of 37 °C to determine faecal coliforms (FC) according to NM ISO 9308-1/2007. Physicochemical parameters such as pH (NM ISO 10523-2012), conductivity (NM ISO 7888-2001), and temperature were measured in situ using a multi-parameter analyser.

Evaluation of WSPs performances

Quantitative and qualitative determinations of the chemical properties of 7 WSPs were carried out at the central laboratory of ONEE-BO. To obtain representative concentrations, frequent and regular sampling was carried out throughout the year following these steps:

- A sampling plan was developed taking into account seasonal variations,
- Sampling frequency was determined based on the expected variability of concentrations. In some cases, monthly samples may be sufficient, but in others, more frequent sampling may be necessary,

- Sampling locations: representative sites for each WSP were identified,
- Samples analysis: appropriate methods were used to determine properties of each sample,
- Statistical treatment: data were statistically processed to identify seasonal trends and calculate representative averages,
- Results examination: results were analysed to understand variations over time, identifying seasonal or other influencing factors,
- Reporting: the findings are presented in a report, emphasizing average concentrations, seasonal variations, and other relevant observations [6].

It is important to note that the representativeness of data depends on the quality of sampling planning and the accuracy of the performed analyses.

RESULTS AND DISCUSSION

Climatic conditions

Temperature

Temperature variations affect bacterial life and the biological processes for wastewater treatment. However, they can pose a threat of thermal contamination to the receiving environment, as they contribute to improving the kinetics of organic matter degradation [7]. The highest average temperature was recorded in ER'RISSANI in July. This city, characterized by a desert climate, reaches a temperature of 34 °C, followed by KELAA M'GOUNA (32 °C), CHICHAOUA (30.5 °C), M'RIRT (29.4 °C), AIN TAOUJDATE (28.5 °C), and BEN AHMED (28.5 °C) (Figure 2). The last two cities have a semi-continental climate. In contrast, the city of AZILAL does not exceed 27 °C in August at an altitude of 1377 m. Despite these relatively high temperatures, the recorded values are within the permissible limits for discharge standards and comply with Moroccan standards for irrigation water quality [8].

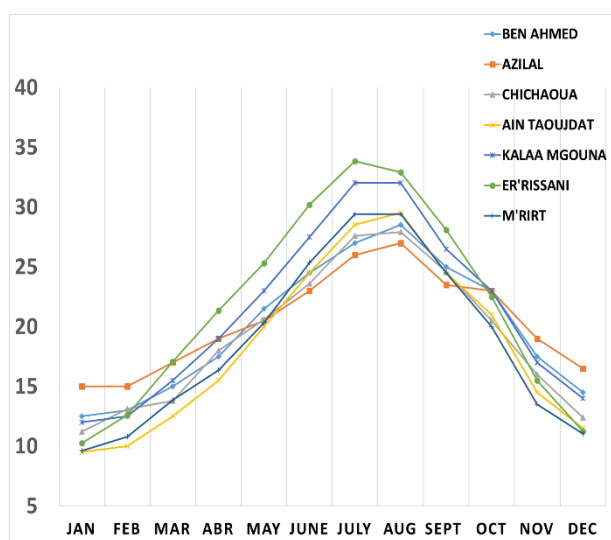


Figure 2. Average monthly temperature curves

Precipitation

The average rainfall in the 7 studied sites shows considerable variability, as shown in Figure 3, ranging from a particularly low value of 76 mm/year in ER'RISSANI to 165

mm/year in KELAA M'GOUNA, 190 mm/year in CHICHAOUA, 393 mm/year in BEN AHMED, 467.5 mm/year in AIN TAOUJDATE, 584 mm/year in M'RIRT, and 600 mm/year in AZILAL [9].

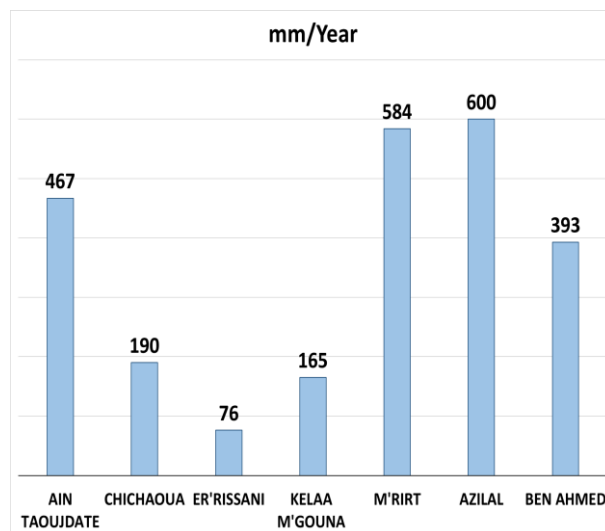


Figure 3. Annual precipitation

Characteristics of raw wastewater at the inlet

Wastewater treatment in lagoons results in a reduction in dissolved oxygen (DO) concentration, which ranges from 20 % to 50 % at the process outlet depending on the type of lagoon, which is attributed to the photosynthetic activity of algae or the dissociation of dead tissues in the lagoons [10]. The raw wastewaters at the inlet of the 7 WSPs show partially similar characteristics ($362 \text{ mg/l} \leq \text{SS} \leq 593 \text{ mg/l}$, $236 \text{ mg/l} \leq \text{BOD}_5 \leq 865 \text{ mg/l}$, $909 \text{ mg/l} \leq \text{COD} \leq 1831 \text{ mg/l}$), generally in line with values commonly encountered in domestic wastewater in Morocco according to the National Master Plan of Sanitation (NMPS). In general, they are more concentrated than wastewaters in Europe and North America, which is consistent with common observations and is explained by significantly lower water consumption in Morocco. Based on the results of the analysis of raw wastewaters at the inlet of the WSPs, it can be concluded that the wastewaters are significantly more demanding in terms of COD, especially in KELAA M'GOUNA (1831 mg/l), CHICHAOUA

(1124mg/l), and ER'RISSANI (1097mg/l), followed by M'RIRT and AIN TAOUJDATE, with BOD₅ being practically similar for all WSPs.

pH variation over time

The pH, a crucial element in assessing water quality, requires constant monitoring throughout all phases of treatment. It is important to note that pH is an excellent indicator of pollution, which is influenced by the nature of the effluents. The biological pH range is between 6.5 and 8.5 [10]. At the inlet of the WSPs, the pH shows a slight tendency towards alkalinity (varied from 7.10 to 7.94, with an average of 7.69, Figure 4). The values recorded at the outlets of the WSPs varied between 8.13 and 8.41 throughout the year, with an average of 8.27. This alkalinity can be attributed to a dominant photosynthetic activity due to the development of algae that consume dissolved CO₂ in water [11]. However, these values remain within the permissible limits for direct discharges [12] and comply with Moroccan standards for irrigation water quality [13].

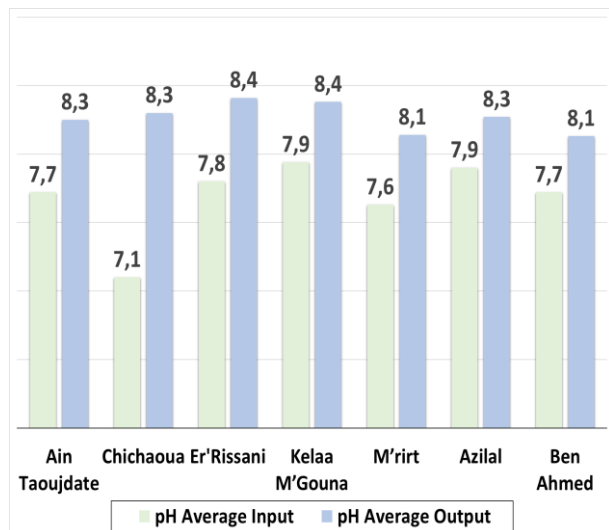


Figure 4. Average pH at the inlet and outlet of WSPs

Specific pollution loads

The specific pollution loads of various key parameters can be calculated based on the

results of the analysis of raw wastewaters at the inlet of the 7 WSPs and adjusting the values of other parameters to a specific pollution load of standard BOD₅ of 35 g/E·day, as shown in Figure 5. These values are relatively similar, on one hand, to those resulting from a study characterising wastewater in Morocco, as indicated for medium-sized cities. They are also very close to the NMPS values (unit ratios of pollution loads: 32 g of BOD₅/E·day, 60 g of COD/E·day, 42 g SS/E·day, 9 g of total Kjeldahl nitrogen (TKN)/E·day, and 1.5 g of phosphorus (P)/E·day) [14].

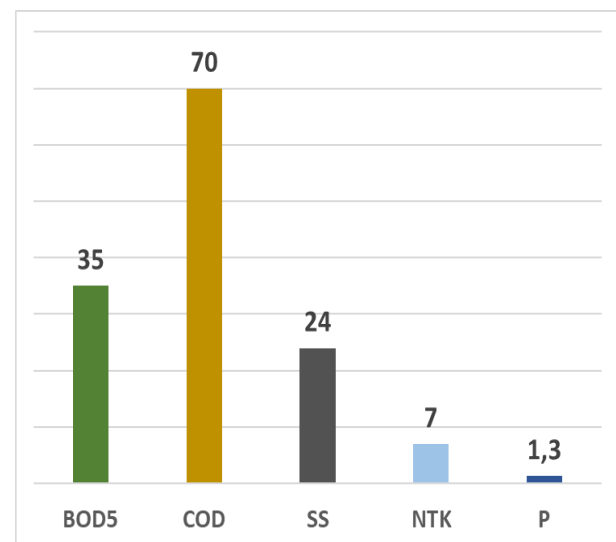


Figure 5. Average concentrations in g/E·day of specific pollution loads from WSPs

Specific volumes of wastewaters

The specific average volumes of wastewaters, calculated for the 7 WSPs based on measured volumes and the theoretical connected population, are shown in the Figure 6.

The specific wastewater flows range from 47 to 81 liters per equivalent inhabitant per day (l/E·day), indicating a relatively consistent pattern despite the diverse nature of the sanitation networks. These values correspond well with the statistical findings of the wastewater characterization study in Morocco conducted by National Office of Drinking Water "ONEP" and Deutsche Gesellschaft fur Technische Zusammenarbeit "GTZ" in 1998.

According to this study, the specific volume of discharged wastewater, or discharge unit rate (DUR), was estimated at 40 l/E·day for small communities (< 20,000 inhabitants), such as ER'RISSANI and KELAA M'GOUNA, and 70 l/E·day for medium-sized cities (20,000 to 100,000 inhabitants), representing other medium-sized cities. In the NMPS, the recommended value is 65 l/E·day.

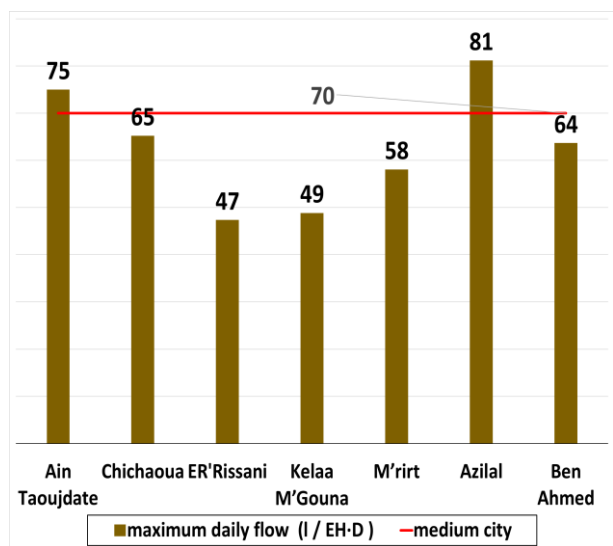


Figure 6. Specific wastewater flows measured on the 7 WSPs studied

Concentrations of suspended solids (SS)

The concentrations of suspended solids at the inlet to the lagoons are within the typical design values for this type of process, and the average concentration was 455 mg/l. Concentrations of suspended solids was lower at the outlet of the lagoons, which is attributed to sedimentation from wastewater in the natural lagoon basins [13]. However, the results of the analysis of treated waters show concentrations exceeding the limit set by Moroccan regulations (shown by the red line), except for the BEN AHMED and M'RIRT WSPs (Figure 7).

This increase in SS concentrations can also be attributed to exceeding the design horizon (between 5 and 12 years). This should not occur solely due to an increase in algae concentration [11]. Therefore, it can be concluded that there is an evident deficiency in

the design of these facilities, which indicates the need for optimization in their design.

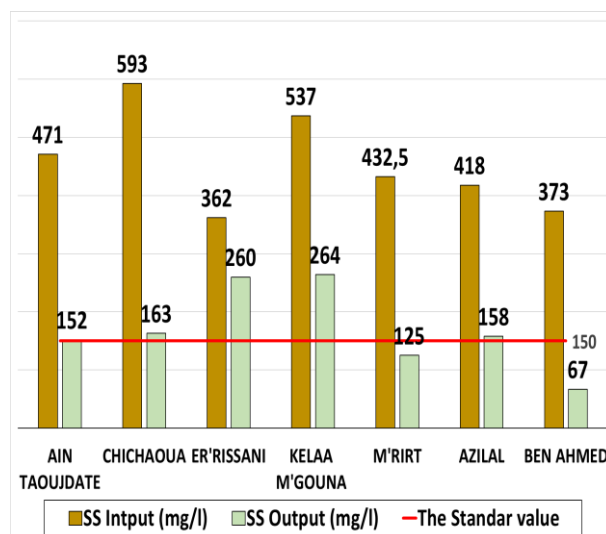


Figure 7. Concentration of suspended solids at the inlet and outlet of WSPs

Biochemical oxygen demand (BOD₅)

The 7 WSPs show quite similar purification performances and rejection levels (Figure 8), slightly above the discharge limit of 120 mg/l (red line) [15]. One WSP had higher values than the others, (KELAA M'GOUNA, 382 mg/l at the outlet) and low efficiency (56 %), indicating a potential malfunction in the wastewater treatment plant (WSP).

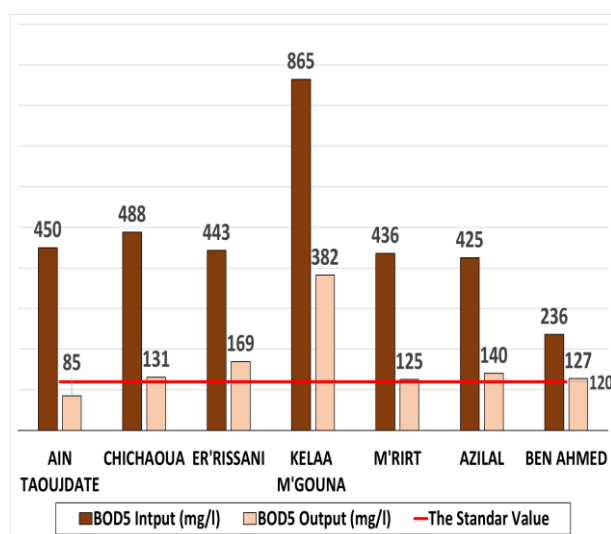


Figure 8. Concentration of BOD₅ at the inlet and outlet of WSPs

Chemical oxygen demand (COD)

Analysis of the results obtained from plants distributed throughout the Moroccan territory (Figure 9) shows that wastewater treated with the lagoon technique has an average COD removal efficiency between 65 and 80 % (discharge limit is 250 mg/l, red line) [15]. The specific case of the KELAA M'GOUNA WSP is confirmed by a high average concentration of COD of 803 mg/l, with a removal efficiency of 56 %. These results consistently indicate malfunction issues of the mentioned WSP.

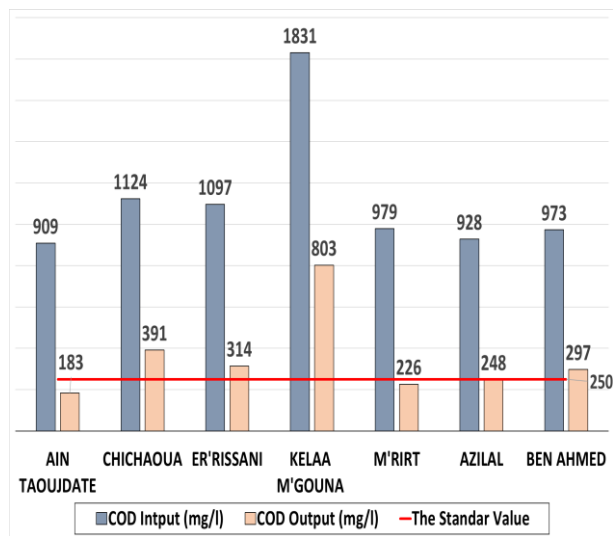


Figure 9. Concentration of COD at the inlet and outlet of WSPs

The average COD values appeared to have a relatively similar trend to those for BOD₅, also showing a slight overall decreasing gradient from inlet to outlet waters.

Nutrients

The elimination of nitrogen at the outlet of the lagoons is negligible, with nitrate being the predominant form, and the total nitrogen levels varying little. The total nitrogen removal rate does not exceed 30 %, as shown in Figure 10.

Similarly, the degree of the total phosphorus elimination is low and unstable, with an efficiency not exceeding 40 %, as shown in Figure 11. This can be explained by the absence of nitrification, which makes the

overall treatment process inefficient in all WSPs [13].

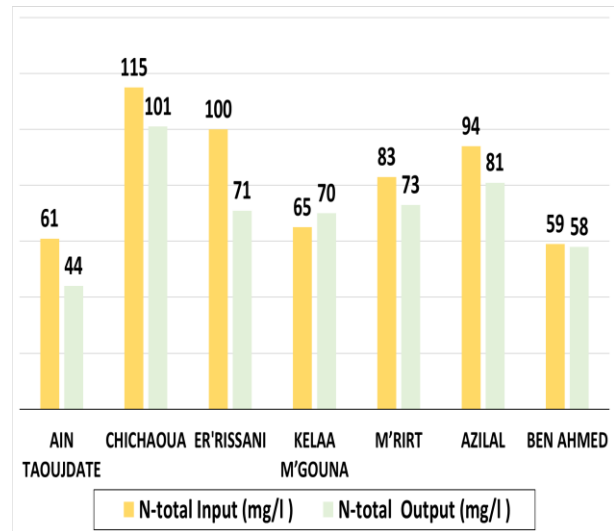


Figure 10. Concentration of total nitrogen at the inlet and outlet of WSPs

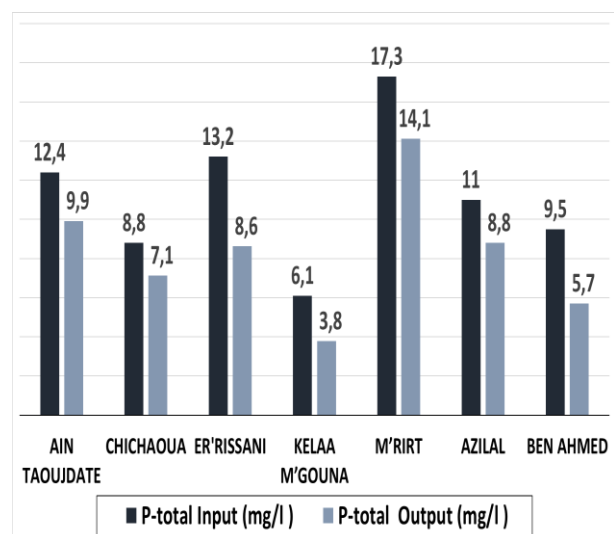


Figure 11. Concentration of total phosphorus at the inlet and outlet of WSPs

Living microorganisms do not assimilate dissolved phosphorus, and its concentration remains relatively constant in environments with low oxygen. However, in the final stage of treatment, an additional increase in phosphorus can be observed, as a result of the decomposition of organic matter and the release of microorganisms [16].

Hygienic parameters

Faecal coliforms (FC)

The average concentrations of FC measured at the outlet of facultative lagoons are generally acceptable. However, for all WSPs, these concentrations are observed irregularly. Typically, for WSPs (Figure 12), the calculation of FC concentrations remains a supplementary analysis with a very low number of FC analyses, which does not provide a representative picture of the situation. Regular monitoring usually occurs when there is a tendency to reuse treated water for irrigating green areas or golf courses. The interest in researching FCs is generally equivalent to pathogenic contamination caused by faecal matter [17].

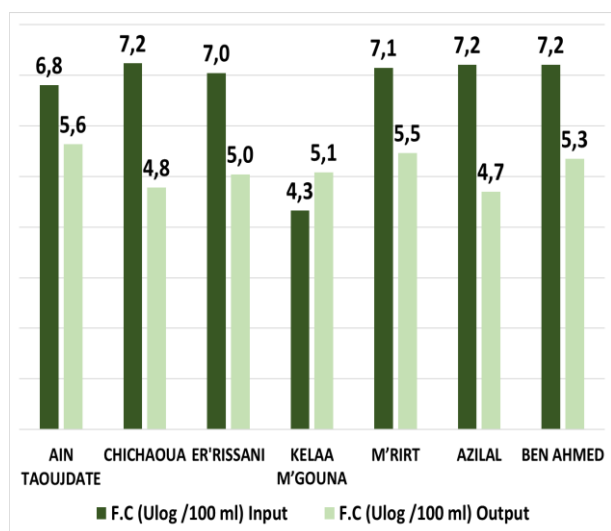


Figure 12. Concentration of FCs

Helminth eggs

The measured concentration of helminth eggs at the outlet of facultative lagoons is consistently very close to 0 eggs/L (Figure 13), as is the calculated concentration. The only exception was observed in the case of the BEN AHMED WSP (2 eggs/L) in one analysis, which theoretically should not occur and is contrary to tests conducted for similar cases with two lagoons in series under Sahelian climatic conditions [18, 19]. There is no convincing explanation for this phenomenon. However, it can be concluded that the

prediction model for the reduction of helminth eggs in relation to the increasing number of lagoons in series gave very realistic values for the treated water at the outlet of all WSPs.

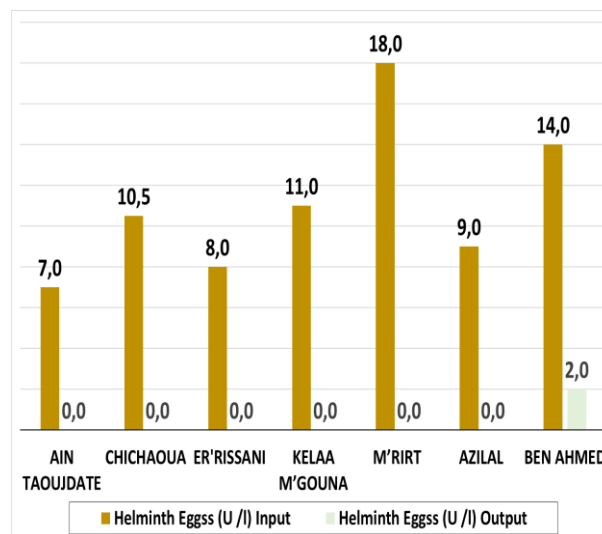


Figure 13. Concentration of helminth eggs

CONCLUSION

This study evaluated the performance of urban wastewater treatment plants, focusing on seven stations located in different regions of Morocco. The results reveal significant variations in the physicochemical and bacteriological quality between the stations. Data analysis showed that the biodegradability of the effluent is easily achieved only at the stations AIN TAOUJDATE and CHICHAOUA ($COD/BOD_5 \leq 3$), while for the other stations, the biodegradability is more complex ($3 < COD/BOD_5 \leq 4.14$).

In general, reductions in COD, BOD₅, and SS at the effluent discharge of the WTPs are greater than 55 %, 57 %, and 47 %, respectively. However, these reductions do not meet the concentration limits values for BOD₅ (120 mg/l), COD (250 mg/l), and SS (150 mg/l), specified by the Moroccan standards for domestic wastewater discharge. A notable exception is the M'RIRT station (BOD₅ = 125 mg/l, COD = 226 mg/l, and SS = 125 mg/l), which has been converted to treatment in an aerated lagoon. Although this technology is commonly used to reduce organic pollutant

load, it causes an additional energy cost. Therefore, the AIN TAOUJDATE station has better performances, due to its specific lagoon configuration and the position of the wastewater inlet and outlet.

The reuse of treated wastewater using the studied natural lagoon plants as a purification method is limited due to its quality. It is important to note that natural lagoon is not effective enough to significantly improve the hygienic quality of wastewater, nor to affect other key parameters, which are poorly affected by this process. The reuse of the treated wastewater for irrigating urban green areas requires additional tertiary treatment phase, such as constructed wetlands, and therefore vegetation filters (phytodepuration systems) are object of ongoing research by the authors, which show promising results that could help achieve values complying with the established standards. It is therefore crucial to fully exploit this reuse potential, especially in the context of the water scarcity that most regions face.

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