Hydro-biological characterization and efficiency of natural waste stabilization ponds in a desert climate (city of Assa, Southern Morocco)

Badre Achag, Hind Mouhanni and Abdelaziz Bendou

ABSTRACT

The city of Assa is located in a Saharian area characterized by an arid climate and water scarcity. Like any other Saharian city in a developing country, the city is facing the challenges of rapid urbanization and the need to improve wastewater treatment and management. The main objective of this work is to assess the performance of waste stabilization ponds in an arid area. This evaluation concerns microbiological and physico-chemical monitoring over three and twelve months respectively. Microbiological results indicate bacterial elimination rates of over 90% in autumn–winter due to the effectiveness of facultative ponds with 20–25 days of retention time, water clarity, ponds depth, and high sunlight exposure and penetration. Physico-chemical parameters surpass the Moroccan standards for reuse except Ph and T^0 by 20–30%, this wastewater is relatively loaded with various pollutants, especially high organic load and low oxygen content. Statistical analysis has been made by principal component analysis (PCA), and confirms that dissolved oxygen, total suspended solids, COD and BOD_5 do not reach the threshold for discharge into the natural environment, and moreover their reuse. For the improvement of the quality of these waters, it is legitimate to provide an upgrade of this plant by a tertiary treatment with maturation ponds.

Key words | microbiological and physico-chemical analysis, performance, principal component analysis, waste stabilization ponds, wastewater

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HIGHLIGHTS

- Research has a considerable impact on the decision to modernize the treatment plant of the waste stabilization ponds in the Saharan region of Morocco.
- The methods used over the 13 months in this study are new to the Moroccan water office.
- Problems were defined and methods to resolve them were put in place.
- This research will be considered as a basic study in the development of other wastewater treatment plants in Morocco.

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INTRODUCTION

Waste stabilization ponds (WSPs) are increasingly being used for the treatment of domestic wastewater as they can deliver entirely natural purifying processes. In addition, WSPs are also attractive in developed countries due to the simplicity of construction and low cost (Ho *et al.* 2017; Ho & Goethals 2020). Stabilization ponds are highly recommended due to their efficient operation over a wide range of levels of flow and load, as well as minimum energy consumption. Additionally, this process is highly recommended for treating urban wastewater from small populations. Moreover, the prevailing climate and local environmental conditions in Assa region are ideal for treating domestic wastewater using stabilization ponds (Ali *et al.* 2020). This is mainly due to the domination of high temperature and sunlight that kills the pathogens, as well as reducing organic materials by oxidation.

The purification of the Assa wastewater is ensured by a waste stabilization pond type treatment plant, with two anaerobic basins, two facultative basins and three drying beds for sludge. Waste stabilization ponds are utilized as a successful wastewater treatment method based low-cost technology and limited maintenance. For a long time, their low capital and operating costs and their capacity to handle fluctuating organic and hydraulic loads have been valued in Assa region and in numerous other Saharan and arid small cities (Ali *et al.* 2020). Be that as it may, one of their major downsides is the need for a rational approach to their design that takes into consideration all the chemical, physical and biological processes governing the purification kinetics of the system.

Stabilization pond effluent is an immediate resource for irrigation in arid areas. Recognition of this has resulted in larger ponds with better capacity to provide for local needs and improved treatment efficiency and much work has been done on this subject (Hosetti & Frost 1995; Yagoubi *et al.* 2000; Kouraa *et al.* 2002; Kaya *et al.* 2007; Hind *et al.* 2011, 2012; Adhikari & Fedler 2020). As an important tool in pollution control and decision analysis, the wastewater pollution evaluation model can provide a scientific basis for comprehensive improvement and management. In this study, water pollution is characterized and detailed by principal component analysis, making full use of the measurements taken of all the different parameters to study the possibility of utilization of this treated wastewater as a new resource (Gonzalez-Serrano *et al.* 2005; Liu *et al.* 2019; Praus 2019; de Oliveira *et al.* 2020; Spina *et al.* 2020).

The purpose of this paper is to investigate Assa's existing waste stabilization ponds and the appropriateness of the treatment performance required for reuse systems. In addition, the use of maturation ponds and other processes is discussed as an additive system for wastewater treatment prior to reuse (Wang *et al.* 2020).

MATERIALS AND METHODS

Study zone

Assa is a small town south of Morocco, as shown in Figure 1, with a population of 20,041 inhabitants and 3,472 households; all are subscribed to the ONEE for their drinking water and sanitation, with a total sanitation network of 40 km without any rainwater network and no pumping station. The volume consumed each year in Assa in 317,772 m^3 and the volume billed for sanitation is 191,526 m^3. This volume of wastewater is treated with a waste stabilization pond system with a capacity of 1,469 m^3/day.

The province of Assa-Zag can be divided into two large natural areas: sub-Saharan in the north and

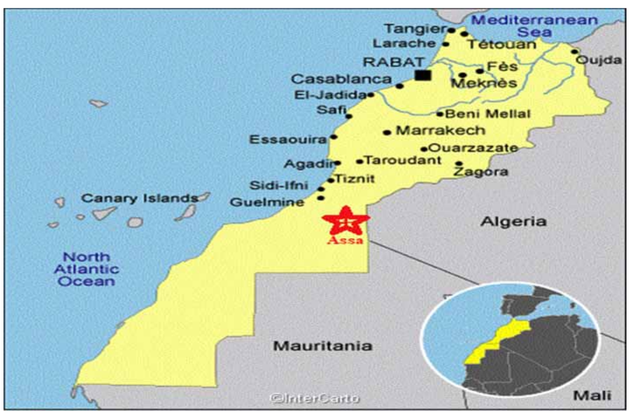

Figure 1 | Geographic location of the study area.

northeast and Saharan in the south and southwest. The relief of the area is composed of several entities, the main ones being:

- Mount Ouarkziz and the vast plateau of Hamadas;
- the mountainous area, occupying approximately 10% of the area of the province is inaccessible by road.

The climate in the area is of the pre-Saharan type, the average annual rainfall is around 100 mm, characterized by intense intra- and interannual variations. The maximum and minimum temperatures reach 49 and 4 °C respectively. The winds are very frequent and blow during all seasons causing sandy accumulations of different shapes ranging from simple sails a few centimeters thick to dunes of several meters. Table 1 presents the climatic data gathered while conducting station monitoring during the twelve months of 2019.

The urban center of the study area (Assa) is supplied with drinking water from the facilities of ONEE, which mobilize groundwater resources. The rate of access to drinking water in urban areas of the study area is 100%.

The wastewater treatment plant of the city of ASSA is characterized by the criteria shown in Figure 2 and Table 2.

It should be noted that raw wastewater is sent to the treatment plant by the sewer network from the center.

Table 1 | Climate parameters of Assa station per month

Month	Average temperature (°C)	Average precipitation (mm)
January	26	7.7
February	25	12.9
March	27	12.4
April	29	13.2
May	30	8.4
June	32	6.4
July	34	5.8
August	37	2
September	35	2.2
October	30	0.6
November	28	1.4
December	24	2.7

Figure 2 | The city's wastewater treatment plant.

Table 2 | Treatment plant criteria of Assa

Location	South of the center about 4 km from the center of the city
Orientation (direction of flow)	To the south
Average altitude	258 NGM
Average slope of the land	1%
Average temperature of the coldest month	24 °C
Station	Natural lagooning (waste stabilization ponds)
Components	Two anaerobic ponds and two facultative, and three drying beds

Sampling scenario

- Recording of data that influence the sample (climatic conditions, temperature, location, etc.).
- Measure the water level and the hydraulic parameters before sampling.
- Collection of the sample in a container suitable for the analysis provided, description of the sample and measurement of in-situ parameters (pH, temperature, conductivity, dissolved oxygen level, etc.).
- Appropriate storage of the sample.
- Describe and identify all the samples taken.
- Storage and transport.
- Equipment decontamination. (NF EN ISO 5667-1. NF EN ISO 5667-3. ISO 5667-10).
- The sampling points used to monitor the station performance are:
  - entrance to the station with a composite sampling mode;

- exit from the two anaerobic basins with a simple sampling mode;
- exit from the station with a composite sampling mode.

A monthly sampling frequency was carried out at the intervention points selected between January 2019 and December 2019 for physico-chemical analysis and every 15 days between December and January for bacteriological analysis.

Sampling methods

Composite samples

Composite samples are prepared by mixing multiple grab samples or collecting a continuous fraction of the wastewater stream. There are two types of composite samples:

1. Time-weighted samples;
2. Samples weighted according to the flow rate.

We chose time-weighted composite samples which consist of point samples of equal volume taken at constant intervals during the sampling period.

Time-weighted composite samples are appropriate when the average quality of wastewater or effluents is of interest (for example, to determine compliance with a standard based on average quality or to determine average pollution of wastewater for the purpose of treatment process design).

Each grab sample should have a volume greater than 50 mL. Then, it is recommended that the grab samples have a volume between 200 and 300 mL in order to be able to take representative samples. Homogenous samples of 1 L were taken in sterile glass bottles from each point with a frequency of nine samples for each month. Samples were stored in an icebox at a temperature of 4 °C in darkness to avoid any disinfection effects of sunlight and changes to microbial presence. All samples were transported to the laboratory of Gelmim for analysis within 24 h of sampling.

Analysis methods

The physicochemical parameters studied were: water and air temperature, pH, chemical oxygen demand (COD), biochemical oxygen demand for 5 days (BOD_5), total suspended solids (TSS), dissolved oxygen (DO) and electrical conductivity (EC)(Rodier *et al.* 2016).

The pH and temperature were determined by a CONSORT C831 type pH meter fitted with a temperature measuring probe (Moroccan Standard 2001). The biochemical oxygen demand for 5 days (BOD_5) was determined by the OxiTop method (International Standard ISO 5815-2 (1/4/2003)). For COD and TSS measurements, they were carried out respectively by the colorimetric method and the gravimetric method (Moroccan Standard 1996) with a BAXTRANE type balance with a precision of 5 μg.

The isolation and enumeration of bacteria indicative of fecal contamination such as: total coliforms (TC), fecal coliforms (FC) and fecal Streptococci (FS) were carried out in an appropriate liquid medium using the most probable number method (NPP method) for enumeration of microorganisms.

RESULTS AND DISCUSSION

Physico-chemical characterization of wastewater from the city of Assa

Temperature of the wastewater during 2019

It is important to know the temperature of the water with good accuracy. Indeed, it has a role both in the solubility of salts, and especially gases, and in the dissociation of dissolved salts. Therefore, electrical conductivity and pH were engaged in its determination (Rodier *et al.* 2016).

The temperatures of the raw wastewater from the town of Assa, shown in Figure 3, were between 20.5 and 34 °C with an average of 26.33 °C at the entrance of the station, and in the exit of the anaerobic ponds it was between 19

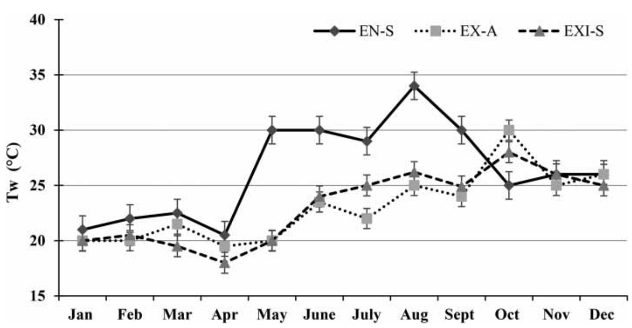

Figure 3 | Wastewater temperatures during 2019.

and 29 °C with an average of 24 °C. Also, that of the treated wastewater at the outlet was between 18 and 28° with an average of 23.09 °C. These recorded temperatures are included in the range of limit values for direct discharge to the receiving environment (Law no. 1276-01, Joint Order of the Moroccan Minister of Equipment and the Minister responsible for land use planning, town planning and housing and the environment no. 1276-01 of 10 chaabane 1423 (October 17, 2002) establishing the quality standards of water intended for irrigation) and in the range of Moroccan standards for the quality of water intended for irrigation (Decree no. 2-04-553, the Moroccan Minister of the Interior, the Minister of Land Development, Water and the Environment, the Minister of Industry, Trade and Upgrading of the Economy, the Minister of Energy and Mines and of the Minister of Tourism, Crafts and Social Economy, determining general limit values for rejection).

The change in the difference between the three curves of the inlet, exit of anerobic ponds and outlet is explained in the first part by the effect of the pressure in the sewage network so the water entering the station is warmer than the water leaving. They are also affected by the temperature of the air during the long retention time of the wastewater in the ponds.

The temperature of the wastewater greatly influences the efficiency of the treatment process, for example, settling is more effective at higher temperatures, and the biological activity taking place during the treatment decreases with the cold.

Potential of hydrogen of the wastewater during 2019

The pH indicates the degree of acidity or basicity of a sample. It is calculated according to the concentration of H_3O hydronium ions and it depends on the origin and nature of the water (Buck 2002).

The pH of raw sewage entering the station, shown in Figure 4, varies between 7.42 and 7.9. These values are in the range of direct discharge limits of pH which is between 6.5 and 8.5 and then in the exit of the anerobic ponds it varies between 7.63 and 8.01. The purification led us to stable pH values between 7.87 and 8.6 and the rise in this parameter is due to the diurnal photosynthetic cycle, but its values remain within the range of direct discharge limits (Law n ° 1276-01) and is within the range of Moroccan

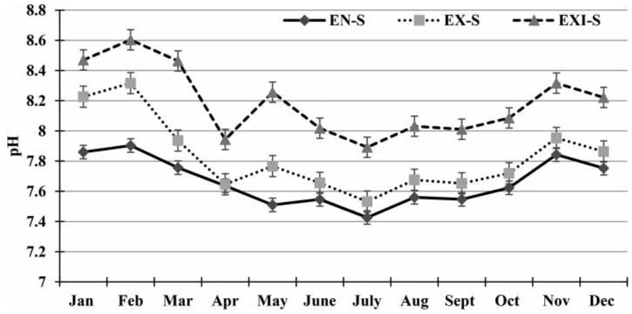

Figure 4 | Wastewater pH during 2019.

standards for the quality of water intended for irrigation (Decree n ° 2-04-553) except in February when it was 8.6.

The variation in pH values is intimately linked to algal proliferation. Thus, this link is responsible for the consumption of CO_2 dissolved in water, and therefore for the alkalization of water according to the following equation:

$$HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow H_2$$

There is a strong correlation between the alkalinity of treated water and the density of microalgae, and this is explained by increased photosynthetic activity.

Electrical conductivity of the wastewater during 2019

The conductivity values, shown in Figure 5, recorded at the level of raw wastewater in the city of Assa, vary between 2,160 and 2,789 μS/cm with an average of 2,573 μS/cm, at the exit of the anaerobic ponds between 2,003 and 2,348 μS/cm, and the treated wastewater is between 2,500 and 3,060 μS/cm with an average of 2,779 μS/cm. It is noted that the conductivity of the wastewater is high from the entrance of the station, and it tends to increase in the facultative

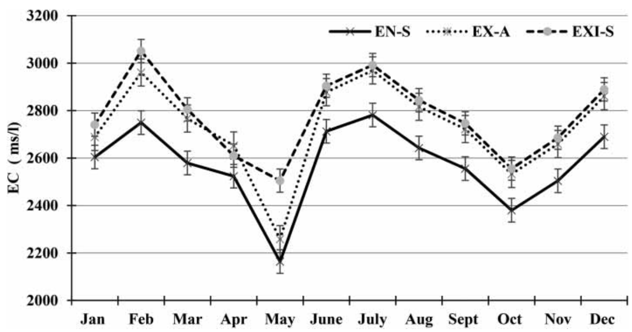

Figure 5 | Wastewater conductivity during 2019.

ponds. Sometimes a decrease is observed at the end of the wastewater treatment plant (WWTP), but it always remains higher than the limit value for discharge into the natural environment, which is 2,500 μs/cm (Law n ° 1276-01).

The high conductivity values at the entrance to the station are due to the salinity of the drinking water upstream. In the aerobic and facultative ponds level, the degradation of organic matter by bacteria contributes to the production of nutritive salts such as nitrogen and phosphate; which results in an increase in electrical conductivity at the station exit.

Biochemical oxygen demand of the wastewater during 2019

BOD_5 is the amount of oxygen consumed after 5 days of incubation at 20 °C, and in the dark. BOD_5 concentrations at the entry vary between 340 and 660 mg/L, values at the exit of the anerobic ponds vary between 245 and 554 mg/L, and at the exit of the station vary between 135 and 228 mg/L with an average of 157 mg/L. These values at the station exit indicate a high abatement of BOD_5 that can reach up to 65.4%. On the other hand, these recorded values of BOD_5 at the outlet exceed the Moroccan discharge standards which are limited to 100 mg/L for this parameter (Law no. 1276-01).

Given that BOD_5 was measured on unfiltered samples, it is concluded that the high values observed in summer are due to the significant proliferation of algae at this time of the year (Figure 6). This is mainly due to abiotic factors such as increased temperature and sunshine.

Chemical oxygen demand of the wastewater during 2019

The COD values results are presented in Figure 7. At the input, COD vary between a minimum value of 687 mg/L

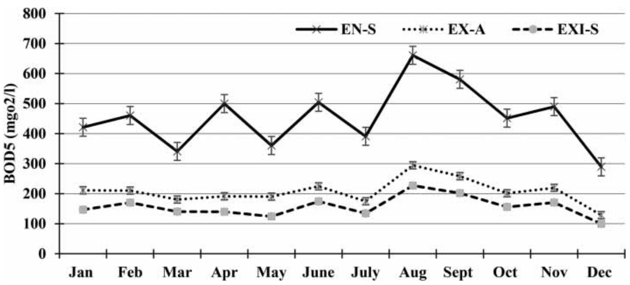

Figure 6 | Wastewater BOD_5 during 2019.

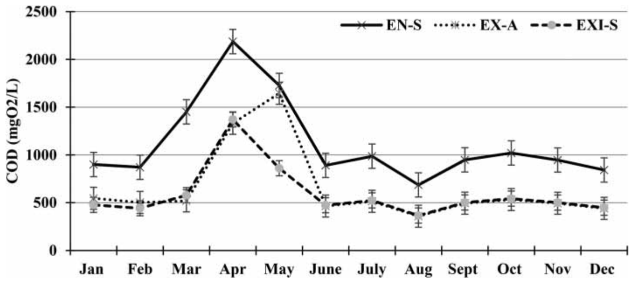

Figure 7 | Wastewater COD during 2019.

and maximum value of 2,188 mg/L. The values at the exit of anaerobic ponds vary between 467 and 1,875 mg/L, and the values at the exit of the station vary between 365 and 1,373 mg/L with an average of 591 mg/L. These values show us the good reduction of the ponds with respect to carbon pollution, this reduction reaches 47%. On the other hand, these recorded values do not comply with the specific limit values for domestic discharge (Law no. 1276-01).

Total suspended solids of the wastewater during 2019

The quantity of the total suspended solids is presented in Figure 8. At the inlet of the station, TSS values varies between 258 and 840 mg/L, with an average of 538 mg/L. The concentration at the exit of the anerobic ponds is between 292 and 646 mg/L with an average of 457 mg/L and at the outlet they vary between 172 and 476 mg/L with an average of 291 mg/L. These TSS values at the outlet are not included in the range of specific limit values for domestic discharge (Law no. 1276-01). The abatement yield reaches up to 43%.

We noticed an increase of the TSS from the anaerobic pond to the exit of the station, and that is due to the formation of micro-algae in the aero-pond.

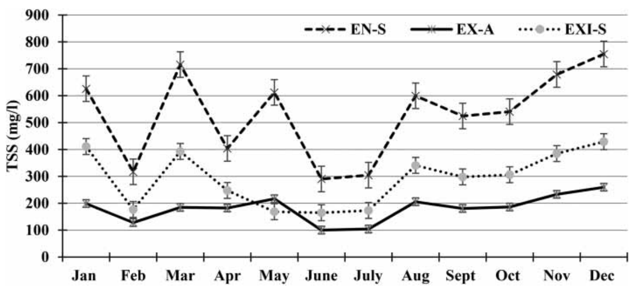

Figure 8 | Wastewater total suspended solids concentrations during 2019.

Dissolved oxygen of the wastewater during 2019

Dissolved oxygen is an essential component of water because it supports the life of wildlife and it affects the biological reactions that take place in aquatic ecosystems. The solubility of oxygen in water depends on various factors, including the temperature, pressure and ionic strength of the milieu (Waki *et al.* 2018). Figure 9 presents the results of DO. The concentration of dissolved oxygen at the entrance to the station is zero, due to the high organic load in the raw wastewater, and the degradation of this pollution during purification has led us to average concentrations between 0.02 and 0.32 mg/L at the exit of the anaerobic ponds, then at the exit of the station a high increase with average concentrations between 0.78 and 1.2 mg/L. The concentration of dissolved oxygen leaving the station is higher in the winter months and lower in the summer due to temperature and atmospheric pressure.

Bacteriological characterization of wastewater in the city of Assa

The determination of the total coliforms, fecal coliforms, and fecal streptococci, can give an indication of the risks linked to the use of this wastewater in agriculture. Tables 3 and 4 show successive microbiological results of the water entering the station and the water leaving the station.

Total coliforms

The results of the total coliforms in Table 3 show that the raw wastewaters are characterized by high contents of germs which vary between 110×10^6 CFU/L and 46×10^6 CFU/L. This constant large load of total coliforms in

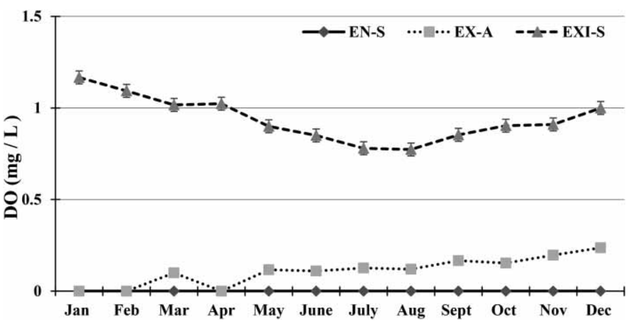

Figure 9 | Wastewater dissolved oxygen during 2019.

Table 3 | Microbiological results of the station entrance

Dates Germs	P_1 05/12/19	P_2 20/12/19	P_3 05/01/20	Average
TC (CFU/L)	110×10^6	110×10^6	46×10^6	$\mathbf{88 \times 10^6}$
FC (CFU/L)	110×10^6	110×10^6	24×10^6	81×10^6
FS (CFU/L)	29×10^6	21×10^6	15×10^6	21×10^6

Table 4 | Microbiological results of the station exit

Dates Germs	P_1 05/12/19	P_2 20/12/19	P_3 05/01/20	Average
TC (CFU/L)	110×10^5	46×10^5	24×10^5	60×10^5
FC (CFU/L)	7.5×10^6	12×10^6	4.3×10^6	7.93×10^6
FS (CFU/L)	9.3×10^6	4.3×10^6	3.8×10^6	5.8×10^6

raw wastewater is due to the enrichment in organic matter which makes the environment favorable to bacterial development, hence the proliferation of this type which depends on the nature of the substrate present.

At the exit (Table 4), there is a significant reduction in germs after the facultative ponds, with values varying between 110×10^5 CFU/L and 24×10^5 CFU/L which corresponds to the Moroccan standards (10^6) for discharge into the natural environment, but exceed that of irrigation.

Fecal coliforms

The results obtained are shown in Table 3, and there is an average of 81×10^6 CFU/L. This value greatly exceed the threshold of the standards corresponding to the average content discharged wastewater (10–10^6). The high number of fecal coliforms in raw wastewater is due to the ability of germs to withstand harsh environmental conditions. However, the data received at the output which are mentioned in Table 4, between 12×10^6 and 4.3×10^6 CFU/L with an average of 7.93×10^6 CFU/L. The number of these germs has decreased in purified water and it is very close to the standards given by the WHO (10–10^6).

Fecal streptococci

These germs are Gram-positive, spherical or ovoid cocci, arranged in pairs to form diplococci and which can be in the form of long chains, they do not produce or form spores. All the streptococci possessing the antigenic substance (teichoic acid), that is to say essentially: *Enterococcus faecalis*, *E. faecium*, *E. durans*, *E. hirae*, *Streptococcus bovis*, *S. suiset, S. equinus*. These group D streptococci are generally taken into account globally as witnesses of fecal pollution, since all have a fecal habitat relating to or resembling feces (Rodier *et al.* 2016).

The results in Table 3 show an average of 21×10^6 CFU/L for raw water, while at the exit (Table 4), we notice a significant reduction of germs in purified water, with results between 3.8×10^6 and 9.3×10^6 CFU/L with an average of 5.8×10^6 CFU/L, which are slightly above the standards given by the WHO ($10–10^6$).

Discussion of the station performance

Table 5 demonstrates the abatement rates of all the parameters measured during the year 2019. We notice the high performance of the anaerobic ponds in the removal of BOD_5, COD and TSS with –54.39, –41.68 and –66.28% respectively, and the great role of the facultatives ponds in the uprising dissolved oxygen concentration and the high coliforms removal of more than 90%.

BOD removal efficiency of the facultative ponds is poor and the oxygen required is not sufficient for the degradation of organic materials. Effluents which have high concentration of BOD and COD can cause depletion of oxygen in the aquatic environment or in the receiving water bodies. Therefore, the BOD/COD removal (–24.13 and –9.67%) and the consequent quality of the effluent depend on the amount of oxygen present, retention time and temperature of the ponds.

Table 5 | Station abatement during 2019

Ponds Parameters	Anaerobic (%)	Facultatives (%)	Total
Tw	–12.5	+ 0.2	–12.31
pH	+ 2.15	+ 4.73	+ 6.91
EC	+ 6.08	+ 1.72	+ 7.90
BOD_5	–54.39	–24.13	–65.39
COD	–41.68	–9.67	–47.33
TSS	–66.28	+ 60.2	–45.99
DO	–	+ 749.86	–
Total coliforms	–	–	–93.18
Fecal coliforms	–	–	–90.20
Fecal Streptococci	–	–	–72.38

The temperature of the wastewater greatly influences the efficiency of the treatment process (LaPara *et al.* 2001), for example, settling is more effective at higher temperatures in the summer and the biological activity taking place during the treatment decreases with the cold, but the oxygen dissolves much more in low temperatures. Temperature also influences the rate of chemical and biological reactions. It affects the level of dissolved oxygen in water, photosynthesis in aquatic plants, metabolic rates of aquatic organisms, and the susceptibility of these organisms to pollution, pests and disease.

Winter water temperatures were observed to be about 12–13 °C lower than the summer (June–August) temperatures. Although the temperature of the anaerobic ponds at different depths is not available, it is possible that the temperature of the anaerobic pond at lower depths may be higher than the pond surface temperature or the raw influent. This is because the anaerobic process itself is an exothermic process and the heat retention must be further aided by long sludge retention time, thereby likely favoring BOD and COD removal even though the surface temperature of the pond water is low during the cold winter period. The monthly variation of influent and effluent COD is shown in Figure 7. Influent COD was observed between 842 and 2,186 mg/L although an unusually high COD recorded for the month of April 2019 is possibly due to the weeding season in the region and the increase of bloods and food waste into the stream. We also noticed an increase of the TSS from the anaerobic pond to the exit of the station, and that is due to the formation of micro-algae in the facultative ponds, also sand storms in November and December increase the TSS in the water.

BOD_5 concentrations (Figure 6) at the entry vary between 340 and 660 mg/L, and values at the exit vary between 135 and 228 mg/L with an average of 157 mg/L. These values at the exit tell us about the good abatement of the anaerobic basins with respect to carbon pollution and whose values can reach 65.4%. On the other hand, these recorded values of BOD_5 at the outlet thus exceed the discharge standards limited to 100 mg/L for this parameter (Law no. 1276-01). It is concluded that the high values observed in summer are due to the significant proliferation of algae at this time of the year; This is mainly due to abiotic factors such as increased temperature and sunshine (Ragush *et al.* 2017).

Biological data is one of the most important parameters for evaluating the performance of the plant, especially if the final effluent is for reuse (Coggins *et al.* 2020). Municipal waste water treatment plants are a very efficient process for the removal of all kinds of pathogens (Wang *et al.* 2017). Although the final effluent for this particular treatment plant is not intended for any reuse, its discharge to the river is a concern, especially if the river downstream is used for human consumption. However, there are no reports of human consumption downstream of the river. The river flows during the winter period vary from 3.0 to 5.0 m^3/s and therefore a high dilution factor is usually achieved after discharge of the effluent. The data observed shows that total and faecal coliform numbers were lowest at positions in the ponds and times where pH, temperature, dissolved oxygen and algae were high. Also UV radiation can have a direct effect on killing these germs by their photochemical action, inducing damage in the genetics material of cells, leading to their destruction. The depth of the basin as well as the residence time are also two important parameters controlling the elimination of coliforms. Indeed, the better reduction of bacterial germs are often observed at the end of the facultative ponds. This is explained, in addition to the significant algal proliferation at this station level, by the shallow depth of the pond (1 m) and the long retention time of about 20–25 days.

The high conductivity values at the entrance to the station are due to the salinity of the drinking water upstream. At the facultative ponds level, the degradation of organic matter by bacteria contributes to the production of nutritive salts such as nitrogen and phosphate, which results in an increase in electrical conductivity at the station exit. The concentration of dissolved salts can be an element limiting bacterial growth (and therefore the biodegradability of an effluent). Therefore, it is necessary to provide a better treatment of the conductivity in the Assa WSP.

The concentration of dissolved oxygen at the entrance to the station is zero due to the high organic load in the raw wastewater, and the concentration of dissolved oxygen leaving the station is higher in the winter months and low in the summer due to temperature and atmospheric pressure.

The oxygen dissolved measures in the Assa WSP suggests that for a balanced system the amount of DO produced by the photosynthesis process is enough to keep the system healthy. The leading process of oxygen utilization was due to total respiration of bacteria in the facultative ponds that consume the organic matter (Kayombo *et al.* 2000). The fact that algal photosynthesis meets the oxygen demand as predicted is false in our case and there is a need for injected oxygen in the two facultative ponds.

We can conclude that the wastewater from this discharge has a domestic character, a high organic load and is biodegradable.

The high value of COD/BOD_5 and TSS/BOD_5 indicate the biologically degradable nature of the raw wastewater which is one reason for high removal of BOD_5 by anaerobic ponds. Moreover, the desludging period of the anaerobic pond was six years since commissioning of the plant, against the expected period of five years, which indicates the high biodegradability of the raw wastewater.

Algae usually contributes to about 70–90% of the BOD, COD and TSS values, however the performance of the Assa plant in organic removal is still higher. Although the data on the algae is not available for these ponds, it is highly likely that the wastewater effluents from the facultative ponds could contain algae. This is because the presence of nutrients in the facultative pond water aided by sunlight and slight atmospheric mixing at the pond surface could provide conditions for the growth of certain amounts of algae. The visual appearance of algal growth in the facultative pond, especially during the warm summer months, was confirmed. Because of high algal contents in facultative ponds, these results therefore indicate that these ponds perform quite well in the hot climate of Assa region and therefore is very suitable technology for domestic wastewater treatment.

Comparison of the performance with other stations in the region

Tantan, Elouatia and Bouzakan are three plants with waste stabilization ponds treatment processes and they are situated in the same region. So, they have approximately the same meteorological data and the same anthropic, artisanal and industrial activities. Table 6 presents the average abatement rate of each station during three months monitoring.

Comparing these results, we notice a significant similitude in most of the abatements rate of each ponds (anaerobic and facultative) like BOD_5 (–70%; –75%; –85%) and COD (70%; –74%; –77%) and TSS (–75%; –78%; –80%). Therefore we define the reactions that control the treatment and the influence of the weather and climate on the abatement rates and the plant performance in general. These results allow us to compare and to understand two anomalies: the increase of the electrical conductivity and the total suspended solids from the facultative ponds to the exit of the plant. This phenomenon is similar in two out of these three plants, although facultative ponds performance depends on water and air temperatures, the depth of the ponds and the nature of the pollution entering, these parameters are almost identical in these three stations. Unfortunately, this region is characterized by a hot and dry climate, an inconvenient parameter for high performance in this process.

The most important observation here is the stability of the abatement rate in all these stations although some are some older than others, so the performance of waste stabilization ponds in general is not due to the city's wastewater nature but is due to the climate, weather, the source of water and the surrounding environmental characteristics (Ragush *et al.* 2017; Ho *et al.* 2019; Ali *et al.* 2020).

Finally, the Assa waste stabilization ponds have good treatment performance, it is a new station that did not yet exceed the limit of its capacity and comparing it with these three stations we have a clear idea on what we should add so that we can arrive at the Moroccan irrigation standards and have a significant new source of water that could help us combat the water scarcity of our region.

Table 6 | Abatment rate of Tantan, Elouatia and Bouzakarn wastewater treatment plants

Ponds		Anaerobic (%)	Facultative (%)	Total (%)
Tw	Tantan	+2.92	+5.71	+8.82
	Elouatia	+2.92	+2.85	+5.88
	Bouzakarn	–8.57	–12.5	–20
pH	Tantan	+7.96	+6.28	+14.75
	Elouatia	+0.23	–0.95	–0.71
	Bouzakarn	–1.51	+8.83	–7.61
EC	Tantan	+2.53	+27.59	+24.36
	Elouatia	–16.38	+4.64	–12.5
	Bouzakarn	–5.75	–4.19	–9.71
BOD_5	Tantan	–73.07	–10.71	–75.96
	Elouatia	–83.33	–10	–85
	Bouzakarn	–43.24	–48.8	–70.94
COD	Tantan	–42	–55.53	–74.23
	Elouatia	–47	–44	–77
	Bouzakarn	–57	–50	–70
TSS	Tantan	–55	–56	–80.64
	Elouatia	–92	+200	–78.04
	Bouzakarn	–79	+ 18.42	–75.27

Principal component analysis of physicochemical results

To better interpret the results obtained relating to physicochemical parameters, a statistical study was made using a multivariate analysis method: principal component analysis (PCA), using the XLSTAT 2009 software. The objective of the PCA is to present, in a graphical form, the maximum of the information contained in a data table, based on the principle of double projection on the factorial axes, data processing by principal component analysis, using the physicochemical parameters Tair, Tw, pH, Cond, DO, BOD_5, COD, and TSS, and the 12 months of sampling.

Analysis of the results shows that most of the information is explained by the first two factorial axes (Tables 8 and 9). In the factorial plan F_1xF_2, the two components F_1 and F_2 contribute to the total inertia with a percentage of 70.21% of total data set. The first component (F1) cumulates 45.92% of the total variance and the second component (F2) cumulates about 24.29% of the total variance of the data set (Table 5). Reduction of the dimensionality of the total data using the PCA analysis is from eight to two axes (eight parameters to two parameters) and generates 75% of reduction and resulted in 29.79% loss of information contained in the dimensions.

Positive contribution of studying variables to the first component (F1) were Tair, Tw and BOD_5 contrary to COD and DO which correlate negatively with this axis. The second component (F2) had negative loadings for COD and positive loading to the pH and TSS.

Thus, the first principal component (F1) can be interpreted as organic component because it was mainly related to the most significant variables, being BOD_5.

However, the second component indicates mineral component since it is linked to pH and TSS.

Examination of the correlation matrix between variables (Table 7 and Figure 10) reveals the presence of different correlations between variables. The air temperature is positively correlated with the water temperature, BOD_5 ($r = 0.841$; $r = 0.753$) and negatively correlated with COD, dissolved oxygen ($r = –0. – 670$; $r = –0.724$). Also, the water temperature is positively correlated with the BOD_5 ($r = 0.542$) and negatively correlated with COD, dissolved oxygen ($r = –0.585$; $r = –0.653$). The pH is positively correlated with dissolved oxygen ($r = 0.723$), while the BOD_5 is positively correlated with air temperature and water temperature ($r = 0.753$; $r = 0.542$), and the COD is negatively correlated with air temperature and water temperature ($r = –0.670$; $r = –0.585$). The dissolved oxygen is positively correlated with the pH ($r = 0.723$) and negatively correlated with COD, air temperature and water temperature ($r = –0.724$; $r = –0.653$). Finally, the conductivity and total suspended solids are non-correlated with any other parameter.

Table 7 | Station abatement ratios and characterization parameters of wastewater of the Assa WWTP

COD/BOD_5	2.47
TSS/BOD_5	**1.18**
OM	**676.64 mg/L**

Table 8 | Eigenvalues of correlation matrix and related statistics

Component	Eigen value (Eig)	% Total variance	Cumulative Eig	Cumulative %
F1	4,592	45.92	4,592	45.92
F2	2,429	24.29	7.02	70.21

The projection of samples taken during these months on the factorial plane F1xF2 in Figure 11 corroborate the existence of three more or less distinct groups. The first group (G1) concerns the cold period that shows a decrease of algae quantities which consume mineral salt and produce oxygen by photosynthetic phenomena. Hence, we notice a decrease of biochemical oxygen demand (BOD_5). The pH, chemical oxygen demand (COD), total suspended solids (TSS) and dissolved oxygen (DO) increased in the cold months.

The dissolved oxygen that comes from ambient air and algae photosynthetic phenomena is the most important source of the high performance of our station at removing organic pollution. In the same way, TSS in wastewater is generally added to the ponds by wind storms that blow sand to the ponds, and that is because our plant is in a desert area and our treatment process is in open-air. We noticed that the five months (November, December,

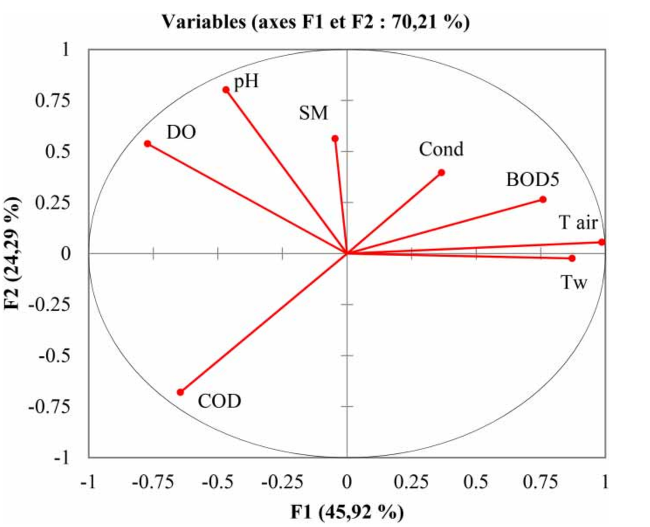

Figure 10 | Biplots of the two axes of PCA performed on physicochemical variables.

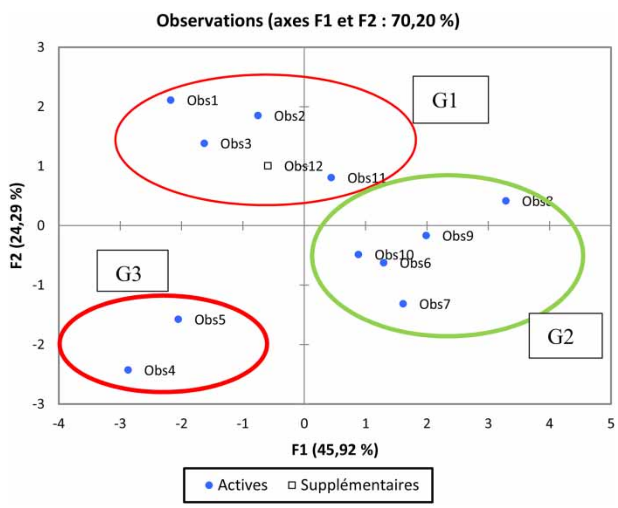

Figure 11 | Projection of variables in the axis space.

Table 9 | Factors models and correlation matrix

Variables	F_1	F_2	Tair	Tw	pH	Cond	DBO5	COD	TSS	DO
T air	0.986	0.055	1	0.841	–0.431	0.381	0.753	–0.670	0.003	–0.724
T w	0.871	–0.024		1	–0.412	0.047	0.542	–0.585	0.094	–0.653
pH	–0.469	0.802				0.131	–0.176	–0.293	0.315	0.723
Cond	0.365	0.396				1	0.284	–0.528	–0.264	–0.068
BOD_5	0.758	0.265					1	–0.512	0.206	–0.396
COD	–0.645	–0.680						1	–0.219	0.158
TSS	–0.046	0.563							1	0.339
DO	–0.772	0.538								1

January, February and March) have a distinctive abatement rate of physical and biodegradable parameters.

The second group (G2) dominated by hot weather indicates different abatement rates (June, July, August, September and October) that are characterized by a high biochemical oxygen demand (BOD_5) and low dissolved oxygen. During these months, the production of drinking water becomes limited, the artisanal activities in seasonal cooperatives of natural products reaches its peak, and the discharged liquid and solid become more concentrated. In this situation, the pH and chemical oxygen demand (COD), total suspended solids (TSS) and dissolved oxygen (DO) decreased due to the high water temperature, the low wind speed and high proliferation rate of algae in the facultative pond.

The third group (G3) includes months with medium temperatures (April and May) and medium values of all the physicochemical parameters

The interpretation of the data collected on the installations spread over the whole year (2019) shows that the waste stabilization ponds technique constitutes a solution compatible with certain quality objectives, in particular due to good elimination of bacteria and BOD during low water temperatures periods. It should also be noted that the concentration of pollutants in treated wastewater is not always the most relevant parameter for evaluating the performance of a wastewater treatment plant; the flows turn out to be representative throughout the year to assess the yields and the impact of the discharges on the receiving environment due to the rare precipitations and the high temperature during the 12 months of monitoring. A detailed examination of the results shows that the long retention time of the waters in the ponds is related to the strong weather influence. Clear trends can be identified and they should help to find the best field of application for waste stabilization ponds. With strictly combined sewers, cases of dysfunction are also more frequent.

For these reasons there is a need to add maturation ponds to improve the disinfection rates and eliminate more BOD_5 and COD (Pearson *et al.* 1996). We recommended the authorities of the city to upgrade the recent waste stabilization ponds station that only have two anaerobic and two facultative ponds. Upgrading the performance of the existing Assa's waste stabilization ponds to achieve the appropriate treatment required for reuse systems and discharge to the environment is very necessary. In addition, adding maturation ponds to the current station is the most cost-effective system for wastewater treatment prior to reuse.

Maturation ponds (low-cost polishing ponds), which generally follow either the primary or secondary facultative pond, are primarily designed for tertiary treatment, i.e. the removal of pathogens, nutrients and possibly algae. They are very shallow (usually 0.9–1 m depth), to allow light penetration to the bottom and aerobic conditions throughout the whole depth (Von Sperling 2005).

The size and number of maturation ponds needed is determined by the required retention time to achieve a specified effluent pathogen concentration (Bracho *et al.* 2006).

Each of the maturation ponds can expected to remove one log cycle of MEN in the removal of faecal coliforms (Grabow *et al.* 1973). In the absence of effluent limits for pathogens, maturation ponds act as a buffer for faculative pond failure and are useful for nutrient removal. They will also produce an effluent suitable only for restricted irrigation. Therefore, additional maturation ponds will only be needed if a higher quality effluent is required for unrestricted irrigation (Tanner *et al.* 2005).

CONCLUSIONS

This study has shown that the release of effluents from our WSP into the nearby river is a source of contamination. High concentrations of electrical conductivity were observed although levels for most other indicators were slightly surpassing the limits of effluents standards. The removal efficiency of most contaminants is low with the exception of bacteriological. Despite attempts being made by local authorities to treat their wastewater, more treatment procedures are encouraged so as to increase the removal efficiencies of contaminants, and until then, such water is deemed unfit for irrigation and agricultural purposes. To improve the treatment of this wastewater, it is highly recommended to add maturation ponds as another treatment step downstream of the pre-existing station, in order to eliminate the micro-algae, total suspended solids and further reduce existing germs. Finally adding maturation ponds would be excellent to improve the disinfection rates and eliminate more BOD_5 and COD.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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