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Improving the performance of waste stabilization ponds in an arid climate

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ABSTRACT

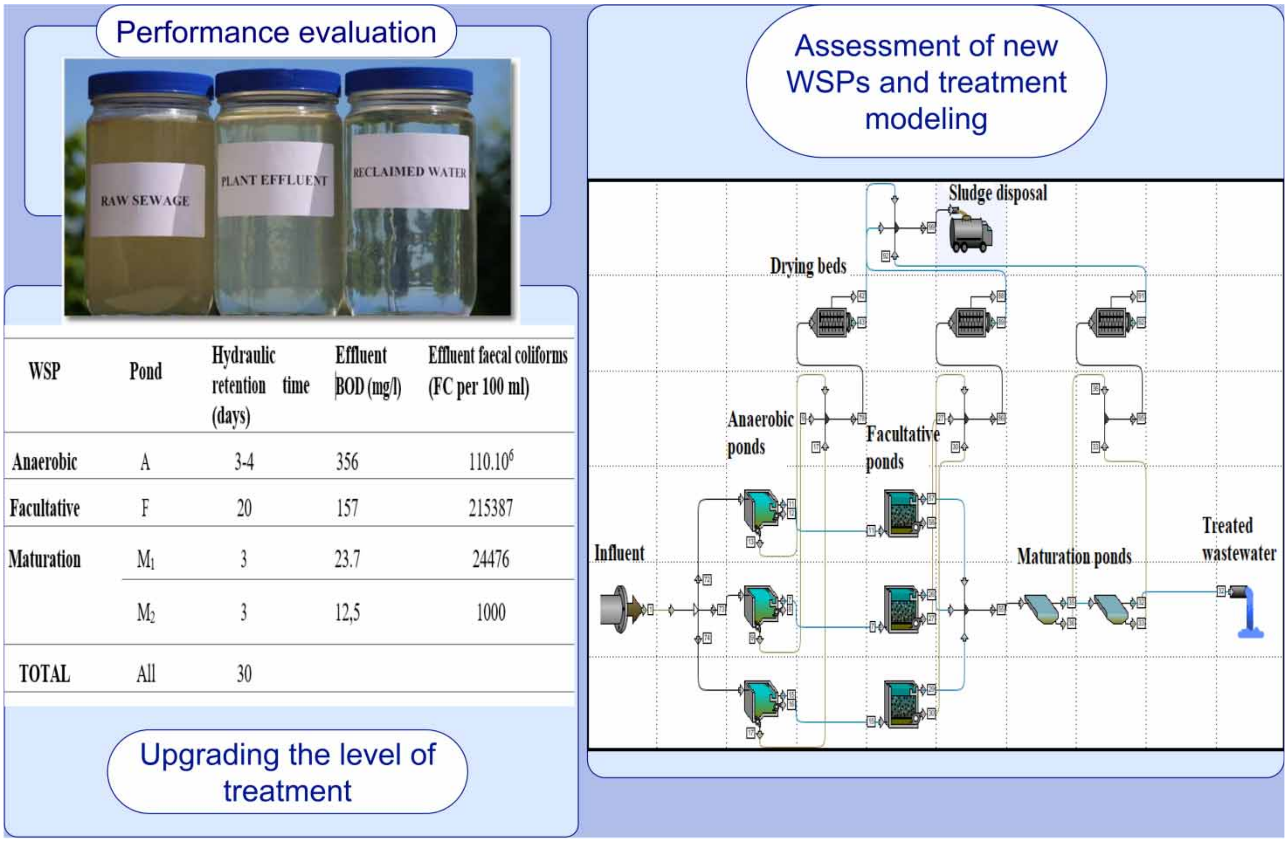
In many parts of the world, waste stabilization ponds (WSPs) are currently the preferred wastewater treatment method for municipal wastewater. The objective of this research is to examine the performance of a WSP in an arid climate region and to identify ways to improve its purification efficiency so that it can meet the criteria for reuse. The results attributed the poor performance to both improper process and physical design after 12 months of physicochemical and bacteriological analyses, as well as monitoring of operation, maintenance and loading rates. In tertiary treatment, maturation ponds are added, an increase in the capacity of the station, and management of the flow rate and retention time for each pond. By simulating the new WSP with GPS-X, the best pond area ratio obtained is 2.5 m^2/capita, with a retention time of 4 days for anaerobic ponds, 20 days for facultative ponds and 3 days for two maturation ponds in series, which is suitable and provides reduction rates of BOD and fecal coliforms of 95 and 99%, respectively, with an average effluent concentration of 20 mg/L and 195 CFU. According to the results, well-maintained WSPs provide a viable, self-sufficient and environmentally friendly wastewater treatment solution for irrigation water supply in dry areas.

Key words: extension, maturation ponds, modulization, waste stabilization ponds, wastewater

HIGHLIGHTS

- Low cost and efficient upgrading option for waste stabilization ponds (WSPs).
- Design and simulation of WSPs.
- Assessment of performance according to similar WSPs and 12 months of analyses.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The purpose of wastewater treatment plants (WWTPs) is to remove or reduce contaminants in water that impose threats to humans and the environment if discharged to surface and/or ground waters without proper treatment. As developed countries continue to work on more efficient treatment processes in the sewage treatment plant and establish new technologies to meet the growing demand for water, undeveloped countries are still struggling to establish the required infrastructure for the treatment.

Waste stabilization ponds (WSPs) were highly recommended due to their efficient operation over a wide range of levels of flow and load, as well as minimum energy consumption. Additionally, WSPs are recommended for treating urban wastewater with small populations (Abbas *et al.* 2006; Astaraie-Imani *et al.* 2013; Ho *et al.* 2017). Moreover, the prevailing climate and local environmental conditions in Morocco are ideal for treating domestic wastewater using stabilization ponds. This is mainly due to the domination of high temperature and sunlight that kill the pathogens, as well as high organic material oxidation. Stabilization ponds can be a combination of one or three different ponds: anaerobic, facultative and/or maturation, depending on the design criteria and operating conditions of each type. Choosing the most effective configuration of ponds in terms of purification efficiencies varies significantly according to various parameters such as organic loading rate, available land area, climate data, influent characteristics and the required effluent values. Anaerobic digestion is commonly used in the first pond due to its stability at higher volumetric organic loading. A properly designed and operated anaerobic pond will achieve about 40% removal of BOD at 10 °C. Normally, those ponds do not contain dissolved oxygen (DO) or algae. The effluent from the anaerobic ponds is further treated through facultative ponds (FPs). In the FP, a complex wide range of microorganisms (algae, virus, protozoa, rotifers, insects, crustaceans and fungi) interacts to promote the biodegradation process. The DO consumed by bacterial action and organic degradation process is generated by photosynthesis using algae, the main pond oxygenators. Consequently, aerobic, facultative and anaerobic zones, as well as different biochemical processes, take place within the pond layers (Von Sperling 2005). To eliminate fecal coliforms (FC) and viruses in wastewater, the effluent from the FPs is subsequently introduced to the last stage, the maturation pond (MP). These ponds are shallow (optimum depth of 1.0 m), allowing for complete oxygenation and penetration of sunlight radiation throughout their depth (Tanner *et al.* 2005; Bracho *et al.* 2006).

Wastewater reuse becomes possible when it is physically, chemically and biologically treated by an appropriate wastewater treatment technology (Pearson *et al.* 1996; Hind *et al.* 2013; Arnell *et al.* 2017). The WSP is advocated as one of the most efficient and economical technologies to remove pathogens and fecal bio-indicators from wastewater. The city's current WSP station has only two stages of treatment, anaerobic pond and FP. The purpose of this paper is to evaluate the performance of Assa's WSP physicochemically and bacteriologically over 12 months, and to investigate the operation, maintenance and loading rates, to decide at the end the best alternative approaches to upgrade its purification efficiencies to meet reuse standards. In addition, the verification of these alternatives is done by the GPS-X software. This software helps in understanding the plant's performance under different conditions as well as in deciding the future expansion works needed for increased hydraulic and organic loadings.

2. MATERIALS AND METHODS

2.1. Study zone

Assa is located in the Moroccan desert of north Africa, as seen in Figure 1. It is a small town with a population of 20,041 inhabitants and 3,472 households all are subscribed to the national office of water and electricity 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 is 317,772 m^3, and the volume billed for sanitation is 191,526 m^3. This volume of wastewater is treated with a WSP 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 North East and Saharan in the South and South West. The climate in the area is of the pre-Saharan type, and 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 measured climate precipitations and temperatures during the year 2020 are shown in Table 1.

Figure 1 | Geographic location of the study area according to the world map.

Table 1 | Measured average temperature and precipitations in Assa's city

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

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

2.2. Treatment plant criteria

The WWTP of the city of ASSA is characterized by the following criteria, as shown in Table 2. The specific dimensions of each pond are shown in Table 3. Figures 2 and 3 present a satellite picture of Assa's current WWTP and a layout of Assa's WWTP, respectively.

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
Saturation date	2022
Capacity (E.H.)	24 427
Flow (m^3/d)	1,469
Capacity of treatment (kg DBO5/d)	273

Table 3 | Assa's WSPs and specific dimensions

Ponds	Number	Dimensions	
		Length (m)	Width (m)
Anaerobic ponds	3	50	31
FPs	3	193	66
MPs	2	190	70

Figure 2 | Satellite picture of Assa's current WWTP.

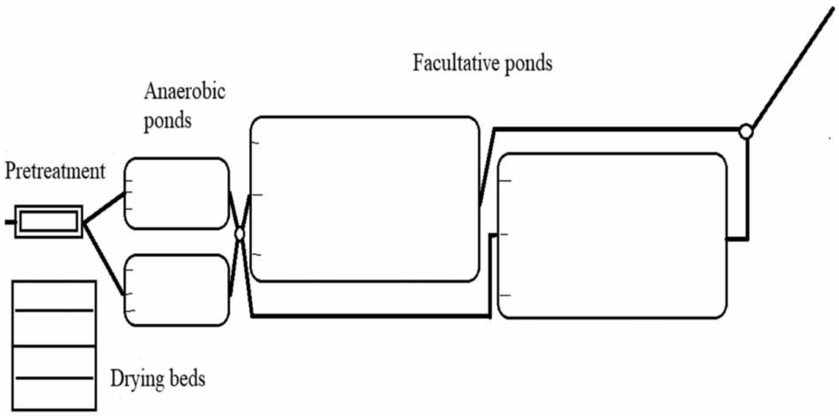


Figure 3 | Layout of Assa's WWTP.

2.3. Analytical methods

The frequency of analysis, period of analysis and weather data had been undertaken to directly assess the improvement in effluent quality. The physicochemical parameters studied are water and air temperature, pH, chemical oxygen demand (COD), biochemical oxygen demand for 5 days (BOD5), total suspended solids (TSS), DO and electrical conductivity (EC). The pH and the temperature were determined by a CONSORT C831 type pH meter fitted with a temperature measuring probe. The BOD5 was determined by the OxiTop method (International Standard ISO 5815-2 (1 April 2003)). For COD and TSS measurements, they are carried out, respectively, by the colorimetric method and the gravimetry method with a BAX-TRANE type balance with a precision of 5 μg. The isolation and enumeration of bacteria indicative of fecal contamination such as total coliforms (TC), FC and fecal streptococci (FS) are carried out using the most probable number method, and it is a statistical method used to estimate the viable numbers of bacteria in a sample by inoculating broth in 10-fold dilutions and is based on the principle of extinction dilution. It is often used in estimating bacterial cells in wastewater (Yagoubi *et al.* 2000; Phuntsho *et al.* 2016; Daee *et al.* 2019; Ali *et al.* 2020).

To allow comparison of such data sets, a simulation by the GPS-X software is performed to evaluate the efficiencies of the modifications and to determine the best configuration for these WSPs.

3. RESULTS AND DISCUSSION

3.1. Station performance

The WWTP is a WSP, with two anaerobic ponds and two FPs, both in parallel. The following physicochemical and bacteriological parameters, T_{air}, T_w, pH, Cond, DO, BOD5, COD and TSS, were monitored over 12 months in Assa's WSPs for the year 2019. The bacteriological parameters of TC, FC and FS were monitored for 3 months.

The results of wastewater entering the WSP are shown in Table 4 for the physicochemical, and Table 5 for the bacteriological. The abatement rates for each pond are mentioned in Table 6. Finally, the station abatement ratios and characterization parameters are shown in Table 7.

Water temperatures in the winter were found to be 12–13 °C lower than those in the summer (June–August). Although the temperature of anaerobic ponds at various depths is unknown, it is probable that the temperature of anaerobic ponds at lower depths is higher than the pond surface temperature or the raw influent. This is because the anaerobic process is an exothermic process, and heat retention is assisted by a long sediment retention time; thus, BOD and COD removal are likely to be favorable even when the pond water's surface temperature is low during the cold winter months. COD levels of influence ranged from 842 to 2,186 mg/L, although an unusually high COD for the month of April could be attributed to the weeding season in the area and an increase in blood and food waste entering the creek. An increase in TSS is noticed from the anaerobic pond to the station's outflow, which is attributable to micro-algae development in the FPs. Likewise in marsh, sand storms in November and December raise the TSS in the water.

BOD5 concentrations at entry range from 340 to 660 mg/L, while values at exit range from 135 to 228 mg/L, with an average of 157 mg/L. These results at the exit indicate that anaerobic ponds are effective in reducing carbon pollution, with values as high as 78%. These measured BOD5 values at the exit, on the other hand, surpass the discharge limits for this parameter,

Table 4 | Assa's wastewater physicochemical parameter values during the year 2020

Months	T_{air} (°C)	T_w (°C)	pH	EC (μS/cm)	BOD5 (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)
Jan	22	20	8.45	2,740	146	477	411	1.2
Feb	26	20.5	8.6	3,060	170	441	176	1.08
Mar	23.5	19.5	8.48	2,810	140	579	392	1
Apr	18	18	7.9	2,610	140	1,373	248	1
May	21	20	8.26	2,500	125	861	168	0.9
June	30	24	8.01	2,911	174	473	164	0.84
July	34	25	7.87	2,995	135	524	172	0.78
Aug	39	26.2	8.02	2,841	228	365	340	0.77
Sept	36	24.9	8.00	2,747	201	503	297	0.85
Oct	31	28	8.08	2,556	156	542	307	0.91
Nov	28	26	8.31	2,685	170	502	384	0.92
Dec	27	25	8.22	2,889	100	448	428	1

Table 5 | Microbiological parameter values of the station entrance

	Dates			
Germs (CFU/L)	P1 5 Dec 2019	P2 20 Dec 2019	P3 5 Jan 2020	Average
TC	$11{\cdot}10^6$	$11{\cdot}10^6$	$46{\cdot}10^6$	$88{\cdot}10^6$
FC	$11{\cdot}10^6$	$11{\cdot}10^6$	$24{\cdot}10^6$	$81{\cdot}10^6$
FS	$29{\cdot}10^6$	$21{\cdot}10^6$	$15{\cdot}10^6$	$21{\cdot}10^6$

CFU, colony formative unit.

Table 6 | Current WSP performance

	Ponds		
Parameters	**Anaerobic (%)**	**Facultatives (%)**	**Total (%)**
Tw	−12.5	+0.2	−12.30
pH	+2.15	+4.73	+6.88
EC	+ 6.08	+1.72	+7.80
BOD5	−54.39	−24.13	−78.52
COD	−41.68	−9.67	−51.35
TSS	−66.28	+60.2	−6.08
DO	–	+749.86	–
TC	–	–	−93.18
FC	–	–	−90.20
FS	–	–	−72.38

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

COD/BOD5	2.47
TSS/BOD5	1.18
Organic matter	676.64 mg/L

which are set at 100 mg/L. The high levels recorded during the summer are attributed to the substantial growth of algae at this time of year, which is mostly attributable to abiotic factors such as higher warmth and sunlight.

The high conductivity values at the entrance to the station are due to the salinity of the drinking water upstream. The degradation of organic materials by bacteria at the FP level adds to the formation of nutritive salts like nitrogen and phosphate, resulting in an increase in EC at the station exit. The concentration of dissolved salts can be a factor in bacterial growth (as well as the effluent's biodegradability). As a result, a better treatment of the EC in the Assa WSP is required.

Because of the high organic load in the raw wastewater, the concentration of DO at the station's entry is zero; however, due to temperature and atmospheric pressure, the concentration of DO exiting the station is greater in the winter months and low in the summer.

The DO measurements in the Assa WSP show that the quantity of DO produced by the photosynthetic process is sufficient to maintain a healthy system in a balanced process. Total respiration of microorganisms in FPs that digest organic materials was the dominant mechanism of oxygen use. In our situation, algae photosynthesis does not fulfill the oxygen requirement as expected, and injected oxygen is required in the two FPs.

Biological data is one of the most essential parameters to consider when evaluating a plant's performance, especially if the final effluent is intended for reuse. The elimination of pathogens from municipal wastewater treatment facilities is a fairly efficient procedure. Total and FC levels were lowest, where pH, temperature, DO and algae were high, according to the data. UV light can also have a direct effect on eliminating these bacteria by photochemical activity, causing damage to the genetic material of cells and ultimately leading to cell death. The pond's depth as well as its residency duration are two key criteria to consider.

Indeed, near the ending of the FPs, a greater decrease of bacterial germs is frequently observed. This is explained by the shallow depth of the pond (1 m) and the prolonged stay of 20–25 days, in addition to the substantial algal growth at this station level.

Table 7 shows that the wastewater from Assa's city has a domestic character, is high in organic matter and is biodegradable. The high COD/BOD5 and TSS/BOD5 values show that the raw wastewater is biologically degradable, which is the most important cause for the high BOD5 removal by anaerobic ponds. Furthermore, the desludging time of the anaerobic pond was 6 years after the plant was commissioned, compared to the predicted period of 5 years, indicating the raw wastewater's strong biodegradability.

The analysis of the data obtained on the pond's effectiveness reveals that the WSP technique is a viable solution for achieving specific quality goals, particularly in terms of bacterial and organic pollution removal. A closer look at the data reveals that this process requires a considerable residence period for the effluents and is heavily influenced by the seasons. There are clear trends that should aid in determining the optimum field of application for WSPs.

For these reasons, there is a need to add MPs to improve the disinfection rates and eliminate more BOD5 and COD and to achieve the appropriate treatment required for reuse systems and discharge to the environment. In addition, the use of MPs as being the best cost-effective systems for wastewater treatment prior to reuse.

The size and number of MPs needed in series are determined by the required retention time to achieve a specified effluent pathogen concentration.

3.2. Details on the added system (MPs)

MPs (low-cost polishing ponds), which generally follow either the primary or secondary FP, are primarily designed for tertiary treatment, for the removal of pathogens, nutrients and possibly algae (Grabow *et al.* 1973; Jagals & Lues 1996; Tanner *et al.* 2005; Von Sperling 2005). They are very shallow (usually 0.9–1 m depth) to allow light penetration to the bottom and aerobic conditions throughout the whole depth as shown in Figure 4.

The size and number of MPs needed in series are determined by the required retention time to achieve a specified effluent pathogen concentration. In the absence of effluent limits for pathogens, MPs act as a buffer for FP failure and are useful for nutrient removal. If an anaerobic and secondary FP is used, this will produce an effluent suitable only for restricted irrigation. Therefore, additional MPs will be needed if a higher quality effluent is required for unrestricted irrigation.

3.3. Standards and design criteria

This section contains a description of the standards and criteria adopted in this study for the purpose of developing preliminary designs of the project facilities and establishing the bases for evaluating the various projects.

In this WWTP design, the characteristics of the effluent of wastewater are adopted based on Moroccan National Standards for irrigation by Treated Municipal Wastewater to surface watercourses. Based on these guidelines, the treatment processes must reduce BOD5 by more than 90%, COD by more than 80% and TSS by more than 50%. Moreover, the Moroccan National Standard for Treated Domestic Wastewater has limits for all the parameters (maximum concentrations) applicable to the wastewaters. For BOD5, it is 20, 30 mg/L for TSS and 100 CFE/100 ml for FC. In addition, the industrial discharges to public sewers have to be controlled by regulations for the discharge of industrial wastewaters into the sanitary sewer system

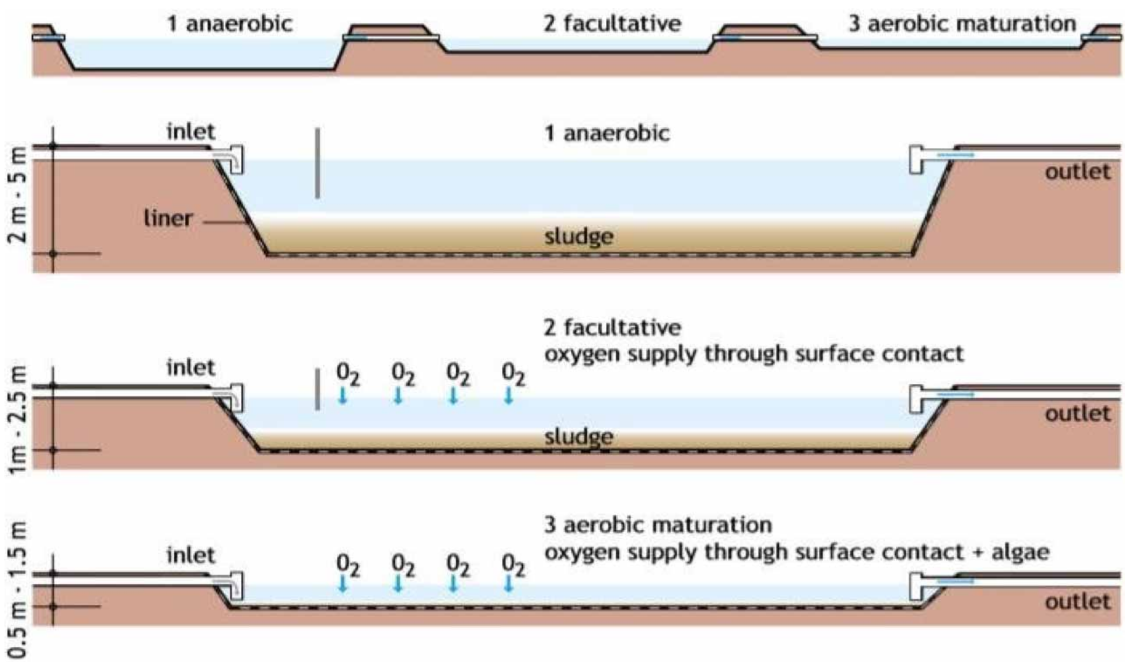


Figure 4 | WSP general scheme.

that require pretreatment before discharge (such as phosphorus). Chlorides, sulfates and many other inorganic dissolved solids are not considered to be problems. Thus, their concentrations in the effluent depend on the drinking water source.

3.4. WSP dimensions evaluation

The model developed as part of this project allows for easy sizing of wastewater treatment facilities based on feedback from the field and monitoring of the purifying performance of five WWTPs in Morocco. The meteorological data is similar to that of Assa. Data from the five Moroccan wastewater stabilization pond treatment plants are shown in Table 8. In the MPs, FC removal yields an average between 98 and 99%, with a maximum observed at the Settat WPS level.

The surface area of the MPs varies between 1.57 and 0.78 m^2/inhabitant for the treatment plants studied. The maximum yield is observed for the Settat WSP which corresponds to an area of the maturation basin of approximately 1.2 m^2/inhabitant. The total area of the treatment plant is equal to the total area of the anaerobic pond, FP and MP.

The method using the ratio makes it easy to calculate the area of the WSPs, based on the number of the population. This method is widely used in France and Africa and is based on experience feedback on the treatment of wastewater by natural lagooning. The anaerobic pond area ratio generally remains similar for the different stations, while the areas of the FPs are very different. An area of around 1.2 m^2 per inhabitant, as is the case for the town of Settat, seems the most adequate. The sizing model of the Settat WSPs seems to be the most suited to the local context of the study area as shown in Figure 5, and it allows for very high purification yields in the different treatment stages.

The examination of the purification performance shows that the sizing model adopted for the town of Settat is the most adequate with anaerobic pond, FP and MP's areas, respectively, equal to 0.1, 1.2 and 1.2 m^2/inhabitant, and a total surface area of the WSP station estimated to be 3.1 m^2/inhabitant. Such an area makes it possible to meet the specific discharge limit values of domestic wastewater and also allows purified wastewater to meet reuse standards.

3.5. Dimensions obtained with the empirical formula and guidelines from the observed stations

WSPs are large, shallow ponds in which raw sewage is treated entirely by natural processes involving both algae and bacteria (Amahmid *et al.* 2002; Abbas *et al.* 2006). They are used for sewage treatment in temperate and tropical climates and represent one of the most cost-effective, reliable and easily operated methods for treating domestic and industrial wastewater. The design criteria are similar in terms of land area and pollution treatment.

The existing practices relate generated wastewater to the per capita water consumption. The amount of wastewater generation is estimated as a factor of water consumption of 81 L/capita/day. Wastewater return factor of 0.75 suggested for a sewage project of Morocco was used in the design. Therefore, the amount of generated sewage from Assa's city in 2030 was estimated to be 1,747 m^3/day.

The design of the actual size of the anaerobic pond was based on permissible volumetric BOD loading of 300 g/m^3/day usually below the upper limit of 400 g/m^3/day recommended to avoid risks of odor production (Pearson *et al.* 1996; Roebuck *et al.* 2019). Thus, it was suitable in determining the actual size of the anaerobic pond.

The volume of the pond was determined using the following equation:

$$\lambda_v = \frac{L_i Q}{V_a}$$

where λ_v is the volumetric organic loading rate (g/m^3/day); L_i is the influent BOD (mg/L); Q is the flow rate; and V_a is the volume of the pond.

Table 8 | Data from five effective Moroccan waste stabilization pond treatment plants

Step	Settat	Berrechid	El Gara	Ben Ahmed	Soualem-Sahel
Surface of the anaerobic ponds (m^2/hab)	0.11	0.11	0.08	0.08	0.11
Surface of the FPs m^2/hab)	1.20	0.78	0.67	0.66	0.86
Surface of MPs (m^2/hab)	1.20	0.78	–	–	0.61
Total surface of ponds (m^2/hab)	2.5	1.67	0.75	0.74	1.58
Total surface of the station (m^2/hab)	3.12	2.08	0.93	0.92	1.97

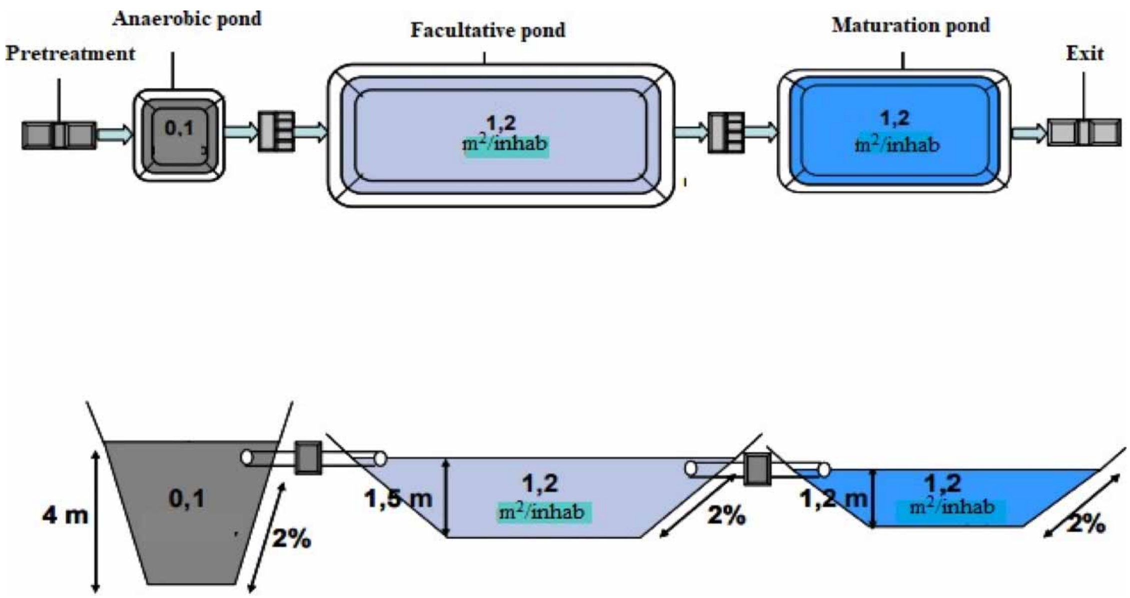


Figure 5 | Dimensions of the best performance of WSPs in the study area.

The volume of the anaerobic pond determined was 7,272 m^3. By assuming a design depth of 2.5 m, the surface area of the anaerobic pond was 2,909 m^2.

The design of FP was based on permissible surface BOD loading of 253 g/m^3/day. With this BOD loading, the surface area determined was 31,742 m^2.

The hydraulic retention time in the MP is recommended to be more than 3 days (Bracho *et al.* 2006). Thus, the area of the first MP is 13,343 m^2, and the effluent BOD is 23.7 mg/L. Two MPs were considered to provide the recommended minimum hydraulic retention time of 3 days. The area of M2 was determined to be 13,343 m^2 (same as for M1). Therefore, effluent BOD was 12.5 mg/L, and effluent flow from MP M2 would be 1,900 m^3/day. Table 9 and Figure 6 demonstrate and give specifics data for the upgraded WSP dimensions.

A growth rate of 1.75% is maintained for the calculation of the population between the years 2020 and 2030.

$$\text{Future population} = \text{Current population}*(1 + a)n$$

where a is the rate of increase, and n is the difference between the future and the current horizon.

3.6. Verification of the design guideline using mathematical modeling

GPS-X is a modular, multi-purpose modeling environment for the simulation of municipal WWTPs. This allows examining the complex interactions between various unit processes in the plant interactively and dynamically (Jasim 2020). Figure 7 shows the modeling for the Assa WSP based on the influent flow, which is 2,204 m^3/d after the project completion.

The results were calculated from the detailed sampling, after which GPS-X models were developed and calibrated to the plant data. This calibration effort involved the detailed review and analysis of the plant data and the development of influent fractions for the model. An example of one of the screen views of a model for the Assa WSP is shown in Figure 7. The simulation with the GPS-X software is used, and the results showed significant and satisfactory control performance of the WWTP.

Table 9 | Assa's future WSP dimensions

			Surface (m^2)		
	Population	Flow rate (m^3/j)	Anaerobic ponds	Facultative ponds	Maturation ponds
2020	22,239	1,469	2,446	26,686	26,686
2030	26,452	1,747	2,909	31,742	26,686

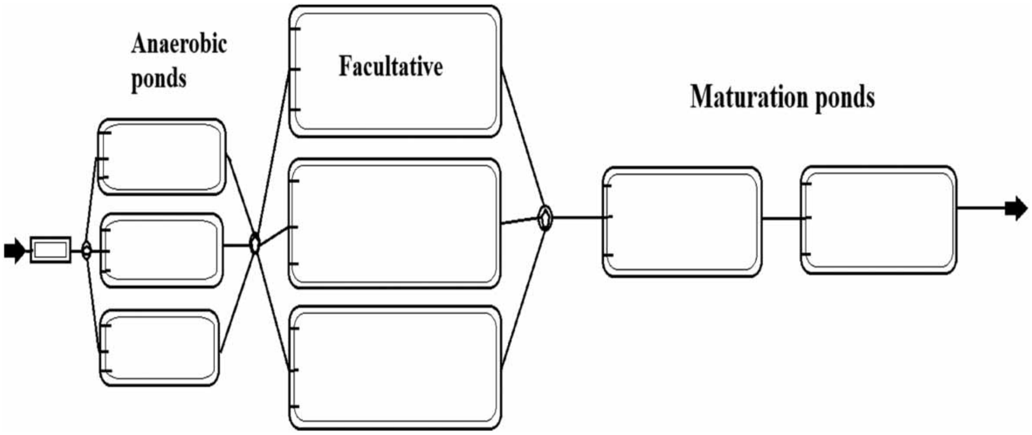


Figure 6 | Layout of the upgraded Assa's WWTP.

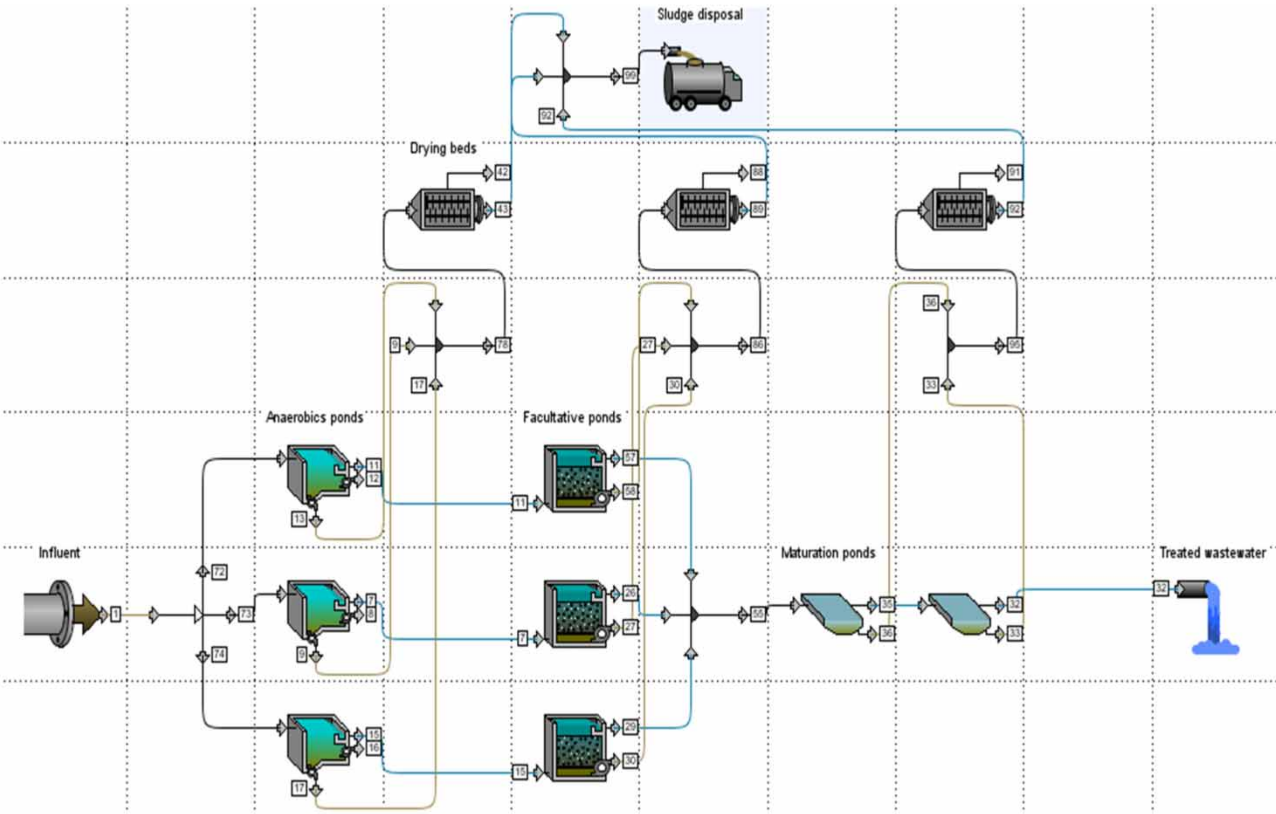


Figure 7 | Modelized new Assa's WSP layout (GPS-X software).

The results indicate a good functioning of WSP along the studied period where almost all measured parameters were below the standards.

Based on the GPS-X analysis, Figure 7 represents the systematic diagram of the extended Assa WSP process. This process is started with the influent flowing to the anaerobic pond, then FP and at the end MP. Basically, our design criteria are started with preliminary treatment through secondary treatment and tertiary treatment ending up with the effluent of the WWTP.

Figures 8 and 9 represent the relationship between the layer index and the TSS for each added MP. The results display an increase in the amount of TSS with the increasing index values. This allows us to predict the range of TSS concentrations given a typical range of growth rates. These results are for MPs 1 and 2 for the tertiary treatment process.

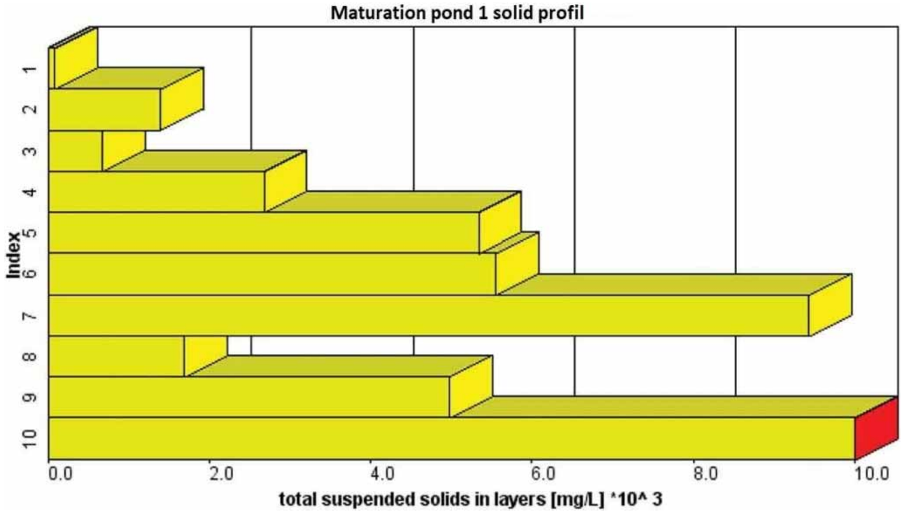


Figure 8 | Relationship between TSSs in layers and index values of each layer in the first MP according to the simulation by GPS-X.

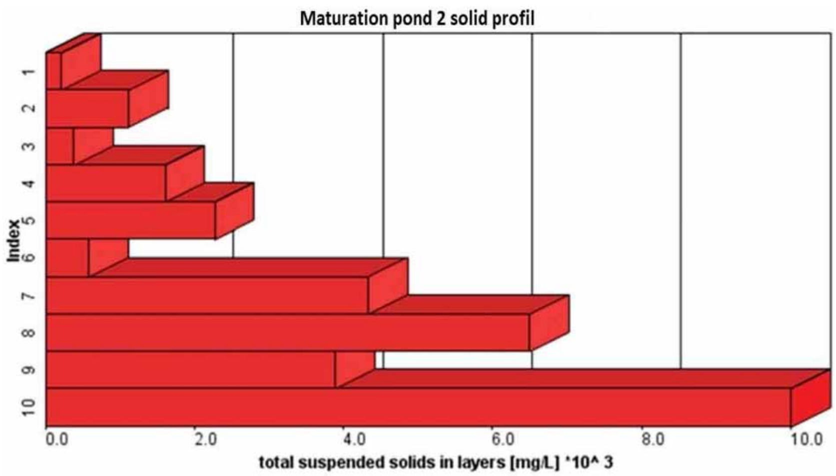


Figure 9 | Relationship between total suspended solids in layers and index values of each layer in the second MP according to the simulation by GPS-X.

Figure 10 displays the correlation between the removal of TSS and the time. Thus, the variation in the amount of TSS is considered with the variation of the time of the simulation. The time is specified in this analysis, but the effluent flow is considered with the deliberation of the time of the treatment process. The time is based on the population of Assa's city. Thus, the modeling results indicated that the increase of the retention time in the ponds increases the removal of TSS, so the overall efficiency of the treatment system is enhanced too.

The results were obtained by GPS-X models and were developed and calibrated to the plant data. This calibration effort involved the detailed review and analysis of the plant data and the statistical development of influent fractions for the model (Eris *et al.* 2018). The results indicate a good functioning of the WSP along the studied period, where almost all measured parameters were below the Moroccan standards. Moreover, the GPS-X is utilized for improving capacity, operating efficiency and effluent quality by the existing facility.

From the summarized results in Tables 10 and 11, the simulation gives the predicted performance of the new improved wastewater stabilization ponds. From the simulated performance results of the new WSPs in Table 11, the added tertiary treatment provides a significant reduction in all the physicochemical parameters, especially for BOD5 and COD with −24.13 and −29.67%, but the most important role of these ponds is eliminating microbiological parameters to achieve the standards for

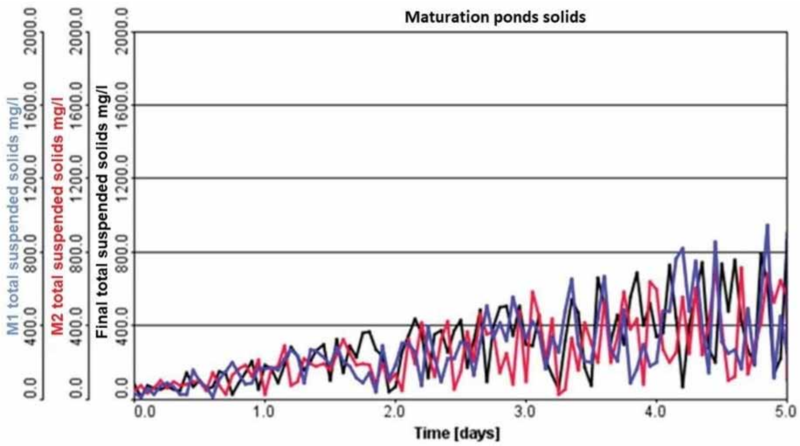


Figure 10 | Relationship between total suspended solids removal and time (time simulation is 5 days).

Table 10 | Hydraulic retention time for each pond and effluent BOD and FC values

WSP	Pond	Hydraulic retention time (days)	Effluent BOD (mg/L)	Effluent FC (FC per 100 ml)
Anaerobic	A	3–4	356	110.10^6
Facultative	F	20	157	215,387
Maturation	M1	3	23.7	24,476
	M2	3	12.5	1,000
Total	All	30		

Table 11 | Simulated new WSP performance

Ponds	Anaerobic (%)	Facultative (%)	Maturation (%)	Total (%)
Tw	−8.57	−12.5	−1	−22
pH	+1.51	+5.83	+5	+12.34
EC	+5.75	+2.19	−16.23	−8.29
BOD5	−43.24	−31.8	−17.2	−92.24
COD	−48.15	−11	−25.45	−84.5
TSS	−72	+16.42	−23	−78.58
TC	/	−92	−7.96	−99.96

reusing this water without any danger to groundwater. The treated wastewater is of 1,747 m^3/day; this huge amount of water will not be wasted in the river anymore, but shall be used to irrigate crops, palm trees and public gardens.

Table 11 shows the final effluent quality of the upgraded WSP. Overall, the very good quality is obtained in the final effluent for most parameters of interest in domestic sewage treatment (physical–chemical and bacteriological), especially considering that a simple natural treatment system is applied. The effluent concentrations from the new treatment line are for the most part lower than the concentrations from irrigation standards, with emphasis on suspended solids and organic matter, which are constituents that are generally given priority in sewage treatment in developing countries. If the main objective of the final effluent depends on having an even better bacteriological quality, then the incorporation of two shallow MPs should be considered. The study results observed that well-maintained and operated WSPs showed an efficiency of 80–90% in removing the organic matter and a 99% removal of TC. The results from the present study clearly support that WSPs are a viable and sustainable alternative for peri-urban and even urban areas for the effective treatment of domestic wastewater.

4. CONCLUSION

Wastewater treatment is required as a part of eliminating contaminants to a sufficient degree to protect water and to reuse. Assa's WSP is one of the largest plants in the southern desert of Morocco. The receiving river and ecosystem have suffered severe harm as a result of the low operating efficiency and high organics content of the effluent. As a result, updating this WSP with an integrated design that takes into account all of the physicochemical and bacteriological characteristics, as well as the pond ratio and hydraulic retention duration, is critical. The use of GPS-X simulation allows us to test the appropriateness of the modifications and provide estimated values for the enhanced WSP performance. It may be determined that the optimum option for the treatment of municipal sewage is a well-constructed anaerobic pond and FP followed by two MPs in series. Increasing the number of ponds in a series improves the hydraulic efficiency and the pathogen elimination efficiency in general. This has allowed almost all of the effluent to be utilized for irrigation, with just the surplus that can be dumped into the river being discharged. This kind of design has shown to be the most cost-effective in terms of capital, operating and maintenance costs.

DATA AVAILABILITY STATEMENT

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

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