World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:18, No:2, 2024

Integrated Wastewater Reuse Project of the Faculty of Sciences Ain Chock, Morocco

Nihad Chakri, Btissam El Amrani, Faouzi Berrada, Fouad Amraoui

Abstract**—**In Morocco, water scarcity requires the exploitation of non-conventional resources. Rural areas are under-equipped with sanitation infrastructure, unlike urban areas. Decentralized and low-cost solutions could improve the quality of life of the population and the environment. In this context, the Faculty of Sciences Ain Chock (FSAC) has undertaken an integrated project to treat part of its wastewater using a decentralized compact system. The project will propose alternative solutions that are inexpensive and adapted to the context of peri-urban and rural areas in order to treat the wastewater generated and to use it for irrigation, watering and cleaning. For this purpose, several tests were carried out in the laboratory in order to develop a liquid waste treatment system optimized for local conditions. Based on the results obtained at laboratory scale of the different proposed scenarios, we designed and implemented a prototype of a mini wastewater treatment plant for the faculty. In this article, we will outline the steps of dimensioning, construction and monitoring of the mini-station in our faculty.

Keywords**—**Wastewater, purification, response methodology surfaces optimization, vertical filter, Moving Bed Biofilm Reactors, MBBR process, sizing, prototype, Faculty of Sciences Ain Chock, decentralized approach, mini wastewater treatment plant, reuse of treated wastewater reuse, irrigation, sustainable development.

I.INTRODUCTION

MOROCCO, like many other countries, is threatened by water shortage. The water situation is indeed alarming since its water resources are currently estimated at less than 650 m^3/inhabitant/year, compared to 2,500 m^3 in 1960, and are expected to fall below 500 m^3 by 2030 [1].

Despite the success of ambitious water mobilization policies carried out for decades, Morocco has no choice today but to adapt and renew its strategy to meet the country's ever-increasing water needs [2]. Water resources have reached a very high level of mobilization and exploitation and are undergoing an increasingly worrying degradation of their quality [3], this is due to the economic growth and population expansion that the country is experiencing [1], [3]. In addition, this socio-economic development generates significant water potential in the form of urban effluent and industrial waste, which is often discharged into receiving environments without prior treatment, even though it represents an alternative source of water, once purified, for irrigation and watering green spaces.

In 2005, the National Sanitation Plan (NSP) [4] was launched with the main objective of improving the sanitary and environmental conditions of the municipalities and water basins. The specific objectives of this plan are:

- To connect in urban areas up to 95% of the population to the sewerage network by 2030-2040 and to treat 80% of wastewater by 2040, compared to 45% at present, by setting up several wastewater treatment plants spread over the Moroccan territory [5]. It should be noted that currently only 43% of these volumes are treated [2], [6];
- To generalize liquid sanitation services in rural areas to more than 1000 rural centers and thus be able to treat 43 mm^3 of wastewater by 2040 [5].

For better management of liquid discharges and in order not to overload the treatment plants, a decentralized approach to wastewater treatment at the level of production units upstream would be necessary. In this context, wastewater treatment projects of public institutions (Agronomic and Veterinary Institute Hassan II, Faculty of Sciences Bouchaib Doukkali of El Jadida, etc.) have been carried out [7], [8]. To do this, different treatment systems have been implemented, namely: the combination of an anaerobic reactor and a high-efficiency channel [7] or an anaerobic reactor with a submerged bacterial bed [8]. These technologies are efficient and effective but require continuous management and monitoring.

We propose in this research work to set up a pilot treatment of part of the wastewater of the FSAC - Casablanca and to reuse this purified water for cleaning the premises and irrigation of the educational garden around the platform [9].

Three treatment methods were studied, namely:

- Settling followed by a vertical flow filter (VF) alone or planted with reeds [10];
- Settling followed by two Moving Bed Biofilm Reactors (MBBR) [11];
- Settling followed by two MBBR process reactors and then a VF planted with reeds.

To achieve this, several wastewater treatment trials were conducted at the laboratory scale of the sanitary block of the FSAC using the three proposed scenarios [10]-[13]. Subsequently, we optimized the selected treatment processes. To do this, we employed the Response Surface Methodology (RSM) to understand the influence of predominant factors on the purifying power of VF and MBBR processes [11], [12].

Based on the results obtained at the laboratory scale of the different proposed scenarios, we designed and implemented a prototype of a mini wastewater treatment plant for the faculty.

This paper deals with the sizing and implementation of the FSAC mini-wastewater treatment plant, and the study of the efficiency of each component of the treatment system (septic

Nihad Chakri*, Btissam el Amrani, Faouzi Berrada, and Fouad Amraoui are with Hydroscience team, Laboratory of Geosciences Applied to the Arrangement Engineering (G.A.A.E.), Faculty of Sciences, Aïn Chock Hassan II University, Casablanca, Morocco (*Corresponding author, e-mail: nihad.chakri-etu@etu.univh2c.ma).

tank, VF, and MBBR process), on the one hand, and of the purification efficiency of the whole system, on the other hand.

II. Materials and Methods

A. Study Site Description

The FSAC is located in the South-West of Casablanca (Morocco) at about 6 km from the Atlantic coast on a surface of 3.62 ha. Its sewerage network is of the unitary type with two outlets 1 and 2 (see Fig. 1):

Exit 1 near the library (Fig. 1), drains a total area of 1.24 ha and includes four buildings occupying about 6370 m^2. The remaining area, about 6370 m^2, includes covered walkways and green spaces. The terraces of the buildings drain their rainwater directly into the green spaces. This manhole (outlet 1) therefore drains wastewater from the buildings (laboratories, deanery, and libraries), water from the teachers' refreshment room and water from the students' refreshment room, as well as rainwater from the parking lot 1 and the terrace of the deanery building.

Fig. 1 Location of the proposed choices for the FSAC pilot

Exit 2 near the main exit of the faculty (Fig. 1) drains a total area of 2.39 ha which includes 27 buildings, occupying an area of 8940 m^2. The remaining area of 14960 m^2 includes uncovered walkways, a central covered walkway, green areas, and asphalt surfaces. The building terraces drain their rainwater directly into the green spaces. This manhole, therefore, drains wastewater from the laboratories and practical rooms, the administrative buildings, and the student toilets. This manhole, opposite the first one, also drains rainwater from parking lot 2 and the building terraces.

B. General Information

In a wastewater treatment plant design project, it is essential to follow the following steps:

- Sizing of the works using the evaluation of the flow and the characteristics of the wastewater to be treated (pollutant loads);
- Selection of the site according to various criteria (availability of land, characteristics, etc.);
- Determination of the treatment process adapted to the local constraints etc.

1. Choice of the Location of the FSAC Wastewater Treatment Pilot Plant

The implementation of a wastewater treatment system requires the right choice of its location according to different criteria (available land surface, land use, the situation in relation to the receiving environment, daily flow and type of wastewater to be treated). Taking into account these different criteria, we have chosen site N 4 (Fig. 1) for the implementation of the wastewater treatment.

The site chosen for the pilot (Fig. 1) is an area of 127 m^2, located behind the sanitary blocks, which are the only sources of wastewater arriving in the sampling chamber. The latter is easily accessible with a satisfactory and regular daily flow for the laboratory scale tests (Fig. 2).

The objective of the pilot is to treat domestic types of water while respecting the installation instructions of a decentralized liquid waste treatment system [14]-[16]. The installation of this pilot for the treatment of wastewater from the sanitary blocks requires the installation of:

- A septic tank to collect only the wastewater for which this station is designed;
- A technical room to manage the operation of the pumps, the electro-valve, and to carry out on-site water analyses, etc.;
- A storage tank to recover the treated wastewater.

In order to optimize the sizing of these units, a perfect knowledge of the wastewater flow, the pollutant load, and the population equivalent of the FSAC is essential.

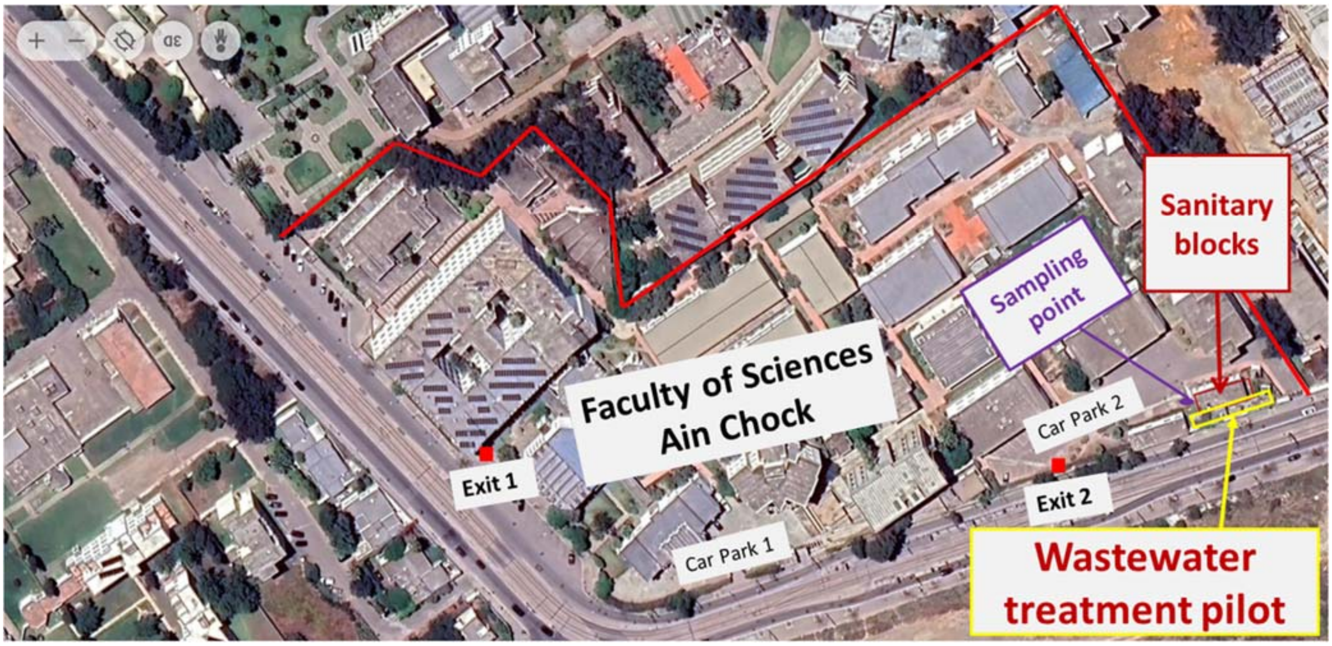

Fig. 2 Sampling point and FSAC pilot location

2. Estimation of Wastewater Flow

Since 2014, our faculty is experiencing development works (high consumption of drinking water due to construction works, accommodation of workers, etc.), in order to calculate the flow of wastewater discharged, we called on a previous study conducted in the framework of this project by our research team [17].

The statistical study of the average daily consumption of drinking water (period 2006- 2012) allowed us to estimate the liquid discharges shown in Table I.

TABLE I
WASTEWATER FLOW

Average daily flow rate		31.3
Maximum daily flow	m^3/d	61.8
Minimum daily flow rate		14.6

At the 95% confidence level, the average daily flow is estimated to be between 26.2 m^3/d and 36.4 m^3/d [17], taking into account a return to the sewer of 80% of the consumed drinking water according to National Office of Electricity and Drinking Water (ONEP).

3. Estimated Population Equivalent of the FSAC

The useful capacity of the treatment system is determined based on the population equivalent (PE) of the house or group of houses served by the system. For single-family dwellings that generate only domestic wastewater, the pollutant load produced daily is expressed as a number of PEs equal to the number of occupants.

According to the Student Affairs Department, the total number of occupants (students, faculty, staff, and service agents, etc.) during the 2016-2017 academic year amounted to 7521 people.

We will take 10 occupants for one inhabitant equivalent for the FSAC since the facility does not include baths or showers [18], which would result in an inhabitant equivalent of approximately 752 inhabitant equivalent (EH), calculated based on the 7521 headcounts registered during the 2016-2017 academic year.

4. Pollutant Load Estimation

Sampling is carried out regularly during 2016 at the manhole located right next to the toilet blocks (see Fig. 2). This wastewater is of domestic type. The formula for the pollutant load (PL) is as follows:

$$PL = Q_j * C_{pollutant}$$

Q_d = Daily flow in m^3/j; $C_{pollutant}$ = Concentration of the pollutant parameter in mg/L.

The values of the pollutant load of the wastewater of our establishment are represented in Table II.

TABLE II
CALCULATION OF THE WASTEWATER POLLUTION LOAD OF THE FSAC

Parameter	Concentration (mg/L)	Pollution load (kg/d)
COD	541	17
BOD_5	285	9
TSS	415	13
NH_4^+	45	1,4
PO_4^{3-}	3	0,1

The sizing of the components of the mini wastewater treatment plant (septic tank, storage basin, etc.) was carried out based on the results obtained from the diagnosis of the current conditions, assessment of the initial situation (including volumes of water consumed and discharged), etc. [19]. This also includes results from laboratory-scale studies of the three proposed systems for treating wastewater at FSAC

[12], [20], as well as calculations for wastewater flow rates, pollutant load, and equivalent population.

C. Sizing the FSAC Pilot

Generally, the effective capacity of the treatment system is determined based on the number of PE of the dwelling or group of dwellings served by the system.

For 752 PE, an area of at least 1674 m^2 is required to implement the FSAC wastewater treatment pilot. This area is calculated based on the number of PE for the entire treatment process [21], [22]. The space made available to us by the institution for the implementation of this wastewater treatment pilot is about 127 m^2, and therefore insufficient to treat such a capacity. This is why we have chosen to treat only a part of the wastewater of our establishment. Furthermore, given the financial and logistical means at our disposal, we decided to build a mini-treatment plant capable of treating a daily flow of about 1 m^3.

1. Septic Tank

We dimensioned the septic tank taking into account the university vacation periods so that the pilot would be in service for up to 40 days even without the use of the sanitary blocks source of wastewater. In fact, the useful volume of the septic tank was calculated according to: $V_{useful} = (Q_m * vacancy\ period) + (Q_m * t_{stay})$.

The cleaning of the tank can be done once every two years. According to the literature, sludge accumulates on average from 0.18 to 0.30 L/user/day and the recommended number of years between two sludge emptying is 2 to 5 years [22], [23].

Table III gives the dimensions of the septic tank following the guidelines proposed by WHO for individual sanitation [22].

The total volume of the septic tank required is 14 m^3, which is divided into three chambers separated by two non-waterproof brick walls. The first and third chambers are equipped with two control openings (Fig. 3).

TABLE III
SIZING OF THE SEPTIC TANK

Population served	-	inhab	4
Average wastewater flow	-	m^3/d	0.32
Average wastewater flow « Q_m »	-	l/s	320
Residence time « t_{res} »	-	d	2
Length « L »/ Width « l »	L/l	m/m	2.5
Tank cleaning interval « t_{cr} »	$1000V_{utile}/(0,3*4*365)$	years	31
Useful volume « V_{utile} »	$(t_{res}*Q_m) + (40*Q_m)$		13.44
Maximum volume of sludge « V_{sludge} »	t_{cr}*4% number of students	m^3	0.8
Total volume of the pit « V_T »	$V_T = V_{utile} + V_{sludge}$		14.3
Internal usable area « $S_{uti\text{-}int}$ »	$S_{uti\text{-}int} = V_T/1,5$	m^2	7
Water height « H_{water} »	-		1.5
Width « l »	$l = \sqrt{S_{uti-int}/2,5}$		2
Total length « L_T »	$L_T = 2,5*l$	m	4
Length of the 1st compartment « L_1 »	$L_1 = (2/4)*L_T$		2
Length of the 2nd compartment « L_2 »	$L_2 = (1/4)*L_T$		1
Length of the 3rd compartment « L_3 »	$L_3 = (1/4)*L_T$		1

The dimensions calculated and presented in the table are derived from the guidelines outlined in [22].

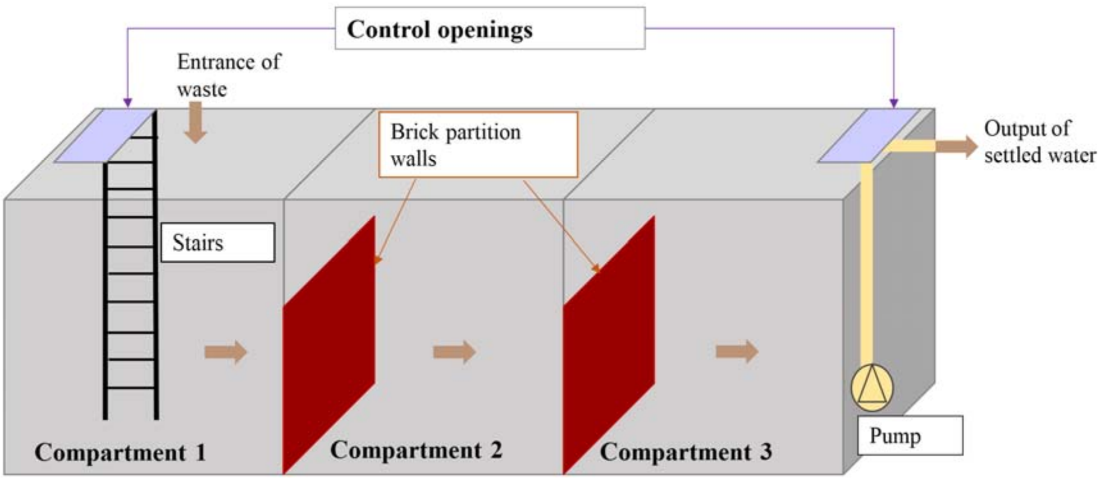

Fig. 3 Schematic of the septic tank

2. Technical Local

This unit is used to protect the electrical cabinet and the different scientific equipment from bad weather, to store the equipment, and to carry out in-situ measurements of certain parameters: pH, DO, EC, Turb, etc.

The planned surface of the room is 7.5 m^2 with a height of 3 m. The door and the two windows are dimensioned according to the NFP20- 101 standard, which specifies the dimensional characteristics of doors and door blocks (width between 63 cm and 93 cm and thickness between 2.9 cm and 40 cm) [24]. In our case, the width of the door and the windows will be respectively 90 cm and 60 cm.

3. Treatment Processes

The treatment process is composed of the combination of the moving bed biofilm process (MBBR process) with the vertical flow filter planted with reeds using gravel or pozzolan as a filtering material. This choice was made on the basis of the results obtained with the laboratory-scale prototypes [10]-[12].

The optimal residence time according to the laboratory scale tests is 17 h and 13 h 26 min successively for the MBBR process [11] and the vertical flow filter using pozzolan as biomedia and filtering material [12]. Indeed, at full scale, we will redo the optimization to confirm these results.

Table IV lists the characteristics of each process.

TABLE IV
TREATMENT WORKS FOR PART OF THE FSAC'S WASTEWATER

Work	Material	Dimensions	Quantity
Cylindrical tank	Polyethylene plastic (PVC)	Volume = 0.5 m^3 Height = 1.12 m Diameter = 0.82 m	2
Rectangular tank	Polyethylene plastic (PVC)	Volume = 1 m^3 Height = 0.82 m Width = 1.18 m Length = 1.48 m	1

The last component of the treatment system is the concrete storage tank for the treated wastewater with a volume of 6 m^3, with a control manhole.

In total, the space required for the implementation of the mini-plant is about 52 m^2, from the septic tank upstream to the treated water storage basin downstream. The remaining space will be laid out as a small demonstration garden with different species of ornamental and medicinal plants (cactus, rosemary, lavender, etc.), and some fruit trees.

D. Construction and Implementation

The construction of the pilot plant for the treatment of liquid waste from the sanitary blocks of the FSAC was carried out by calling on a project manager. Afterward, we proceeded to the filling of the treatment units and the phase of exploitation:

1. Filling of the Vertical Flow Filter

The filling of the filter was performed based on the results obtained with the laboratory scale prototype and the literature [25]-[27]. The filter is composed of three layers of sandstone with decreasing grain size from the bottom to the top:

- A drainage layer with a thickness of 10 cm is used to evacuate the treated water. It is composed of coarse sandstone (12-20 mm);
- A transition layer of 20 cm thickness is used to prevent the migration of fine sandstone from the filtering layer to the draining layer. It is composed of medium sandstone (8-10 mm);
- A filtration layer of 40 cm thickness is used to purify wastewater through its capacity for biomass development and physical retention of solid particles. It is composed of fine sand (2-6 mm).

This filling is preceded by a washing (oxygenated water and tap water) and sieving of the filtering material, as indicated in Fig. 4.

Fig. 4 Refilling of the vertical flow filter

The filter in Fig. 4 is divided into two parts: the first one is one meter wide (the active zone of the filter) where we put the sandstone layers according to the granulometry described above. The second part is 18 cm wide and is used to drain the treated wastewater. In this part, the drain valve has been placed in height (see Fig. 4) in order to favor the phenomenon of sedimentation and thus increase the residence time of the water. The separation between these two parts was made with a plexiglass plate to ensure the vertical flow of water. The filter is fed with tarpaulins to increase the contact surface between the wastewater and the filtering material. In order to uniform the flow of wastewater over the entire filter surface, we set up a gridded drip system as shown in Fig. 4.

1. Filling of the MBBR Process Reactors

The first reactor was used as an MBBR process fluidized by a mechanical agitator that we made from recycled materials (Fig. 5).

Fig. 5 Manufacture and assembly of mechanical agitators

For the filling of the MBBR bioreactor, we used foam that comes from the offcuts of furniture upholstery (density is 20-30 kg/m³, number of pores between 40-50 ppi) that we cut into cubes of dimensions 2*2*2 cm^3 [19]. The thickness of the biomedia layer is 45% (Fig. 6).

The second reactor was used as a secondary sedimentation tank.

Fig. 6 Preparation of the bio-media and filling of the reactor

2. Operation Phase

For the supply of the purification system, we have chosen a distribution of tarpaulins. Indeed, a solenoid valve, linked to the timer, was installed upstream of the works, just after the upper tank, and feeds, regularly, the purification system. We have operated the pilots with tap water in order to adjust certain operating parameters (residence time, the flow rate of the incoming water, and pumping time etc.).

The pump is programmed to pump regularly six times a day with a precise flow rate of 167 L/h. The water arriving at the pipes is automatically discharged into the successive basins up to the storage basin.

The reactors of the MBBR process and the upper tank are covered with fabric covers to prevent eutrophication.

The reeds were planted at a rate of 4 plants/m^2 between June and August. Fig. 7 shows the development of the reeds.

Fig. 7 Development of the reeds

Finally, the exact distances of the constructed structures were measured. Fig. 8 shows the final plan after the completion of the mini-station.

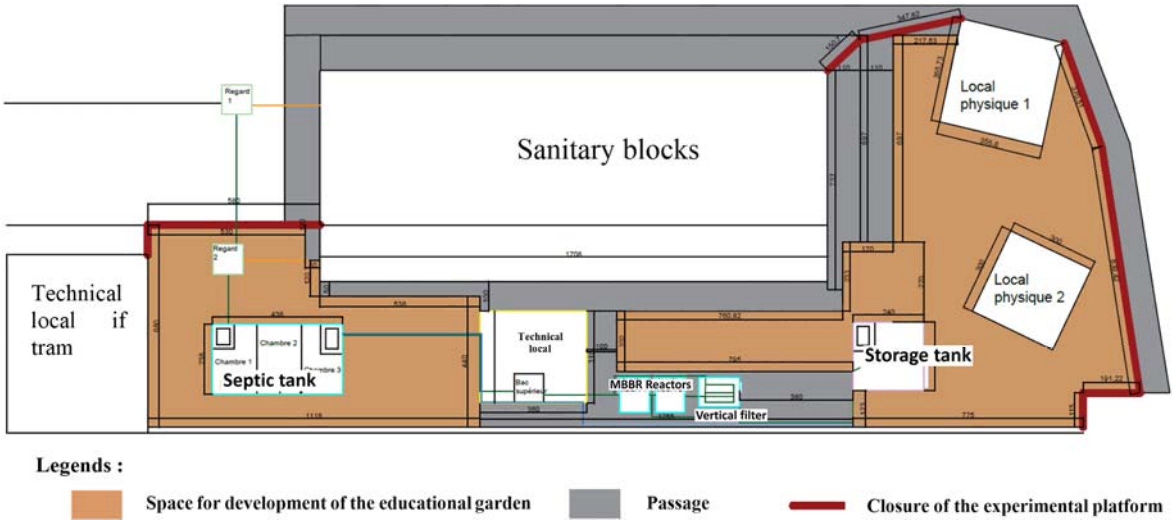

Fig. 8 The final design of the FSAC mini wastewater treatment plant

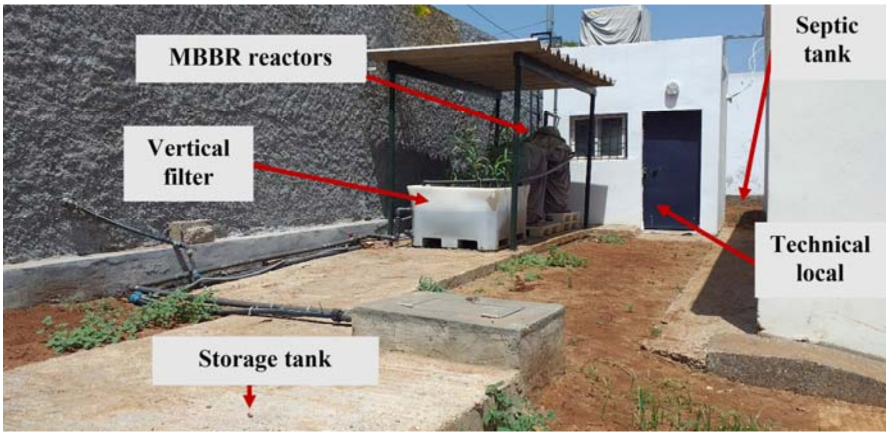

Fig. 9 The FSAC mini wastewater treatment after implementation

The FSAC wastewater treatment pilot (Figs. 8 and 9), consists of upstream to downstream of the following compartments:

- A septic tank: composed of three chambers separated by brick walls;
- A MBBR process: composed of two bioreactors, the first one operates with mechanical agitation, and the second one is a secondary sedimentation basin;
- A vertical flow filter lined with gravel and planted with reeds;
- A storage tank for the treated water.

The mini-plant, in terms of the septic tank, is therefore, able to treat a larger volume of wastewater than expected, and can be autonomous over a longer period of time even during vacations.

The total cost of the construction and the installation of this pilot is about 100000 MAD financed by multiple partnerships: FSAC, GAIA Laboratory, and ARADD association.

The feeding of this pilot is made by tarpaulins (of a volume of 150 L) with a flow rate of 167 L/h, a maximum residence time of about 3 days, and the volume treated is one cubic meter per day. The connection between the structures was made taking into account the possibility of treating the wastewater by the three methods described in the second chapter.

Functional tests of each facility were carried out to verify the performance of each component of the treatment system separately and preliminary tests on the complete system were carried out to evaluate its purification capacity.

E. Collection and Sampling

The waters were manually sampled according to the periods of occupation of the establishment (back to school, vacations, seasons, etc.) and by respecting the standards of sampling according to Rodier [28].

Water Analysis

The evaluation of the treatment efficiency of the pilot is carried out on the basis of the characterization of a certain number of physicochemical and bacteriological parameters, according to the standardized methods Rodier and AFNOR [28], [29] within our Laboratory "GAIA".

The choice of the analyzed parameters is based on the objective sought: the reuse of the treated wastewater for irrigation.

Physicochemical Characterization

For this characterization, the analyses focused on the following parameters:

- Temperature T, electrical conductivity EC, pH, and dissolved oxygen OD measured in-situ with a multi-parameter Eutech Instruments Pcd650;
- Turbidity Turb measured with a turbidimeter;
- Chlorides Cl- measured by volumetric dosage.
- Suspended solids measured with an oven and a balance;
- Chemical Oxygen Demand (COD) measured with a COD meter and a mass spectrometer;
- Biological oxygen demand in 5 days (BOD_5) measured using a BOD meter;
- Sulfates SO_4^{2-}, nitrites NO_2^-, nitrates, NO_3^-, ammonium NH_4^+, orthophosphates PO_4^{3-}, and color Coul were measured using a mass spectrometer.
- Magnesium Mg, potassium K, calcium Ca, sodium Na, manganese Mn, chromium Cr, cadmium Cd, copper Cu, zinc Zn, nickel Ni, lead Pb and iron Fe, measured with a flame atomic absorption spectrophotometer, Schimadzu AA 7000.

Physicochemical Characterization

For this characterization, we enumerated the following bacteria: Total germs (GT), total coliforms (CT), Fecal coliforms (CF), Fecal streptococci (STR), Clost clostridia or sulfite-reducing spores: strict aerobic (SSR_{AS}), strict anaerobic (SSR_{AnS}), and facultative anaerobic-aerobic (SSR_{AAnF}) using liver meat agar.

Water Standards

The selection of parameters analyzed is based on the following standards:

- Specific domestic discharge limit values [30] and the usual urban raw water range [31], for FSAC sanitary block wastewater;
- The limit values for water intended for irrigation [32] for treated water according to the three proposed processes.

III. Analysis and Results of Wastewater Treatment

The monitoring of the quality of treated wastewater is carried out at the outlet of each unit of the pilot: The septic tank (the first chamber (CH_1) and the third chamber (CH_3)), the MBBR reactor, and the VF.

Taking into account the limit values for irrigation water [33], the analyzed parameters are subdivided into four groups:

- Group A: parameters whose concentrations, at the outset, meet the limit values of water intended for irrigation;
- Group B: parameters whose concentrations do not meet the limit values for irrigation water and which, after treatment, meet them;
- Group C: parameters whose concentrations, after treatment, do not reach the limit values for water intended for irrigation;
- Group D: parameters for which the limit values for water intended for irrigation are not defined.

A. Quality of Treated Wastewater in the Septic Tank

In order to verify the settling phenomenon of the wastewater in the tank (Fig. 3), samples at the inlet and outlet of this unit were taken between the months of March and November 2019. During the 9 months of sampling, we went through three seasons (rainy, temperate, and hot) and all school periods, namely, back to school, schooling, exams and tests as well as different vacations. We can estimate that this period is representative of the annual activity of the faculty.

The sampling and analysis of the samples were carried out according to standard methods [28], [29] described in the paragraph materials and methods.

Table V gives the averages of 17 measurements of physicochemical parameters after settling in the pit and Fig. 10 presents their rates of variation. We note that 63% of the tested parameters show good behavior at the exit of the septic tank.

Table VI gives the average behavior of some bacteriological parameters. Each of them, measured separately three times, has undergone a decrease of more than 90% in the number of germs after decantation (Fig. 10). This can be explained by the infiltration of the decanted water through the two brick walls that separate the three chambers.

The abatement of some of the parameters in Group A (EC, SO_4^{2-}, Cr, Zn, Cu, and Fe) improves water quality. The increase in the values of the rest of the parameters (T, NO_3^-, Pb, and Ni) maintains the good behavior of this group (Fig. 10): The increase in NO_3^- is due to the nitrification of ammonium ions while that of Pb and Ni would be explained by the presence of metal accessories in the septic tank (Fig. 3) and the use of detergents for cleaning toilets.

Sedimentation achieves the limit values for irrigation water for chlorides (Group B, Table V and Fig. 10). In this case, sedimentation played its role perfectly because the residence time (three months during the installation period of the treatment works) in the septic tank is very long. The significant reduction of the parameters of group C (COD, BOD_5, TSS, and CF) is evident due to the biological oxidation of the microorganisms (self-purification) and the physicochemical phenomena (liquid-solid separation) [34]. These results are in agreement with those obtained by Mujawamariya [35].

Some parameters of group D (Turb, Coul, GT, CT, STR, SSR_{As}, SSR_{Ans}, and SSR_{AAnF}) underwent a significant decrease during decantation while others (NH_4^+, PO_4^{3-}, K, Mg) underwent only a non-significant decrease. The low concentrations of orthophosphates can be explained by the phenomenon of chemical precipitation with calcium, iron, or aluminum ions and biological assimilation [36]. A decrease in the concentration of NH_4^+ is noted, which could possibly be linked to nitrification into nitrates. The decrease in bacteriological parameters is probably due to the infiltration of water through the two brick walls that separate the three chambers of the pit (Fig. 3).

TABLE V
VARIATION OF THE PHYSICOCHEMICAL PARAMETERS OF THE WATER FROM 1ST TO 3RD COMPARISON OF THE SEPTIC TANK

Category	Parameter	Unit	Mean		Probability of decision	Decision at 95% significance level
			CH_1	CH_3		
A	T	°C	19.7	19.8	$4.22E^{-01} >> 0.05$	VNS*
	pH	-	8.08	7.99	$2.97E^{-01} >> 0.05$	VNS*
	EC	mS/cm	4.438	3.145	$1.07E^{-05} << 0.05$	VS*
	NO_3^-		0.544	1.293	$1.55E^{-01} >> 0.05$	VNS*
	SO_4^{2-}		219	125	$1.41E^{-03} < 0.05$	VS*
	Cr		0.136	0.069	$9.79E^{-02} > 0.05$	VNS*
	Pb		0.013	0.024	$2.39E^{-01} >> 0.05$	VNS*
	Zn		0.577	0.128	$8.29E^{-03} < 0.05$	VS*
	Cu		0.040	0.007	$2.68E^{-03} << 0.05$	VS*
	Fe		2.439	1.985	$2.08E^{-02} < 0.05$	VS*
	Ni	mg/L	0.098	0.132	$1.14E^{-01} >> 0.05$	VNS*
B	Cl^-		534	340	$3.31E^{-07} << 0.05$	VS*
C	COD		457	174	$8.52E^{-06} << 0.05$	VS*
	BOD_5		317	41	$4.39E^{-08} << 0.05$	VS*
	TSS		809	110	$1.00E^{-03} < 0.05$	VS*
	Mn		2.143	0.789	$4.47E^{-02} < 0.05$	VS*
	Cd		0.041	0.018	$1.99E^{-01} >> 0.05$	VNS*
	Na		2743	1521	$9.21E^{-03} < 0.05$	VS*
D	Turb	NTU	272	82	$1.18E^{-05} << 0.05$	VS*
	Coul	Pt- Co	407	162	$3.08E^{-05} << 0.05$	VS*
	DO		0.68	1.54	$6.99E^{-06} << 0.05$	VS*
	NH_4^+		18.303	17.732	$3.90E^{-01} >> 0.05$	VNS*
	NO_2^-		0.222	0.489	$6.74E^{-02} > 0.05$	VNS*
	PO_4^{3-}	mg/L	4.905	2.849	$6.36E^{-02} > 0.05$	VNS*
	K		279	214	$1.81E^{-01} >> 0.05$	VNS*
	Mg		444	305	$1.85E^{-01} >> 0.05$	VNS*
	Ca		153	214	$2.18E^{-02} < 0.05$	VNS*

*VNS: Variation Not Significant, VS: Variation Significant.

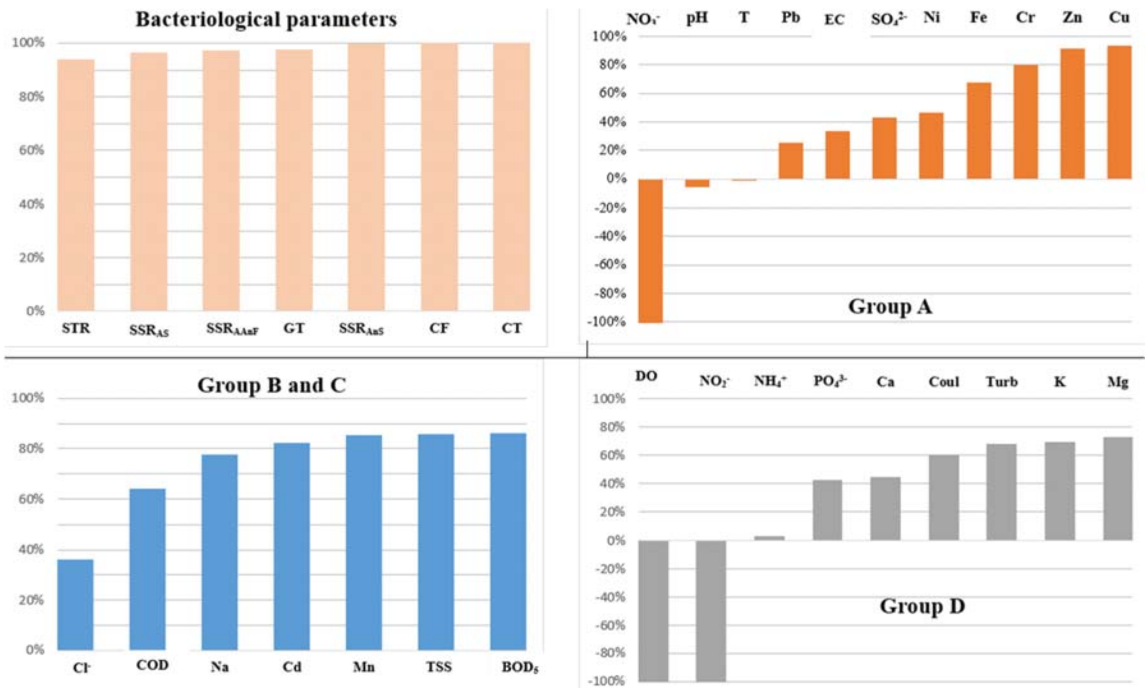

Fig. 10 Relative variations of the four groups of physicochemical and bacteriological parameters at the septic tank outlet

TABLE VI
MEANS, STANDARD DEVIATION, AND COEFFICIENTS OF VARIANCE OF BACTERIOLOGICAL PARAMETERS MEASURED AT THE INLET AND OUTLET OF THE SEPTIC TANK

Category	Parameter	Mean (germ/100 mL)		Standard deviation (germ/100 mL)		CV (%)	
		CH_1	CH_3	CH_1	CH_3	CH_1	CH_3
C	CF	1.29E+07	3250	1.92E+07	354	100	11
D	GT	2300	155	1.70E+03	64	74	41
	CT	1.70E+06	3650	2.94E+06	4.88E+03	100	100
	STR	1650	155	1.64E+03	64	100	41
	SSR_{AS}	1.50E+04	550	7.07E+03	495	47	90
	SSR_{AnS}	7.61E+05	1400	6.33E+05	283	83	20
	$SSR_{A,\ AnF}$	1.23E+05	1.02E+04	1.55E+05	283	100	3

TABLE VII
AVERAGE CONCENTRATIONS OF THE PARAMETERS MEASURED AT THE ENTRANCE AND EXIT OF THE TWO PROCESSES MBBR AND VF, FOR RETENTION TIMES OF 2, 4, AND 6 HOURS

Residence time		2 hours			4 hours			6 hours		
Parameter	Unit	CH_3	MBBR	VF	CH_3	MBBR	VF	CH_3	MBBR	VF
T	°C	21.6	22.9	22.5	26.5	26.3	26.4	25.1	26.5	26.3
pH	-	7.8	7.6	7.5	8.1	7.7	7.7	7.5	7.9	7.8
EC	mS/cm	2.0	2.1	2.0	2.0	2.2	2.1	2.1	2.1	2.1
Turb	NTU	34.6	18.8	14.2	16.7	0.0	0.0	7.0	0.0	0.0
Coul	Pt-Co	45.8	23.6	17.8	18.5	0.0	0.0	2.9	0.0	0.0
DO	mg/L	7.0	7.4	7.7	6.1	3.2	3.5	6.8	2.2	5.6
NH_4^+		11.8	16.5	11.8	13.8	9.2	9.2	13.7	21.5	15.5
NO_2^-		10.0	13.4	18.9	13.4	15.8	24.1	17.7	15.6	18.7
NO_3^-		0.2	0.1	0.4	0.2	0.2	0.2	0.2	0.2	0.2
PO_4^{3-}		7.5	7.5	6.5	7.0	8.2	6.1	6.2	6.0	6.3
SO_4^{2-}		94	87	77	112	161	160	116	115	101
Cl^-		362	367	364	512	497	503	392	452	476
COD		37	17	19	35	13	25	36	10	21
BOD_5		34	30	20	20	11	11	30	6	10
TSS		60	45	48	30	15	19	31	10	0.0

The DO, Ca and NO_2^- that belong to the group D, on the other hand, underwent an increase. The increase in DO may be related to the amount of water in relation to the total volume of the pit, as well as to the presence of control openings which could make the environment aerobic and change the degradation metabolism. The illogical increase in calcium is explained by the construction of the technical room during this period (the workers washed their hands after their construction work and discharged water loaded with calcium into the third chamber of the septic tank). The increase in NO_2^- concentrations could be explained by incomplete degradation of NH_4^+ or by a reduction of NO_3^-.

The analysis of the septic tank water confirms the results obtained by Chaouki et al. [37]: sedimentation decreases bacteriological parameters and organic and inorganic matter such as orthophosphates, sulfates and some heavy metals. This is probably due to anaerobic digestion, self-purification, liquid-solid separation and the mechanical effect of settling [34], [35], [38], [39]. The latter could have been improved by adding alum and polymer to chamber 3 of the septic tank according to Sovana [38].

B. Quality and Comparison of MBBR and Vertical Filter-Treated Water

To improve the quality of wastewater from chamber 3, two techniques are proposed: the MBBR process and the vertical filter. The analysis of these two techniques is done on water that was stagnant for four months, during the containment period of the COVID-19 epidemic. The treatment of these waters was analyzed on retention times of 2 h, 4 h, and 6 h.

MBBR wastewater treatment uses a fluidized bed reactor with a mechanical agitator, an anaerobic process, that promotes the removal of nitrogenous forms from wastewater [40], [41]. The treatment by the vertical flow filter is carried out before the planting of the filter by reeds. Sequential feeding and resting time allow aeration of the filter bed and promote aerobic degradation phenomena [42].

Table VII shows the average concentrations of physicochemical parameters measured at the inlet and outlet of the two treatment processes (MBBR and VF) for retention times of 2 h, 4 h, and 6 h.

We note that some parameters (COD, BOD_5, TSS, turbidity, and color) decrease significantly, however, the variation of other parameters is qualified as random given the low concentrations initially. In fact, for a 6-hour retention, the decrease of COD, BOD5, and TSS, exceeds 70% at the MBBR process outlet and 40% at the vertical filter outlet and confirms the optimization results obtained in the laboratory (see Chapter III) and those obtained by Moretti [43].

For turbidity and color, the abatement rates increase with the residence time in both treatment plants. On the other hand, the relative variations of the parameters: DO, Cl^-, SO_4^{2-}, PO_4^{3-} and nitrogenous forms can be explained by the formation of biofilm for the MBBR process and the growth of bacteria at the filter [44]. These elements play a role in bacterial metabolism and enzymatic reactions of the bacteria [44].

Taking into account these results, the best retention time is 6 hours for the decrease of the concentrations of the majority of the analyzed parameters except for Cl-whose concentration remains higher than the limit value of water intended for irrigation. In fact, in order to further improve the quality of the water treated by these two processes, it is recommended to add an additional treatment for de-chlorination.

Table VIII shows the average concentrations of the physicochemical parameters after treatment by the MBBR process and by the vertical filter for a residence time of 6 hours. It can be seen that about 80% and 73% of the parameters show good behavior at the outlet of the MBBR process and the vertical filter, respectively.

TABLE VIII
AVERAGE CONCENTRATIONS OF PHYSICOCHEMICAL PARAMETERS MEASURED AT THE INLET AND OUTLET OF THE REACTOR AFTER A SIX-HOUR RESIDENCE TIME

Group	Parameter	Unit	Mean			VLI** [32]
			CH_3	MBBR	VF	
A	T	°C	25.1	26.5	26.3	35
	pH	-	7.5	7.8	7.8	6.5-8.4
	EC	mS/cm	2.094	2.076	2.088	12
	NO_3^-	mg/L	0.19	0.18	0.21	30
	SO_4^{2-}		116	115	101	250
B	COD		36	10	21	125*
	BOD_5		30	6	10	40*
	TSS		31.33	10	0	2/ 35*
C	Cl^-		392	452	475	350
D	Turb	NTU	7	0	0	-
	Coul	Pt-Co	2.86	0	0	-
	DO	mg/L	4.77	2.2	5.7	-
	NH_4^+		13.7	21.5	15.5	-
	NO_2^-		17.7	15.6	18.7	-
	PO_4^{3-}		6.2	6.1	6.3	-

* Limit values according to the guidelines for treated water for irrigation [45]
**VLI: Limit value for water intended for irrigation [32]

Table VIII shows that the two processes behave in the same way with respect to all the parameters studied, with nevertheless a better efficiency for the MBBR process. Indeed, these two processes have no effect on the evolution of the parameters of group A and do not impact the good behavior of the latter. This can be explained by the fact that we started the monitoring just a few days after the start of the two processes: no adaptation period to allow time for the development of the bacterial activity. These results are in agreement with those of Schubert et al. [46] and Vieira et al. [47].

These two treatment techniques allow us to reach the limit values of water intended for irrigation for COD, BOD_5, and TSS that were initially part of group C (Table V and Fig. 10), with an abatement rate that exceeds 50%. This confirms the results obtained at the laboratory scale [13]. For the MBBR process, normally, the fluidized supports by mechanical agitation favor the denitrification phenomenon, under specific conditions such as the absence of oxygen [48]. However, in the case of FSAC wastewater, which has already been stagnated for four months (a period of confinement linked to COVID-19), this reduction in COD, BOD_5, and TSS, accompanied by a sharp decrease in the concentration of dissolved oxygen, seems normal since the presence of oxygen blocks the anaerobic treatment of nitrogenous forms [49], [50].

Chloride concentrations underwent an increase. This is probably due to the period of biofilm formation for the MBBR process and the growth of bacteria for the vertical flow filter or to the mineralization of organic matter [44].

For the parameters of the last group, significant consumption of dissolved oxygen can be noticed, which could be explained by its use in the biological degradation of pollutants [46] and by the biological degradation of pollutants [43]. The increase in ammoniacal nitrogen can be explained by the transformation of organic nitrogen into ammoniacal nitrogen [36].

For the rest of the parameters of group D, it is noted that this treatment, after 6 h of retention, has no effect on the evolution of nitrites and ortho-phosphates. The treated water will be used for irrigation, the presence of PO_4^{3-} does not present any problem since phosphorus is a nutrient often used for soil fertilization.

In conclusion, these two treatment methods are effective for the treatment of domestic wastewater from the FSAC. It should be noted that the MBBR process gives better results than the vertical flow filter, but both processes have no effect on the removal of chlorides. Therefore, chemical de-chlorination with sulfite or sulfur oxide should be considered [51].

C. The Treatment Capacity of the Complete Treatment System

After having studied the efficiency of each treatment pilot unit, the performance of the complete system was evaluated. Five samples were taken on a regular basis with optimal retention times for each treatment unit: first chamber (CH_1) third chamber (CH_3) of the septic tank, MBBR reactor, and vertical flow filter (VF).

Table IX compares the concentrations of the physicochemical parameters of the wastewater obtained at the outlet of each treatment unit: chamber 3 of the septic tank, MBBR process alone, and coupling of the two processes, MBBR + VF.

TABLE IX
AVERAGE VALUES OF THE PHYSICOCHEMICAL PARAMETERS ANALYZED IN THE WASTEWATER BEFORE AND AFTER TREATMENT

Group	Parameter	Unit	CH_1	CH_3	MBBR	MBBR+VF	VLI** [32]
A	T	°C	25.7	25.9	25.9	25.4	35
	pH	-	7.8	7.7	7.5	7.5	6.5-8.4
	EC	mS/cm	3.182	2.255	2.224	2.239	12
	NO_3^-	mg/L	0.09	0.22	0.25	0.28	30
B	SO_4^{2-}		274	157	156	152	250
	COD		232	59	12	5	125*
	BOD_5		154	30	10	3	40*
	TSS		367	50	21	0	2/ 35*
C	Cl^-		791	504	509	547	350
D	Turb	NTU	8.4	1.3	0	0	-
	Coul	Pt-Co	1.4	0.6	0	0	-
	OD	mg/L	2	4	3	4	-
	NH_4^+		12	11	14	13	-
	NO_2^-		7	15	19	24	-
	PO_4^{3-}		7.2	4.2	4.6	4.5	-

* Limit values according to the guidelines for treated water for irrigation [45]
**VLI: Limit value for water intended for irrigation [32]

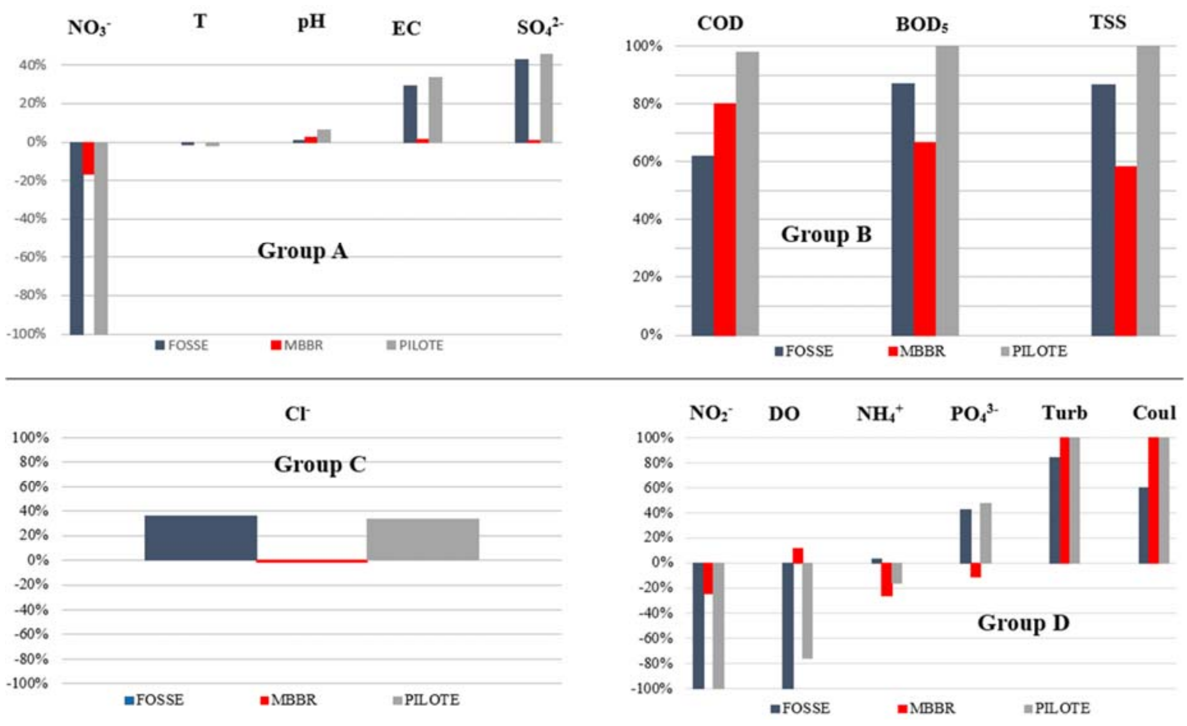

Fig. 11 Relative variation of analyzed parameters in wastewater treated by different pilot facilities

The analysis of the results obtained in Table IX shows the beginning of the adaptation of the treatment system after one month of operation. The concentrations of some parameters, before treatment, are lower than the limit values for water intended for irrigation. These are T, pH, EC, and NO_3^- (group A in Table IX). The decrease of some of these parameters during the complete treatment improves the quality of the water.

At the exit of the pilot (MBBR + VF), the concentrations of SO_4^{2-}, COD, BOD_5, and TSS reach the irrigation limit values (group B of Table IX), while the decrease in the concentration of chlorides remains insufficient.

For the parameters of group D, which do not have limit values associated with irrigation, an improvement in concentrations is noted: a decreasing concentration of Turb, Coul, NH_4^+, NO_2^- and PO_4^{3-} and an increasing concentration of dissolved oxygen.

Fig. 11 shows the rates of change calculated from only the parameters at the outlet of the first chamber. The analysis of the parameters at the outlet of the whole treatment process (Fig. 11) shows that the complementarity of the two treatment processes has allowed the removal of more than 60% of the Turb, Coul, COD, BOD_5 and TSS contents and about 40% of the electrical conductivity, chloride, sulfate and orthophosphate contents. The oxygenation rate of the treated water has increased by 50%.

For the biological parameters, we can predict that the wastewater treatment of the sanitary blocks within the mini-plant will be satisfactory in terms of elimination of pathogens and viruses. This prediction is based on the results of the as-built septic tank, which showed over 70% germ removal. The treatment process used is composed of a pre-treatment: septic tanks (fosse), secondary treatment: MBBR process and tertiary treatment: vertical flow (VF), which could promote the elimination of biological parameters [52].

The complementarity of the selected treatment processes (septic tank, MBBR, and VF) in this study is evident and has allowed for improvement in the quality of the treated wastewater, which can be used without risk for the irrigation of the green spaces of the FSAC. On the other hand, we have seen that the chloride content does not meet the limit value for water intended for irrigation. Chemical de-chlorination, using sulfite or sulfur oxide [51] may be necessary to remedy this.

It should be noted that studies to optimize the performance of this process should be carried out using "fresh" wastewater with a residence time of no more than 48 hours in the septic tank. Then, to better understand bacterial metabolism, it would be sufficient to increase the retention time while alternating aerobic and anaerobic conditions.

IV. Conclusion and Recommendations of the FSAC Project

In this project, we have shown that the reuse of non-conventional resources (treated wastewater) for cleaning and watering green areas is an alternative solution to reduce the consumption of drinking water in our establishment.

The results obtained from this study show that the combination of the MBBR process with the vertical flow filter leads to satisfactory performance in terms of the abatement rate of the pollution parameters. The removal of the organic substrate is good, with 89%, 90%, and 99% for COD, BOD_5, and TSS reductions, respectively (effluents, COD < 80 mg/L; BOD_5 < 48 mg/L). We also observed a significant reduction in electrical conductivity (67%), turbidity (83%), color (76%), and pathogens (90%). This purified water can be used without danger for irrigation, watering of green spaces as well as road cleaning.

The implementation of the mini wastewater treatment plant in the sanitary blocks of the FSAC is an opportunity for training and experimentation for the students of the basic and professional courses (licenses and Master) of the establishment. In addition, this project will undoubtedly contribute to the transfer of good environmental and ecological practices and to the change of behavior of students and teachers with regard to natural resources and their valuations.

This multidisciplinary project, which integrates the environmental, social, and economic aspects, is part of an undisputed sustainable development perspective in order to respond to the problem of liquid sanitation at the level of urban, peri-urban, and rural centers (neighborhoods, industries, Douars, hammams, ovens, schools, public establishments, etc.) by allowing decentralized management of wastewater that is economically profitable and more efficient.

This demonstrative wastewater treatment pilot can certainly be improved by adding some important units such as:

- The use of renewable energies to power the lifting pumps and thus reduce the electricity bill;
- The installation of an educational garden (project in progress) in order to show that water once purified and as soon as respects the standards in force, can be reused for irrigation without any risk;
- The insertion of more efficient processes in terms of chloride abatement.

References

[1] CESE, “Rapport Annuel 2019,” 2019.
[2] SNDD, “Stratégie nationale de développementt durable: 2016- 2030,” Rabat, 2017.
[3] Conseil Economique Social et Environnemental, “La gouvernance par la gestion integrée des ressources en eau au Maroc: Livier fondamental de développement durable,” Rabat, Maroc, Auto-saisine AS n°15 / 2014, 2014.
[4] Secrétariat d’Etat chargé du développement durable, “Plan national d’assainissement liquide (PNA),” Rabat, 2005.
[5] Secrétariat d’Etat chargé du développement durable- Ministère de l’Intérieur- Ministère d’économie et de Finance, “Programme National d’Assainissement Liquide,” Rabat, Maroc, 2019.
[6] Secrétariat d’Etat chargé du développement durable, “Stratégie nationale de l’eau,” Rabat, 2018.
[7] B. El Hamouri, *Réacteur anaérobie et chenal à haut rendement: pour l’épuration des eaux usées des petites communautés*. Rabat: Institut Agronomique et Vétérinaire Hassan II, 2004.
[8] Y. Salama, “Traitement des eaux usées domestiques par un lit bactérien dénitrifiant immergé,” Université Chouaïb Doukkali- Faculté des Sciences El Jadida, 2014.
[9] [9] A. Saidi, B. Elamrani, and F. Amraoui, “Mise en place d’un filtre planté pour le traitement des eaux usées d’un Hammam et leur réutilisation dans l’irrigation d’une ferme solidaire dans le périurbain Casablancais,” *Mater. Environ. Sci.*, vol. 5, no. 2028–2508, pp. 2184–2190, 2014.
[10] N. Chakri, B. El Amrani, F. Berrada, and F. Amraoui, *Study of wastewater treatment’s scenarios of the Faculty of Sciences- Ain Chock, Casablanca Proposal I: vertical flow filter*, AI2SD 2018., vol. 1. Tanger: Springer International Publishing, 2019.
[11] N. Chakri, B. El Amrani, F. Berrada, H. Nourredine, and F. Byoud, “Optimization of the wastewater treatment of the Faculty of Sciences Ain Chock by an MBBR process,” in *International Conference on Energy and Environment and Storage of Energy ICEESEN 2020*, 2020, pp. 483–487.
[12] N. Chakri, B. El Amrani, and F. Berrada, “Modeling and optimization of wastewater treatment, from the ain chock faculty in morocco, using the

vertical flow filter filled with pozzolana," *Desalin. Water Treat.*, vol. 234, pp. 376–385, 2021.
[13] N. Chakri, "Implémentation et évaluation du fonctionnement d'une filière décentralisée pour l'épuration des eaux usées de la faculté des sciences Ain Chock 'FSAC'. Étude de son application application pour un hammam périurbain dans la commune de Dar Bouazza (Casablan," University Hassan II of Casablanca- Morocco, 2021.
[14] SPGE, "Guide de mise en oeuvre d'un système d'épuration individuelle," Wallonie, France, 2019.
[15] S. Reuter, B. Gutterer, L. Sasse, and T. Panzerbieter, *Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries*, vol. 49, no. 0. Water, Engineering and Development Centre (WEDC), Loughborough University, UK, in association with Bremen Overseas Research (BORDA), Germany, 2009.
[16] N. S. Reynaud, "Operation of decentralised wastewater treatment systems (DEWATS) under tropical field conditions," Technical University, Dresden., 2014.
[17] L. Chaaibi and F. Berrada, "Dimensionnement de la station d'épuration, à filtre planté, de la Faculté des Sciences Ain Chock.," Casablanca, 2013.
[18] Arrêté du Gouvernement wallon, *Fixant les conditions intégrales et sectorielles relatives aux systèmes d'épuration individuelle*. 2016, p. 11.
[19] A. Saidi, "Approche décentralisée pour une gestion efficace des eaux usées : cas d'études à Casablanca et à Berlin," Université Hassan II-Faculté des Sciences Ain Chock- Casablanca, 2016.
[20] N. Chakri, B. El Amrani, F. Berrada, and H. Jounaid, "Environmental diagnosis of traditional hammams of Dar Bouazza's Commune, Morocco," *Desalin. Water Treat.*, vol. 170, 2019.
[21] Agence de l'eau Rhin-Meuse, "Les procédés d'épuration des petites collectivités du bassin Rhin-Meuse: éléments de comparaison techniques et économiques," France, 2007.
[22] R. Franceys, J. Pickford, and R. Reed, *Guide de l'assainissement individuel*. Suisse, 1995.
[23] R. Bourrier, M. Satin, and B. Selmi, *Guide technique pourl'assinaissement: cellete- épuration- conception- exploitation*, 5ème éditi. Groupe Moniteur, 2017.
[24] AFNOR, *NF P20-101: Portes et blocs portes - caractéristiques dimensionnelles*. France, 2011, p. 31.
[25] IRSTEA- SIEAM, "Cahier des prescriptions techniques: station d'épuration type Filtres plantés à écoulement vertical," Mayotte, 2015.
[26] R. L. Lombard and P. Molle, "Les filtres plantés de végétaux pour le traitement des eaux usées domestiques en milieu tropical - guide de dimensionnement de la filière tropicalisée," France, 2017.
[27] A. Reuillon, L. Vasseur, and P. Molle, "Filtre à écoulement vertical, non saturé- saturé," Action 40-2, 2015.
[28] N. melet et coll Jean Rodier, Bernard Legube, *L'analyse de l'eau*, 9e Edition. Paris, France, 2009.
[29] Association française de normalisation (AFNOR), *Recueils des normes AFNOR, Tomes 1 à 4*. 1999.
[30] Bulletin officiel N° 5448, *Fixation des valeurs limites spécifiques de rejet domestique*, vol. 1427, no. 12. ministre de l'intérieur, du ministre de l'aménagement du territoire, de l'eau et de l'environnement et du ministre de l'industrie, du commerce et de la mise à niveau de l'économie, 2006, p. 2.
[31] ONEP, "Approche de la typologie des eaux usées urbaines au Maroc," Rabat, 1998.
[32] "Arrete conjoint du ministre de l'equipement et du ministre charge de l'amenagement du territoire, de l'environnement, de l'urbanisme et de l'habitat n° 1276-01 du 17 octobre 2002portant fixation des normes de qualite des eaux destinees a l'irrigation," *Bull. Off.*, vol. N° 1276-01, pp. 1–5, 2002.
[33] Bulletin officiel N°1276-01, *Fixation des normes de qualité des eaux destinées à l'irrigation*, vol. 1423, no. 1. Ministre de l'équipement et du ministre chargé de l'aménagement du territoire, de l'urbanisme, de l'habitat et de l'environnement, 2002, p. 5.
[34] P. Dodane and M. Bassan, "Bassins de décantation et d'épaississement," in *TECHNOLOGIE*, 2015, pp. 131–150.
[35] M. Mujawamaria, "Optimisation de la décantation primaire par ajout de produits chimiques – Jar-Tests," Quebec, Canada, 2012.
[36] The Cadmus Group, "Nutrient control design manual: state of technology review report," 2009.
[37] I. Chaouki, L. Mouhir, S. Souabi, and M. Fekhaoui, "Étude de la performance de la STEP du centre emplisseur de la société Salam Gaz – Skhirat, Maroc Résumé," *Afrique Sci. Rev. Int. des Sci. Technol.*, vol. 09, no. 3, pp. 91–102, 2013.
[38] T. Sovana, "Optimisation des unités de décantation primaire des stations d'épuration de la ville de Québec," 2010.
[39] J.-P. Canler and J. M. Perret, "La décantation lamellaire des boues activées," 1994.
[40] U. Barry, "Comportement du procédé R3F en nitrification: suivi, modélisation dynamique et limites du procédé," Institut des Sciences et Industries du Vivant et de l'Environnement (AgroParisTech), 2013.
[41] A. H. Javid, A. H. Hassani, B. Ghanbari, and K. Yaghmaeian, "Feasibility of utilizing moving bed biofilm reactor to upgrade and retrofit municipal wastewater treatment plants," *Int. J. Environ. Res.*, vol. 7, no. 4, pp. 963–972, 2013.
[42] J. Rochard, E. Marengo, D. Marengo, J.-L. Mangiacotti, and A. Joubert, "Ecoconception des caves: réduction de la consommation d'énergie et intégration paysagère du traitement des effuents de cave avec le dispositif de lit planté de roseaux sur support de zéolithe Zeofito," *BIO Web Conf.*, vol. 15, no. 02002, pp. 1–10, 2019.
[43] P. Moretti, "Performances, modélisation et limites d'un procédé à lit fluidisé associant culture libre et fixée (IFAS) pour le traitement du carbone et de l'azote des eaux résiduaires," Université Claude Bernard-Lyon, 2015.
[44] UMVF, "Croissance des bactéries," 2014.
[45] OMS, *Lignes directrices pour l'utilisation des eaux usées municipales dans la région méditerranéenne*. Athène: Programme des Nations Unies pour l'environnement, 2005, p. 73.
[46] R. Schubert, M. Boulestreau, M. Christensson, and B. Lesjean, "Novel wastewater process scheme for maximum COD extraction: high load MBBR followed by microsieve filtration," in *The 9th International Conference on Biofilm Reactors*, 2013, p. 8.
[47] D. V. Minegatti de Oliveira, M. D. Rabelo, and Y. N. Nariyoshi, "Evaluation of a MBBR (Moving Bed Biofilm Reactor) pilot plant for treatment of pulp and paper pill wastewater," *Int. J. Environ. Monit. Anal.*, vol. 2, no. 4, pp. 220–225, 2014.
[48] A. Saidi, K. Masmoudi, E. Nolde, B. El Amrani, and F. Amraoui, "Organic matter degradation in a greywater recycling system using a multistage moving bed biofilm reactor (MBBR)," *Water Sci. Technol.*, vol. 76, no. 12, pp. 3328–3339, 2017.
[49] A. Cébron, "Nitrification, bactéries nitrifiantes et émissions de N2O," Université Paris VI – Pierre et Marie Curie, 2004.
[50] A. Zafarzadeh, B. Bina, M. Nikaeen, H. Movahedian Attar, and M. Hajian Nejad, "Performance of moving bed biofilm reactors for biological nitrogen compounds removal from wastewater by partial nitrification-denitrification," *Iran. J. Environ. Heal. Sci. Eng.*, vol. 7, no. 4, pp. 353–364, 2010.
[51] L. Boudreau, S. Cloutier, and I. Guay, "Position technique sur le rejet d'eaux chlorées dans le milieu aquatique," Québec, 2009.
[52] S. Vandermeersch, "Etude comparative de l'efficacité des traitements d'épuration des eaux usées pour l'élimination des micro-organismes pathogènes," 2006.