Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2019.24601

170 (2019) 405–414
December

Environmental diagnosis of traditional hammams of Dar Bouazza's Commune, Morocco

Nihad Chakri[a,*], Btissam El Amrani[a], Faouzi Berrada[b], Halima Jounaid[b]

[a]*Treatment and Valorisation of Water Laboratory of Geosciences Applied to the Arrangement Engineering (G.A.A.E.), Faculty of Sciences, Aïn Chock Hassan II University, Casablanca, Morocco, email: n.chakri2009@gmail.com (N. Chakri)*
[b]*Hydrosciences, Laboratory of Geosciences Applied to the Arrangement Engineering (G.A.A.E.), Faculty of Sciences, Aïn Chock Hassan II University, Casablanca, Morocco*

Received 22 February 2019; Accepted 19 June 2019

ABSTRACT

Traditional hammams are essential elements in Moroccan social and cultural life. They consume large quantities of wood energy and water and therefore release equivalent quantities of wastewater and black smoke and ash. The nuisances they generate prevent them from developing sustainably: deterioration of the environment, lower profits taking into account energy bill. In this context, the Eco–Hammam project was initiated to implement innovative solutions adapted to the local context to limit the negative impacts of hammams on the environment and reduce water and wood energy consumption. This will be done through the treatment and reuse of wastewater through a compact system with heat recovery and the use of alternative energy sources to increase the energy efficiency of traditional steam rooms. To do this, first, an inventory was established at the level of traditional hammams of the Commune of Dar Bouazza (suburbs of Casablanca) in terms of water and energy. Then, the quality of incoming and outgoing water from these units was evaluated. The results obtained show that the management of some hammams is not rational and leads to excessive consumption of water and wood energy. These hammams contribute significantly to air pollution through the release of harmful gases, the waste of water and ultimately the degradation of the forests and contamination of the water table.

Keywords: Traditional hammams; Sustainable development; Water characterization; Energy saving; Environmental diagnosis

1. Introduction

Public baths or hammams occupy an essential place in the Moroccan urban and peri-urban fabric, they are part of the cultural heritage. Urbanization in Morocco has led to a sharp increase in the number of these traditional hammams: between 6,000 and 10,000 units that operate with a traditional heating system [1]. Numerous studies on the energy consumption of public baths [1–3] indicate that the hammam consumes between 60 and 120 m^3 of water and between 1 and 2 tons of wood per day. On average, a ton of wood costs 650 Moroccan dirhams (about €60), so that the daily combustible cost is about 1,300 Moroccan dirhams (about €120) [1]. These high consumption levels result in significant environmental pollution generated by:

- Wastewater: in the case of hammams located on the outskirts of Casablanca, such as our study area (Commune of Dar Bouazza), most of this water is discharged directly into the receiving environment without prior treatment because it is not connected to the sanitation network.
- Black smoke and ash emissions produced by the often incomplete combustion of wood.

* Corresponding author.

Presented at the Fifth International Conference on Small and Decentralized Water and Wastewater Treatment Plants (SWAT 2018), 26–29 August 2018, Thessaloniki, Greece

1944-3994/1944-3986

In this context, the project Eco–hammam is initiated. Its goal is to implement innovative solutions adapted to the local context of these units, in order to limit the negative impacts of these units on the environment. To do so, the implementation of a compact and ecological purification process of liquid discharges is proposed. Wastewater treated in this way can be used for irrigation, watering, cleaning the roads.

For the energy aspect, and in order to optimize the energy efficiency of a traditional hammam, the use of improved boilers, the improvement in terms of heat loss through the walls of the building, the recovery of heat from warm wastewater before treatment and the use of solar collectors in the view of the availability of surfaces for hammams located in the suburbs are recommended.

Previous work has focused mainly on urban hammams and in particular the problem of wood energy to reduce the consumption of wood through the use of improved boilers [4,5], installation of heat exchangers, voltaic panels, improved heating floors instead of traditional chebkas [6] and qamariyyats [3,7]. A study on a hammam in Marrakech has worked on the treatment of wastewater from this hammam by planted filters [1]. In addition, Saidi & Co in 2014 published a study on the treatment of wastewater from the hammam of Douar Ouled Ahmed and the reuse of the water thus purified for the irrigation of a solidarity garden [8].

In the present work, first an inventory by means of a survey was carried out with all the hammams of the Commune of Dar Bouazza in the suburbs per urban of Casablanca. Then the physico-chemical and bacteriological characterization of the well water supplying these units and that of the wastewater discharged was carried out in order to define the quality of these waters.

The results obtained show that the management of some hammams is not rational and leads to excessive consumption of water. The characterization of well water and wastewater showed a physico-chemical and bacteriological contamination. In fact, the waters analyzed do not comply with Moroccan standards (drinking water quality grid, limit values for discharges into surface and underground water) [9,10]. These hammams probably present a health risk and contamination of the water table.

2. Description of the study area (Commune of Dar Bouazza)

The commune of Dar Bouazza (outline in blue on the map in Fig. 1 is an urban commune which comes under the province of Nouaceur, part of the Casablanca – Settat region [11]. This commune is bounded by the Atlantic Ocean to the North, the Commune Casablanca to the East, the Rural Commune Ouled Azzouz to the South and the Rural

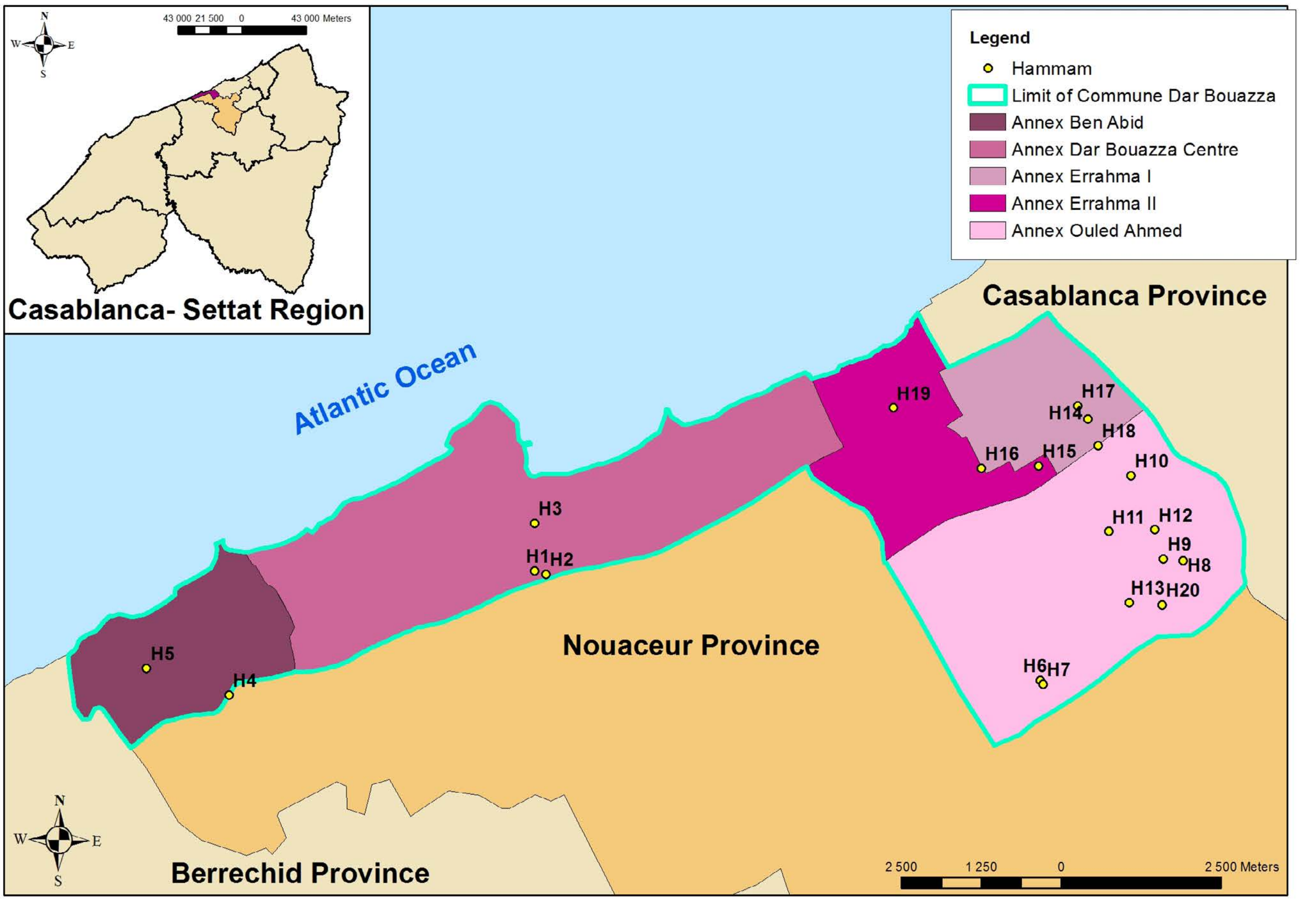

Fig. 1. Study site (Commune Dar Bouazza) and location of hammams.

Commune Soualem Trifiya from the Berrechid Province to the West (Fig. 1). It is subdivided into five Administrative Annexes: Annex Ben Abid, Annex Dar Bouazza Center, Annex Errahma I, Annex Errahma II and Annex Ouled Ahmed (Fig. 1). Its population is estimated at 151,373, with a population growth rate of about 10% per year; one of the highest rates in the country [11]. This municipality concentrates a large number of projects of economic habitats, as well as large seaside tourist projects.

3. Results

Two investigations were carried out: The first concerns the state of play of hammams in Dar Bouazza in terms of consumption of water and wood energy and the second concerns the physico-chemical and bacteriological characterization of the water discharged by the hammams and the well water used in the latter.

3.1. State of the hammams of the Dar Bouazza Commune

The data are collected using a questionnaire composed of four sections:

- *Location and identification*: the geographical coordinates of these hammams, from a GPS, have been inserted on the map created using the ArcGis software.
- *General data*: the number of customers per day, the daily consumption of water and wood energy, the nuisances generated: odor, mosquitoes, black smoke and puddles of water.
- *Well water data*: use or not, protected or unprotected well, piezometric level.
- *Specific characteristics*: thermal insulation, boiler quality, use or not of chebka (heating system for the floor of the hot room of the hammam).

3.1.1. Overview

Twenty hammams have been identified in the Commune of Dar Bouazza (Fig. 1), one of which, the number 4, belongs to the Commune Ouled Azzouz that was added voluntarily, because it discharges its wastewater in the grounds of our study site. Sixteen units are in operation, three have no operating license, three others are shut down and one is under construction (Fig. 1).

The responses of the owners of the operating hammams, on the questionnaire, made it known that these hammams use well water and rarely drinking water. They are located in densely populated areas and have the advantage of having a certain surface to create an adequate sewage treatment system whose water, once treated, can be reused for cleaning, watering green spaces and irrigating the neighboring agricultural parcels. In addition, all have roofs on which solar collectors can be installed to preheat the well water before sending it to the boiler and photovoltaic panels to supply the hammams with electricity and operate the lift pumps to raise the water. Well water to the boiler.

3.1.2. Environmental pollution

No hammam has a flue gas filtering system. Just two chimneys have regulated in terms of construction (height, dimensions, etc.). The other fourteen have poorly regulated chimneys, two of which cause direct nuisance to their neighborhood (Table 1). Six hammams among the sixteen reject the ashes produced directly in the nearby lands (Table 1).

For the discharge of wastewater, nine hammams have septic tanks, six of which are undersized, the surplus of these wastewater are, therefore, discharged into the nature often at high temperatures. Only a hammam uses, with a nearby school, a well-sized common grave and the delegate (Lydec, Morocco) periodically takes care of its evacuation. The remaining seven hammams discharge their water directly into the urban network, sometimes at temperatures higher than those defined by the Moroccan norms of indirect discharges (Fig. 2).

3.1.3. Thermal status of the building and boilers

The investigation also focused on the heat loss aspect of the building, the heat recovery systems and the condition of the boilers used by the steam rooms.

The majority of the studied hammams are built without taking into account heat losses, except for three who tried to thermally isolate their “hot” room and only one who installed a double door connecting the “warm” room to the “lukewarm” room (Fig. 3).

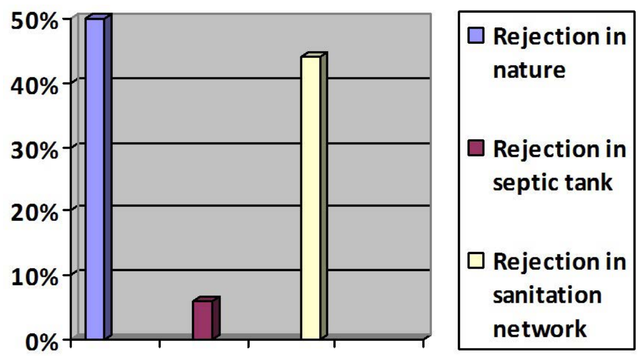

Fig. 2. Spillage of liquid waste from hammams.

Table 1
Pollution due to the use of water and energy

	Environment/energy		Environment/water		
	Smokes	Ashes	Puddles of water	Mosquitoes	Odors
Hammam (%)	37.5%	37.5%	37.5%	37.5%	43.75%

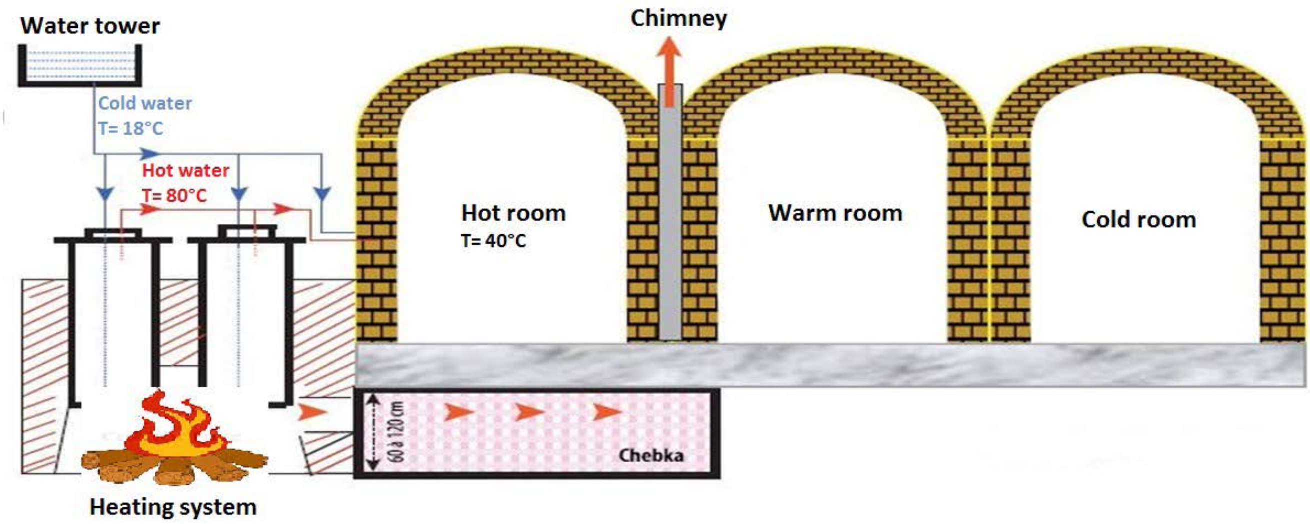

Fig. 3. Diagram of a traditional hammam.

All boilers work with wood (Fig. 3), they are either poorly insulated or not isolated at all. Only 3 hammams out of 16 have boilers of fairly good quality and thus see their consumption of wood energy suitably reduced.

92% of these entities are equipped with a chebka (Fig. 3), which allows the floor of the so-called "hot" room to be heated from wood combustion fumes, of which 84% have an insulated chebka. A single hammam has an insulated chebka from the bottom allowing it; a large part of the energy is transmitted to the room "hot".

3.1.4. Consumption of water, wood and electricity

The water and wood consumption survey conducted among the 16 hammam owners revealed that some of them gave contradictory answers (e.g., very few customers announced for a very high consumption of wood and water). For this purpose, it was essential to perform statistics on only hammams that gave non-contradictory values that could be considered reliable. After validation, we selected 10 units:

- Seven have boilers considered non-performing and consume an average of 194 L of water and 7.8 kg of wood per day per customer (Table 2).
- Three have boilers qualified as efficient and consume an average of 250 L and 4.6 kg of wood per customer per day (Table 3).

The seven hammams spend between 3.15 and 10.50 dhs with an average of 4.70 dhs of fuel wood per customer. In addition to excessive consumption of fuel wood, homeowners see their profits weaken with the age of their boiler compared with those who use boilers a priori "good" and who observe a gain of about 3.00 dhs more. Indeed, it can be seen (Table 3) that the wood-energy expenditures of steam rooms using "good" boilers are between 0.90 and 3.20 dhs with an average of about 1.90 dhs/customer.

It is also interesting to note that hammams with "good boilers" receive on average more customers than others, 340 customer/d against 110 customer/d, respectively. Their average water consumption per day and per customer is also very high, it is about 250 L/customer. This value seems too

Table 2
Consumption of wood and water per customer, for seven steam rooms with old boiler

	Maximum	Minimum	Average	Median	CV%
Quantity of wood (kg/customer)	15.0	4.5	7.8	6.5	46.5%
Quantity of water (L/customer)	360.0	100.0	194.0	245.0	40.1%

Table 3
Wood and water consumption per customer, for steam rooms with improved boilers

	Maximum	Minimum	Average
Quantity of wood (kg/customer)	4.6	1.3	2.7
Quantity of water (L/customer)		250	

excessive but could be explained by the fact that customers in steam rooms with good boilers might feel more comfortable and stay longer!

All hammams have an electric meter. Electricity is used for lighting and to operate the well raising pumps at the boiler. It should be noted that, on average, the Hammams studied need about 20 bulbs, some of which remain lit for several hours a day (Table 4). Only a hammam uses economic bulbs (LED).

Most hammams have the inconvenience of using a large amount of wood energy and water but have the advantage of having nearby cultivable areas. Therefore, in addition to raising the awareness of users of steam rooms to consume less water or to encourage homeowners to protect themselves from a tap system that reduces water wastage, it is proposed to use appropriate wastewater treatment systems so as to reuse for cleaning, watering and irrigation. Therefore, characterization of both discharged and well water is essential.

3.2. Results of physico-chemical and bacteriological characterization

3.2.1. Materials and methods

All analyzes were performed according to standardized methods [12–14] in the Laboratory "Applied Geosciences Engineering of Planning" (GAIA).

In order to evaluate the quality of the water used in the wells then those rejected by the hammams of this Commune, samples were taken and physico-chemical and bacteriological analyzes were carried out. These are the:

- In-situ measurements of temperature (T), electrical conductivity (EC), pH and dissolved oxygen (DO) using a multiparameter Eutech Instruments PCD650 (waterproof).
- Assays in the laboratory of the following parameters: chlorides (Cl^-), sulfates (SO_4^{2-}), nitrites ($N–NO_2^-$), nitrates ($N–NO_3^-$), ammonium ($N–NH_4^+$), Kjeldahl nitrogen (N–NTK), total nitrogen (NT), orthophosphate ($P–PO_4^{3-}$), total phosphorus (PT), chemical oxygen demand (COD), suspended solids (TSS), biological oxygen demand in 5 days (BOD_5), oxidation by potassium permanganate or permanganate index (IP), heavy metals (Mn, Fr, Cr, Cd, Cu, Zn, Ni and Pb).
- Bacteriological parameters measured using several culture media, namely nutrient agar (GT_1) and nutrient broth (GT_2) for total germs. Deoxycholate lactose agar (CT_1), BCP glucose agar (CT_2), MacConkey agar (CT_3) and MacConkey broth (CT_4) for total coliforms. The rotten broth for fecal streptococci. And liver meat agar for sulfito-reducing spores.

Table 4
Number of bulbs used in hammams

	Bulbs
Minimum	5
Maximum	40
Average	19.27
Median	18
CV%	53.3

The results have been validated. Few measures have been ruled out due to the filtering techniques "Winsorizing" and validation [15] used.

The decision rule that we have adopted is that of the Student's test which systematically rejects at the 95% threshold the decision to consider that the measure follows a certain standard for wastewater the standard values is the general limits of the underground (lake, lake, etc.) or underground, and for the water is the Grid of drinking water quality. We have thus identified, according to each characteristic of the water, the percentage of the parameters which do not check the norms. Similarly, we tested, at 95% confidence level, whether or not the average of a characteristic, calculated for all the waters tested, meets the standard. This test makes it possible to make a judgment on the quality of these waters as a whole.

3.2.2. Wastewater characteristics

The comparison of the wastewater discharged by the customers of the traditional hammams of Dar Bouazza was made with the general limit values of rejection in the superficial waters (river, lake, etc.) or underground [9].

3.2.2.1. Physico-chemical characteristics

Fig. 4 shows the percentage of wastewater samples that meet the standard in terms of certain characteristics.

About 76% of the tested characteristics comply with the discharge standards in surface or underground waters, while the rest do not fall within these standards. This is, therefore, a problem since 50% of the Dar Bouazza hammams discharge their water directly into the natural environment (see section 3.1.2, Fig. 2).

The temperatures of the liquid discharges vary between 27.3°C and 35.5°C, this variation can be explained by the distance between the sampling point and the main outlet of the wastewater from one hammam to another, knowing that these waters are lukewarm upstream. The average temperature recorded is slightly above the threshold of 30°C generally indicated for discharges into surface water or groundwater [9]. This promotes the development of microorganisms [14].

The electrical conductivities (EC) of the wastewater studied show excessive mineralization (>2,669 mS/cm) and 79% of the analyzed water surpassing the limit value of discharge in the natural environment (2,500 μS/cm) [16]. This may be due to the use of well water with high salinity.

Kjeldahl nitrogen (NTK) values range from 2.80 to 86.86 mg/L with an average of 16.22 mg/L, with only 7% of the analyzed waters (Fig. 4) exceeding the standard [9].

The analysis of the rejects of the hammams of the Commune of Dar Bouazza revealed the presence of the following heavy metals: copper (Cu), nickel (Ni), manganese (Mn), chromium (Cr), cadmium (Cd), iron (Fe)), lead (Pb) and zinc (Zn). 71%, 57% and 7% of the waters are above the norm in terms of (Mn), (Cr), (Cd), (Fe), (Pb) and (Zn). This is a limiting factor for the reuse of these waters for irrigation [17].

In addition to the natural presence of iron (Fe) and manganese (Mn) in deep wells where groundwater has little

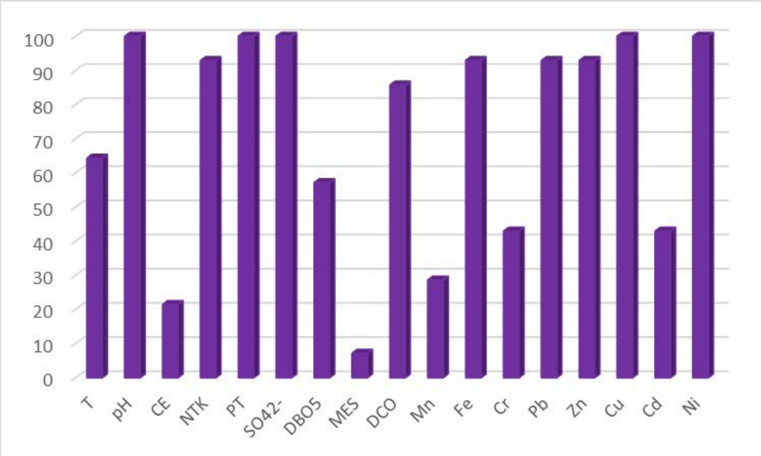

Fig. 4. Classification of physico-chemical characteristics of wastewater discharged by all hammams.

oxygen, in areas where water flows through soils rich in organic matter, these two elements may be of artificial origin. They can come from the casing of wells, pipes, pumps, tanks and other objects made of cast iron or steel that can be in contact with water [18]. Chromium (Cr) and cadmium (Cd) are used for the interior cladding of boilers and ovens operating at high temperatures [19]. This probably explains the high concentration of these metals in the wastewater analyzed.

The values of the COD range from 64 to 836 mg/L with an average of 385.8 mg/L, given that 14% of the analyzed releases (Fig. 4) are above the norm (≤500 mg/L) [9], they show a not significant variation from one hammam to another. This is probably due to the diversity of the customers and their products that they use for the bath (ghassoul, shampoo, shower gel, etc.).

The concentrations of organic pollution expressed in BOD_5 show a considerable variation between the various sampling points, these values vary between 10 and 410 mg/L with an average of 167 mg/L, of which 43% of the water analyzed (Fig. 7) do not meet the standard (<100 mg/L) [9]. This can be explained by the abundance of organic matter in these waters [22].

With regard to the TSS of the analyzed wastewater, the values vary between 35 and 724 mg/L with an average of 431 mg/L and a percentage of 93% of the wastewater analyzed (Fig. 7) are not compliant with the standard (<100 mg/L) [9]. This is probably due to the liquid discharges (impurities and wastes removed from the human body, soap and shampoo, ghassoul and black soap).

3.2.2.2. Typology of the wastewater of the hammams of the commune of Dar Bouazza

This typology makes it possible to optimize the physico-chemical parameters of the wastewater and to propose an adequate mode of treatment. For that effect, it will be necessary to evaluate the ratios COD/BOD_5, BOD_5/COD, TSS/BOD_5 (Table 5) and to estimate the oxidizable material (OM) from the relation.

$$OM = \frac{(COD + 2BOD_5)}{3}$$

- The ratio COD/BOD_5 varies from 0.29 to 7.44 with an average of 3.28 ($3 < COD/BOD_5 < 5$ = medium biodegradable effluent). It reflects the contribution of a moderately biodegradable effluent [14]. It can be said that the wastewater from the hammams of the commune of Dar Bouazza is of a domestic character [20].
- The BOD_5/COD ratio varies from 0.13 to 3.45 with an average of 0.74 ($BOD_5/COD > 0.3$ = biodegradable effluent) relatively high, which indicates a very high organic load [21]: the wastewater from the hammams of the Commune of Dar Bouazza is, therefore, predominantly organic [21,22].
- The ratio TSS/BOD_5 is relatively high and varies from 0.53 to 14.62 with an average of 3.62: this confirms that these wastewaters are heavily loaded with organic matter [21–23].
- The oxidizable material (OM) is particularly used for an overall assessment of organic pollution of wastewater. The values obtained vary from 74.63 to 501.33 mg/L with an average of 236.79 mg/L (Table 5), which is a high value, it joins the ratios TSS/BOD_5 and BOD_5/COD which confirm that these waters are loaded with organic matter [21,22].

3.2.2.3. Bacteriological characteristics

The study of bacteriological parameters, wastewater from the hammams of the Commune of Dar Bouazza, focused on the quantification of parameters of fecal origin, namely:

Table 5
Ratio of raw sewage from hammams in the commune of Dar Bouazza

	Average	Minimum	Maximum	Ecart–type
OM (mg/L)	236.79	74.67	501.33	128.79
COD/BOD_5	3.28	0.29	7.44	2.44
BOD_5/COD	0.74	0.13	3.45	0.92
TSS/BOD_5	3.62	0.53	14.62	3.77

Total germs: The controlled wastewater contains total germs whose average values vary between 2.79E + 06 germs/100 mL and 8.89E + 09 germs/100 mL.

Total coliforms: Controlled wastewaters contain total coliforms whose average values vary, from one culture medium to another, between 3.20E + 03 germs/100 mL and 1.21E + 0 germs/100 mL.

Fecal Streptococci: The search for fecal Streptococci in the well water analyzed showed that the average concentration of these germs is 1.65E + 05 germs/100 mL.

Sulfito-reducing germs: The analysis revealed the presence of three types of sulfite-reducing spores, namely:

- Anaerobes strict (AS) with average loads ranging from 1.01E + 05 to 1.61E + 06 germs/100 mL between 16 and 48 h of incubation,
- Anaerobes strict (AnS) with average loads ranging from 1.68E + 06 to 1.26E + 07 germs/100 mL for an incubation period ranging from 16 to 48 h,
- Aerobic and facultative anaerobes (AAF) with average loads ranging from 1.22E + 03 to 1.42E + 06 germs/100 mL for an incubation period of 16 to 48 h.

These bacterial loads are well above the threshold of 10E + 03grms/100 mL) set by WHO (OMS, 1989 [24]) for direct release into the environment [16].

As a result, the studied wastewater is loaded with pollutants and various contaminants. They can, therefore, pose a problem of degradation of the water quality of the water table as most of these hammams are not connected to the sewerage network. Well water that is used by all Dar Bouazza hammams can be contaminated and can cause health risks in the short, medium or long term (Abdesselem et al. [25]).

3.2.3. Well water characteristics

In order to verify if the water quality of the wells is degraded because of the discharge of wastewater from these hammams into the environment, we carried out the same characterization carried out for the wastewater and we compared each of the characteristics measured with the grid of quality of the following drinking water:

Then we proceeded to the same decision rule of Student's test that we adopted for wastewater (see section 3.2.1).

3.2.3.1. Physico-chemical characteristics

Fig. 6 below shows the well water classification according to the drinking water quality grid of the 21 characteristics we tested.

Fig. 6 shows that the aquifer in our study area, which belongs to the coastal Chaouia, has a complex heterogeneous geological system formed by Plio-quaternary limestone sandstones and altered Paleozoic schists.

Table 6
Grid of drinking water quality [10]

Class 1	Excellent
Class 2	Good
Class 3	Average
Class 4	Poor
Class 5	Very poor

Out that of 21 physico-chemical parameters tested in the well water of Dar Bouazza, six give the water an average quality (for: NH_4^+, Cl^-, BOD_5, Mn, Fe and Cu) and 3 a very poor quality (for: EC, Cr and Cd). All other parameters are rated good to excellent.

The quality in terms of conductivity remains the worst since 52% of wells are concerned (Fig. 5). Its values are between 1.85 and 6.81 mS/cm with an average of 3.628 mS/cm. Since the coefficient of variation is approximately 35%, it could be said that the conductivity of the well water of Dar Bouazza is moderately homogeneous and therefore they would cross the same geological substratum (Fig. 6).

This increase can be explained by:

- The phenomenon of evaporation which concentrates these salts in water since the coastal Chaouia aquifer does not have great depth [26].
- The geological substrate crossed [27], knowing that in our study area, the geological substrates (red silts, consolidated dunes, sandstone limestones and shales) have an influence on the quality of the well water by increasing the mineralization rate of these waters (Fig. 6).
- The possible contribution of marine water invasion in the studied area [28]; especially for wells those are close to the coast (Fig. 6).
- The multiplication of pumping and the reduction of the contributions to the aquifer [29].
- The flow of wastewater along the flow direction, generally from the south–east to the north–west, of the coastal Chaouia aquifer [30].

26% of the wells are of poor quality with high average ammonium content (1.48 mg/L). This is probably due to contamination of well water by untreated wastewater in the studied area. It can also come from the excretion of living organisms and the reduction of biodegradation of waste, without neglecting the contributions of domestic origin, industrial and agricultural sources [31].

47% of the wells have average water quality and 20% have poor to very poor quality (Fig. 5). The average high concentration of chloride (681.80 mg/L) is generally of natural origin since, on the one hand, the aquifer has a shallow depth, which favors strong evaporation and therefore the concentration of salts [24]. On the other hand, it is attributed to the infiltration of marine waters into this aquifer, taking in consideration the percolation through saline ground (Fig. 5) [32].

For BOD_5, 47% of the well water is of average quality and 20% does not meet the standard (poor to very poor quality; Fig. 5). The average concentration is 8.41 mg/L relatively high, may be related to contamination by wastewater rich in organic matter [31] (Fig. 5).

37% of the wells in terms of manganese and copper and 89.5% in terms of iron have an average water quality and 20% in terms of manganese (Mn), iron (Fe) and nickel (Ni) do not satisfy the standard (poor to very poor quality; Fig. 4). This is probably attributed to the percolation of wastewater and leachate through the different layers depending on their degree of permeability [33]. These non-biodegradable pollutants can be very harmful [34].

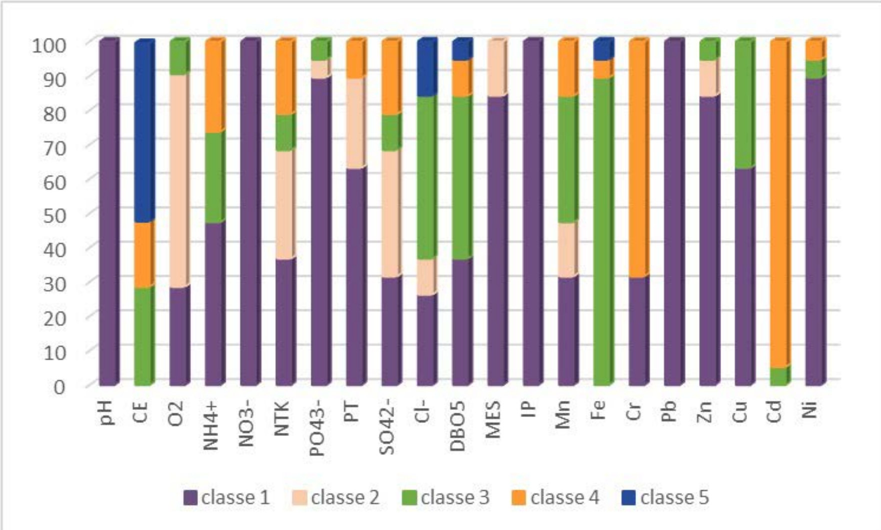

Fig. 5. Classification of physico-chemical characteristics of well water.

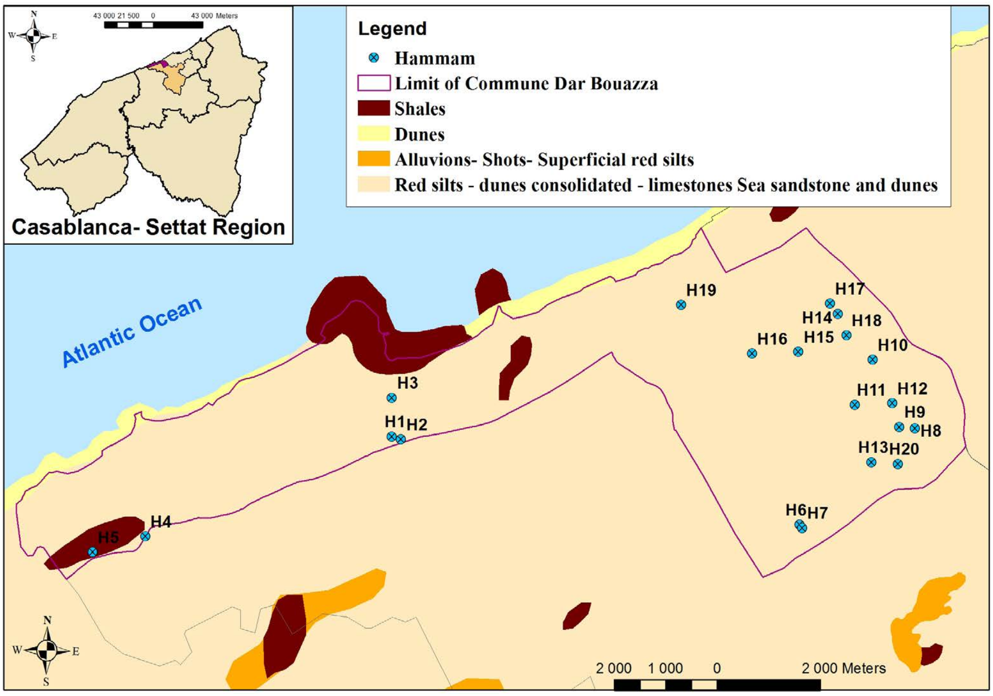

Fig. 6. Geological map of Dar Bouazza Commune.

Regarding cadmium and chromium, we find that a fairly high percentage of wells in Dar Bouazza, respectively, 95% and 68% have poor water quality (Fig. 5). Chromium is often used in the composition of special steels and refractory alloys in order to improve the hardness of metals and their resistance to corrosion [19]. This is probably due to the presence of industrial zones (electroplating, painting, brick making, marble, cement works and rotomolding) upstream of the study area, and also areas of informal settlements that use undersized septic tanks. In addition, wastewater from the Elomrane industrial zone is discharged into the wadi that crosses this area towards the sea. All this contributes to the pollution of the aquifer.

Iron (Fe) and manganese (Mn) are often naturally occurring in deep wells where groundwater has little oxygen, as well as in areas where water flows through soil rich in organic matter [18].

The average sulfate concentration of 214.1 mg/L (approximately 80% of the wells are excellent to medium water quality) is probably due to the presence of gypsum [35] or the high water contact time with the rock. This high content may also be due to human activities that can generate sulfate

Fig. 7. Classification of the bacteriological characteristics of the well water used by all Hammams of Dar Bouazza.

inputs into groundwater through the application of sulfated fertilizers [32]. Note that agriculture (cereals) is the dominant activity in this area.

In conclusion, we can say that these well waters in terms of physico-chemical characteristics can be used provided that they undergo a physico-chemical treatment of normal type beforehand (e.g.: filtration on sand then disinfection by hypochlorite).

3.2.3.2. Bacteriological characteristics

The assessment of the bacteriological quality of the study area was followed by the analysis of the water from the wells of the 15 hammams.

Fig. 7 shows the percentage of wells that comply with the drinking water quality grid according to the bacteriological parameters tested.

Total germs: Controlled well waters contain total germs with mean values ranging from 2.80E + 04 germs/100 mL to 9.99E + 08 germs/100 mL. With a percentage of 100% of the wells that are from medium to poor according to media, respectively, nutrient broth and nutrient agar (Fig. 7). Contamination of these waters by total germs could be due to poor protection of wells (open pits) and lack of knowledge of basic hygiene rules [36]. These microorganisms are not of fecal origin and have significant health risks during bathing and thermal practices [14]. Indeed, the well water analyzed poses a probable health problem on the customers of the hammams of the Commune of Dar Bouazza since they use these waters without any prior treatment.

Total coliforms: Controlled well waters contain total coliforms with average values varying from one culture medium to another between 2.67E + 00 germs/100 mL and 1.35E + 06 germs/100 mL. 77% (for BCP glucose agar), 15% (for lactose–desoxycholate agar) and 7% (for MacConkey bouillon) are the percentages of well water whose quality is poor in the quality grid of the water, the rest of the water is rated excellent to good quality (Fig. 7). This contamination can be caused by domestic discharges, the existence of wells near septic tanks and the infiltration of surface water, by a nearby pollution (breeding, existence of septic tanks and latrines) and the lack of sanitation network [36].

Fecal Streptococci: The search for fecal Streptococci in the well water analyzed showed that the average concentration of these germs is 1.59E + 02 germs/100 mL, all these tested waters are excellent class to good drinking water quality grid.

Sulfito–reducing germs: The analysis revealed the presence of three types of sulfite-reducing spores, namely:

- Aerobic strict (AS) whose average loads vary from 1.25E + 06 to 3.49E + 06 germs/100 mL between 16 hours and 48 hours of incubation,
- Anaerobic strict (AnS) with average loads ranging from 1.25E + 06 to 1.11E + 07 germs/100 mL for an incubation period ranging from 16 to 48 h,
- Aerobic and facultative anaerobes (AAF) with average loads ranging from 0.00E + 00 to 1.89E + 06 germs/100 mL for an incubation period of 16–48 h.

This high contamination is indicative of poor natural filtration in our study area and old fecal pollution [14] probably due to informal habitats nearby that use undersized septic tanks.

In conclusion, the bacteriological analyzes show bacterial contamination (old fecal) of the well water. This is probably due to the superficial flow of wastewater that undergoes slow percolation through the different layers depending on their degree of permeability [33]. Well water should be disinfected; by sand filtration which should be instituted prior to disinfection, which would be of interest for the removal of pests [14].

4. Conclusions and recommendations

Analysis of the results of the survey showed that traditional hammams consume large amounts of water and wood energy. For a country that is under water stress and does not have large forest resources, thousands of public baths in Morocco pose a danger to the environment and public health. In addition, a significant percentage of these entities are not connected to the sewerage network and therefore discharge their wastewater into the natural environment without any prior treatment. On the other hand, they generate black smoke and toxic since the chimneys of all these hammams are not equipped with a system of filtration of the fumes.

In parallel with the field survey, we conducted the physico-chemical and biological characterization of the samples of well water and wastewater discharged from all the traditional hammams of the study site. The results obtained show that both physico-chemical and bacteriological contamination of well water and controlled wastewater are present. The analyzed waters do not comply with Moroccan standards (drinking water quality grid, limit values for discharges into surface and underground water [9,10]), especially for the following parameters: COD, chlorides, sulfates, NTK and conductivity. From the bacteriological point of view, almost 100% of the well water analyzed is contaminated by fecal contamination and cannot be consumed or used without prior treatment. The danger of this chemical and bacteriological pollution poses a potential threat to the customers of the hammams of the Commune of Dar Bouazza and for the environment.

Faced with this situation, areas for improvement can be identified and will allow the reduction or even elimination of these negative impacts generated by these hammams, namely:

- The treatment of well water by filtration (e.g., sand) and disinfection, which would be of interest for the elimination of parasites [13].
- The resizing of septic tanks for hammams that are not connected to the sanitation network.
- The installation of a low-cost system adapted to the local context for the treatment of wastewater for reuse in cleaning premises, watering green spaces and irrigation [8].
- Awareness of the owners and customers of the hammams in terms of saving water and wood energy.
- The detection of leaks and the use of valves with flow control to avoid waste.

References

[1] A. Hajji, B. El Hamouri, R. Moschik, M. Regelsberger, Solar water heating system for a hammam gesign and implementation for a public bath in morocco, Sustain. Water Manage., 3 (2008) 7–9.

[2] B. Kolb, Involving, sharing, analysing—potential of the participatory photo interview, Forum Qualitative Social Res., 9 (2008) 12.

[3] H. Dumreicher, R.S. Levine, M. Sibley–Behloul, Hammam Rehabilitation Reader, Publisher Sonderzahl, Austria, 2012.

[4] A. Lahbabi, Etude du marché de microfinancement en faveur de l'énergie durable au Maroc, 2015.

[5] Agence pour le développement des énergies renouvelables et de l'efficacité énergétique (ADEREE), la deutsche gesellschaft für internationale zusammenarbeit (GIZ), et L'institut pour le développement, l'environnement et l'énergie (IDE–E), Développement des énergies renouvelables et de l'éfficacite énergetique au Maroc, 2012.

[6] Groupe énergies renouvelables, environnement et solidarités (GERES), Le GERES dans les medias, 2016, pp. 4–20.

[7] M. Sibley, M. Sibley, Hybrid transitions: combining biomass and solar energy for water heating in public bathhouses, Energy Procedia, 83 (2015) 525–532.

[8] A. Saidi, B. Elamrani, 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., 5 (2014) 2184–2190.

[9] Arrêté conjoint du ministre de l'intérieur, du ministre de l'énergie, des mines, de l'eau et de l'environnement, du ministre de l'industrie, du commerce et des nouvelles technologies et du ministre de l'artisant n°2942–13 du 1er hija 1434, Bulletin Officiel, 6202 (2013) 1–19.

[10] Arrêté conjoint du ministre de l'équipement et du ministre chargé de l'aménagement du territoire, de l'urbanisme, de l'habitat et de l'environnement n° 1277–01 du 10 chaabane 1423 portant fixation des normes de qualité des, Bulletin Officiel, 5062 (2002) 1–4.

[11] Décret n° 2–15–40 du 1er Joumada I 1436 fixant le nombre des régions, leurs dénominations, leurs chefs–lieux ainsi que les préfectures et provinces qui les composent, Bulletin officiel, 6340 (2015) 1–3.

[12] Association française de normalisation(AFNOR), Recueils des normes Afnor, tomes 1 à 4, 1999.

[13] J. Rodier, B. Legube, Nicole melet et coll, L'analyse de l'eau, 1996.

[14] J. Rodier, B. Legube, Nicole melet et coll, L'analyse de l'eau, 2009, p. 1579.

[15] Ragot, Darouach, validation des données et diagnostic, hermès edi. Paris, 1990, p. 346.

[16] Dogbè Clément Adjahouinou, Boniface Yehouenou, Mouhamadou Nourou Dine Liady, Emile Didier Fiogbe, Caractérisation bactériologique des eaux résiduaires brutes de la ville de cotonou (bénin), J. Appl. Biosci., 78 (2014) 6705–6713.

[17] M. Abouelouafa, H. El Halouani, M. Kharboua, A. Berrichi, Caractérisation physico–chimique et bactériologique des eaux usées brutes de la ville d ' oujda : canal principal et oued bounaïm, Actes Inst. Agron. Vet., 22 (2002) 143–150.

[18] P. Boucard, A. Gouzy, C. Riou, S. Petitgenet, Développement 2015 de l'étude pilote pour le choix d'actions de réduction des émissions à l'aide d'un outil d'analyse multicritère – focus sur l'inventaire des émissions, 2015, p. 48.

[19] A. Gouzy, J.-M. Brignon, Chrome et ses composes, 2015, p. 104.

[20] Ayyach, Fathallah, Hbaiz, Chouki, Elmidaoui, Caracterisation physico–chimique et bacteriologique des eaux usees de la station d'epuration de la vi lle de dar el gueddari (maroc) Larhyss J., 28 (2016) 65–85.

[21] D. Belghyti, Y. El guamri, G. Ztit, My. Lahcen Ouahidi, My Brahim Joti, A.f Harchrass, Hammou Amghar, Ouafae Bouchouata, Khadija El kharrim, Hamid bounouira, Caractérisation physico–chimique des eaux usées d'abattoir en vue de la mise en œuvre d'un traitement adéquat: cas de kénitra au maroc résumé, Rev. Int. des Sci. Technol., 05 (2009) 199–216.

[22] T. Hachi, M. Hachi, H. Ech–chafay, M. Elghabassi, H. Ettayea, K. Elkharrim, A. Khadmaoui, D. Belghyti, Caractéristiques physicochimiques des eaux usées de la ville de m'rirt, (maroc) [physico–chemical characteristics of wastewater from the city of m'rirt, (Morocco)], Int. J. Innov. Appl. Stud., 17 (2016) 791–803.

[23] C. Hajji, A. Bendou, M. Hassou, Caracterisation des rejets liquides d'une unite de reparation, Revue internationale d'héliotechnique, 45 (2013) 29–36.

[24] Organisation Mondiale de la Santé (OMS), L'utilisation des eaux usées en agriculture et en aquaculture: recommandations à visées sanitaires, Genève, 1989, p. 84.

[25] L. Kabour, Abdesselem, Hani, Azedine, Chebbah, Impact des eaux usées domestiques sur l'environnement , et évaluation de l'indice de risque sur la santé publique: Cas de la ville de Bechar, SW Algérien, Eur. J. Sci. Res., 53 (2011) 582–589.

[26] F. Amraoui, Etude hydrochimique des nappes de témara et de la chaouia côtière (meseta marocaine), Bulletin de l'Institut Scientifique – Rabat, 22 (2000) 71–80.

[27] O. El rhaouat, I. El kherrati, F. El khayyat, H. Chiguer, K. Ezziani, A. Ibeda, M. Fareh, Y. Saidi, K. El Kharim, D. Belghyti, Physic–chemical evaluation of urban wastewater of the town of sidi kacem, Comput. Water Energy Environ. Eng., 3 (2014) 30–35.

[28] El Achheb, Mania, Mudry, Processus de salinisation des eaux souterraines dans le bassin Sahel– Doukkala (Maroc occidental), First Int. Conf. Saltwater Intrusion Coast. Aquifers, (2001) 1–13.

[29] Zerouali, Lakfifi, Larabi, Ameziane, Modélisation de la nappe de chaouia côtière (Maroc), First International Conference on Saltwater Intrusion and Costal Aquifers – Monitoring, Modeling, and Management, 1 (2001) 1–11.

[30] S. Najib, A. Fadili, M. Khalid, R. Joelie, Etude de l'évolution de l'intrusion marine dans l'aquifère de la chaouia côtière. Study of seawater intrusion evolution in the aquifer of coastal chaouia, J. Sawis, 2015-N°1 (2015) 5–12.

[31] E. Derwich, L. Benaabidate, A. Zian, O. Sadki, D. Belghity, Caracterisation physico–chimique des eaux de la nappe alluviale du haut sebou en aval de sa confluence avec oued Fes, Larhyss J., 08 (2010) 101–112.

[32] N. Nouayti, D. Khattach, M. Hilali, Evaluation de la qualité physico–chimique des eaux souterraines des nappes du jurassique du haut bassin de ziz (haut atlas central, Maroc) assessment ofphysico–chemical quality of groundwater of the jurassic aquifers inhigh basin of ziz (Central High Atlas, Morocco), J. Mater. Environ. Sci., 6 (2015) 1068–1081.

[33] B. Abbou, M. Elhaji, M. Zemzami, F. Fadil, Determination de la qualite des eaux souterraines des nappes de la province de taza, Larhyss J., 16 (2013) 77–90.

[34] A. Fakih lanjri, J. Brigui, A. El cadi, M. Khaddor, F. Salmoune, Caracterisation physico–chimique et bacteriologique des eaux souterraines de Tanger, J. Mater. Environ. Sci., 5 (2014) 2230–2235.

[35] M.L. Belghiti, A. Chahlaoui, D. Bengoumi, R. El Moustaine, Etude de la qualite physico chimique et nappe plio–quaternaire dans la région de meknès, Larhyss J., 14 (2013) 21–36.

[36] W. Ayad, M. Kahoul, Evaluation de la qualité physico–chimique et bactériologique des eaux de puits dans la région d'el –harrouch (N.E–algérie) [assessment of physico– chemical and bacteriological quality of well water in the region of El–Harrouch (N.E– Algeria)]," J. Mater. Environ. Sci., 7 (2016) 1288–1297.