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Production of drinking water through double treatment (conventional and demineralization) of Ait Massoud Dam water at the Kasba Tadla station (Morocco)

T. HACHI[a], I. IDRISSI[a], M. DOUBI [b], O. Boumalkha[a], T. AINANE[a], M. KHAFFOU[a], E.H. ABBA[a]*

[(a)]Biotechnology, Analytical Sciences and Natural Resources Management research team. Khénifra Higher School of Technology. Sultan Moulay Sliman Univ. Beni Mellal. Morocco.

[(b)] Laboratory of organic chemistry, inorganic, electrochemistry, and environment, Faculty of Science, University Ibn Tofail, B.P 133, 1400, Kénitra, Morocco

** Corresponding author:*
e.abba@usms.ma

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Abstract

Drinking water program for the people of the Tadla plain and the phosphates plateau aims to secure in the short, medium and long- term the services of 1080,000 inhabitants, of which 530,000 are in rural areas. This program covers Tadla’s "central Morocco" treatment station with a flow rate of 1600 L/second, a demineralization station of 330 L/second and a 15000 m3 reservoir that is continuously fed. The raw water from the Ait Massoud dam undergoes several treatments at the station before being distributed in the drinking water circuits, including conventional treatment with its various stages (settling, coagulation, flocculation, and decantation) and bilayer filtration. Some of these treated waters then pass through the reverse osmosis to undergo demineralization. The demineralized waters are remineralized by lime water and are mixed with the filtered waters of the conventional station.The water produced at that station meets the requirements of the Moroccan standard NM 03.7.001 and the WHO guidelines, in addition a pH of 8 to 8.5; turbidity less than 0.3 NTU 95% of time and less than 0.5 NTU 5% of time; chlorides are less than 400 mg/l; iron, aluminum, and other components shall not exceed the maximum permissible values.

Keywords: *Ait Massoud dam, conventional treatment, demineralization, drinking water, Tadla plain, phosphate plateau.*

1. Introduction

In a planet where water cover 70% of its surface, one would think there would be no shortage in raw supply of the element that is the most vital for life. Freshwater on the other hand is becoming scarce and more difficult to acquire as time goes by, it accounts for only 3% of the world's supply of water, of which two thirds are either stored in frozen glaciers or downright unavailable for our use. Being in a semi-arid area in Africa, Morocco is no exception to the problem at hand [1, 2, 3]. In order to overcome the freshwater shortage, the significant degradation of its quality due to various anthropic activities [4, 5] and to close the increasing gap between water supply and demand in urban areas, the Government of Morocco is investing heavily in implementing large water infrastructures projects, inter-basin water transfer projects and desalination plants for its coastal cities. Moreover, through various nation-wide programs the country is working on improving access to water supply, domestic, industrial wastewater collection, treatment, and integrated water resources management, implemented by nine river basin agencies. Here, as an example of the aforementioned projects, we look at the brackish water desalination station Ait Massoud in the Tadla plain, which is located in the Khouribga phosphate plateau.

2. Materials and methods

2.1. Presentation of area study

The climate of the Khouribga region ranges from humid and sub-humid in the mountains to continental semi-arid to arid in the middle and south parts of the region. In addition, is characterized by two distinct seasons, the warm period, lasting from April to October with little or no precipitation episodes, and the cold season from November to March, generally associated with abundant precipitations. The average annual temperature is 18 °C reaching its peak at 38-40 °C in August, and its minimum at 3-4 °C in January. The annual precipitations range from 100 to 600 mm with an average of 280 mm. The region's main geological formations is composed of limestone, marls and sandstone, with ages ranging from Paleozoic to Quaternary. The water resources are derived from two system types: (i) the karst aquifer of the Atlas Mountains, and (ii) the superficial and deep aquifers of the Tadla plains, the so-called ''multi-layered system". The latter is composed of four aquifers: (1) Mio-Plio-Quaternary, (2) Eocene, (3) Senonian, and (4) Turonian (Liass), the latter being the main productive aquifer in the region. Figure 1 shows one of the most important aquifers in the Beni Mellal-Khenifr region and the water catchments for the Khouribga Centre region. The hydrologic network of the Khouribga region is characterized by the presence one of the largest rivers in the country "Oued Oum Er Rbiaa" with a length of 555 km; it takes source in the north-western High Atlas limestone and in the Middle Atlas. The river runs across the plain of Tadla and plateau of Phosphates, through the plain of Doukkala, to finally flow into the Atlantic Ocean at Azemmour city. The main tributaries of the Oum Er Rbiaa are Oude Derna, El Handek, Tessaout, Lakhdar and El Abid Rivers. It is regarded as an important hydraulic reservoir for the country. A set of eight dams have been built on it in order to generate hydroelectric power, to provide water for irrigation, and to supply domestic and industrial water. (Figures 2). Figure 1 shows the hydrographic network of the region and the main dams built in the Oum Er Rabia water basin.

2.2. Pretreatment

Membrane fouling and scaling in reverse osmosis units presents a major impediment to the effective and efficient operation of the system. As a result, the choice for an adequate pretreatment of brackish water is fundamental to protect the membrane from mineral, organic or bacterial fouling that can lead to a premature failure/malfunction of the membrane [6].

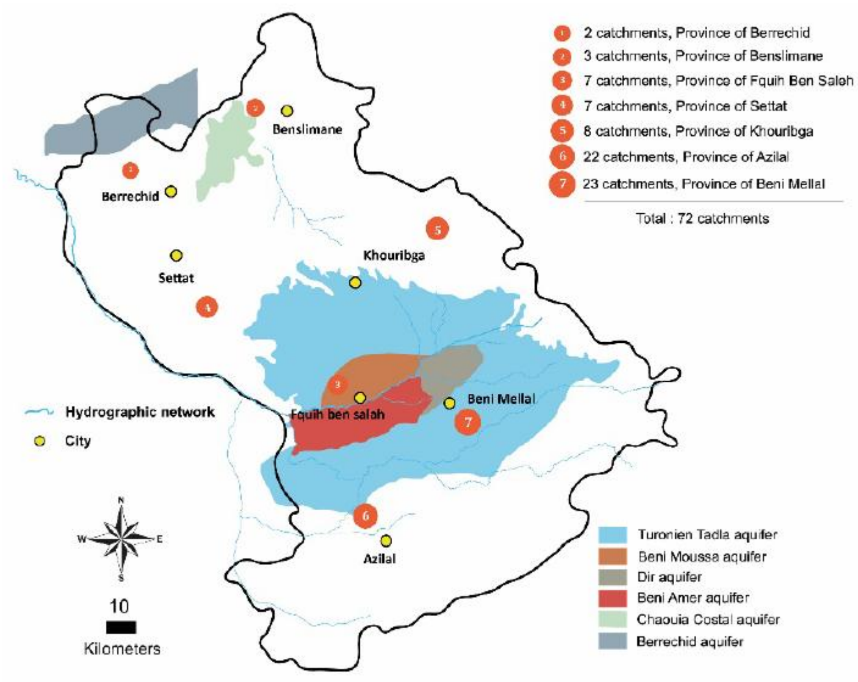

Figure 1. Aquifers and catchment of the Center Khouribga Region.

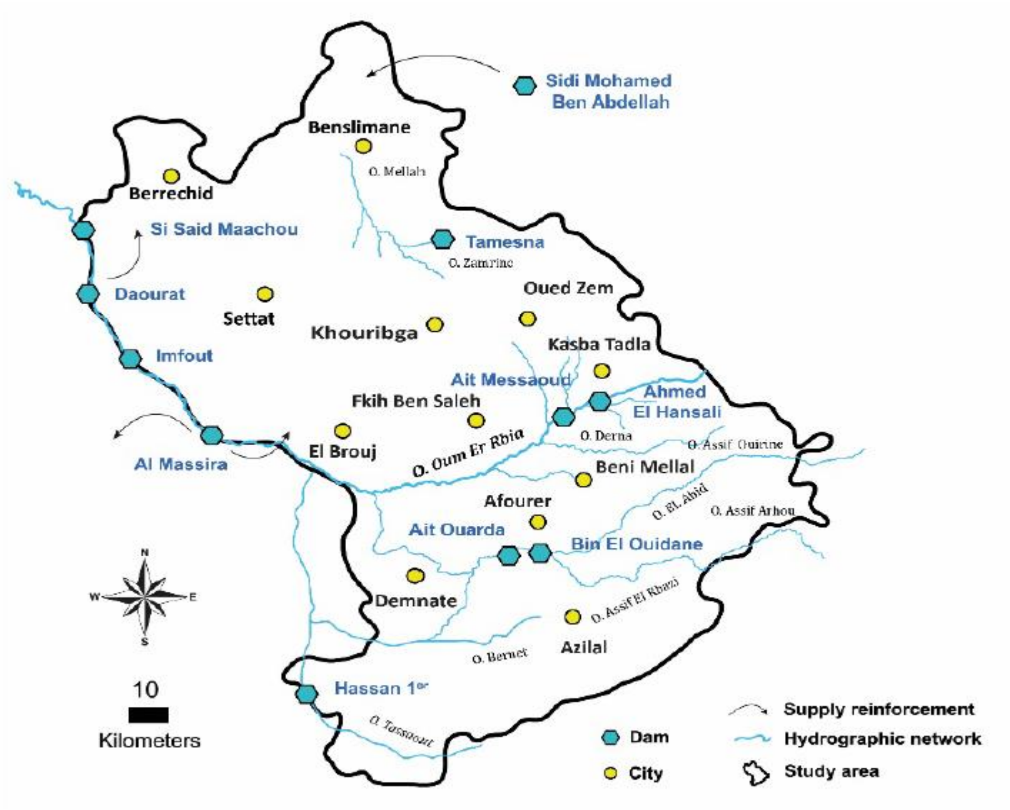

Figure 2. Hydrographic network and dams of the Center Khouribga Region.

Pretreatment of brackish water is intended to:

- Considerably reduce raw water turbidity as well as removing suspended matter/sediment associated with it.

- Eliminate all forms of hydrocarbons that are present in raw water
- Remove algae during their seasonal growth
- Reduce the fouling characteristics of water

2.2.1. Clarification

Feed water supply provided from the Ait Massoud dam presents high variability of suspended solids. To remove an important amount of suspended solids during periods of high load, and to make water suitable for the upcoming clarifying steps, a clarifying step is necessary. This is accomplished by 3 trains of rapid mixing and 6 trains of clarification all in parallel and independent. The clarifiers in use in the Ait Massoud plant are Inclined Plate Lamella type separators equipped with central drive scraper and can achieve 80g/L of Suspended matter in extracted sludge for every 10g/L of Suspended solids in raw water. To further optimize the clarifying efficiency, a polymer is injected with a dosage of 0,5mg/l on average and 2mg/l in peak. The clarifiers are in use only when the suspended solids concentration exceeds 2g/l, otherwise they can be bypassed with no consequence on the quality of treated water.

Table 1. Characteristic of clarifier station

Parameter	**Unit**	**Value**
Nominal feed flow rate	l/s	1 842
	m^3/h	6 631
Rapid mixing: Coagulation		
Number of trains	u	3
Nominal feed flow rate by train	l/s	614
	m^3/h	2 210
Coagulation vessel volume	m^3	74
Residence time in the coagulation vessel	min	2
Lamellar clarification		
Number of trains	u	6
Nominal feed flow rate by train	l/s	307
	m^3/h	1 105

2.2.2. Decantation

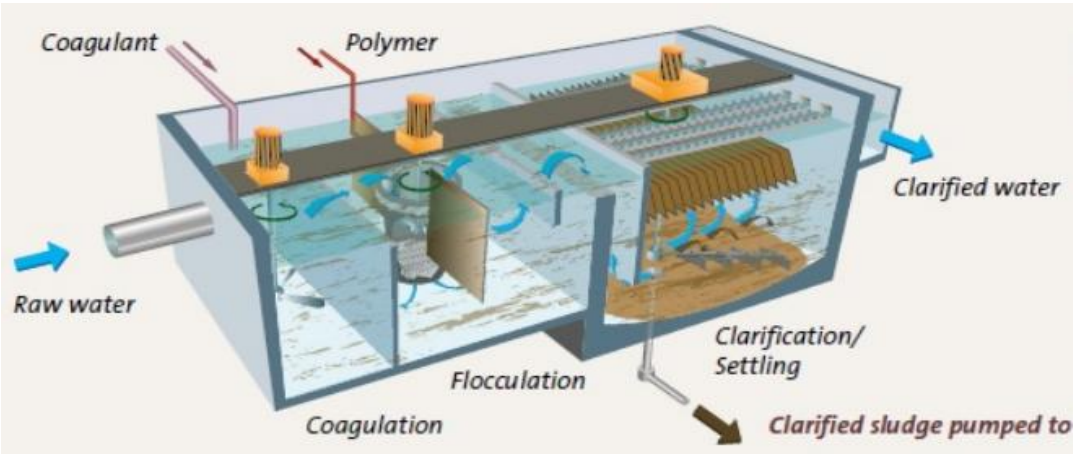

Figure 3. Lamellar clarifier.

The decantation station is comprised of 3 trains with 2 clarifiers (Figure 3), each is preceded with physiochemical conditioning in order to increase the size of the floc thus improving the settleability of the suspended solids.
The decantation is comprised of the following steps:

Coagulation: every pair of clarifiers is equipped with a coagulation vessel with rapid mixer configured to ideally mix the reagents. The membranes are very sensitive to metallic salts which are eliminated by coagulation using the reagents alumina sulfate and ferric chloride according to the following reactions:

Alumina Sulfate: $Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2$

Ferric Chloride : $2 FeCl_3 + 3 Ca(HCO_3)_2 \rightarrow 3 CaCl_2 + 2 Fe(OH)_3 + 6 CO_2$

Flocculation: a polyelectrolyte polymer is used to destabilize suspended solids and induce them to approach close enough together, make contact and progressively form larger flocs making them heavy enough to be settled [7, 8]. The degree or extent of flocculation is governed by both applied velocity gradients and time of flocculation. These two parameters influence the rate and extent of particle aggregation and the rate and extent of breakup of these aggregates. This is achieved by slow mixing and residence time of 20min in the flocculation vessel.

Decantation: The clarifier used in the Ait Messaoud station is Inclined Plate Lamella type separators. This choice of this type of clarifier is due to the advantage in space saving compared to conventional settlers. It's enhanced hydraulic distribution of the water and the decreased turbulences improve the settleabilty of less soluble flocs [9].

2.2.3. Dual media filtration

Water from the decantation station is directed by gravity to the 12 dual media filter sand-pumice stone bank [10], (Figure 3).

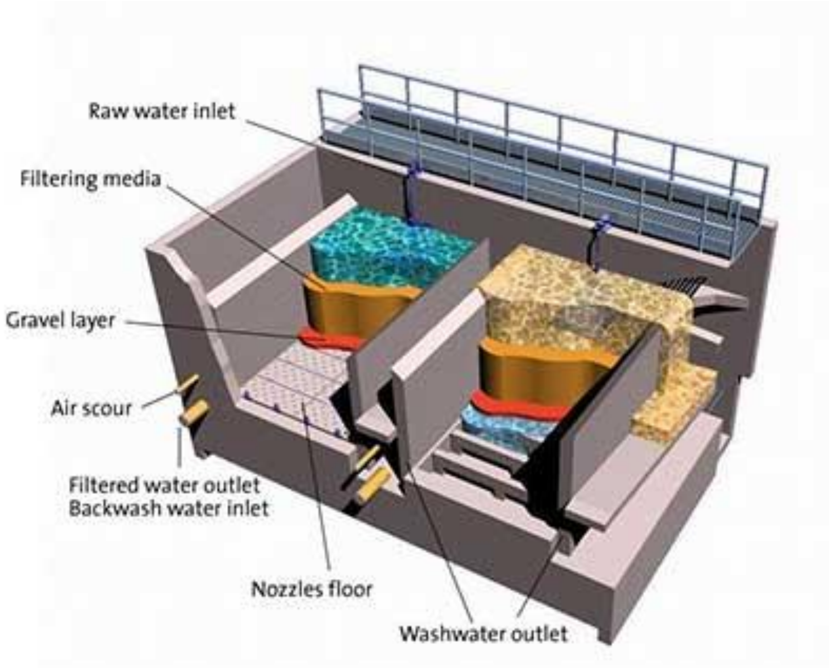

Figure 4. Dual media filter.

After the clarification phase, water is directed by gravity to 12 dual media filter sand-pumice stone bank. The dual media filter applied in the Ait Massoud station is Filtraflo dual media. At this stage suspended solids in the water is of 3 NTU (95% of the time) otherwise 5 NTU (5% of the time). The filter is comprised of a gravel layer of thickness 0,1m covered with a 0,7m sand layer, itself covered with a 0, 7 thick layer of pumice stone. Water height above the filter media is 1m in order to prevent the eventual degassing, the resulting hydrostatic load/pressure allows maintaining a positive pressure within the filtering media (Table 1).

Table 2. Granulometry of the different elements

Media	Grain size	Uniformity coefficient
Gravel	5 mm	1,5
Sand	1,25mm to 1,95mm	1,3
Pumice stone	0,6mm to 2mm	1,4

2.3. Demineralization

2.3.1. Low pressure pumps and microfiltration

Four dry centrifugal low pressure pumps supply water to the microfiltration station [11]. Physical treatment of the filtration step is followed by a chemical treatment in order to avoid carbonated precipitation, this is achieved by injection of sequestrant to eliminate untreatable precipitations by simple acidification, and in particular silica salts precipitation. A Hydrex sequestrant is used for this purpose (Figure 5). A filter bank comprised of three micro cartridge filters with 5um mesh is used as a last protection step of the membrane fouling before water reaches the reversed osmosis plant [12].

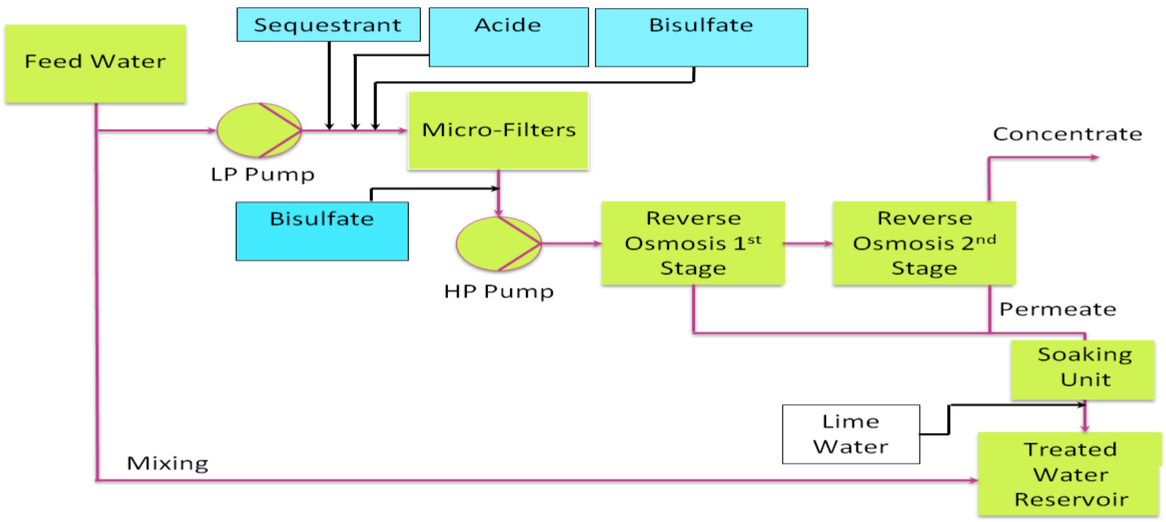

Figure 5. Demineralization process.

2.3.2. High pressure pumps and demineralization

Pressurization of the microfiltered water is ensured by four high-pressure pumps each with a nominal flow rate of 147 l/s, one of which is a stand by pump to ensure the pressurization function in case of emergency. The demineralization station is comprised of three identical trains capable of treating 147 l/s for a combined nominal flow of 440 l/s.

Each train is composed of a chassis containing 67 pressure vessels divided into two stages, 45 vessels in the first stage and 22 vessels in the second stage. Each vessel is loaded with 8 membranes for a total of 536 membranes per train and

1608 membranes for the entire plant. The two pressure stages are installed in “series-rejection” with no pumping in between, ie the concentrate coming from the first stage is the feeding supply for the second stage. The Table 4, shows the different characteristics of the reverse osmosis station.

Table 3. Characteristic of microfiltration

Parameter	Unit	Value
Flow rate to be treated	m3/h	1584 (3 x 528)
Number of microfiltres	U	3
Type		Polypropylene Cartridge
Cutoff point	µm	5
Flow rate per microfiltre With N µfilters With N-1 µfilter	 m3/h m3/h	 528 792
Maximum filtering speed	m/h	6

Table 4. Characteristic of reverse osmosis station

Parameter	Unit	**Value**
Number of osmosis trains	u	3
Data per osmosis train		
Feed flow rate	m3/h	528
Conversion rate	%	75
Permeate flow	m3/h	396
Concentrate flow	m3/h	132
Operational pressure vessels	u	67
1st stage pressure vessels	u	45
2nd stage pressure vessels	u	22
Number of membranes per pressure vessel	u	8
Number of membranes	u	536
Number of membranes in 1st stage	u	360
Number of membranes in 2nd stage	u	176
Flow through the membranes	l/m2.h	19,9

2.4. Remineralization

2.4.1. Lime water saturator

The reverse osmosis process is non-selective, it removes all the minerals that makes it safe for human consumption, and it is highly corrosive and can cause dietary. To conform with the Moroccan standards/directive NM 03.7.001 relating to the quality of water intended for human consumption, a remineralization step is in order to bring the properties of osmosis water to the qualitative guarantees: CaCO3 saturation level between 1 ,2 and 1,5 (or saturation index comprised between 0 and 0 ,1-0,2), minimum of 8°F Ca, minimum of 8°F of TAC (complete alkalimetric title), pH of 8 to 8,5, turbidity NTU less than 0,5 (5%of the time) and 0,3 (95% of the time). In Ait Massoud station this is

done by injecting lime water into treated water reservoirs .RO water is remineralized by the reaction of CO2 contained in RO water and lime water according to the following reaction:

$$2CO_2 + Ca(OH)_2 \rightarrow Ca^{2+} + 2HCO_3^-$$

The injection point is located downstream so as to ensure a minimum contact time of 30min between osmosis water and Chlore in optimal pH conditions. Lime water is prepared in two saturators from lime milk, itself/originally made of hydrated lime.

2.4.2. Treated water.

Water out of the osmosis plant is conducted by gravity to the Treated water Reservoir to be mixed with filtered water coming directly from filtered water reservoirs. It is possible to bypass the demineralization step entirely in order to send the nominal flow of the filtering station directly to the treated water reservoir.

3. Results and discussion

3.1. Temperature

The recorded temperatures (Figure 6) of the feed water showed a gradual increase from one month to another during the year, ranging from 11,6°C in the winter/January and reaching its peak at 28,6°C in summer/July. Change in feed water temperature influences heavily the separation performance, mass transfer and surface fouling for brackish water RO membranes. Also, it takes much less pressure to produce a desired flux at higher feed water temperatures [13, 14].

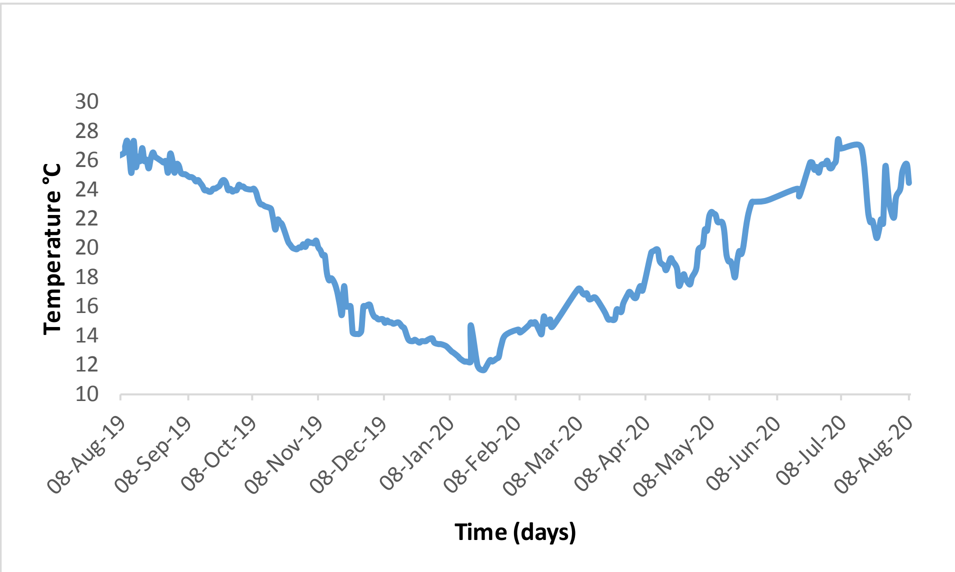

Figure 6. Evolution of the temperature of feed water.

3.2. Electrical Conductivity

The electrical conductivity (Figure 7) depends on the load of the endogenous and exogenous organic matter, generating salts after decomposition and mineralization, and also on evaporation phenomenon, which concentrate salts in water. High levels of conductivity are observed in raw/feed water, which may increase the fouling of the membranes [15]. These important values of EC are due to significant amounts of dissolved salts and likely also linked to both agricultural and domestic activities. Water out of the demineralization process shows very low levels of EC ranging from 11,6 µs/cm to 44 µs/cm, proving that the RO successfully removed an important amount of minerals and salts from the water. After the remineralization step by lime water we observe values of EC directly in proportion

with flow rate of feed water, this is due to the increased filtered water to osmosis water ratio in the treated water in periods of high demand, but always in line with [16] for drinking water that states that EC value should not exceeded 2500 µS /cm at 20°C.

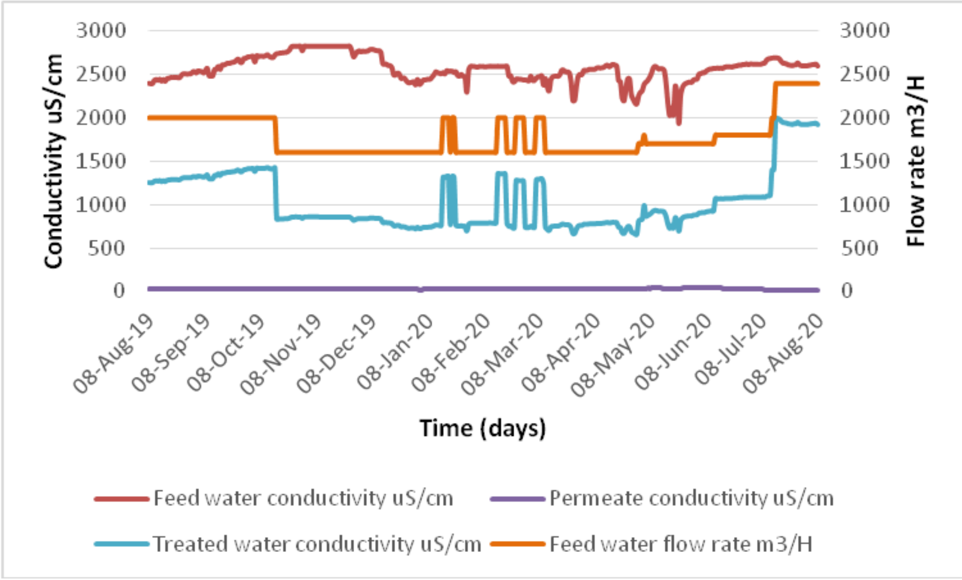

Figure 7. Evolution of conductivity of water in different stages.

3.3. Turbidity

For Turbidity, (Figure 8) shows high variability of turbidity in feed water with a wide range between 4NTU and 97NTU, indicating that the water in Ait Messaoud dam has moderately polluted quality according to Moroccan standards. This is likely attributed to the colloidal and inorganic materials present in the water. The observed peak turbidity could be attributed to runoff after storm events. Water turbidity values downstream the filtration station are less than 3 NTU, proving that the clarifying steps (coagulation, flocculation, decantation) succeeded in reducing fine particles in water interfering with the transmission of light [17]. Observed treated water turbidity of less than 0,5NTU shows that the filtration and RO steps operate successfully, thus bringing turbidity to low levels (less than 0,5NTU) to comply with the Moroccan and WHO standards for drinking water.

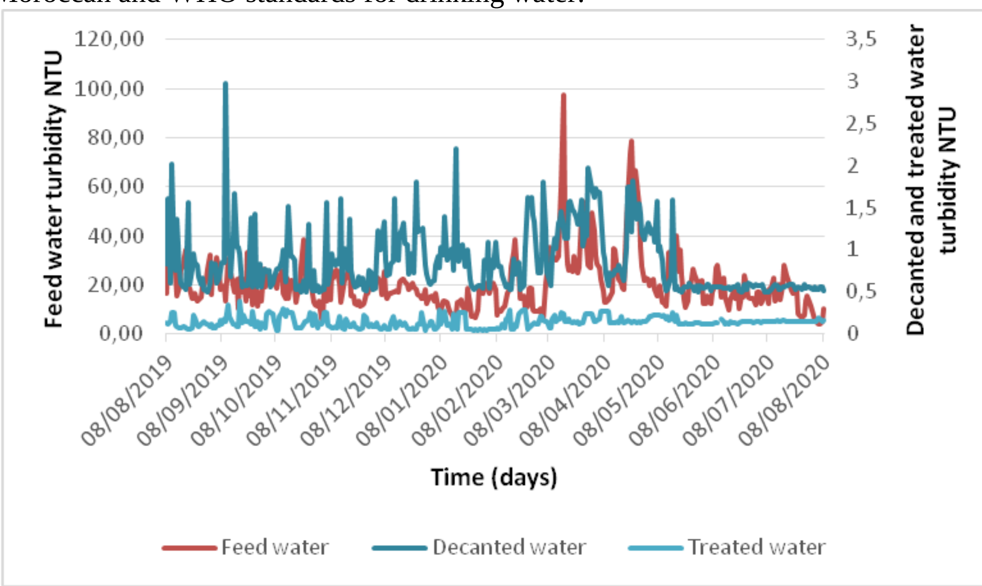

Figure 8. Evolution of water turbidity at different stages.

3.4. Potential Hydrogen

Potential Hydrogen (pH) is a crucial parameter to evaluate the acid-base nature of water. It indicates the acidic or alkaline condition of water. The measured pH (Figure 9) values in feed water range from 8 to 8, 85. This alkaline character could be attributed to the photosynthetic activity of phytoplankton. Decanted water shows an average decrease in pH by 1, this is due to elimination of dissolved carbon dioxide by coagulation and flocculation in the clarifying step. The remineralization process brings pH level to a range of 6,5 to 8,5 which is within the desirable levels recommended by the WHO (6,5 to 8,5) and complies with the Moroccan standards

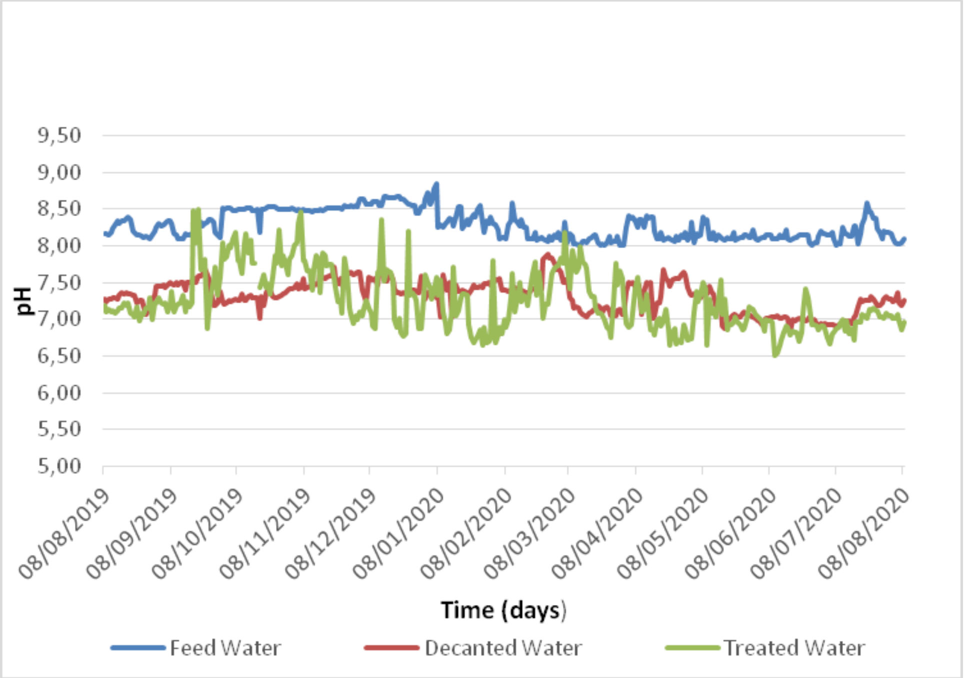

Figure 9. Evolution of pH in different stages.

4. Conclusion

The water produced at that station meets the requirements of the Moroccan standard NM 03.7.001 and the WHO guidelines, in addition a pH of 6.5 to 8.5; turbidity less than 0.3 NTU 95% of time and less than 0.5 NTU 5% of time; chlorides are less than 400 mg/l; iron, aluminum, and other components shall not exceed the maximum permissible values.

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