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Wastewater reuse and mapping of irrigable soils: Case of Sidi Bel Abbes City, Algeria

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Abstract

This work aims to evaluate the treated wastewater from the activated sludge treatment plant in the City of Sidi Bel Abbes (North-Western Algeria) which is required for reuse in irrigation. The control of irrigated areas downstream is done based on a pedological study. Physico-chemical analysis such as (pH, BOD_5, *COD* and *SS*) indicate results in Algerian and international standards required by the WHO. The Sodium Adsorption Ratio and Electrical Conductivity values of the treated wastewater belong to the C3-S1 class. The treated wastewater has a fairly good microbiological quality that meets Algerian standards. The helminth eggs are practically absent. The concentrations of heavy metals are much lower than the limits prescribed in the Algerian decrees. Therefore, the overall processing plant efficiency is satisfactory and has the characteristics of a good treated water quality for reuse in the field of irrigation while protecting the environment. The pedological study of the soil samples shows that the most dominant fraction is undeveloped calcimagnetic. The planned irrigation plain covers an area of about two thousand hectares. Depending on the crops to irrigate; the development and nature of the necessary or recommended improvements, the proposed irrigation perimeter could be classified into five categories in which only three categories are irrigable. Water projects have been proposed to ensure the irrigation of three subdivided sectors.

Key words: *bacteriology, physico-chemical parameters, reuse, soil, Sidi Bel Abbes City, wastewater, wastewater treatment plant (WWTP)*

INTRODUCTION

Treated wastewater has been increasingly used around the world for irrigation, environmental applications, industrial use, groundwater recharge, urban use, indirect potable use and in some rare cases, direct potable use [DEHGHANI *et al.* 2007; GATTA *et al.* 2016]. About 80% of urban water use is in wastewater [WAGHMARE *et al*. 2010]. The quality of wastewater can be defined by physical, chemical and biological properties. The principal causes preventing the expansion of effluent reuse worldwide are public health and environmental concerns. To reduce the potential risks to acceptable levels, many countries have set regulations or guidelines governing effluent reuse. Wastewater treatment and irrigation is an attractive option, especially in arid and semi-arid areas, as it provides an additional source of water and renewable and reliable fertilizer [FAO 2003].

In Europe, despite the fact that water reuse is already becoming an essential and reliable water supply option for many municipalities, there is still significant potential for an increased utilization of reclaimed wastewater [HOCHSTRAT *et al*. 2005]. In Algeria, the strategy of the Water Resources Ministry in purification has several objectives such as: 1) the protection of water resources, 2) the eradication of septic tanks, 3) the comfort and well-being of citizens, 4) the protection of the coastline in accordance with international conventions and 5) the reuse of treated wastewater, in particular for agricultural purposes as well as the protection of groundwater [BEMMOUSSAT *et al.* 2019].

The arid and semi-arid development policy pursued by the Algerian government aims to promoting the natural potential and coping with the scarcity of water which is caused by drought and the human potential by improving the standard of living of the rural populations. By reserving freshwater resources for drinking water and other priority uses, the treatment of wastewater reuse contributes to water conservation and has many economic and environmental benefits.

The World Health Organization (WHO) requires reuse to be in line with quality standards; otherwise it may cause a major health risk eg. consumption of vegetable crops irrigated with raw or partially treated wastewater can cause disease such as cholera.

Currently, Algeria has about 153 functional treatment plants, including 75 activated sludge stations, 75 natural or aerated lagoon stations and 3 planted filters. The installed capacity of the wastewater treatment plants (WWTPs) is more than 10 million equivalent inhabitants. The daily discharge of treated wastewater is more than 1.5 $hm^3 \cdot day^{-1}$.

The scientific objective of this work is firstly the evaluation of the pollutant load of the treated wastewater from the Sidi Bel Abbes City in order to reuse it in irrigation. The second purpose is to classify the soils and hence to identify the crops to be planted, given the lack of maps of irrigable areas in such semi-arid zone [FARAOUN, BENABDELI 2010]. These areas are classified based on the soil studies cited below.

MATERIALS AND METHODS

MATERIALS

The WWTP of Sidi Bel Abbes City includes primary treatment works such as the sand and the oil separator in addition to two primary settling tanks. The secondary treatment works include six aeration tanks and six sludge stabilization tanks as well as two secondary settling basins and a clarification tank. The activated sludge is conveyed to a thickening basin and then to the drying beds.

The activated sludge wastewater treatment plant is located North-East of the Sidi Bel Abbes City (North-West of Algeria) and it is operational since 1993 (Fig. 1). It has a capacity calculated for 220 thous. PE or of 28 000 $m^3 \cdot day^{-1}$ but remains under exploited comparing to its capabilities; it gets only 9000 to 9200 m^3 daily either barely 33% utilization rate. According to our investigation one observed that a large part of the wastewater is poured into the wadi [ONA 2014]. Through of Sidi Bel Abbes City for a distance of 4.4 km, Wadi Mekerra became a natural collector of urban and industrial untreated wastewater.

The pedological study of the plain of Sidi Bel Abbes, carried out on a topographic background with a total prospected surface covering about 2163 ha, has for main objective the inventory of soils and their potential; the consideration of various constraints to the development of the region and the creation of irrigable zones with an estimated area of 1618 ha.

The wastewater treatment plant is an activated sludge station certified ISO 14001. It is located on the edge of the Wadi Mekerra North-East of Sidi Bel Abbes City (Fig. 2).

According to various studies, the analysis of the climate data notes that the study area is semi-arid type with cold winter and a dry 6 months period [KORICHI *et al.* 2016; MAREF, SEDDINI 2018]. Average monthly temperatures are between 11°C and 25°C [INRA 2003] and the average annual rainfall are greater than 350 mm. The first frosts appear in October and vary from November to May and disappear in summer. The average annual evapotranspiration varies from 1400 to 1500 mm, the minimum is in December with a rate of 36.2 mm and a maximum is in

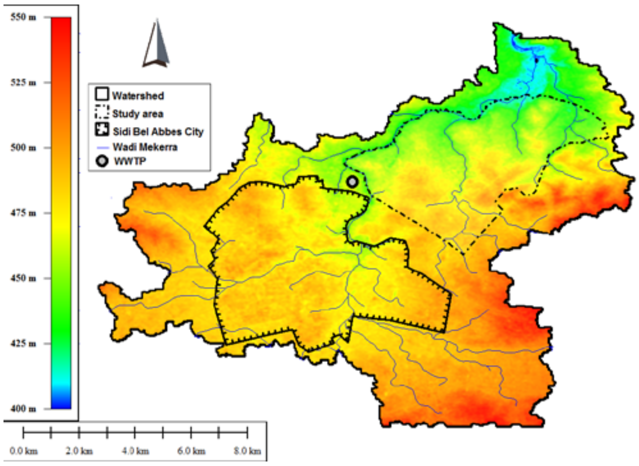

Fig. 2. Watershed of the study area; WWTP = wastewater treatment plant; source: own elaboration

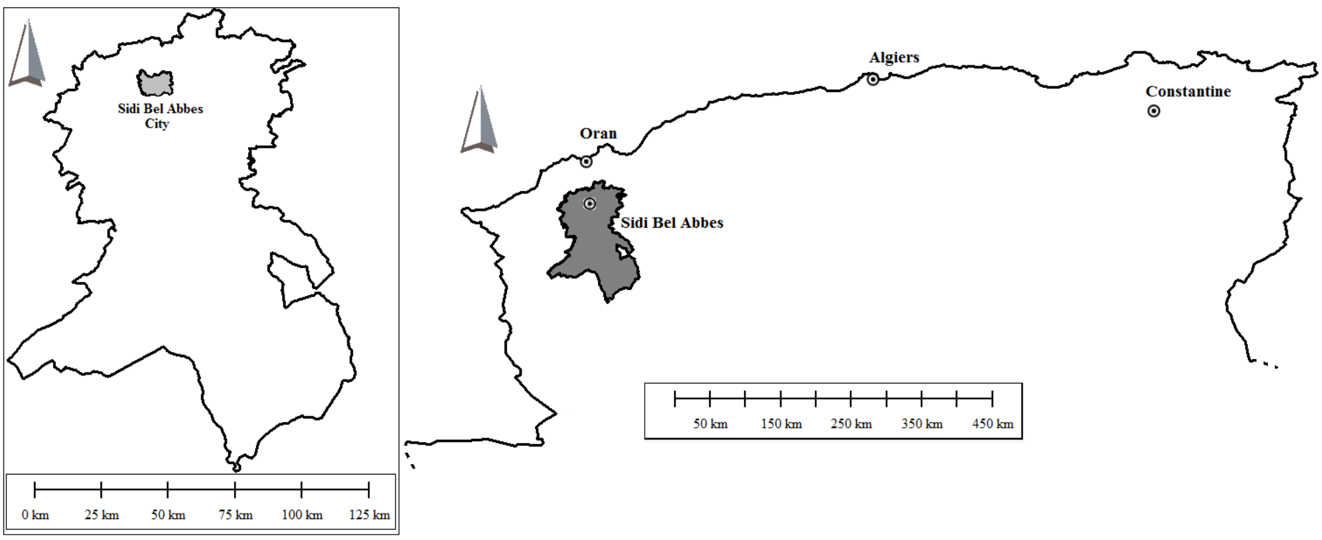

Fig. 1. Location of the study area; own elaboration

July with 242.3 mm. The annual evapotranspiration is about four times the annual average rainfall, which implies the need for irrigation.

Domestic waste from the Sidi Bel Abbes City represents a potential source of sewage that contributes to irrigation (Tab. 1).

Table 1. Domestic water needs and wastewater production at different horizons of the Sidi Bel Abbes City

Parameter	Horizon				
	2013	2015	2020	2025	2030
Total population $\cdot 10^5$	2.72	2.8	3	3.18	3.4
Water needs ($m^3 \cdot day^{-1}$) $\cdot 10^3$	40.88	41.95	44.75	47.73	50.92
Annual water needs ($hm^3 \cdot day^{-1}$)	14.92	15.31	16.33	17.42	18.59
Annual wastewater production (hm^3)	11.94	12.25	13.07	13.94	14.87

Source: own study.

EXPERIMENTAL PROTOCOL

Physico-chemical analysis

The samples were taken at the inlet and outlet of the treatment plant in the period from 2014 to 2017. These samples have been analysed in the laboratory of the National Sanitation Office (Fr. Office National d'assainissement – ONA), conform to the norm ISO/IEC 17025:2017. The parameters measured *in situ* are the pH, the temperature and the electrical conductivity (*EC*). The parameters analyzed in the laboratory are the Biochemical Oxygen required for five days (BOD_5), the chemical oxygen demand (*COD*) and the suspended solids (*SS*), according to the techniques recommended by RODIER [2005].

To determine the pH, the electrochemical measurement system was used using a pH meter of type pH 340i. Electrical conductivity is determined in accordance with ISO 7888: 1985. The BOD_5 was determined by the instrumental method using a *BOD* meter adapted to the incubation conditions and equipped with an agitator.

The determination of the *COD* is essentially by oxidation with potassium dichromate, $K_2Cr_2O_7$ in a solution boiled under reflux for two hours in the presence of the Ag^+ ions as oxidation catalysts and Hg^{2+} ions for complexing the chloride ions.

The suspended solids are measured using a centrifuge equipped with 100 cm^3 graduated buckets. Fill each well with 80 cm^3 sludge and centrifuge at 4000 to 5000 rpm for 10 minutes. At the end of the operation, one removes the supernatant and carefully recover all the mud pellets which are allowed to dry in an oven at 105°C until constant mass (at least for 12 h).

Ammonia nitrogen, nitrates and nitrites, calcium, magnesium and the sodium are determined according to the ISO 11732:2005, ISO13395:1996, ISO 6058:1984, ISO 6059:1984 and NFT90-019 respectively.

Bacteriological analysis

The study of bacteriological parameters focused on the quantification of faecal origin parameters: helminth eggs, faecal coliforms, total coliforms. The enumeration faecal and total coliform was performed in accordance with ISO 7937, incorporating the results of new epidemiological studies [BLUMENTHAL *et al*. 2000]. The modifications concern mainly the standard "helminth eggs" which, for certain categories ranged from 0.1 to 1 eggs per dm^3 according to [RODIER 2005].

RESULTS AND DISCUSSION

Since the implementation of the Environmental Management System (EMS) in 2010 according to the ISO 14001 standard in force by the National Sanitation Office (ONA), we have recorded zero non-compliant samples on 1445 analyzed samples. Note that the samples were taken carefully and almost daily.

pH VARIATION

The pH evolution of raw and treated wastewater from the Sidi Bel Abbes wastewater treatment plant during the study period (January 2014 to December 2017) showed that they are relatively neutral with values between 8.2 and 8.4 respectively (Fig. 3). However, it should be noted that pH values below 5.0 or above 8.5 favour the survival and growth of microorganisms.

ORGANIC MATTER AND SUSPENDED SOLIDS

Generally, the main quality parameters used to evaluate the overall organic load contained in the treated wastewater are the biological oxygen demand (BOD_5), the chemical oxygen demand (*COD*) and the suspended solids (*SS*) (Fig. 3).

Thus, for the treated wastewater and during the study period, the recorded BOD_5 values are between 23 and 33 $mg \cdot dm^{-3}$, with an average value of 26.25 $mg \cdot dm^{-3}$. For the raw water, these values are between 261 and 508 $mg \cdot dm^{-3}$ with an average of 359 $mg \cdot dm^{-3}$ (Fig. 3).

With respect to *COD*, the measurements indicate concentrations between 34.5 and 70 $mg \cdot dm^3$ with an average of 56.37 $mg \cdot dm^{-3}$ and between 704 and 845 $mg \cdot dm^{-3}$ with an average of 769 $mg \cdot dm^{-3}$ for raw water (Fig. 3).

The measurement values of suspended solids for treated wastewater are between 9.33 and 10.0 $mg \cdot dm^{-3}$ and between 542 and 728.7 $mg \cdot dm^{-3}$ for raw water (Fig. 3).

NUTRIENTS

The amount of excess nitrogen can have negative effects on the environment. Indeed, a large quantity of nitrogen can, on the one hand, contaminate groundwater and on the other hand, delay the maturation of certain crops and accentuate the trend towards the lodging of cereals [FABY, FRANÇOIS 1997].

Nitrogen. The average concentration of ammonium ions in treated wastewater is 3.73 $mg \cdot dm^{-3}$ with extreme values of 3.26 and 3.93 $mg \cdot dm^{-3}$. (Fig. 3). Similarly; the analysis indicates an average concentration of nitrites of the order of 0.055 $mg \cdot dm^{-3}$ for treated wastewater (Fig. 3) and of 0.14 $mg \cdot dm^{-3}$ (Fig. 3) for nitrates.

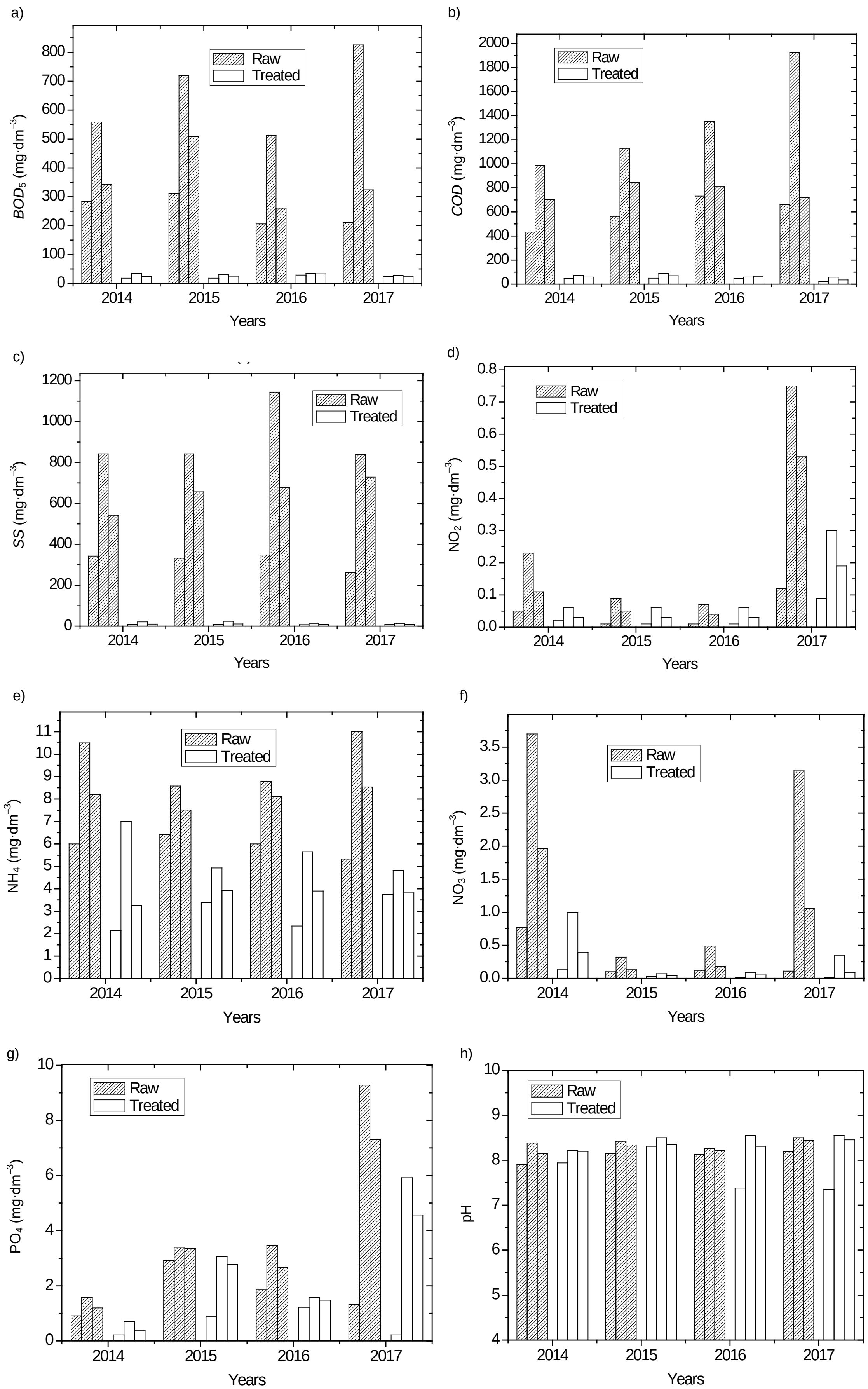

Fig. 3. Min-max-avg. results of physico-chemical analysis of raw and treated wastewater: a) biological oxygen demand (BOD_5), b) chemical oxygen demand (COD), c) suspended solids (SS), d) nitrites (NO_2), e) ammonium ion (NH_4), f) nitrates (NO_3), g) phosphates (PO_4), h) reaction (pH); source: own study

Phosphorus. The annual evolution of the phosphate concentrations in treated wastewater has shown that they are more concentrated with a mean value of 2.30 mg·dm^{-3}, in which the extreme values range from 0.39 to 4.57 mg·dm^{-3} (Fig. 3). In agriculture, phosphorus represents an essential component for the functional activity of the plant, which assimilates it in the form of orthophosphate [SOLTNER 2003].

CALCIUM, MAGNESIUM AND SODIUM

Table 2 shows the analysis results of the treated wastewater. It is noted that the concentrations of calcium, magnesium and sodium are respectively of the order of 102 mg·dm^{-3}, 29 mg·dm^{-3} and 220 mg·dm^{-3}. These minerals represent the calculation parameters to identify the absorption rate of sodium.

Table 2. Analysis results for the treated wastewater of calcium (Ca), magnesium (Mg), sodium (Na), electrical conductivity (*EC*) and sodium adsorption ratio (SAR)

Parameter	Measurement unit	Analysis method acc. to	Results (treated wastewater)
Ca^{2+}	mg·dm^{-3}	ISO 6059	102
Mg^{2+}	mg·dm^{-3}	ISO 6059	29
Na^{+}	mg·dm^{-3}	NFT90-019	220
EC	µS·cm^{-1}	ISO 7888	1 417
SAR		–	4.95

Source: own elaboration

ELECTRICAL CONDUCTIVITY AND SALINITY

The salinity level for the treated wastewater expressed in mean electrical conductivity is 1417 µS·cm^{-1} (Tab. 3). According to the American classification, this water is classified in the category C3. The SAR (sodium adsorption ratio) value is around 4.95, so the treated wastewater contains a small amount of sodium.

HEAVY METALS

The analysis of the treated wastewater from the treatment plant revealed the absence of heavy metals such as: aluminum, arsenic, beryllium, boron, cyanide, fluorine, phenol, lithium, molybdenum, selenium, vanadium (Fig. 4). However, the presence of cadmium, total copper, mercury, lead, total chromium, manganese, total nickel, total zinc and cobalt was detected with extreme values between 0.002 and 0.01. Certain elements such as iron, manganese, zinc, copper, boron and molybdenum are considered necessary, in very small quantities, for the development of plants [ABOUELOUAFA *et al*. 2002]. The different answers proposed are also examined by CAMACHO *et al*. [2008] and GUPTA, SOLANKI[2013].

BACTERIOLOGICAL ANALYSIS

Several tests were carried out. The average results of the microbiological analysis in the WWTP of Sidi Bel Abbes City show an acceptable level of total and faecal coliform in which the values are respectively (14.2 CFU·(100 cm^3)$^{-1}$ and 18.4 CFU·(100 cm^3)$^{-1}$. The helminth eggs are completely absent.

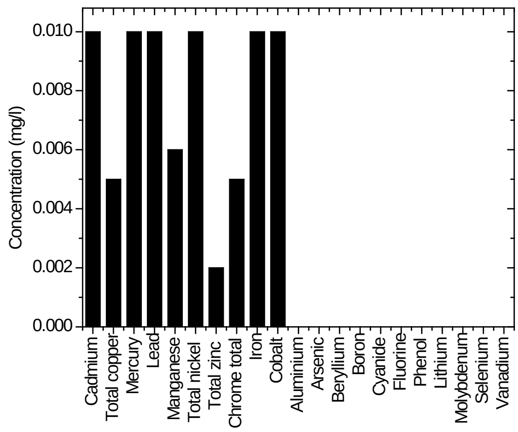

Fig. 4. Average concentration of heavy metals in treated wastewater; source: own study

The chlorination of effluents from the WWTP of Sidi Bel Abbes City has been stopped because it creates the regrowth of coliforms and faecal coliforms in the effluent chlorinated [PIGNATA *et al*. 2012; SANDERS *et al*. 2013]. However, the chlorination improves the microbiological quality of wastewater, without guaranteeing perfect safety given the resistance of certain microorganisms to the oxidizing agents. This could be achieved by boosting chlorine levels, which would increase the impact of chlorinated effluents on the environment [ABARNOU *et al*. 1990].

SOIL RESOURCES

Distribution of soils in the plain of Sidi Bel Abbes

The analysis of the 115 samples taken from the study area downstream of the WWTP concerns the following parameters: granulometry, organic matter, pH, electrical conductivity (salinity), active and total limestone which is of a great importance when it is on the surface.

The results of the analysis allow classifying the soils of the study area and evaluating their suitability for cultivation and irrigation. This classification is based on the degree of soil development, the alteration method of the materials and the composition and distribution of organic matter [LEGROS 1996].

The soil survey and the analysis of the different samples have showed the existence of two main soils classes.

- **Weakly developed soils**

These soils are not very dominant compared to the entire plain, they occupy 371.40 ha or 20.63% of the total area. One may found this type of soils on the edge of the wadi. They are generally formed on recent alluvium and agricultural inputs transported by water and non-coarse deposits. They are characterized by an important depth, a fine to medium texture and their salinity which exceeds 3 µS·cm^{-1}. The alluvial group is represented by three subgroups such as: salt-affected soils, modal soils and blackened soils.

1. Salt-affected soil:
- 0–20 cm: plow horizon, fresh state, light brown, incoherent, medium porosity, clay-silty texture, fine to medium structure, average biological activity, shell debris, effervescence with HCl;
- 20–50 cm: dry, dark brown, medium to low porosity, loamy clay texture, coarse polyhedral structure, quite compact, low biological activity, whitish spots probably saline, effervescence with HCl;
- 50–80 cm: fresh, low porosity, clay loam texture, coarse polyhedric structure fairly developed, accumulation of whitish trails, effervescence with HCl.

2. Modal soils:
- 0–20 cm: plow horizon, fresh state, dry, light brown, porous, inconsistent, texture balanced, fine polyhedric structure, good biological activity, effervescence with HCl;
- 20–55 cm: dry, dark brown, low aggregate porosity, balanced texture, coarse polyhedral structure, quite compact, effervescence with HCl;
- 55–85 cm: fresh, balanced texture, some limestone pebbles, continuous limestone accumulation in the form of encrustation, effervescence with HCl.

3. Blackened soil:
- 0–20 cm: plow horizon, humus, dry, light brown, good porosity between aggregates, little coherent, silty clay texture, fine polyhedral structure, good biological activity, effervescence with HCl;
- 20–50 cm: dry, dark brown, clay loam texture, coarse polyhedral structure, quite compact, effervescence with HCl;
- 50–80 cm: fresh, clay loam texture, coarse structure quite developed, some limestone pebbles, effervescence with HCl.

- **Calcimagnetic soils**

These soils are located in the elevated areas and quite far from the wadi, on a crust, or shallow limestone incrustation. They occupy an area of 1250 ha or 71.94% of the total area. The morphological characteristics of these soils are determined by the physico-chemical importance of the alkaline earth ions in the profile. Their genesis is mainly related to the calcium and magnesium richness of the parent rock in the form of carbonates. The studied soils belong to the subclass of carbonate soils which comprises two groups such as:

1. Group of calcareous brown soils

This type of soil dominates the plain of Sidi Bel Abbes City and includes the modal and blackened soils subgroups.

1.1. Modal soils:
- 0–30 cm: plow horizon, humus, dry, light brown, friable, medium to good porosity, incoherent, silty clay texture, fine to medium polyhedral structure associated with coarse polyhedral, good biological activity, effervescence with HCl;
- 30–60 cm: dry and darker, friable, medium porosity, silty clay texture, coarse polyhedric structure, rather compact, effervescence with HCl;
- 60 to 120 cm: fresh, friable, low porosity, clay-silty texture, fairly well developed coarse structure, some pebbles, effervescence with HCl.

1.2. Blackened soils

The blackened subgroup developed on recent alluvia from the wadi. Their relief has the appearance of a slight depression where the runoff accumulates. This darkening is due to waterlogging of ancient phenomenon.

1.3. Halomorphic soils

These soils evolve on an encroachment that is about 80 cm and has a salinity of up to 4 $\mu S \cdot cm^{-1}$ from 50 cm. They are found in enclosed and poorly drained areas.
- 0–20 cm: horizon plowing, humus, dry, light brown, friable, medium to good porosity, inconsistent, silty-clay texture, fine polyhedric structure, good biological activity, effervescence with HCl;
- 20–50 cm: dry, dark brown, friable, medium porosity, loam-clay texture, medium cohesion, medium biological activity, coarse polyhedric structure, fairly compact, effervescence at HCl;
- 50–80 cm: Fresh, low porosity, loam-clay texture, fairly developed coarse structure, some calcareous pebbles, effervescence at HCl;
- >80 cm: continuous calcareous accumulation in the form of encrustation.

2. Group of rendzina

The rendzina has a large amount of coarse elements (crust debris), the pH is alkaline, the electrical conductivity is low, and it is around 1.18 $\mu S \cdot cm^{-1}$ in the superficial horizon and drops to 0.13 $\mu S \cdot cm^{-1}$ in depth. This group includes a modal subgroup characterized by:
- 0–20 cm: horizon plowing, humus, dry, light brown, porous, inconsistent, silty clay texture, fine polyhedric structure, good biological activity, effervescence with HCl;
- 20–50 cm: dry, dark brown, slightly porous, medium biological activity, silty clay texture, coarse polyhedric structure, fairly compact, effervescence with HCl.

Mapping homogeneous areas of enhancement

According to the parameters studied, and the suitability of the soils for irrigated cultivation, the study area can be divided into five categories (Fig. 5). These zones are distributed according to their aptitude for crops to irrigate; the problems posed by their development and the nature of the works and arrangements to use.

- **Category I**

Priority irrigation zone with about of 53.6 ha. These are soils whose depth is greater than 80 cm, with a favourable structure, which do not pose major problems of development. Their irrigation skills are good for industrial and vegetable crops, cereals, fodder and shrubs.

- **Category II**

This zone occupies 513 ha. It is deep to medium-deep soils that require work such as deep plowing or subsoiling before any irrigation. Cultural skills are good for crops industrial, good to medium for vegetable crops and medium for cereals and fodder crops. Development works relate to organic and mineral amendments and flood control facilities.

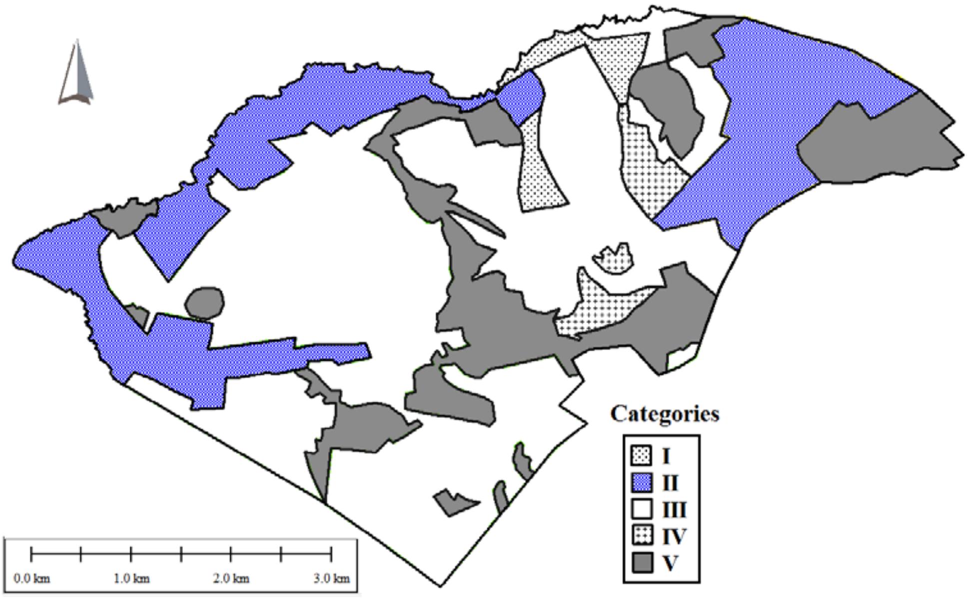

Fig. 5. Mapping of homogeneous areas for irrigation purposes; source: own study

- **Category III**

These are deep soils but need to be developed before any development using deep plowing or subsoiling, organic amendments, surface remediation and work against floods. Cultivation ability is good to medium for industrial and vegetable crops, and medium for cereal and forage crops. This category of soils covers an area of 1105 ha.

- **Category IV**

It covers an area of 61.43 ha. This is a non-irrigable area, characterized by the presence of calcareous encrustation on the surface (0–50 cm). Their development can only be done for dry crops.

- **Category V**

These are excluded areas: agglomeration, infrastructure, forests and rugged topography. It covers 416.27 ha.

From the soil analysis, irrigable plots were classified into three categories of homogeneous zones whose area occupies about 1618 ha or 75% of the total perimeter. As a result, the irrigated perimeter has been divided into three sectors (Fig. 6) based on the pedological, topographic and hydraulic data (Tab. 3).

Two pumping stations, three storage ponds and two lift pump basins are recommended for the irrigation of the three sectors. A series of pipes connects these basins whose characteristics are:

– 4510 m, ø 630 mm, PN16 for the lifting adduction,
– 4500 m, ø 400 mm, PN10 for the gravity adduction.

The storage basins capacities are (B1: 20 000 m^3, B2: 40 000 m^3, B3: 20 000 m^3) – Figure 6.

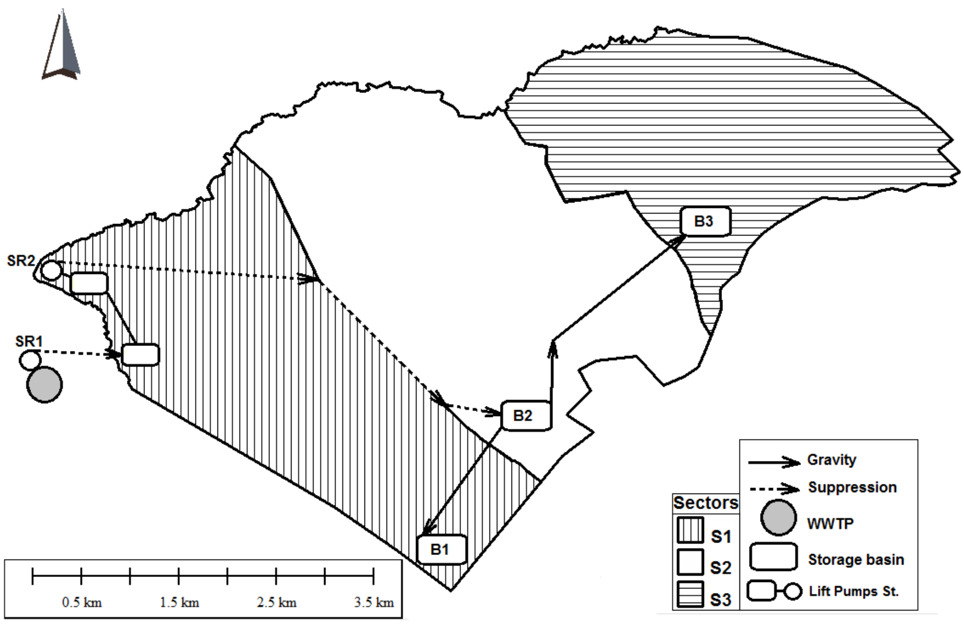

Fig. 6. Segmentation of the plots to be irrigated and the associated hydraulic equipment; source: own study

Table 3. Domestic water needs and wastewater production at different horizons of Sidi Bel Abbes City

Parameter	Measurement unit	Horizon			
		2015	2020	2025	2030
Discharge rate	$(m^3 \cdot day^{-1}) \cdot 10^3$	16.75	20.5	24.25	28
Volume of produced treated wastewater	$hm^3 \cdot year^{-1}$	6.11	7.48	8.85	10.22
Volume of treated wastewater collected for reuse	$hm^3 \cdot year^{-1}$	4.89	5.99	7.08	8.18
	$m^3 \cdot day^{-1} \cdot 10^3$	13.4	16.4	19.4	22.4
	$dm^3 \cdot s^{-1}$	155.09	189.81	224.54	259.26
Projected irrigation plots	ha	978.20	1197.20	1 416.20	1 635.20

Source: own study.

DISCUSSION

The irrigation plains of Sidi Bel Abbes City, especially those downstream of the wastewater treatment plant (WWTP) are little used for lack of water. Although in recent decades the use of new irrigation techniques has increased. In this work we have discussed the problem of the reuse of wastewater for agricultural purposes. These waters must meet the criteria required by Algerian legislation but also to international standards.

The activated sludge treatment plant in the city of Sidi Bel Abbes is not operating at full capacity. Approximately 16 410 m^3 of raw water is treated. The characterization of the quality of the treated wastewater from the purification plant of the Sidi Bel Abbes City requires the knowledge of certain essential parameters, namely the physico-chemical parameters (SS, BOD_5, COD, pH and EC) and microbiological parameters (faecal coliforms, total coliforms, helminth eggs).

Basically, the physico-chemical and microbiological analyses carried out on samples taken upstream and downstream of the WWTP in the period between 2014 and 2017 indicate a good purification performance. The values of the pH obtained in treated wastewater are almost neutral and acceptable for irrigation.

The treated wastewater from the Sidi Bel Abbes wastewater treatment plant, which is the subject of our study, has the characteristics of an effluent of generally satisfactory quality and meets Algerian standards aimed at achieving environmental objectives such as reuse. These values are also in line with WHO international standards.

In our case, the treated wastewater intended for the irrigation of the food crops does not pose a risk to the public health since the indicated values are acceptable comparing to the Algerian standards.

They contain little suspended solid (SS: 9.68 $mg \cdot dm^{-3}$ on average). The average biological and chemical oxygen demand is significantly lower than the limits prescribed in the Algerian decrees: namely (COD: 56.3 < 90 $mg \cdot dm^{-3}$, BOD_5: 25.5 < 30 $mg \cdot dm^{-3}$).

During the study period, the COD/BOD_5 ratio reflects generally an easily biodegradable organic material with a high purification performance of the WWTP.

For nitrogenous substances, the average concentrations of ammonium ions obtained for the treated wastewater are low. This is explained by the oxidation of organic matter, resulting in an increase of ammoniacal nitrogen. Nitrites and nitrates exist in treated wastewater in very small quantities and sometimes in almost negligible proportions which do not exceed 0.05 $mg \cdot dm^{-3}$ for nitrites and 0.1 for nitrates.

Phosphorus is present in wastewater in the form of mineral salts, mainly washing powders, and in the form of organic matter, especially faecal matter. The average phosphorus concentration is 2.3 $mg \cdot dm^{-3}$; which is close to the required limit value [WHO 1989].

The measured electrical conductivity (EC) is on average 1417 $\mu S \cdot cm^{-1}$ little than the required value 2250 $\mu S \cdot cm^{-1}$. It is the class of waters with high salinity: It is unusable especially for a weakly drained soil. However, it is allowed to salt-tolerant crops. The SAR value is 4.95; it is inferior to the American standard – 10. The water contains a small quantity of sodium, which is allowed to be used for irrigation. It belongs to class C3–S1 according to the riverside diagram classification. It is water suitable for plants with good salt tolerance and well arranged soil (good drainage) that requires a periodic monitoring of the evolution of salinity.

The analysis of the results for heavy metals, especially iron, zinc and manganese, shows that the concentrations do not exceed the recommended standards for irrigation purposes.

The water leaving the treatment plant in Sidi Bel Abbes City has a pretty good microbiological quality according to Algerian law [Arrítè interministèriel… 2012] setting specifications for treated wastewater used for irrigation purposes). This is confirmed by the results obtained for total (14.2 $CFU \cdot (100\ cm^3)^{-1}$ and faecal coliforms (18.4 $CFU \cdot 100\ cm^3)^{-1}$. The helminth eggs are completely absent.

CONCLUSIONS

The pedological study of the Sidi Bel Abbes plain allowed us to know the physico-chemical characteristics of the soils in the study area. According to the results of the analysis, the most dominant soils are calcimagnetic and little developed. Depending on the parameters studied and the suitability of the soil for cultures, the study area was divided into five categories in which only three categories are cultivable. The total irrigable area is approximately 1618 ha. Therefore, it is recommended and projected several hydraulic structures and works such as (two lifting stations and three storage basin connected by several ducts).

Since the installation of the Environmental Management System (EMS) in accordance with ISO 14001 which aims to achieve environmental objectives. The WWTP in the City of Sidi Bel Abbes manages to accomplish integrated waste management through the recovery of treated wastewater.

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