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Reuse study of sustainable wastewater in agroforestry domain of Marrakesh city

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ABSTRACT

The current work aims to perform a feasibility study of sustainable urban wastewater reuse in agroforestry domain of Marrakesh city in order to assess the environmental and the sustainability of urban wastewater reuse in agroforestry irrigation. To this end, wastewater physicochemical characteristics from Marrakesh full-scale wastewater treatment plant, soil physicochemical analysis and climate analysis were investigated. Finally, treated urban wastewater potential production in Marrakesh WWTP and challenge related to its reuse are provided. The obtained results of the present study reveals the feasibility of this practice in Marrakesh region. Regarding the actual situation, climate analysis highlight that the local climatic conditions is an ultimate challenge for water resources; soil analysis reveals a loss of soil fertility due to the decline in soil organic matter. To face this condition, treated urban wastewater reuse is a sustainable and promising strategy to face water scarcity, enhance soil fertility, preserve natural resources, develop local products and improve living conditions of agriculture and farmers.

1. Introduction

Morocco is a country where the availability of water resources is a key factor in the development of the agricultural sector, which is the basis of the Moroccan economy. Rainfall, hydroelectric dams, rivers and groundwater supply daily water for the farmland. However, these water resources have known in recent decades a drop in volume, due to natural conditions more difficult, the lack of political management at the institutional level and the lack of sensitivity to the water users, including farmers. Indeed, this pressure led to water resources has had severe impacts on the agricultural sector in many parts of Morocco and consequently on the economy.

The treated wastewater reuse is one of the alternatives that could be reliable and highly beneficial for irrigation and at the same time for agriculture. In fact, the treated wastewater can be an alternative to the use of clean water for agriculture, leaving fresh water used for other purposes including drinking water supply (WHO, 1989; WHO, 2006). Indeed, environmental and socio-economic advantages of this reuse can only be achieved if water through a WWTP (wastewater treatment plant) that will eliminate the components liable to harm the environment and public health (El Moussaoui et al., 2017).

The present study is within the framework of the FAO project GCP/RAB/013/ITA "Regeneration of Forests in Algeria, Egypt, Morocco and Tunisia by the use of treated wastewater in order to support livelihoods of smallholders and farmers." This project involves the construction of demonstration projects on the use of wastewater in forestry and agro-forestry systems in the different partner countries. In areas with arid or semi-arid climate, characterized by weakness of water resources, wastewater is a significant potential for forestry. The low level of health risk in agro-forestry applications also allows extending the interest to the reuse of water with a high content of organic matter and nutrients (N and P) (El Moussaoui et al., 2014). In this way we increase the value of reclaimed water and reduce the environmental impacts associated with the water treatments. Some experiences in Southern Italy did

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not show any kind of problem after 10 years of experimentation (Lopeza et al., 2006; Palese et al., 2009). In the Marrakesh region, and in order to protect the environment and water resources, by supporting their sustainable management and conservation, the FAO project will allow through the treatment and reuse of treated wastewater in irrigation of forest plantations who settled as part of the creation of a green belt throughout the OuedTensift over an initial area of about 10 hectares, extensible.

The current work aims to perform a feasibility study of urban wastewater reuse in agroforestry domain in Marrakesh city in order to assess the environmental and the sustainability of urban wastewater reuse in sustainable irrigation. To this end, wastewater physicochemical characteristics from Marrakesh WWTP, soil physicochemical analysis and climate analysis of the study site were investigated. Furthermore, treated urban wastewater potential production in Marrakesh WWTP and challenge related to it is reuse were illustrated and provided.

2. Materials and methods

2.1. Project site

The study area is located in the city of Marrakech, on the left side of the OuadTensifet located in the Haouz plain enclosed by the massive central High Atlas to the south and the north of Jbiletes and extends an area of 60 km^2. In order to protect the environment and water resources in this region. Through, supporting their sustainable management and conservation, the present project (FAO project) will allow through the treatment and reuse of treated wastewater in irrigation of forest plantations who settled as part of the creation of a green belt throughout the OuedTensift over an initial area of about 10 hectares, extensible (El Moussaoui et al., 2013) (Fig. 1).

2.2. Analytical methods

2.2.1. Wastewater physicochemical analysis

Wastewater physicochemical analysis such as total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), nitrate (NO_3^-), nitrite (NO_2^-), total phosphorus (TP) and orthophosphate (PO_4^{3-}) were determined in accordance with Standard Methods (AFNOR, 1997; APHA, 2005; Rodier et al., 2009).

2.2.2. Soil physicochemical analysis

Soil physicochemical analysis such as, such as pH, Electrical Conductivity (EC), Moisture, Organic matter (OM), total organic carbon (TOC), total phosphorus (TP) and assimilablephosphorus (Polsen) were performed according standard analytical methods (AFNOR, 2000).

2.2.3. Climate analysis

Climate analysis of Marrakesh city was performed for the period 1998–2012. The daily series of observed data of mean temperature, maximum and minimum temperatures, cumulative monthly and annual precipitation, wind velocity, relative humidity form SAADA weather station whose characteristic are presented in the following table (Table 1).

3. Results and discussions

3.1. Wastewater physicochemical characteristics

Physicochemical characteristics of wastewater along treatment stage from Marrakesh activated sludge wastewater treatment

Fig. 1. The study site.

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Table 1
Characteristic of SAADA weather station.

Latitude	31°38′10″
Altitude	411.6 m
Longitude	8°04′36″

plant during the experimental campaign are summarized in Table 2.

3.1.1. pH and electrical conductivity

The output effluent pH average was about 8.20 ± 0.03, which is in the range of Moroccan applied discharge standards limits [6.5–8.5] (Arrêté conjoint, 2013). Concerning the electrical conductivity (EC), the output effluent EC average was around 1623.75 ± 112 μs/cm, which was close to the Moroccan discharge standards limits (Arrêté conjoint, 2013).

3.1.2. Total suspended solids TSS

The amount of TSS in the effluent affects the efficiency of the disinfection process and defines the recommended TSS value of discharged effluent. The TSS average concentration of the final effluent was about 11 ± 1.5 mg·l^{-1}, which satisfy Moroccan applied discharge standards (TSS < 30 mg·l^{-1}) (Arrêté conjoint, 2013). The TSS average reduction was about 97%, which indicates that the Marrakesh WWTP process has performed adequately at conditions equal to or less than its design capacity with respect to the TSS removal and complied with discharge standards (RADEEMA, 2012).

3.1.3. Organic matter: COD and BOD$_5$

Activated sludge refers to a mass of microorganisms cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds. The COD and BOD$_5$ are used as the surrogate parameters to measure the organic matter available for the microorganisms. During this campaign experiment, the input effluent COD and BOD$_5$ average concentrations were 825.29 ± 44 mg·l^{-1} and 550 ± 25 mg·l^{-1}, respectively. In contrast, their concentrations in the output effluent were 29.93 ± 2.2 mg·l^{-1}and 6 ± 1.1 mg·l^{-1}, respectively, which are below Moroccan applied discharge standards (for COD < 120 mg·l^{-1}and for BOD5 < 40 mg·l^{-1}) (Arrêté conjoint, 2013).

In addition, the COD and BOD5 removal efficiencies were significant during this campaign period, up to 94% and 95% respectively. This result confirms that the Marrakesh plant performed well with respect to COD removal efficiency within the review period and complied with permit limits and Moroccan applied discharge standards (Arrêté conjoint, 2013; RADEEMA, 2012).

3.1.4. Nutrients: Nitrogen and phosphorus

Nitrogen removal has become an important part of wastewater treatment processes due to the significant impact of nitrogen compounds (NH_4^+-N, NO_3^--N andNO_2^--N) on the aquatic environment and more stringent legislation on wastewater discharges. To meet this demand, the most commonly used method for nitrogen removal is biological treatment based on aerobic nitrification and anoxic denitrification, both of which may produce nitrous oxide (N_2O) (Colliver and Stephenson, 2008).

The TKN input effluent average concentration was around 83.76 ± 11.2 mg·l^{-1}, whereas the output TKN concentration was about 15.7 ± 3 mg·l^{-1} which is close to the European Standards (10–15 mg·l^{-1}) (Jonsson et al., 2001) and bellow Moroccan applied discharge standards (40 mg·l^{-1}). The overall total kjeldahl nitrogen removal was 81% on annual average. This indicates a good overall performance during the campaign period.

Large quantities of phosphate present in wastewater is one of the main causes of eutrophication that negatively affects many natural water bodies, both fresh water and marine. It is desirable that water treatment facilities remove phosphorus from the wastewater before they are returned to the environment. Total removal or at least a significant reduction of phosphorus is obligatory, if not always fulfilled, in most countries (Jeanmaire and Evans, 2001; Gaterell et al., 2000; Stratful et al., 1990).

The TP input effluent average concentration was around 10.35 ± 2.1 mg·l^{-1}, whereas the output TP concentration was about 5.36 ± 0.8 mg/l, which is above the Moroccan applied discharge standards (2 mg·l^{-1}) (Arrêté conjoint, 2013). The average TP removal was 48%.

3.2. Soil physicochemical characteristics

The site physicochemical analysis result is summarized in the Table 3.

The pH was relatively high 8.25 ± 0.51 on average (Mallouhi, 1997). The electrical conductivity EC is typically used to indicate soluble salt concentration in soil. Because crops only remove small amounts of salt, salt movement and distribution in soil is directly related to water movement (Nakayama, 1986). In our case the EC average value was about 325.67 ± 107.11 μs/cm.

The total organic carbon (TOC), organic matter (OM), total kjeldahl nitrogen (TKN) and total phosphorus (TP) average contents of

Table 3
Soil physicochemical characteristics.

Parameters	Unit	Result (mean ± SD)	
pH	–	8.25	±0.51
Moisture	%	0.12	±0.03
Electrical Conductivity (EC)	μs/cm	325.67	±107.11
Total organic carbon (TOC)	%	0.75	±0.08
Organic matter (OM)	%	1.30	±0.15
Total kjeldahl nitrogen (TKN)	%	0.10	±0.01
Ratio C/N	–	7.47	±0.69
Total phosphorus	mg/g	1.57	±1.20
Assimilable phosphorus	mg/g	0.04	±0.02

Table 2
Physicochemical characteristics of wastewater along treatment stage.

Parameters	input effluent	primary treatment	secondary treatment	tertiary treatment	Removal efficiency
pH	7.89 ± 0.01	7.59 ± 0.02	8.05 ± 0.01	8.20 ± 0.03	
EC (μs/cm)	1964.43 ± 125	1790.71 ± 115	1641.71 ± 120	1623.75 ± 112	
TSS (mg/l)	346.86 ± 2.5	82.67 ± 3.2	53.79 ± 1.5	11.15 ± 0.5	97%
BOD5 (mg/l)	550 ± 25	325 ± 15	20.4 ± 1.5	6 ± 1.1	98%
COD (mg/l)	825.29 ± 44	488.43 ± 31	34.87 ± 3	29.93 ± 2.2	96%
TKN (mg/l)	83.76 ± 11.2	65.71 ± 8	15.96 ± 2.1	15.7 ± 3	81%
NO_3 (mg/l)	–	0.83 ± 0.2	5.61 ± 0.5	6.13 ± 0.7	
NO_2 (mg/l)	–	–	0.65 ± 0.1	0.58 ± 0.2	
TP (mg/l)	10.35 ± 2.1	8.1 ± 0.7	4.96 ± 0.1	5.36 ± 0.8	48%
PO_4 (mg/l)	6.83 ± 0.5	6.16 ± 0.2	4.68 ± 0.7	5.05 ± 0.7	26%

soil were 0.75%, 1.30%, 0.10% and 1.57 mg/g respectively. In addition C/N was about 7.47 (less than 10) which indicate that the soil of site study is mineralized with low organic matter reserves. In front of this situation, treated wastewater reuse could be an attractive option in order to improve soil fertility through (El Moussaoui et al., 2014; Lopeza et al., 2006).

3.3. Climate analysis

The Fig. 2 represents the daily observed data of monthly Temperature (minima and maxima T°C) and precipitation (P mm) during the period 1998–2012 form SAADA weather station whose characteristics are presented in Table 1.

According to Emberger, the zone of Marrakech is located in the arid bioclimatic stage characterized by scarce precipitation, grouped during the cold season, from September to May. The city is subject to an arid continental climate (hot and dry in summer, cold and wetter in winter). High evaporation and a high average temperature, with large temperature deviations (monthly and daily). The prevailing winds are from the west and northwest.

The temperature is influenced by the topography of region (Alain and Robert, 1966). As presented in Fig. 2 the temperature curve analysis showed a significantly increase of average monthly temperature from January to August. Thereafter, the significant decrease took place until January. In addition, July and August are the hottest months with a monthly average temperature of 27.64 °C; by contrast, January was the coldest month with a monthly average temperature of 10.96 °C.

Concerning precipitation, the analysis of monthly and annual rainfall can reveal a rainy period represented by five months (October, November, January, February and March), as more than 65% of annual rainfall received, and a dry season from May to September.

The ombrothermic diagram, which is the graphical depiction of temperature conditions and the monthly precipitation for the region of Marrakech during the period between 1998 and 2012, reveals a dry season form the end of May to the end of September.

3.4. Treated urban wastewater reuse in agroforestry

3.4.1. Potential of treated urban wastewaters in Marrakesh

Every year significant amounts of wastewater are discharged in the environment. The annual discharged volumes of Moroccan cities strongly increased during the last three decades. Therefore, they increased from 48 to 600 million m^3 from 1960 to 2005 to

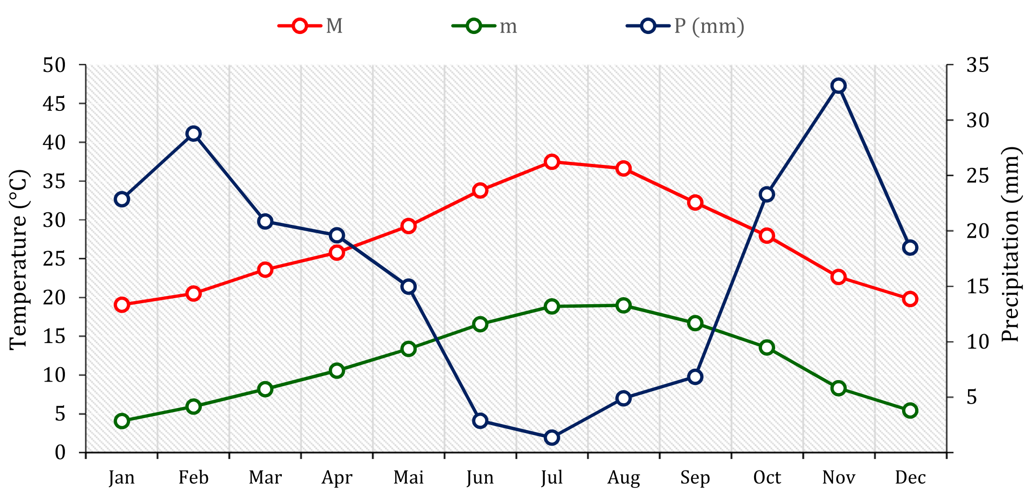

Fig. 2. Graphical representation of T-P Omrothermic diagram (1998–2012) (El Moussaoui et al., 2012).

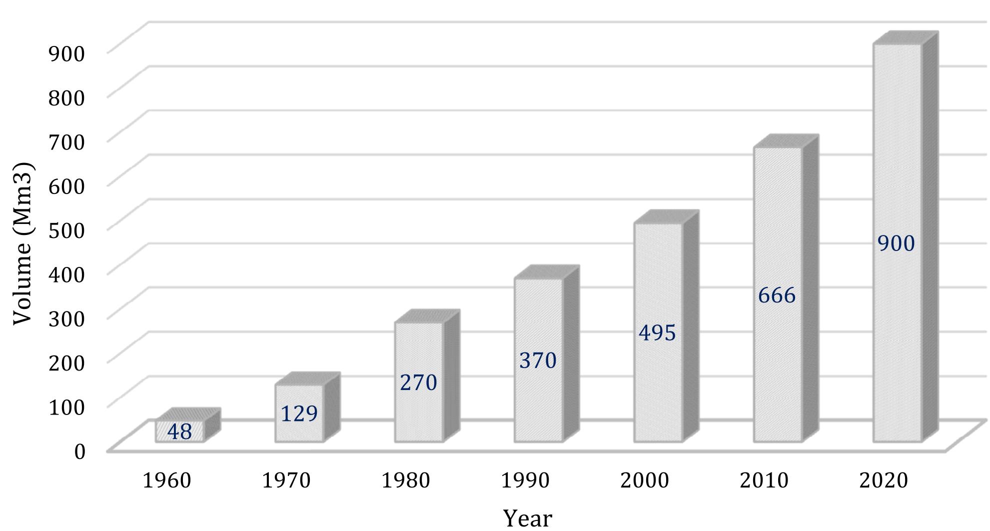

Fig. 3. Statistics and forecasts of wastewater production in Morocco (MnEnvr, 2015).

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reach approximately 666 million m^3 in 2010 (Fig. 3). In the same way, the established forecasts show that wastewater produced volume will continue to increase sharply to reach 900 million m^3 in 2020 (MnEnvr, 2015).

In Marrakech, the annual volume of urban wastewater treated by Marrakech activated sludge treatment plant was 33 million m^3 (RADEEMA, 2012). This WWTP the first activated sludge full-scale treatment plant in Morocco, which collects and treats urban wastewater of Marrakesh city in order to meet both standard requirements of the discharge into the natural environment and the health requirements for reuse of treated water in irrigation of green areas, including golf courses. The activated sludge plants represent the most widely used biological aerobic treatment processes, in which the biological degradation of both soluble organic and inorganic components and particulate matter carried out by microbial flocs. These flocs are traditionally separated from the liquid stream through gravity sedimentation. This medium load WWTP has a nominal capacity of 90,720 $m^3 \cdot day^{-1}$ and treats since 2011 the pollution equivalent of 1.3 million inhabitants per day characterized by 53 tons$\cdot day^{-1}$ of TSS, 58 tons$\cdot day^{-1}$ of BOD_5 and 145 tons$\cdot day^{-1}$ of COD (RADEEMA, 2012). It is considered as the first WWTP in North Africa to integrate wastewater treatment, biogas recovery from sludge, electricity and heat cogeneration, air treatment and water reuse.

3.4.2. Wastewater reuse in agroforestry

The interest in reusing and managing wastewater for irrigation is a rapidly growing practice in the world. Moreover, it is considered an attractive and environmentally option to minimize the ecosystems contamination by the direct wastewater disposal. In addition, it can improve soils physicochemical proprieties and nutrients contents (Sommers, 1977; Pomares et al., 1983; Heidarpour et al., 2007).

The increase in water consumption and awareness of users to protect water resources and the environment is encouraging a greater recovery of wastewater and more efficient and sustainable use of conventional water resources. The treated urban wastewater reuse is an important part of the cycle and is a growing practice. The present interest is due to social, economic and technical factors related to local situations (Mandi and Ouazzani, 2013). Obviously, the most important factor is the lack of traditional water resources caused by the growing population, supply increase linked to economic development (industrial, agricultural, tourism and civil) and change the hydrological cycles. This fact primarily concerns semi-arid and/or arid regions, but it is also of growing interest in areas with heavy rainfall, where the growth of urban centers determines a localized disproportion between resources and need. Therefore, it is necessary to find new water resources at increasing distances. In front of this situation, the wastewater can be an alternative to the use of clean water for agriculture, leaving fresh water used for other purposes including drinking water supply (WHO, 1989; WHO, 2006), also an interesting opportunities to protect water resources and environmental.

In Mediterranean countries, the agricultural sector has the biggest impact on the water consumption balance; therefore treated wastewater reuse for agricultural irrigation would significantly reduce global water consumption, allowing better transfer of water resources to more appropriate uses, such as drinking water. Furthermore, the treated wastewater recovery for irrigation may represent an effective alternative to discharge into lakes, rivers or seas with a lower environmental impact.

In a context of environmental degradation and water scarcity, urban wastewater reuse in agroforestry is an attractive and sustainable option for Morocco. Indeed, this practice could improve soil fertility, crop productivity and environmental sustainability. Indeed, the treated urban wastewater is regarded as a non-conventional water resource that must be valorised in agriculture, forestry and agroforestry domains. However, the current framework does not allow an important development of this sector, to this end several points must be solved and/or improved.

3.4.3. Constraint and challenge in urban wastewater reuse

Compared to the total wastewater amount produced in Morocco urban area, the current wastewater treatment rate is still low and reflects the shortage of municipal wastewater treatment plants (WWTP). In late 2012, the wastewater treatment level was around 37%. About 81 WWTP were in operation: 29% equipped with primary treatment, 45% with secondary treatment and 26% with tertiary treatment (Makhokh and Bourziza, 2011). As a response to this situation the National Program of Sanitation and Wastewater Treatment has been implemented since 2005. Among its main objectives, the PNA aims to achieve a connection rate to sewerage systems in urban areas of 75% in 2016, 80% in 2020 and 100% in 2030, to reach a treatment rate of collected wastewater of 50% in 2016, 60% in 2020 and 100% in 2030, and to treat wastewater with tertiary treatment and reuse at 100% in 2030 (PNA, 2015).

Despite this important progress in urban wastewater treatment. There still a lack and a delay in urban wastewater reuse compared to the total treated volume of wastewater (El Moussaoui et al., 2012; PNA, 2015). The current framework does not allow a significant development of this sector. Several points must be solved and/or improved, in particular:

- Clear definition of wastewater statute (owner/operator);
- Identification of an organization or service provider in charge of their valorisation;
- Definition of technical and administrative constraints to ensure the protection of users, residents and consumers of crops;
- Establishment of specifications for project development, implementation, monitoring and follow-up of installations;
- Taking into account the additional cost related to additional required treatment;
- Definition of financing method of the infrastructure needed for reuse;
- Technical training of treatment and reuse project managers and users;
- The direct involvement of actors and users at all levels;
- The establishment of a policy for the training of technical personnel specialized in the sector is necessary at all levels from the conception to the implementation and management of the projects;
- Similarly, difficulties exist for the development of this sector because of sociocultural blockages, encouraging to opt for a developed and adequate policy of information, consultation and participation of users;
- In view of the additional costs incurred in using wastewater, it seems desirable to have a financial incentive policy;
- Integrated management of treated urban wastewater reuse in order to protect environment and public health.

The combination of the results reported in this research study reveal the feasibility of sustainable wastewater reuse in especially in Marrakech region and generally in Moroccan context.. However, the country has experienced strong growth in its urban population and a proliferation of peripheral areas. Therefore, the population growth, excessive exploitations of groundwater and climate changes, stress on clean water availability and supply required the need to find alternatives water resources. In front of this situation, urban wastewater treatment and reuse is a sustainable and promising strategy. In addition, it is an interesting opportunities to protect water resources and environment.

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4. Conclusion

The reuse of treated urban wastewater has been applied in the last few decades in Morocco. The interest is now focused on the reuse of treated wastewater to solve several health, environmental, agricultural and economical issue. Although, this practice is an excellent strategy to face water scarcity in a context of regional food security, proper wastewater treatment to comply with current water irrigation norms and sanitary control should be in place to prevent abnormal health risks. The obtained results of the present study reveals the feasibility of this practice in Marrakesh. Regarding the actual situation, climate analysis highlight that is local climatic conditions is an ultimate challenge for water resources; soil analysis reveals a loss of soil fertility due to the decline in soil organic matter. To face this condition, treated urban wastewater reuse is a sustainable and promising strategy to face water scarcity, enhance soil fertility, preserve natural resources, develop local products and improve living conditions of agriculture and farmers.

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