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APPROPRIATE SOLUTIONS FOR WASTEWATER REUSE IN AGRICULTURE: A PILOT PLANT IN RAFAH, GAZA STRIP

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Abstract

Water supply represents a constant worldwide challenge for people and authorities. This issue is significantly severe in semiarid regions such as Gaza Strip, where groundwater constitutes the only fresh water source. Furthermore, Gaza Strip area suffers from water scarcity due to the decrease in water recharge and a constantly groundwater over-pumping, along with seawater intrusion, which cause serious problems in fresh water supply. Treated wastewater reuse represents a sustainable approach to increase water resource availability, to alleviate stressed polluted Gaza's coastal aquifer and to contribute to local agriculture development. On this issue, a pilot-scale plant has been designed to evaluate the feasibility of a municipal wastewater recovery for agricultural purposes in Rafah (Gaza Strip), reproducing the working conditions and performances of a real plant, which will be built by summer 2020. The paper aims to describe the case study in the context of Appropriate Technology (AT) for Developing Countries approach.

Key words: appropriate technologies, Gaza Strip, natural treatment system, wastewater reuse

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1. Introduction

The serious situation in Gaza about water supply is worldwide considered as a humanitarian crisis (UNRWA, 2019): the primary freshwater source is, after all, represented by groundwater, which is severely contaminated, and, at present yields, there is almost no water of acceptable quality for domestic use. Considering the presence of about 2 million inhabitants in Gaza, the availability of water is inadequate, both in terms of quantity and quality, with severe risks for public health. According to the latest Palestinian Water Authority (PWA) database, municipal water consumption is about 103.34 million m^3 (52%), of which 13 million m^3 suitable for drinking purposes and agricultural water consumption about 95.3 million m^3 (48%) (PWA, 2014).

The annual net deficit in the groundwater aquifer has been about 90 million m^3 in 2016, and it is expected to reach 180 million m^3 by 2035, because of the massively over pumping for freshwater supply purposes. The aquifer is showing clear signs of imminent failure or collapse, with resulting degradation and robust depletion of the water resources (Al-Dadah, 2013; Aiash and Mogheir, 2017). At the same time, there is an increasing water demand in Gaza Strip depending on the unexpected rise of the population.

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In the recent decades, wastewater recovery and reuse techniques gained attention worldwide as a reliable alternative source of water based on a new approach of integrated water resource management. From one side, recycled water can be used for many different purposes, from irrigation to drinkable water supply, from the other side, the urgent need of wastewater reuse and recycling represents an indicator of scarcity of water, highly demanded for all anthropic uses (Aiash and Mogheir, 2017; PWA, 2014).

Treated wastewater can be an additional water source intended to increase agricultural production in Gaza Strip, where irrigation supplies are actually not sufficient to meet crop water needs (Al-Dadah, 2013). It can play an important role in agriculture, responsible of the major part of fresh water consumption in Gaza Strip (Gharbia et al., 2016), contributing also to increase agricultural production thanks to the presence of important nutrients (WWAP, 2017).

However, if not properly treated and controlled, recycled wastewater may create environmental problems. Most of the wastewater treatment plants in Gaza Strip are not properly managed and fail to provide water at adequate quality for its reuse and the possibility to reuse wastewater depends on the capability to implement wastewater treatment facilities (Al-Dadah, 2013; Abu Sultan, 2015). Reclaimed water can be used mainly for irrigation, industry, surface water and groundwater recharge and municipal purposes as well (Metcalf and Eddy, 2003).

The aim of the project was to contribute to agriculture economic development in Gaza Strip through new synergies, involving several civil society organizations. Specifically, the research has been focused on the examination and development of wastewater treatment methods in Rafah area to study appropriate technologies available for the finishing plant design, by implementing the existing primary treatment plant and the water availability in the north-east of the city.

The concept of "Appropriate Technology" (AT) has been introduced many years ago, by the British economist E. F. Schumacher in his famous book *Small is Beautiful* (Schumacher, 1973) and it is spread considered and accepted. AT is a strategy that enables people to rise out of poverty and improve their economic condition by meeting their basic needs, through developing their own skills and capabilities while making use of their available resources in an environmentally sustainable manner (Murphy et al., 2009). These solutions must have a low environmental impact and a low cost and they have to be easily managed by the communities in order to allow people to improve their socio-economic conditions (Feige and Vonotars, 2017).

The research intends to demonstrate that the identified technologies for wastewater treatment, should ensure the standard effluent's quality required for water reuse purposes, as an integral part of water management in Gaza Strip.

2. Materials and methods

2.1. Description of the project area

The Rafah WasteWater Treatment Plant (WWTP), managed by the Coastal Municipality Water Utilities (CMWU), deals with, about 10,000 -12,000 m^3/day, with a pick of 18,000 m^3/day (ICRC, 2013), of domestic wastewater related to around 145,000 inhabitants (the 70% of the Rafah Governorate citizens). It has been expanded over the years to meet the increasing demand of the growing population. It has established in 1989 for a designed capacity of 1,800 m^3 per day (equivalent to a population of 21,000 inhabitants), augmented up to 20,000 m^3/day in 2011. A first phase had involved the construction of two anaerobic ponds, a new grit removal chamber, sludge drying beds and other improvements of the station. A second phase aimed at the construction of two bio-towers and related pipe-works as well as improving the pipeline for the treated waters collection to the sea (Fig. 1). The general layout of Rafah WWTP is shown in Fig. 2. Despite its poor quality, the effluent is still disposed into the sea by a pumping station and 3 km long pressure line. However, the renovation of the WWTP has allowed to slightly ~~improving~~ improve the quality of the effluent, which is although under the recommended values. The main monitoring data of the effluent of Rafah WWTP are shown in Fig. 3 (CMWU, 2018; ICRC, 2013; PCBS, 2018).

2.2. Characterization of wastewater effluent

Since reclaimed water reuse became an integral component in water supply and management in many countries, several organizations and authorities implemented water reuse guidelines and regulations (Metcalf and Eddy, 2003; Crook and Surampalli, 1996; EPA, 2012). The Palestinian standards of Waste Water (WW) reuse in irrigation are shown in Table 1.

A weekly sampling activity has been conducted during two months, in order to test the effluent, coming from the Rafah WWTP, in terms of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia, Nitrite, Nitrate and Total Phosphorus (TP). Their average concentrations are shown in Fig. 4.

These preliminary results confirm the poor quality of the treated wastewater and the insufficient performances of the existing plant. In this condition, the output water cannot be reused nor for irrigation purposes or safely collected and discharged and it can be dangerous for the health of workers and utilizers.

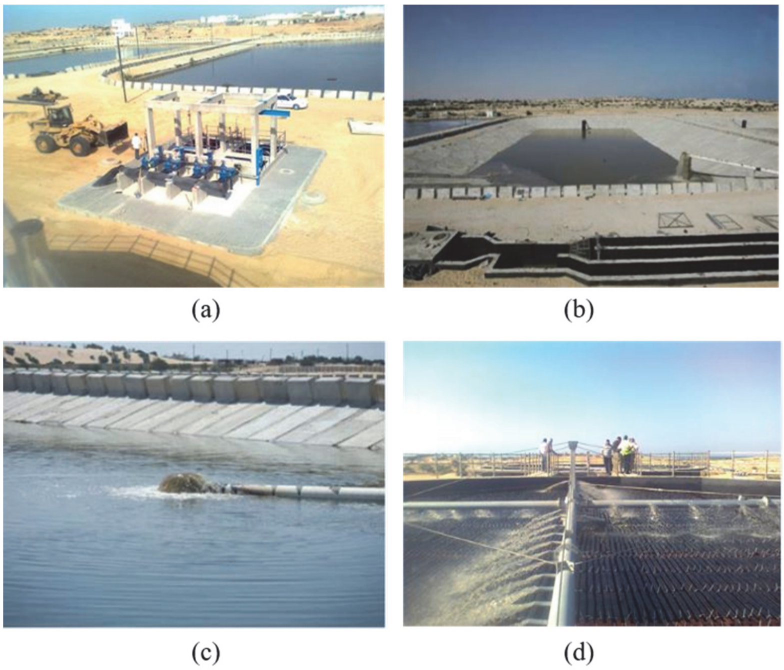

Fig. 1. Representation of Rafah WWTP: (a) Pump station, (b) Grit removal and lagoon, (c) Aeration Lagoon, (d) Bio-Towers (ICRC, 2013)

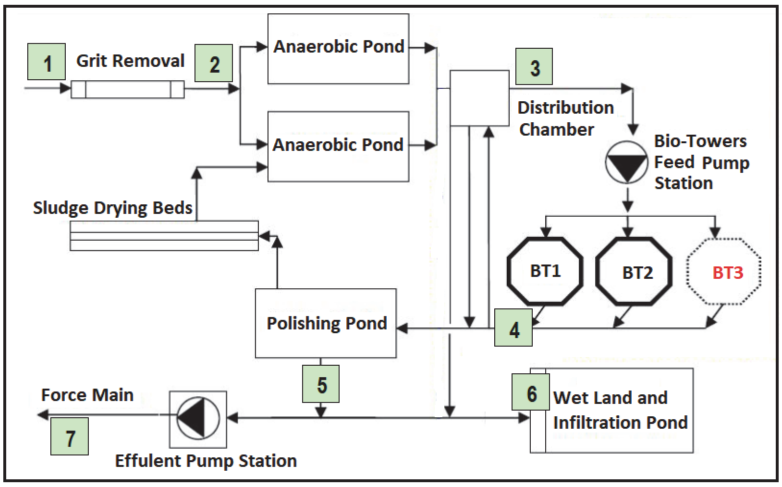

Fig. 2. General Layout of Rafah WWTP (ICRC, 2013)

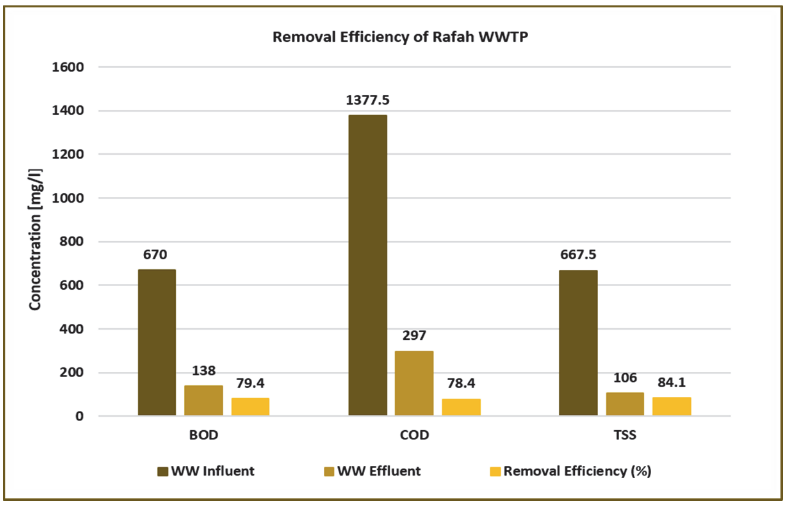

Fig. 3. Removal Efficiency of Rafah WWTP

Table 1. Palestinian Standards of WW Reuse in Irrigation (Aiash and Mogheir, 2017; PWA and MOA, 2012)

Treatment Level	***Quality Characteristics***		***Possible Uses in Irrigation***
Primary	-	-	Not allowed
Secondary low	Total BOD_5 Total SS DO	60 mg/L 50 mg/L 0.5 mg/L	Cotton, sugar beets, dry fodder, forests, seeds, cereals
Secondary high	Total BOD_5 Total SS DO	45 mg/L 40 mg/L 0.5 mg/L	Green fodder, olives, peanuts, citrus, banana, almonds, nuts
Secondary high + disinfected	Total BOD_5 Dissolved BOD_5 Total SS DO Coliform (unit /100 mL) Residual Chlorine	35 mg/L 20 mg/L 30 mg/L 0.5 mg/L 250 0.15 mg/L	Green vegetables for cooking, fruits for canning, deciduous fruits trees, groundnuts, sports grounds.
Tertiary	Total BOD_5 Dissolved BOD_5 Total SS DO Coliform (unit /100 mL) Residual Chlorine	15 mg/L 10 mg/L 15 mg/L 0.5 mg/L 12 0.5 mg/L	Unrestricted use in irrigation, vegetables for fresh consumption, public parks, lawns.

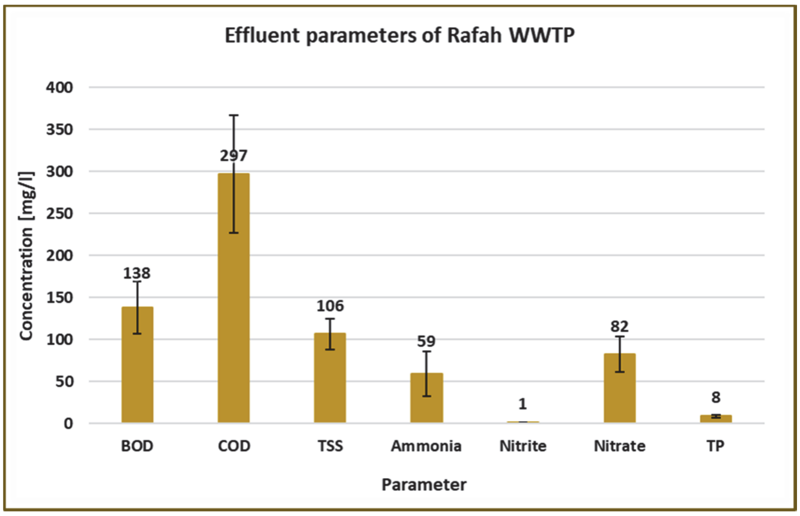

Fig. 4. Effluent Parameters of Rafah WWTP

2.3. Choice of appropriate technologies

In order to reuse the effluents coming from the Rafah's primary treatment plant, it has been considered the opportunity to implement a finishing phase by an AT approach, which is context-specific and depending on the local conditions where they are applied. In this case, preliminary useful information was collected thanks the collaboration of a local agricultural organization, an Italian NGO and the Palestinian Water Authorities (PWA), considering the critical environmental, economic and social issues of the area and the existing water management system.

The starting points for choosing the appropriate technology are:

- the analysed local criticalities suggesting to carry out a treatment system with low energy consumption avoiding chemical reagents in order to obtain a cheaper treated wastewater, to be destined mainly to agriculture purposes;
- previous excellent experiences in other areas, i.e. a case study carried out in Mozambique, that has been considered comparable in terms of weather condition, soil properties and water issues;
- a sustainability assessment approach, enabling to compare the various finishing wastewater treatment technologies feasible in this specific case study (Kakavand, 2019);
- a preliminary analysis of wastewater coming from the existing primary plant in the city of Rafah, provided by Coastal Municipalities Water Utility (CMWU) Central Lab – State of Palestine.

2.4. Technologies selected

This case study focused on implementing a finishing natural treatment composed by phytoremediation and natural disinfections, aiming to optimize the overall wastewater treatment process and manage them for irrigation purposes. The choice of these two technologies, in fact, should ensure the standard effluent's quality required for water reuse purposes.

There are many applications of natural purification techniques, carried out throughout the world (i.e. in Great Britain, France, Denmark, Germany, Sweden, Slovenia, USA, Australia, etc.) (EPA, 2012), which have provided positive answers both in terms of landscape insertion and environmental efficiency, and in terms of depurative efficiency and of cost-effectiveness of implementation and management. In addition, agriculture is one of the worldwide significant destination sectors of reclaimed water (EPA, 2012) and Constructed Wetlands (CWs) are widely applied as a low-cost alternative or supplementary system for wastewater treatment. In addition, proper management of recycling wastewater for the agricultural purpose will help decrease soil and plant contamination in addition to moderating water shortage (FAO, 2003).

The phytoremediation system has been selected because of the quite absence of energy and chemical reagents and its high efficiency in the removal of the main physico-chemical pollutants and nutrients by using plants for environmental depuration, more effective than traditional methods based on chemical extraction of xenobiotics. Biological methods, in fact, do not cause secondary pollution and phytoremediation techniques are cheaper when compared with to conventional techniques (such as activated sludge process, biofilters, trickling filters, etc) (Materac et al., 2015). However, phytoremediation can present some limitations: it requires a large surface for the construction of the system and provides a slow rate of the process.

The aerated lagoon unit, if combined with phytoremediation system, represents the final treatment stage. The aerated lagoon can be considered as a pervading finishing system. It also needs a large surface and a good brightness that allow the penetration of light and consequently the photosynthetic production of oxygen in all over the lagoons. The system works by supporting aerobic bacterial degradation with artificial oxygen supply provided by surface turbo-aerators or submerged aerators or diffusers with blowers, to augment the oxygen supplied from natural means, such as re-aeration surface or photosynthesis (FCM, 2004). Aerated lagoons, typically from 2 to 6 meters deep, provide the mixing of the reactor and a high removal of the main microbial groups.

2.5. Sampling points

The performance of the whole system has been assessed by evaluation of influent and effluent parameters at each treatment unit. Influent and treated wastewater samples have been collected every week during two months, from 2nd December 2019 to 3rd February 2020, respectively at the storage tank (Point A), where the influent of the designed system corresponds to WWTP effluent, after the phytoremediation pond (Point B) and after the lagooning system (Point C) (Fig.5). All samples have been collected using sterile bottles and transported to the "Coastal Municipalities Water Utility (CMWU) Central Lab – State of Palestine" for further analysis, that have been performed according with standard methods for water and wastewater tests (APHA, AWWA, WEF, 2005). The quality of the effluent has been compared to the Palestinian legal limits for wastewater reuse in irrigation (as shown in Table 1). Influent and treated wastewater samples were analysed in order to test the following parameters: Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Phosphorus (TP), Chloride, Free Active Clorine, Ammonia (NH_4); Nitrite (NO_2); Nitrate (NO_3).

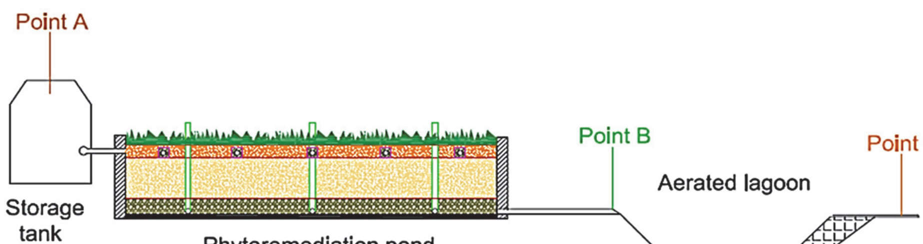

Fig. 5. Sampling points in the scale-pilot plant

3. Results and discussion

3.1. The construction phases of pilot plant

In order to study and monitor effluent contamination parameters and understand the real efficiency of the system, a wastewater finishing pilot plant has been designed and constructed with a capability of about 6 m^3/day. The pilot plant dimensions have been assumed on the base of the USA Environmental Protection Agency indications (Davis, 1994). Fig. 6 shows the scale model drawing.

In Table 2 the main dimensions are reported.

The phytoremediation pilot-scale system presents 3 layers, composed by the following materials: from bottom to top, respectively a big gravel, a washed sand and a vegetative soil and plants (Fig. 7 (A)). The plants selected are “persistent emergent plants”, a mixture of gramineous and legumes, that have two different functions. During their growing, plants provides adhesion places for microbial development and contribute to create a vegetative mass that regulates the water flow direction, while their death creates a release of organic carbon functional for the microbial metabolism (Willey, 2007). Plants also influence the wastewater quality by optimizing various removal processes and consumption of organic matter and other physico-chemical elements (Ko et al., 2011; Ong et al., 2010).

The pilot-scale plant has been fed by the real sewage coming from the municipal WWTP after the primary treatment. The construction phase of this plant has been completed in October 2019.

3.2. Monitoring phase

The monitoring campaign started in December 2019. n the monitoring phase the Biological and Chemical Oxygen Demand (BOD_5 and COD) values and nitrification and denitrification processes taking place in the plant have been measured. These parameters should respect pollutants concentrations limits and be below the Palestinian legal limitations (Table1), maintaining a good efficiency of the process.

3.4. Preliminary results

The values of physico-chemical parameters, recorded at the different sampling points for the entire monitoring period, are reported in Fig. 8. Rafah WWTP is treating municipal wastewater having higher organic pollutant levels, especially for BOD and COD, than the common expected ones.

However, they seem to be in line with the typical wastewater values for the specific area, due to the problem of water scarcity that leads to an high ratio organic load/water and without a proper dilution. In addition, the high organic load may be due both to several different local sources of organic pollutants, such as domestic or restaurants’ exhausted cooking oils, agricultural and soil leachate, laundries wastewater, etc. and to a very bad and irregular maintenance practices and to the lacking or discontinuous electricity supply.

So high values, mainly in terms of BOD and COD, don’t respect the limits needed for agricultural use or for a safe collection and release in the environment. Inside the aerated lagoon, residual nutrients are transformed in biomass. In that way, during the first phases of treatment, some parameters, such as BOD, phosphorus and ammonia, are destined to grow, related with the presence of a convenient and effective biomass, while pathogens decrease.

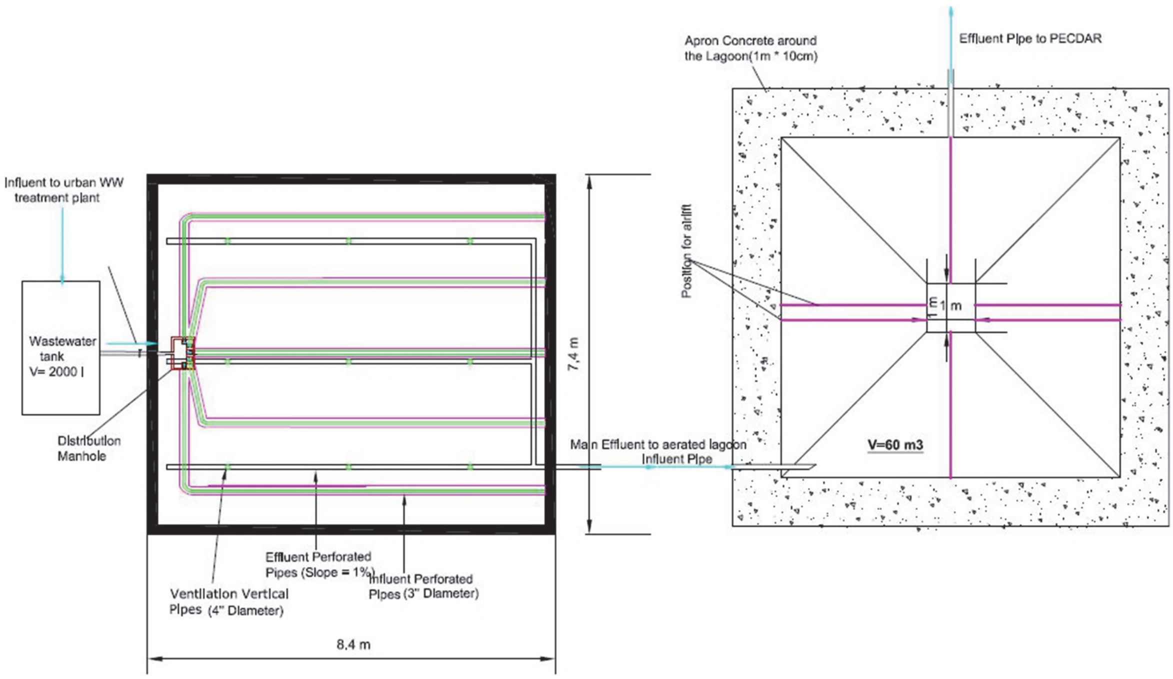

Fig. 6. Plant and dimension of scale model design

Table 2. Dimension of the scale model

Area of the phytoremediation system	$A_{\text{Phytoremediation}} = 62\ m^2$
Volume of Aerated lagoons (considering Depth: H = 3 m and Area: A = 20 m²)	$V_{\text{Useful}} = 60\ m^3$
Capacity of a storage tank	$C_{\text{tank}} = 2000\ l$

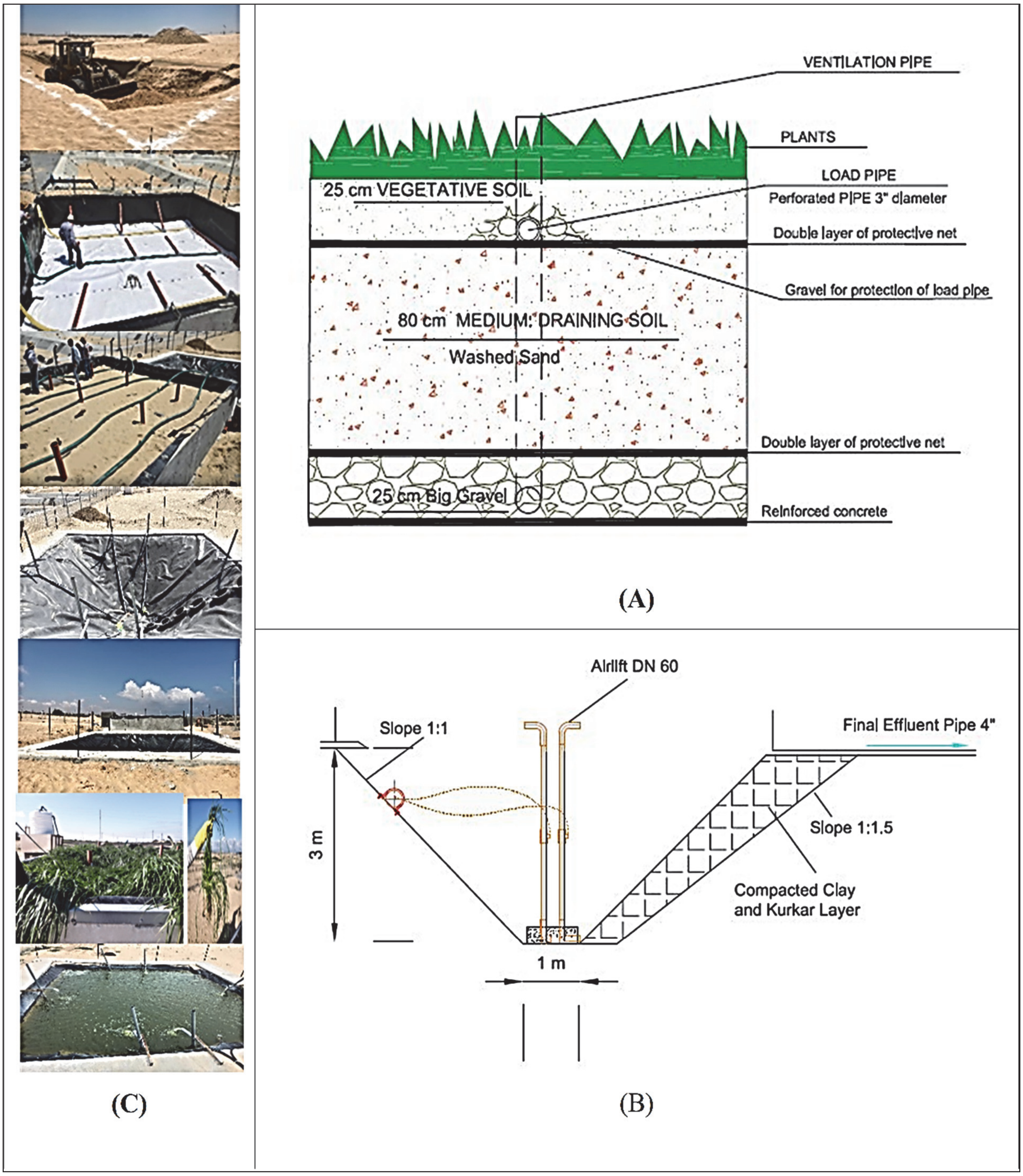

Fig. 7. (A) The 3 layers in the phytoremediation system, (B) Section of the aerated lagoon, (C) General pictures of the main construction phases of the pilot plant

Algae maintain a high level of oxigen, avoiding anoxia risks. Downstream the pilot plant treatment, as shown in Fig. 8, the concentration values are lower than the Palestinian limits for agriculture (Table 1). In this way, it is possible to use the treated wastewater for irrigation also for food production purposes, such as for green vegetables, fruits, deciduous fruits trees, groundnuts and sports grounds. In addition, Fig. 9 shows the average value of inflow and outflow wastewaters and the removal efficiency. The average TSS and BOD_5 values, respectively 20 and 23 mg/L, have been resulted within Palestinian limits for agricultural reuse. Average TSS concentration (106 mg/L in phytoremediation influent) dropped to 20 mg/L, showing a mean removal efficiency of about 81%, that is mainly due to physical processes, such as sedimentation and filtration (Vymazal and Kröpfelová, 2009).

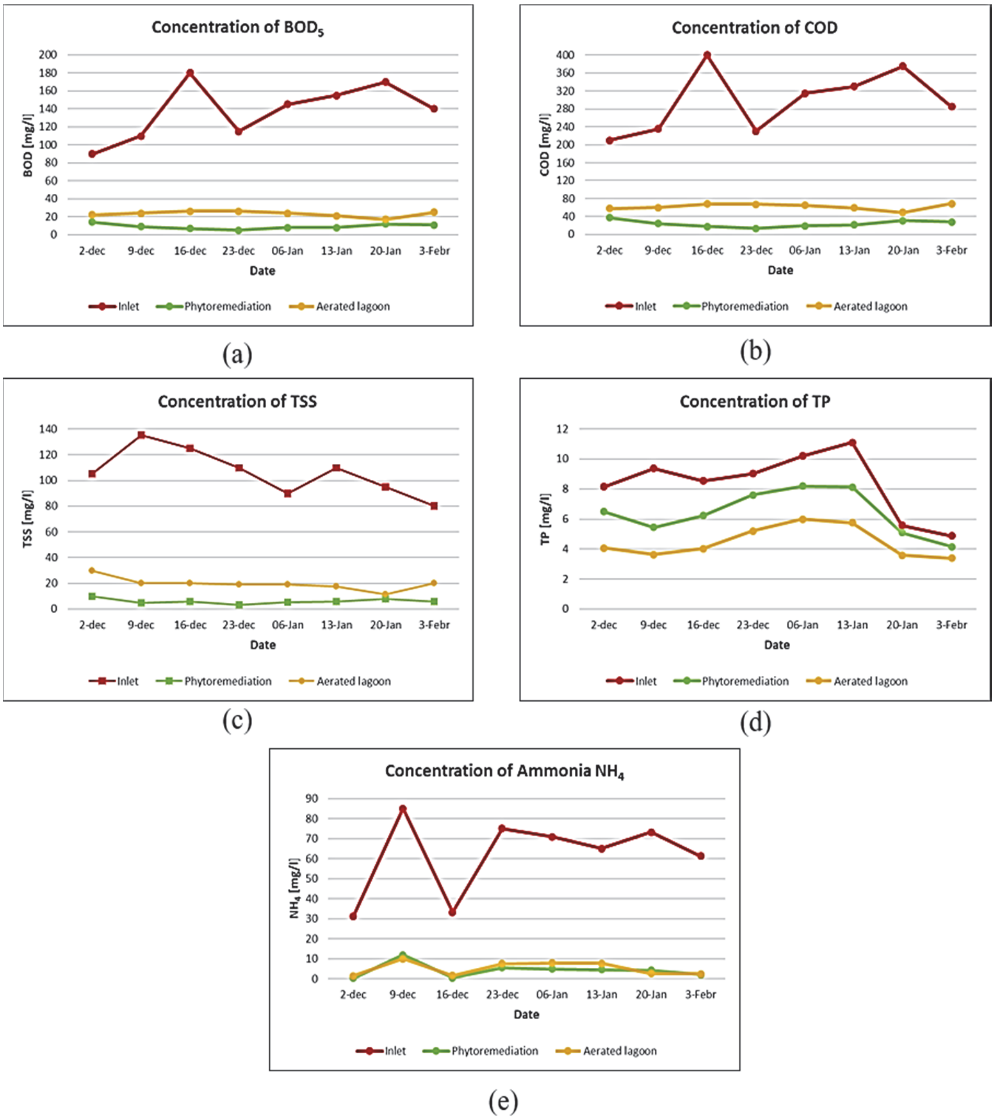

Fig. 8. Concentrations [mg/L] of the physico-chemical parameters at the different sampling points: (a) BOD_5, (b) COD, (c) TSS, (d) TP (e) NH_4

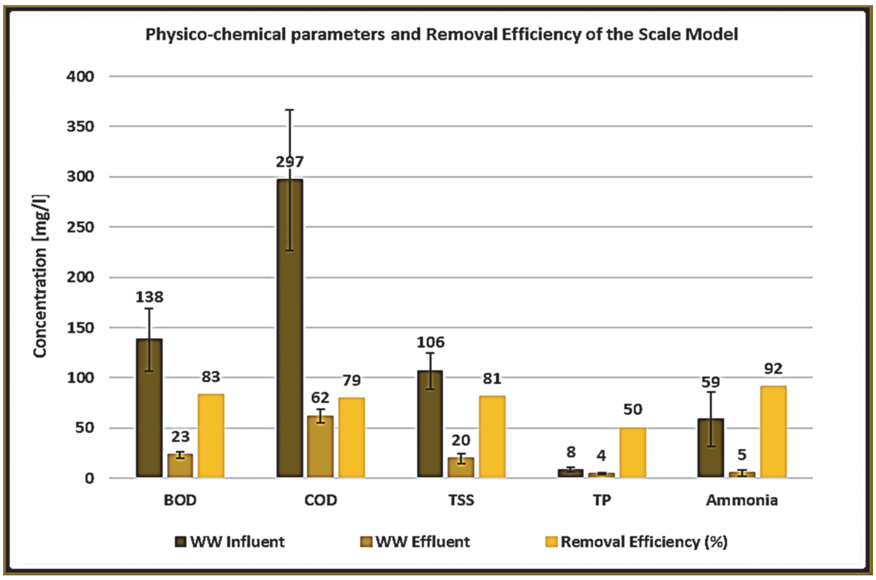

Fig. 9. Influent and effluent at the scale-plant: average values and removal efficiencies of BOD_5, COD, TSS, TP and NH_4

The mean reduction of organic matter concentration during the detention period is about 83% for the BOD_5 and 79% for the COD. The mean percentage of organic components removal is significantly the same for COD and BOD_5, since municipal wastewaters usually contain elevated concentrations of easily degradable organic compounds (Vymazal and Kröpfelová, 2009). The effluent provides BOD_5 values between 17 and 25 mg/L, with a mean value of 23 mg/L, and COD values between 49 and 69 mg/L, with a mean value of 62 mg/L. Both results are compatible with law limits for reuse. The nutrients removal efficiency is 92 % for NH_4 and 50% for TP. Their average values, after the treatment processes, are 5 mg/L and 4 mg/L. The strong reduction of the nutrient's concentration is due to the lagooning unit with the aerobic decomposition of algal substances.

4. Conclusions

The finishing pilot-scale plant, designed to evaluate the feasibility of municipal wastewater reuse in Rafah (Gaza Strip), has shown a very good efficiency, according with the Palestinian regulation for wastewater reuse in agriculture.

The preliminary results highlight that the phytoremediation system, followed by a natural disinfection, improve the overall wastewater treatment process. The analysis of the effluents demonstrates that, under controlled conditions, treated municipal wastewater can be used for agriculture purposes with of effective economic and environmental benefits.

The preliminary pilot-scale results are encouraging to construct a real scale finishing treatment plant, in the same area, able to treat a municipal wastewater flow of about 2000 m^3/day that will be used for local crops (such as olives, citrus, potatoes, grapes and guava) by many farmers, final beneficiaries of the project.

The whole project has been designed according with a sustainability approach, demonstrating an actual environmental, social and economical effectiveness.

Acknoledgements

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