Treated wastewater reuse for green space irrigation in arid and semiarid regions

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Abstract

This research investigated the feasibility of reuse of treated wastewater of the existing treatment facilities in Sistan and Baluchestan province of Iran for green space irrigation as a part of waste management in the form of a pilot study. After investigation of the environmental parameters and wastewater treatment conditions, two pilot plants in zahedan and zabol cities were designed and performed. On the basis of the results of qualitative tests of the soil, before and after establishment of the Zahedan Pilot, we can say that the soil quality has been improved. The values of soil EC, pH, SAR, and ESP prior to establishment of the pilot have been 27.8, 8.05, 44.73 and 38.87 respectively. After irrigation of the pilots for a period of 5 months the said values changed to 8.5, 8.34, 13.62 and 15.61 respectively which show the decrease in EC, SAR and ESP for 30, 30.5 and 40.2 percent respectively. After continuation of the irrigation for 12 months, the said values were decreased to 8.34, 7.89, 13.76 and 15.75 percent respectively. The values of soil EC, pH, SAR, and ESP prior to establishment of the Zabol pilot were 9.55, 8.35, 17.46 and 19.39 respectively. After irrigation of the Zabol pilots for a period of 5 months the said values changed to 5.05, 8.59, 7.35 and 7.81 respectively which shows the promotion of soil properties. After continuation of the irrigation for 12 months, the said values were changed to 3.93, 8.02, 7.91 and 21.82 respectively. The results showed a lack of any adverse effect on the soil quality and growth of the selected plants; the majority of the quality factors were approximately at an optimum level and only soil ESP had been significantly increased in the Zabol pilot. Two solutions are suggested for promotion of the treatment plants operation.

Keywords: waste management, treated wastewater, reuse, arid regions, green space irrigation, soil quality.

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1 Introduction

The ever-increasing populations in urban areas and the critical need for infrastructural facilities in developing countries for water resources and waste management have made the optimum use of suitable methods for overcoming the environmental and social crisis an inevitable necessity.

As one of the arid provinces of Iran, Sistan and Baluchestan Province has been faced with water deficit and environmental crisis for a long time.

It is evident that the careful dealing with some issues like safeguarding the public health, soil protection, protection of the irrigation and water supply facilities, use of nutrient content of the wastewater and the public satisfaction is essential towards implementation of such a movement.

The most important chemical parameters of irrigation water, which are effective on the crop growth, soil fertility, and the environment, are: total saline concentration, electrical conductivity, sodium absorption rate (SAR), toxic ions including boron, chlorine, and sodium, trace elements, and heavy metals including aluminium, beryllium, cobalt, fleuron, iron, manganese, molybdenum, lithium, selenium, tin, titanium, tungsten, vanadium, arsenic, cadmium, copper, lead, mercury, selenium, zinc, and also pH value, and nitrogen, bicarbonates and phosphorous contents. In connection with physicochemical quality of the treated wastewater reused in irrigation, the suggestions of FAO should be observed (Ayers and Westcott [2]).

Considering that the high sodium concentration adversely affects the plant growth, this factor has a significant importance.

The quality of the treated wastewater used for irrigation in arid regions (high temperature, low humidity, high evaporation), has a considerable importance. The physical and mechanical properties of the soil and also its strength, porosity and hydraulic conductivity, all are sensitive to the ion contents of the irrigation water. Another area that needs to be considered, is the effects of wastewater soluble salts on plant growth. The water soluble salts increase the osmotic pressure of soil water and the latter in turn results in increases in energy consumption used for water absorption. As a result, the perspiration increases and the growth becomes limited. Most of the plants are sensitive to the active salts in the soil water, which is effective on the osmotic potential.

The activities and reactions of the elements existing in the soil compounds are usually the result of the equilibrium between the soil minerals, organic materials, ferrous hydroxides, magnesium and aluminium and also the soil pH. The concentration of the heavy elements increase proportionally to the increase in soil pH (alkalinity). In acidic soils (pH = 4.2–6.6), some elements like cadmium, mercury, nickel and zinc become movable, hence arsenic, boron and chrome are partially movable and copper, lead, and selenium are hardly moved and/or have a very low movement velocity. In neutral or alkaline soils (pH = 6.7–7.8), arsenic and chrome are highly movable and boron, cadmium, mercury and zinc have a normal movement and copper, lead and nickel have a very low movement velocity. In the case of increase in soil pH from 5 to 8, the absorption of elements like cobalt, copper, manganese and zinc will increase. Soil pH is the most important effective factor on controlling the absorption of some elements like cadmium and zinc existing in the treated wastewater. The cation exchange capacity of the soil mainly depends on soil volume and type, organic materials and oxides of ferrous, manganese and aluminium. The high soil cation exchange capacity is one of factors which are highly affective on absorption of heavy elements by the soil without any adverse effect on the environment. Some heavy elements like cobalt, copper, manganese, nickel, lead, and zinc are capable to be absorbed by organic materials of the soil, as a result, form a resistive soluble and/or an insoluble compound. Ferrous and manganese oxides normally have an important role on absorption of elements and also their fixation in the soil. Other factors like planting method, duration of plant growth, and also the climatic conditions are also effective on absorption of the elements by the plant. Note that very low contents of copper, nickel, and other similar elements are useful for land fertility and plant growth, but they become toxic and/or may prevent growth in high concentrations (Gried [7]).

Different methods may be used for irrigation by reuse of the treated wastewater. The most important factors to be considered in selection of the appropriate irrigation system are labor, the required technology, topography of the region, type of vegetation, and the existing strategic and infrastructural facilities (Petygrove and Asano [15]).

The quantity of the irrigation water differs in different seasons and depends on the climatic condition and also type of vegetation and plant life. The required quality of the treated wastewaters must have some changes because the nutrients needed by the plant change during different seasons. The different sensitivity of plant species to the soil salinity is a very important fact and should be considered. Some plants are capable of absorbing more water in saline soils, and therefore resist well against the salinity. Another important factor is plant toxicity. The toxicity takes place in the plant and does not relate to the water deficit. The toxic ions including chloride, sodium, and boron are absorbed by water and moved in the plant. As a result of perspiration, the water content of the plant is decreased and the concentration of the ions is increased.

The degree of damage to the plant depends on the time, concentration of the toxic ions, plant sensitivity and the quantity of the absorbed water. In sprinkler irrigation, the chlorine and calcium ions are directly absorbed through foliage. The degree of the hazard is specially increased when the temperature is high and humidity is low. In addition to the above-mentioned elements, the micro nutrients (minor metals) may also cause plant toxicity. Also it should be pointed out that the majority of heavy elements are accumulated in surface soil and adversely affect the plant growth.

2 Methods

2.1 Basic study

Sistan and Baluchestan Province is located in southeast Iran between 25˚, 3' and 31˚, 28' north longitude and 58˚, 47' and 63˚, 19' latitude.

The province area is about 191,000 km^2 which Sistan Region forms 5% and the remaining 95% is Baluchestan. The provinces area is about one ninth of the country area.

Considering that the study was conducted in a special region, Sistan and Baluchestan Province, and Zahedan and Zabol regions have been selected for pilot studies, the investigation and recognition of the natural specifications of the said regions will have considerable importance [11, 12].

The geological formation of the province mainly includes sedimentary and igneous stones of the 3rd era and alluvial deposits of 4th era.

One of the major problems of the province is the improper soil conditions and its relatively low quality. The majority of soils of the province are alluvial soils with poor organic materials. The main source of these soils is alluvium and other settlements moved by the wind all belonging to 4th era. Marn, gypsum, silt, sand, and salt are the main components forming the soils of the province. The soils of the province are alluvial and, therefore, are fine particles and owe their life to Hirmand and Hamoon rivers. The soil erosion in the province is relatively high and this is the result of seasonal floods and heavy winds of the region [6].

Due to special geographic situations and desert conditions, the region has not got rich vegetation. The existing forest and other plant species mainly include Iranian screw bean, tamarisk, Pakistan screw bean, *Accacia bambulah*, marsh arrow grass, reed, wild cotton, cape tree (Khosravi [9]).

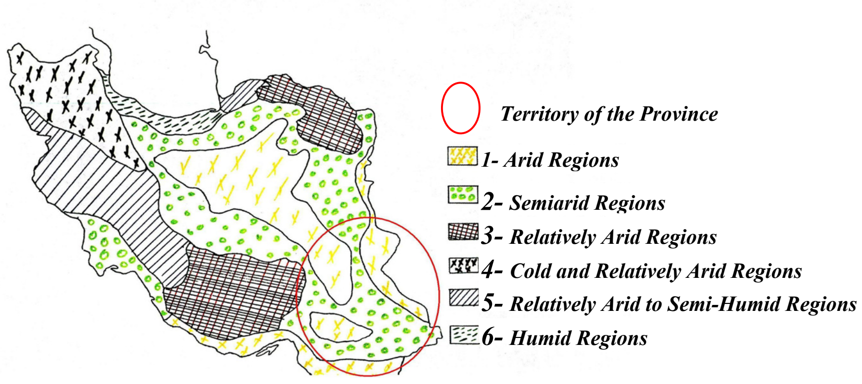


Figure 1: Climatic classification of the country.

As the province is located in a region with an arid and semiarid climate, the annual precipitation is very low and, due to its long distance from humidity resources and west rainfall, does not have rich surface and ground water resources (Bandarian [4]).

Considering the isothermal map of the province, the average annual temperature range of the province is minimum 16 and maximum 26. Only some records of late frost have been recorded in three meteorological stations: Zahedan, Chashmeh Ziarat and Mohammad Abad Koorin and the fruit bearing regions like Khash and Iranshahr are mainly free from frost problems (Parsi [14]).

The calm conditions are lower than all other regions of the country. For example, calm conditions in summer at Zahedan Station occur in less than 8% of cases and in the remaining 92%, the 120-day winds are blowing. Regional winds of the province focusing on 120-day Sistan winds.

From the point of view of the blowing limitation and durability, these winds are unique and are blowing from the northeast mountains of Iran to the southeast region of the country from early May to late September. The wind is very humid and fresh in the south Alborz hills and, after passing through the Kawir and Loot deserts, becomes hot and arid and, especially in the Sistan region, causes serious damage to the vegetation of drastic soil erosion. The accurate blowing duration of the wind is 131 days from May 10th, to September 17 in Sistan and in Zahedan is 117 days from May 11th, to September 5th.

Figure 2: Geographic Situation of Zahedan and Zabol regions.

The number of dusty days in the province is more than almost all other regions in the country, this figure is about 180 days in Zabol.

The winds result in soil erosion and, consequently, destroy the valuable resources of the province. Also the 120-day winds cause some physical injury including 28% of blindness in the Kratit region (Khosravi [9]).

The annual precipitation of the province differs from a minimum of 65mm in Zabol to a maximum of 165mm in Khash Station; considering the average annual precipitation of the country (about 260mm) almost all stations have annual precipitation less than the average of the country.

February and March are the most humid months of the year (20–25mm) and June is the most arid month (0–5mm). The annual radiation in all synoptic stations of the province is more than 3000 hours, where the same in north cities of the country is 2100 hours.

By use of Copen method the province falls into arid desert climates with humid winters.

By use of Demarton method the I_a index of all points of the province were calculated and the province has an arid (I_a <10) climate.

One of the most important specifications of arid regions is little precipitation hence considerable evaporation. The province is not an exception and the evaporation and perspiration is less than the precipitation and in general the crop production is dependant on irrigation.

The lowest evaporation and perspiration occurs in December and January (40–50 mm) and the highest is in July and August (300–400 mm) (Sabeti [17]).

2.2 Pilot studies in Zahedan and Zabol

Considering the results of the investigation and basic information, the place for the pilot and plant species were selected and after preparation of the landscape, the seedlings were planted. The area of each pilot was 2000 m^2 with different dimensions which were established in Zahedan and Zabol wastewater treatment sites.

Figure 3: Zahedan pilot (3 months after planting).

Figure 4: Zabol pilot (3 months after planting).

2.2.1 The chemical quality of Zahedan and Zabol treated wastewater

The wastewater treatment system at Zahedan plant is activated sludge (extended aeration) built in a residential complex, east of Zahedan. The inlet wastewater volume is 8 L/sec and the outlet discharge is approx. 6 L/sec.

Table 1: Average chemical specifications of wastewater treated in Zahedan wastewater treatment plant.

pH	EC	Na	Ca	SAR	Cl (MEC)
7.56	7630	47.82	14.5	17.75	51

The wastewater treatment system of Zabol City is aerated lagoons (first stage) with settlement facultative ponds (second stage) and maturation ponds (third stage). The inlet wastewater volume is 12300 m^3/day and the discharge at the outlet is 9840 m^3/day.

Table 2: Average chemical specifications of wastewater treated in Zabol wastewater treatment plant.

pH	EC	BOD (mg/lit)	COD (mg/lit)	TDS (mg/lit)	SS (mg/lit)
8	4370	82	182	2578	118

Table 3: Chemical specifications of fresh water supplies for the homes.

pH	EC	Na	Ca	SAR	Cl (MEC)
7.3	6660	47	13.5	16.5	51

The comparison between the chemical specifications of the fresh water supplied to the homes and the treated wastewater show that the alkalinity, as well as calcium and magnesium contents of the treated wastewater is high.

2.2.2 Pilot plants

Generally, the soil used for landscapes and green spaces should be light soil with enough depth and suitable EC and pH; otherwise the soil amendment, fertilization and even soil replacement would be required. Prior to pilot establishment, the qualitative structure and classification of the soil was examined through drilling some holes in 0–30 cm, 30–60 cm and also in 1.5–2 m depth. Figure 5 shows the used irrigation systems in Zahedan and Zabol pilots.

The economic issues, climatic conditions, soil and water quality, the results of tests on the inlet and outlet wastewater and soil specifications of the regions are among important factors which should be considered in the selection of the plant species. Therefore, the selected species were those which adapted to the climatic conditions. The planted species are outlined in Figure 6.

Prior to irrigation with wastewater, the irrigation was done by the use of fresh water. In the first week, the irrigation took place on a daily basis and in the second week and thereafter the irrigation took place once every two days and the trend was continued up to one month considering the temperature and evaporation and perspiration rate. The irrigation by wastewater in Zahedan Pilot commenced two weeks after planting.

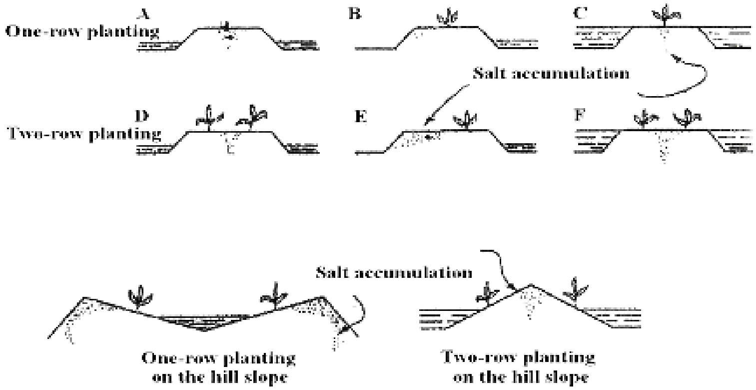
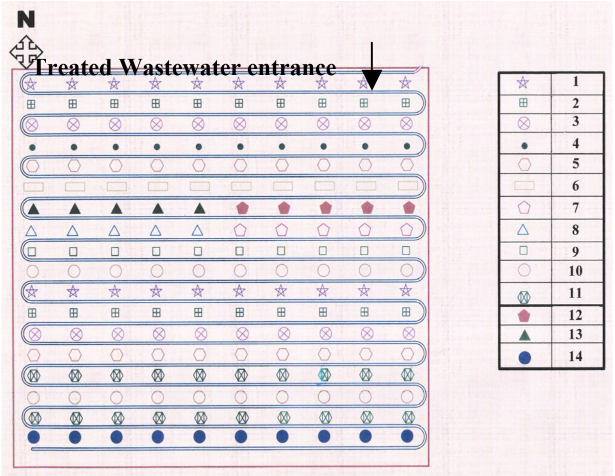


Figure 5: The schematic one and two-row planting in pilots.



1-Eucalyptus
2-Olive Tree
3-Palm
4-Egypt Silk
5-Oleaster
6-Pistachio
7-Osh Tree
8-Pomegrante
9-Oleander Rosebay
10-Type of Pine
11-Ornamentary Palm
12-Marshmallow
13-Sour Orange
14-Juniper

Figure 6: Schematic plan of Zahedan and Zabol pilots.

3 Results

The results of our periodical investigations show the optimum growth and development of most of the planted species. From among the 200 plants only the growth of some pistachio plants was inappropriate; however, the phenomenon was observed only in 4 plants out of the total 20 pistachio plants.

Pistachio is among plants that need little water and in the case of continuous irrigation the plant will be damaged as a result of root rot. Some other factors were also effective in this regard including the failure in appropriate observation of the planting practice principles and root damage at the time of transplanting.

After renewal transplanting and change of the irrigation regime, the problem was removed. The results of soil tests of pilots prior and after operation are summarized in Figures 7 and 15.

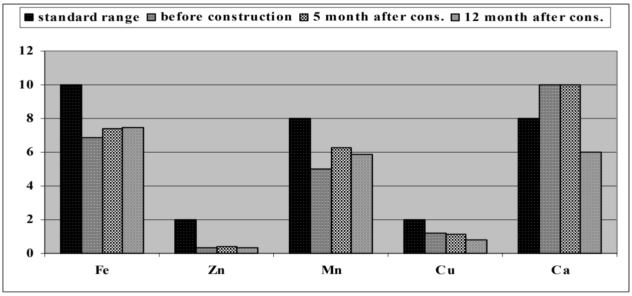


Figure 7: Physical properties of the soil prior and after establishment of Zabol Pilot and their comparison with the optimum properties.

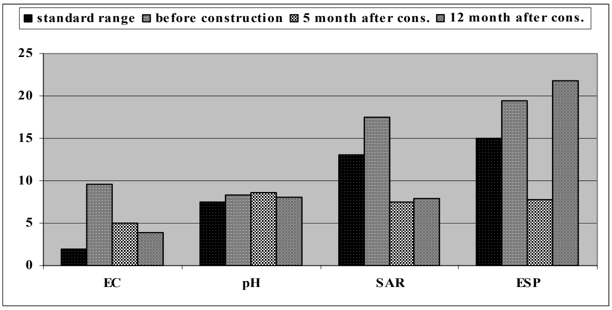


Figure 8: Chemical properties of the soil prior and after establishment of Zabol Pilot and their comparison with the optimum properties.

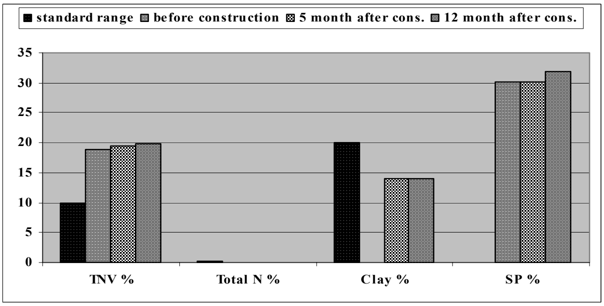


Figure 9: Physical properties of the soil prior and after establishment of abol Pilot and their comparison with the optimum properties.

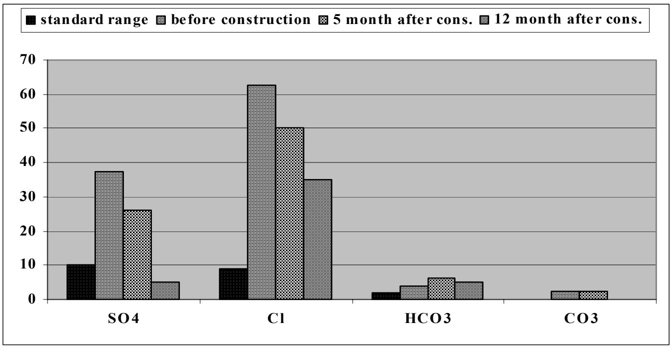


Figure 10: Chemical properties of the soil prior and after establishment of Zabol Pilot and their comparison with the optimum properties.

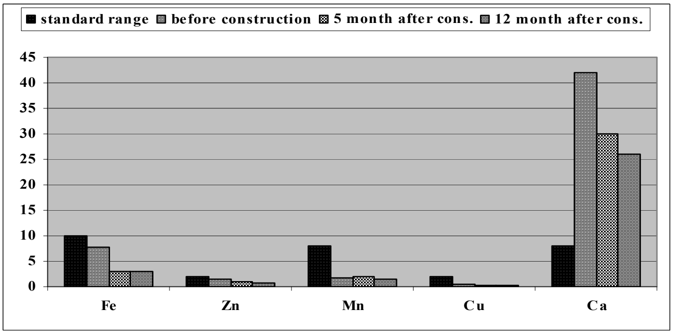


Figure 11: Physical properties of the soil prior and after establishment of Zahedan Pilot and their comparison with the optimum properties.

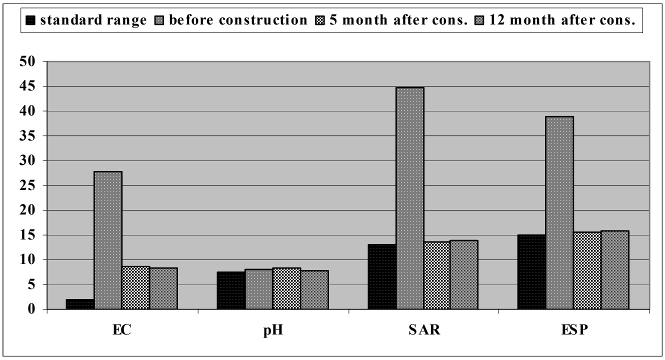


Figure 12: Chemical properties of the soil prior and after establishment of Zahedan Pilot and their comparison with the optimum properties.

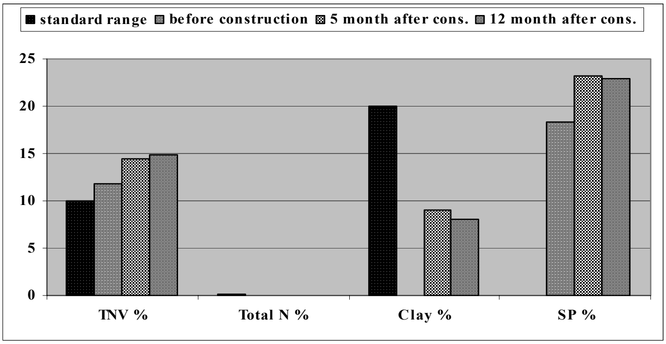


Figure 13: Physical properties of the soil prior and after establishment of Zahedan Pilot and their comparison with the optimum properties.

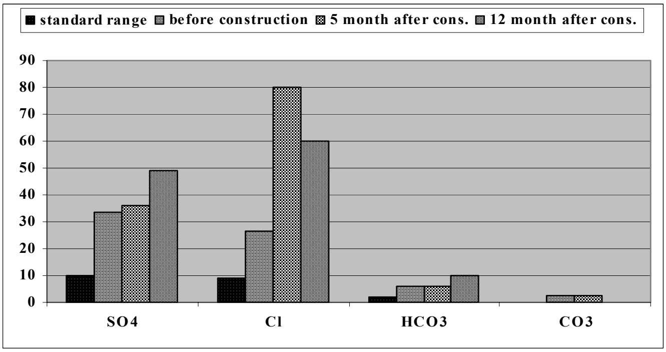


Figure 14: Chemical properties of the soil prior and after establishment of Zahedan Pilot and their comparison with the optimum properties.

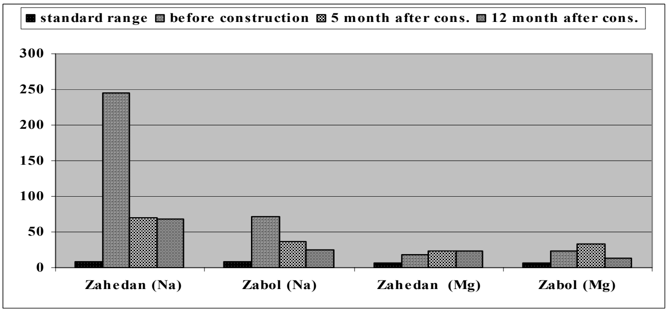


Figure 15: Chemical properties of the soil prior and after establishment of Zahedan and Zabol Pilot and their comparison with the optimum properties.

On the basis of the results of qualitative tests of the soil, before and after establishment of Zahedan Pilot, we can say that the soil quality has been improved. The values of soil EC, pH, SAR, and ESP prior to establishment of the pilot have been 27.8, 8.05, 44.73 and 38.87 respectively. After irrigation of the pilots for a period of 5 months the said values changed to 8.5, 8.34, 13.62 and 15.61 respectively which show the decrease in EC, SAR and ESP for 30, 30.5 and 40.2% respectively. It should be added that soil pH has not followed such trend and has been increased for 3.6% and it can be said that the increase in soil pH is the result of high alkalinity of the treated wastewater which is in turn the result of residuals of alkaline detergents used in households and this implies the improper operation of the treatment plant for removing such residuals. After continuation of the irrigation for 12 months, the said values were decreased to 8.34, 7.89, 13.76 and 15.75 respectively which, when compared with the standard ranges (EC < 2, pH = 7–7.5, SAR < 13, and ESP < 15), the decrease trend seems optimum (the pH value, however, has been increased after 5 months and then decreased).

Also, on the basis of the results of qualitative tests of the soil, before and after establishment of the Zabol Pilot, the values of soil EC, pH, SAR, and ESP prior to establishment of the pilot have been 9.55, 8.35, 17.46 and 19.39 respectively.

After irrigation of the pilots for a period of 5 months the said values changed to 5.05, 8.59, 7.35 and 7.81 respectively which show the promotion of soil properties. After continuation of the irrigation for 12 months, the said values were changed to 3.93, 8.02, 7.91 and 21.82 respectively; here, only ESP has been increased considerably and it is the result of improper operation of the treatment plant and sever qualitative changes of the treated wastewater.

The growth and development of the planted species during the pilots have been optimum and only in one case (pistachio) some problems were found which were removed after changing the irrigation regime (decrease of irrigation).

Considering the results of the 12 month study, we suggest soil amendment through promotion of its quality by use of gypsum and sulphuric acid together with leaching. Also some corrective actions should be done towards promotion of the wastewater quality at the outlet of the wastewater treatment plants either through promotion of quality of the fresh water supplies to household or upgrading the quality of the plants.

4 The suggested solutions for promotion of operations of the treatment facilities

Two solutions are suggested for promotion of the treatment plants operation; in the first solution the activated sludge model and in the second one the settlement pond is considered (Poepel [16]).

4.1 Solution I: Activated sludge facilities

4.1.1 First model

The solution is suitable for regions with hot summers and relatively cold winters. During the cold months, the nutrients must be removed and in the hot months the protection of the nutrients takes priority. In this solution the treatment facilities have some parallel routes which the volume of the aeration pond in the cold months is calculated at average temperature of 12˚C, and the denitrification share of 40. For the hot months the calculations are done at 25˚C. The value of the needed oxygen in the hot months is almost 40% of the said value than in the winter months.

We cannot use the procedure under which one of the routes removes the carbon products and other ponds act as reserve and clarification facilities, could not be used with this solution because the nitrification bacteria are not existent in the active sludge. Therefore, the ordinary procedure together with facilities for the removal of the nutrients in one of the routes should be maintained and in the other routes only the removal of carbon compounds must be done. During the growth season, the best way is to use the routes as follows:
Route I: Remove the nutrients (P, N, C),
Route II: Protection of the nutrients,
Route II: Reserve.

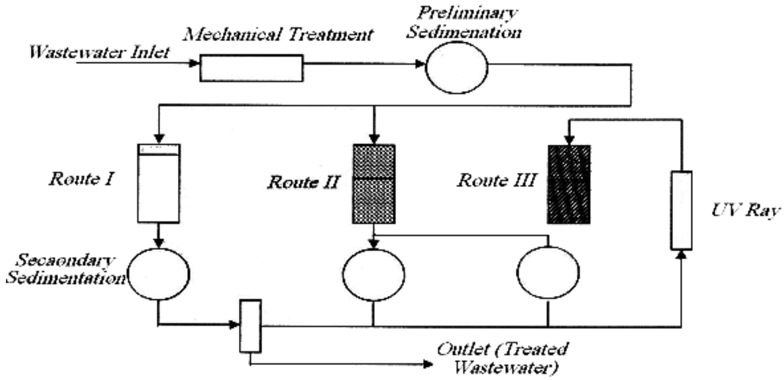


Figure 16: The schematic of exploitation from facilities in growth season – first model.

Among other advantages of this method is attainment to different concentrations of nitrogen and phosphorus by mixing the two flows.

4.1.2 Second model

In this method, the calculations of the needed facilities are done at a temperature of 12˚C for cold months. By increasing the temperature up to about 20˚C about 50% of the preliminary volume will be needed. As the decrease in oxygen content is relatively less, the aeration facilities must be used in all ponds. In this exploitation method shifting from conditions for protection of the nutrients to removal of the nutrients, due to low propagation of nitrification bacteria, has some problems. The water content of the returned sludge and also 100% of the returned solid content of the inlet flow result in relatively high sludge content containing low nitrification bacteria. The decrease in solid load for 50% is suggested for an increase in nitrification bacteria. If the returned solid content is 100%, then the surplus sludge should be stored for two weeks; here 52% of nitrification bacteria became available and if the returned solid load is 50% then the availability of the nitrification bacteria increases to 62%; where if the conditions are prepared for rapid growth of the bacteria, the removal of the nutrients is relatively complete.

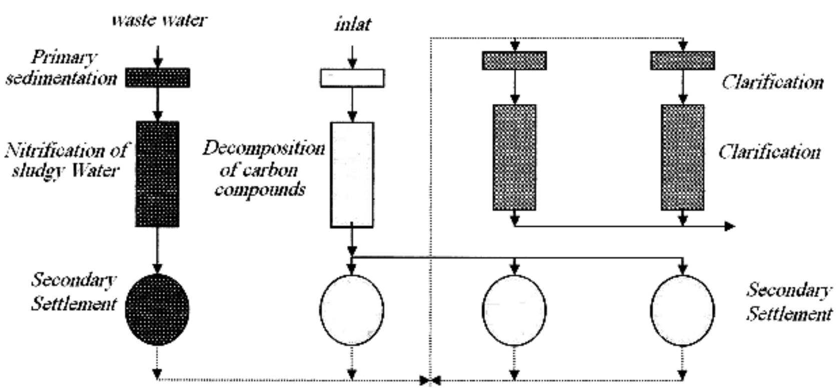


Figure 17: Schematic of exploitation from the facilities in growth season – second model.

It should be pointed out that during the growth phase of plants, a special route will be considered for nitrification of the dark sludgy water and, therefore, the nitrification bacteria are protected in the system.

4.2 Solution II: Wastewater treatment ponds

In this method, the solids are separated from fluid phase in two anaerobic ponds.

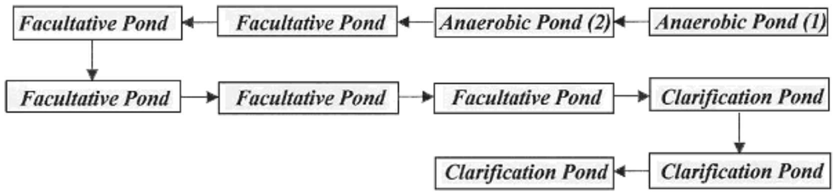


Figure 18: The schematic chart of wastewater treatment pond finally we suggest Accurate pilot studies for attainment to the best operation method of Wastewater treatment facilities.

For attainment to the target of the solution the special volume of the pond is considered 0.5 m^3/p and the pond depth is considered 4 m. The duration of the stay of the wastewater is 3 days, then the wastewater is discharged into optional aerobic ponds with 1.5 m depth. The duration of stay of the wastewater in these ponds will be 20 days. The clarification ponds are located after optional aerobic ponds which are used for eliminating microbial contaminators; the duration of the wastewater in these ponds is 5 days and their depth is 2 m. In the summer months unlimited use of wastewater of these ponds for irrigation is possible and the allowable range of coliform pollution is accessible.

5 Conclusions

Two pilot plants were designed and performed to investigate the impact of 14 kinds of selective plants irrigation using the effluent of wastewater treatment plants in Zahedan and Zabol, in arid region of Sistan and Baluchestan in southeast of Iran. According to FAO standards the quality variation in soil and plants growth is positive. Some solutions for the promotion of soil quality and also some related patterns to the adjustment and development of recent wastewater treatment plants are suggested. The results show the possibility of accessing water resources and waste management goals due to prevent contaminant diffusion in the area, environmental and social consequences and also decreasing the water shortage crises impact on the area.

Acknowledgements

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