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Wastewater Treatment Plant Study and Reuse Assessment, Case study: Al-Khobar Treatment Plant, KSA

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Abstract: Water conservation activities are a measure for human being development. Wastewater reuse techniques are one of the most positive water conservation applications. The current study aimed at studying Al-Khobar wastewater treatment plant and to assess the possibilities of the reclaimed wastewater reuse, securing the safe environment and human health. The study of Al-Khobar treatment plant efficiency proved the suitability of using the treated wastewater as a source of water for irrigation. The Plant recorded removal percentages for the TSS that were ranged between 86.5-89.6%, the COD removal percentages were ranged between 74.8- 78.4%, while for the BOD the records for removal percentages ranged between 94.2-97.4%. The total Coliforms, and TC showed the MPN geomean as 7.49 x 10^2 unit/100 ml; in the chlorinated final effluent; with 4 logs removal. Also, the fecal coliform, FC, have recorded four logs down, 4.96 x 10^2 unit/100 ml in the final chlorinated effluent. The coliphage, CP, have recorded a geomean of 0.64 x 10^2 unit/100 ml in the final treated-chlorinated effluent. The reuse of the reclaimed wastewater of Al-Khobar WWTP, according to the FAO Guidelines recorded positive enviroeconomic impacts upon the environment and human health, while the reclaimed wastewater failed microbiologically according to the Saudi' standards. it is recommended to apply a portion of the secondary treated waste to an advanced treatment, e.g., reverse osmosis, and then to be mixed to the rest of the waste before subjected to the final chlorination.

INTRODUCTION

Scarcity of conventional sources of water in arid and semi-arid regions of the world has been behind the movement to find alternative or additional sources. Some of the possible sources are: deep groundwater, treated wastewater, and brackish water. Deep groundwater is not always available and can be very costly to access. Wastewater, when treated, is a relatively stable water source that has uses in agriculture, industry, recreation, gardening, industrial-plant cooling, and

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recharge of groundwater [1].

At 2.8% Middle East and North Africa countries, MENA, has one of the highest average population growth rates in the world. Combined with scarce natural water supplies these results in very low per capita water availability, expected to decline to 725 m^3 per capita, per year (pcpy), by 2025, far below the benchmark level of 1000 m^3pcpy used as an indicator of severe water stress. Countries in the region which practice wastewater treatment and reuse include Kuwait, Saudi Arabia, Oman, UAE, and Egypt. However, only Tunisia, and to a certain extent, Jordan, already practice wastewater treatment and reuse as an integral component of their water management and environmental protection strategies [2].

The reclaimed water as percent of total wastewater volume in some Middle East countries is recorded as 1, 1, 6, 9, and 15% in Suadi Arabia, Egypt, Jordan, Qatar, and Kuwait; respectively. A number of countries in the Middle East are planning significant increases in water reuse to meet an ultimate objective of reusing 50 to 70 percent of the total wastewater volume [3].

Health risks are one of the major concerns about effluent reuse. Some risk factors are short term and vary in severity depending on the potential for human, animal or environmental contact, while others have longer term impacts that increase with increased use of reused water. The main concerns are pathogens such as viruses, bacteria, protozoa, and Helminthes, and trace organics and heavy metals, endocrine disrupting chemicals, and pharmaceutically active compounds [1].

The Hyderabad Declaration on Wastewater Use in Agriculture 2002, Hyderabad; India, stated that with proper management, wastewater use contributes significantly to sustaining livelihoods, food security and the quality of the environment. In order to enhance positive outcomes while minimizing the risks of wastewater reuse, cost-effective and appropriate treatment should be suited to the end use of wastewater, which is supplemented by guidelines and the different applications [4].

Lazarova *et al*., 1999; stated that over the last decade, an increased number of studies conducted in different countries have shown that stabilization pond systems in series can produce effluent with microbiological water quality suitable for unrestricted irrigation (WHO guidelines category A, < 1000 FC/100 ml and <1 helminthes egg/L)[5].

In Saudi Arabia, all major cities have wastewater treatment facilities with more than 40 treatment plants. Most of them are under loaded and comply with the effluent quality design criteria. For coastal cities like Al-Khobar, Jeddah, and Dammam, the secondary clarifier's effluent is chlorinated before being discharged to the Gulf or the Red Sea. The major applied treatment techniques, in those treatment plants, are activated sludge, trickling filters, aerated lagoons, reverse osmosis, lime softening, filtration, polishing ponds and disinfection [4].

The Eastern Region is the most extended and the largest region in the Kingdom with a total area of more than 497,3 thousand square kilometers which is equivalent to 26% of the Kingdom's area. The 1425H(2004G) census indicates a rise in the number of population of the Eastern Region to about 3,36 million persons which is equivalent to 15.5% of the total population of the Kingdom. The wastewater treatment plants of the eastern province are located in Dammam**,** Al-Khobar, Qatif, Jubail**,** Abqaiq, and Dhahran[6].

The current study aims at studying Al-Khobar wastewater treatment plant and to assess the possibilities of the reclaimed wastewater reuse, securing the safe environment and human health.

MATERIAL AND METHODS

For a whole year field and lab studies have been carried out to assess the efficiency of the WWTP, Al-Khobar WWTP, on daily and weekly basis. The study has started with an elaborate field survey to identify the different processes and the sampling points.

Unit to unit studies have been done, in order to assure the units efficiency. Also, a thoroughly follow up for the final treated wastes has been scoped to investigate the final treated wastes quality.

According to the standard methods the samples were collected, preserved and analyzed. The collected samples have been studied physically, chemically and microbiologically. The Standard Methods for Water and Wastewater have been used to unify the results [(7)].

The physicochemical tested factors were pH, solids, BOD, COD, Nitrogen, Phosphates, chlorides, etc. The microbiological studies have tackled the total coliform, fecal coliform, and coliphage. The Standard Plat Count enumeration is the simplest technique which provides an estimate of the aerobic and facultative aerobic heterotrophic bacteria in water. The microorganisms are measured as colony forming units/100 ml on Standard Methods Agar plat after 48 hr, in 35ºC. Also, Most Probable Number technique has been used to determine the total Coliforms and fecal Coliforms [(7)].

All the collected data were pulled together to study the plant's efficiency for removal of the organic and inorganic pollutants, also, the efficiency of Microbial removal, using the appropriate statistical factors. The study's results were also been assessed on monthly basis to achieve the different impacts of the seasonal variations upon the influent and effluents; quality and quantity.

Finally, studies have been elaborated to investigate the reuse possibilities of the treated wastewater and to establish the needed guidelines for the reuse; including enviroeconomic studies.

RESULTS AND DISCUSSION

Al Khobar Treatment Plant Description:

The plant is running since 25 years ago. Al-Khobar wastewater treatment plant, as shown in figure (1), was designed as a carrousel system, a modified activated sludge system, and it can handle a daily flow of 133,300 m^3/d (35.25 MGD). The principal components of the plant are the inlet structure with screening, grit removal and flow measurement facilities, activated sludge aeration tanks, final clarifiers, sludge recirculation pumping stations, effluent storage lagoons, chlorination facility. Sludge thickeners, thickened sludge pumping station and sludge drying beds.

The plant has the capacity to handle an organic loading of 19,600 kg BOD/d and a suspended solids loading of about 26,700 kg/day at peak of 240,000 m^3/d. Detention time at average and peak flow used for designing was 17 and 9.4 hours, respectively. Typical operating temperatures have been recorded in the range of 15ºC to 35ºC.

Another important parameter of the plant is the F/M designed ratio, which has been reported as 0.05 kg BOD MLSS. The wastewater treatment plant is designed as an extended aeration system, the oxygen requirement is about 60,123 kg/d and for this purpose 18 aerators have been installed in six aeration tanks and six secondary clarifiers. The average detention time in the clarifiers is about 3-7 hours.

The influent is divided into four channels to mechanical screens, then into four parallel flumes and as final physical treatment is led to the grit chambers. The physically treated waste is introduced into the aeration tanks to be mixed with the activated sludge. The biologically treated wastes are clarified in the final clarifiers then to be chlorinated, dose rage 5-15 mg/l, for 5- 15 min detention time; before discharging into the Arabian Gulf. The

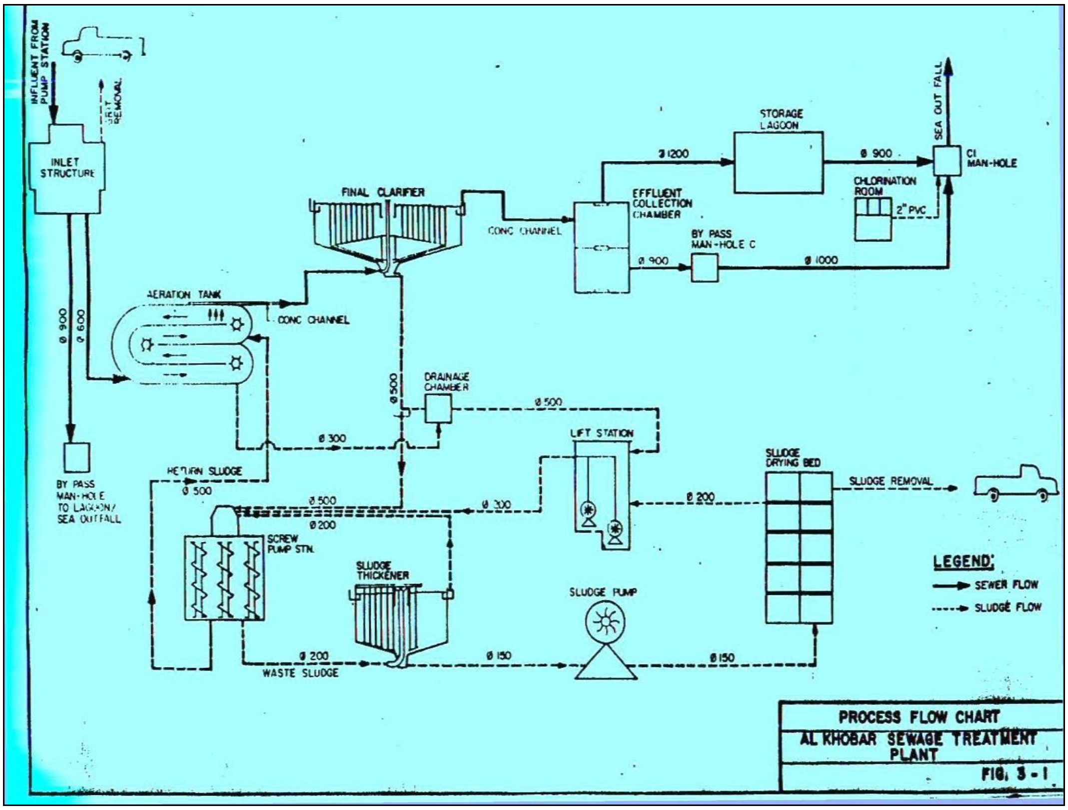

Figure (1): Al Khobar Treatment Plant

produced sludge that settled in the clarifiers partially used as activated sludge after aeration and the rest to be dried in the drying beds. Lime is added to increase the pH of the sludge to achieve the microorganism's inactivation. The sludge is exposed to drying for 14 days, before final disposal.

The Physicochemical Parameters:

On daily, weekly and monthly basis the effluents of the physical, biological treatment units and the final effluents have been studied. As shown in table (1); the average temperature changes with the different seasons to record the highest values, 29.72ºC in the summer time.

Slightly; the pH values changed to record the highest values as 7.58 in the spring time. The TSS values recorded the highest concentration, 270.63 mg/l, in the winter time. In contrary the BOD concentration was 168.87 mg/l in the spring time while the COD highest records, 377.51 mg/l, were in the winter time. In accordance with the BOD records in the spring time the total phosphates recorded it highest values as 10.07 mg/l, while the Ammonia-nitrogen highest values were recorded in the winter times as 28.25 mg/l.

During the whole study, it was noticed that there is a relation between the BOD strength and the chlorine doses and it is proved in table (1) in the proportional relationship between them in the records, where the highest records, 1.41 mg/l, for the residual chlorine were recorded in the spring time. This could be explained by the existence of the main nutritional source, the organics, measured as BOD, and the abundance of the microorganisms.

The treatability efficiency of the whole plant has been studied in two phases, the effluent of the biological treatment and the final effluent after the chlorination process. AS shown in figure (2); the removal percentages for the TSS were ranged between 86.5- 89.6% where the winter time recorded the highest values of removal. The COD removal percentages were ranged between 74.8- 78.4%, while for the BOD the records for removal percentages ranged between 94.2- 97.4%.

The plant flow rate was within the design capacity 133,000 m^3/d, to record a mean of 114,851m^3/d. While it recorded the highest values, in some Islamic feasts, as 126,000- 129,000 m^3/d for single days; all over the study time.

Table (1): Seasonal variations study for the different factors and the treatment removal efficiency:

	Parameter / Season	WINTER	SPRING	SUMMER	AUTUMN	GEOMEAN	Max	Min
INFFLUENT	Temperature c	22.68	29.00	29.71	27.13	26.98	29.71	22.68
	pH	7.48	7.58	7.26	7.44		7.58	7.26
	Vol.s.s ml/L	2.18	3.84	3.45	3.16	3.09	3.84	2.18
	Tss mg/l	270.63	158.94	130.92	186.83	180.10	270.63	130.92
	T.D.S. mg/l	2,016.19	1,442.26	1,354.75	1,604.40	1,585.57	2,016.19	1,354.75
	Alkalinity mg/l	211.56	214.34	209.92	211.94	211.93	214.34	209.92
	Chloride mg/l	884.02	636.93	751.07	757.34	752.28	884.02	636.93
	BOD mg/l	148.05	168.87	148.23	155.05	154.82	168.87	148.05
	COD mg/l	377.51	255.25	260.70	297.82	294.10	377.51	255.25
	NH3 -N mg/l	28.25	26.58	22.11	25.65	25.54	28.25	22.11
	O.Phosphate-P mg/l	10.06	10.07	8.72	9.62	9.60	10.07	8.72
	T.Phosphate-P mg/l	11.83	16.08	11.73	13.21	13.10	16.08	11.73
EFFLUENT	Temperature c	24.79	27.72	29.07	27.20	27.15	29.07	24.79
	pH	7.35	7.65	7.45	7.48		7.65	7.35
	Tss mg/l	28.92	15.23	17.42	20.52	19.92	28.92	15.23
	Turbidity NTU	58.35	11.50	12.95	27.60	22.13	58.35	11.50
	T.D.S. mg/l	2,097.29	991.70	1,144.21	1,411.07	1,353.70	2,097.29	991.70
	Alkalinity mg/l	124.97	2,271.04	136.12	844.04	424.94	2,271.04	124.97
	Chloride mg/l	800.81	522.20	594.93	639.32	631.52	800.81	522.20
	BOD mg/l	7.92	4.35	4.96	5.74	5.60	7.92	4.35
	COD mg/l	74.72	61.09	52.40	62.74	62.24	74.72	52.40
	NH_3 -N mg/l	5.18	6.31	3.64	5.04	4.95	6.31	3.64
	O.Phosphate-P mg/l	5.21	4.41	4.79	4.80	4.80	5.21	4.41
	T.Phosphate-P mg/l	6.95	7.65	6.84	7.14	7.14	7.65	6.84
	Residual cl_2 p.p.m	1.18	1.41	1.27	1.29	1.28	1.41	1.18
REMOVAL%	Tss mg/l	89.6%	88.0%	86.5%	88.0%	88.02%	89.6%	86.5%
	C O D mg/l	78.4%	74.8%	78.1%	77.1%	77.08%	78.4%	74.8%
	B O D 5 mg/l	94.2%	97.4%	96.4%	96.0%	95.99%	97.4%	94.2%
	NH3 -N mg/l	81.5%	75.3%	83.2%	80.0%	79.95%	83.2%	75.3%
	FLOW M^3/d	117,349	115,023	112,224	114,865	114,851	117,349	112,224

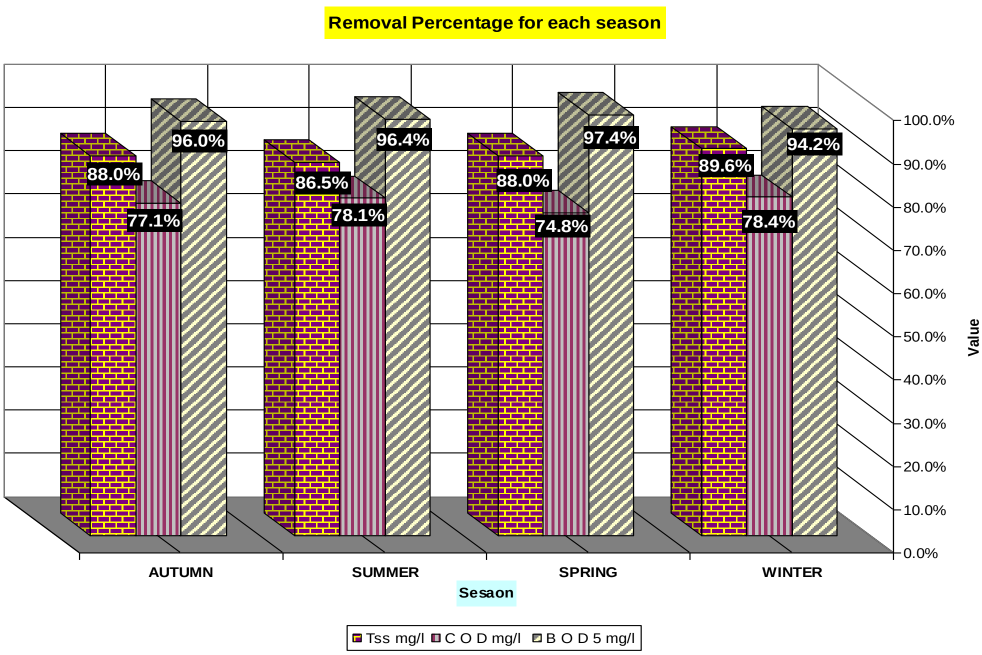

Figure (2): The Seasonal removal percentages of TSS, COD, and BOD, in Al Khobar Wastewater Treatment Plant

Microbiological factors:

During the study, as in Table (2); the total Coliforms, TC, showed the MPN geomean as 7.7 x10^6, 1.36 x $10^{5,}$ and 7.49 x 10^2 units/100 ml; in the influent, after secondary treatment and in the chlorinated effluent, respectively. The fecal coliform, FC, have recorded 1.66 x 10^6 units/100 ml in the studied influents and, with four logs down, 4.96 x 10^2 units/100 ml in the final chlorinated effluent. The coliphage, CP, have recorded 0.64 x 10^2 units/100 ml in the final treated-chlorinated effluent.

So, it is proved as shown in figure (3) that the secondary treatment recorded 99.8, 96.7, and 88.49% removal of TC, FC, and CP; respectively. After the application of chlorine as a disinfectant, it approached removal percentages for the TC, FC, and CP of 99.99, 99.99 and 91.19%, respectively. The coliphage has showed resistance to the chlorination more than the TC and FC, all over the study time.

Fattouh and Al-Kahtani; 2002, in a study on WWTP in Riyadh have found out that the efficiency of removal of total coliform and fecal coliform in the chlorinated effluent had negligible counts of TC and FC with an efficiency of removal of (99.2-100%) and (99-100%) for TC and FC, respectively, whereas the efficiency of removal of coliphages ranged between (91-100%) [8].

Comparatively; between both WWTP in Al-Khobar and Riyadh, it was found that the WWTPs have the efficiency to neutralize the health hazards of the microbial contamination with some coliphage resistance.

Trace Elements and Heavy Metals:

Trace elements and heavy metals are not normally included in routine analysis of regular irrigation water, but attention should be paid to them when using wastewater effluents, particularly if contamination with industrial wastewater discharges is suspected. The studied elements were aluminum, arsenic, cadmium, copper, fluoride, iron, lead, and zinc. All of them have recorded lower values than those of the recommended maximum concentration by the FAO[9] and the Saudi Standards [4] ; in case of using the reclaimed water of the WWTP as a source for irrigation, as shown in Table (3). These recorded lower values are justified by the very minimum intrusion of the industrial wastes in the collected wastewater.

Table (2): The Microbial concentrations of Total Coliform, Fecal Coliform, and Coliphage in the different Plant processes

Sample		Total Coliform **(MPN/100 ml)**	Fecal Coliform **(MPN/100 ml)**	Coliphage **(PFU/100ml)**
Influent	Max	1.06×10^{8}	3.04×10^{7}	2.91×10^{3}
	Min.	5.72×10^{5}	9.14×10^{4}	2.1×10^{2}
	GEOMEAN	7.7×10^{6}	1.66×10^{6}	7.82×10^{2}
Secondary Effluent	Max.	1.01×10^{6}	2.58×10^{5}	1.72×10^{3}
	Min.	1.8×10^{4}	1.12×10^{4}	0.47×10^{2}
	GEOMEAN	1.36×10^{5}	5.37×10^{4}	0.9×10^{2}
Chlorinated Effluent	Max.	1.4×10^{3}	1.35×10^{3}	0.93×10^{2}
	Min.	3.8×10^{2}	1.82×10^{2}	0.44×10^{2}
	GEOMEAN	7.49×10^{2}	4.96×10^{2}	0.64×10^{2}

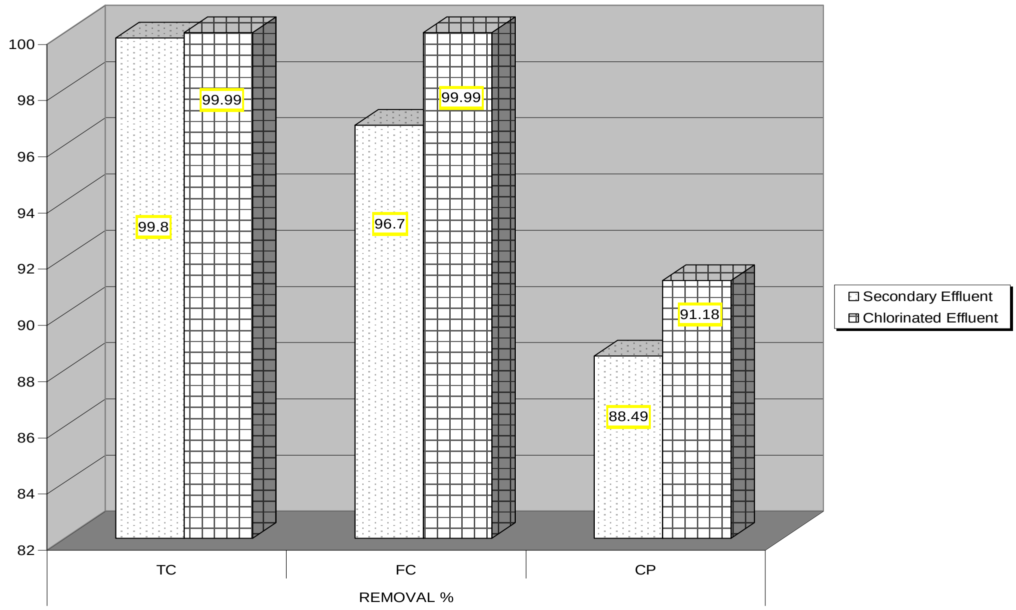

Figure (3): The removal percentages of Total Coliform, Fecal Coliform, and Coliphage after the secondary treatment and chlorination

Table (3): The average of trace metals concentrations in Al-Khobar WWTP:

	Element	CONCENTRATION mg/l	Recommended maximum concentration (mg/l) *	Saudi' Standards **
Al	(aluminum)	0.84	5	1
As	(arsenic)	0.02	0.1	0.1
Cd	(cadmium)	0.001	0.01	0.01
Cu	(copper)	0.06	0.2	0.4
F	(fluoride)	0.35	1	2
Fe	(iron)	2.8	5	5
Pd	(lead)	0.9	5	0.1
Zn	(zinc)	0.27	2	4

* Source: FAO [9], ** Source Saudi' Standards [4]

Assessment of the reuse possibilities:

The reuse of sewage effluent for agricultural practices is not an entirely new concept. WHO (1973); concluded that primary treatment would be sufficient to permit re-use for the irrigation of crops that are not for direct human consumption. Secondary treatment and most probably disinfection and filtration are considered necessary if the effluent is to be used for irrigation of crops for direct human consumption [3].

From the whole study it was found that the final treated chlorinated wastewater is within the guidelines of the FAO [3], for reuse as a source of water for agricultural practices. The treated effluent has failed to meet the Saudi Standards [4], only in the total coliform, turbidity and TSS; whereas the average values in the research have recorded 749 counts/100 ml, turbidity 27.6 NTU, and TSS 20.52 mg/l; while these factors in the Saudi standards were 220 counts/100 ml, 1 NTU, and 10 mg/l, respectively.

So, it is suggested to increase the chlorination detention time or the application of a mix of Chlorine and per acetic acid, PAA. Also, it is recommended to apply a part of the secondary treated waste to an advanced treatment, e.g., reverse osmosis, and then to be mixed to the rest of the waste before subjected to the final chlorination. This application will be economically feasible than applying the whole treated waste to be subjected to the advanced treatment as proposed in the water ministry in the kingdom of Saudi Arabia, for the studied plant.

Enviroeconomic Study:

Properly planned use of municipal wastewater alleviates surface water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in sewage to grow crops. The availability of this additional water near population centers will increase the choice of crops. The nitrogen and phosphorus content of sewage might reduce or eliminate the requirements for commercial fertilizers [(10).]

The annual average flow rate of Al-Khobar WWTP has recorded an approximate value of 120,000 m^3/d. When the treated wastewater will meet the Saudi standards, or if it will be used as it is according to the FAO's guidelines; many enviroeconomic values will be attained.

First of all, the value of using, approximately, 120,000 m^3/d (43.8 Mm^3/y) of reclaimed wastewater; as a source of water for irrigation. When the treated wastewater effluent is used carefully and by applying the new irrigation techniques, a rate of 5000 m^3/ha.year; is expected. So, the treated wastewater of Al-Khobar plant would be used to irrigate an area of 8760 ha annually.

From the other side of the coin, the value of the fertilizers that could be saved, as they already exist in the treated wastewater such as nitrogen and phosphorus:

If the Nitrogen concentration, as in the studied effluent = 5.04 mg/l, and

The Phosphorus concentration, as in the studied effluent= 7.14 mg/l

With the assumption of the application of 5000 m^3/ha.year, the fertilizer economic contribution out of the usage of the reclaimed wastewater would be: 25 kg/ha.year and 35 kg/ha.year for nitrogen and phosphorus; respectively.

So, in the case of reusing the final treated wastewater of Al-Khobar WWTP that would add positive values from many aspects:

- Securing the Arabian Gulf water quality, where currently the treated wastes are disposed, of any possible pollutant.
- Maximizing the value of the reclaimed wastewater as a source for irrigation, especially Saudi Arabia is considered as an arid country.
- Conserving the ground water in the eastern Region
- The value of the nitrogen and phosphorus, and other agriculture aids that may be found in the reclaimed wastewater.

CONCLUIONS AND RECOMMENDATIONS

A. Conclusions:

- The study of Al-Khobar treatment plant efficiency proved the suitability of using the treated waste water as a source of water for irrigation.
- The Plant recorded removal percentages for the TSS that were ranged between 86.5- 89.6%, the COD removal percentages were ranged between 74.8- 78.4%, while for the BOD the records for removal percentages ranged between 94.2- 97.4%.
- The combination of the biological treatment and chlorination processes approached removal percentages for the TC, FC and CP of 99.9, 99.9, and 91.2%, respectively. The coliphage has showed resistance to the chlorination more than the TC and FC, all over the study time.
- The concentrations of the studied

microorganisms are not allowing the reuse of the reclaimed wastewater as a source for irrigation according to the Saudi' standards, without further reduction of the TC, FC, and CP concentrations.

- All of the studied trace and heavy metals have recorded lower values than those of the recommended maximum concentration by the FAO and the Saudi Standards for reusing the reclaimed wastewater.
- The reuse of the reclaimed wastewater of Al-Khobar WWTP, according to the FAO Guidelines recorded positive enviroeconomic impacts upon the environment and human health.

B. Recommendations

- Sodium Adsorption Ratio, SAR, has to be thoroughly studied before applying the studied wastewater, as a source of water for irrigation, because of its possible adverse impacts on the soil nature and consequently the infiltration rate and soil permeability.
- The Mix of Chlorine and PPA; is to be tested on an inplant scale which may secure the reclaimed wastewater from all the existed microbes, including the enteroviruses, as well as; it will minimize the chloroorganic compounds formation in the final wastes.
- Field studies on the different proposed vegetables and fruits would be recommended, in order to secure the adverse health impacts of any pollutants upon human health, including the field workers and the consumers.

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