

ASSESSMENT OF TRACE ORGANICS IN TERTIARY TREATED WASTEWATER AND THEIR REMOVAL USING SOIL AQUIFER TREATMENT SYSTEM (SAT) IN KUWAIT

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ABSTRACT

Wastewater has gained an importance as a source of water in water starved arid and semiarid regions particularly. However, its cost effective treatment is utmost important for utilization. Soil aquifer treatment (SAT) is a cost-effective method for treating wastewater that passes through the unsaturated zone, using either infiltration basins and/or injection wells as a recharge method. A study was carried out to assess the removal of trace organics, represented by total organic carbon (TOC), total petroleum hydrocarbon (TPH) and polycyclic aromatic hydrocarbons (PAHs), from tertiary treated wastewater (TTWW) by SAT using the infiltration basins. The concentration of TOC and TPH in TTWW ranged from 5.10 mg/l to 6.72 mg/l and 0.44 mg/l to 0.84 mg/l, respectively. With regard to PAHs in TTWW, only pyrene was detected in the range from 15 µg/l to 30 µg/l. Benzo[a]pyrene, acenaphthalene and fluoranthene were detected only once in TTWW during the study period. The groundwater samples, collected from below water table at about 30 meters beneath infiltration basins, were analyzed for TOC, TPH and PAHs concentrations. The removal of TOC, TPH and PAHs by SAT was 83.38%, 58.05% and 100%, respectively. The decreased removal efficiency of SAT for TOC raised a concern related to the long-term efficiency of SAT. Results indicated that SAT could be used to reduce the concentrations of organics significantly from treated wastewater. However, results also suggest to determining precisely the long-term removal efficiency of SAT.

Keywords: Infiltration basins, long-term removal efficiency, PAHs, TOC, TPH.

1 INTRODUCTION

Kuwait is an arid country that suffers from limited natural water resources. In fact, it is completely devoid of surface water resources such as lakes, streams and rivers. The current local water resources for Kuwait are groundwater and desalinated seawater. Most of usable groundwater in Kuwait is brackish, except for the small volumes of fresh groundwater in Al-Raudhatain and Umm Al-Aish areas of northern Kuwait. Brackish groundwater is extracted in large quantities and used in irrigation, industrial and construction sectors. It is also used for blending with desalinated water to make it potable. The average total dissolved solids (TDS) content of brackish groundwater in Kuwait is about 4,000 mg/l. Although the desalination plants meet all of Kuwait's freshwater needs, this is a very expensive way of producing freshwater. Also, groundwater is limited and is essentially a nonrenewable resource in this arid environment. Given the limited available water resources and increasing demand, municipal wastewater can have a special role in maintaining and augment the water resources of Kuwait. Treated wastewater effluents, free from health hazards must be considered as valuable water resources for the irrigation of certain crops, greenery enhancement, landscaping, land reclamation, car washing, industrial process water and toilet flushing. It can also be used for recharging aquifers in the areas where aquifers have been depleted by over-exploitation.

Three wastewater treatment plants are operating in Riqqa, Jahra and Umm Al-Hyman areas of Kuwait for domestic wastewater. Wastewater treatment is accomplished in three stages. In the first stage, solids are removed mechanically, whereas the suspended organic matter is removed biologically in the second stage. In the third stage, the treated wastewater is disinfected using chlorine

and then filtered. The treatment of wastewater in three stages involves lot of investment. However, treatment can be achieved also through a natural process called soil aquifer treatment (SAT), which can also be conducted as an integrated approach of groundwater recharge and recovery (Al-Otaibi & Al-Senafy, 2004).

SAT has proved that the quality of wastewater can be improved significantly to meet the requirements of the unrestricted irrigation of all kinds of crops, vegetables and fruits. Where surface soil is permeable, vadose zone has no restricting (low permeable) layers, aquifers are unconfined and without undesirable chemicals in the vadose zone, groundwater can be artificially recharged by surface infiltration systems. When this recharge is done with partially treated sewage effluent, considerable quality improvement of the effluent is achieved as it moves downward through the vadose zone (Bouwer et al., 1990).

1.1 Background

In 1997, a pilot SAT project was initiated in the Sulaibiya area of Kuwait. The main aim of the project was to construct a pilot SAT plant for the treatment of secondary/tertiary treated wastewater and to store the treated water in an aquifer. The pilot plant occupied an area of 2000 m³ and the recharge system was composed of seven infiltration basins, one production well (P1) and 14 monitoring wells. Fig.1 presents the physical setting of the pilot plant. Among the 14 monitoring wells, 12 wells (numbers M1 to M3 and M5 to M13) were drilled to a 50-m depth. The bottom half of the wells was fully screened. Two wells M4 and M14 were deep wells drilled to a total depth of 100 m to collect representative samples of the native groundwater. A production well P1 was also constructed in the study area to recover treated water (effluent). The total depth of the P1 was about 40-m and the saturated zone was fully screened.

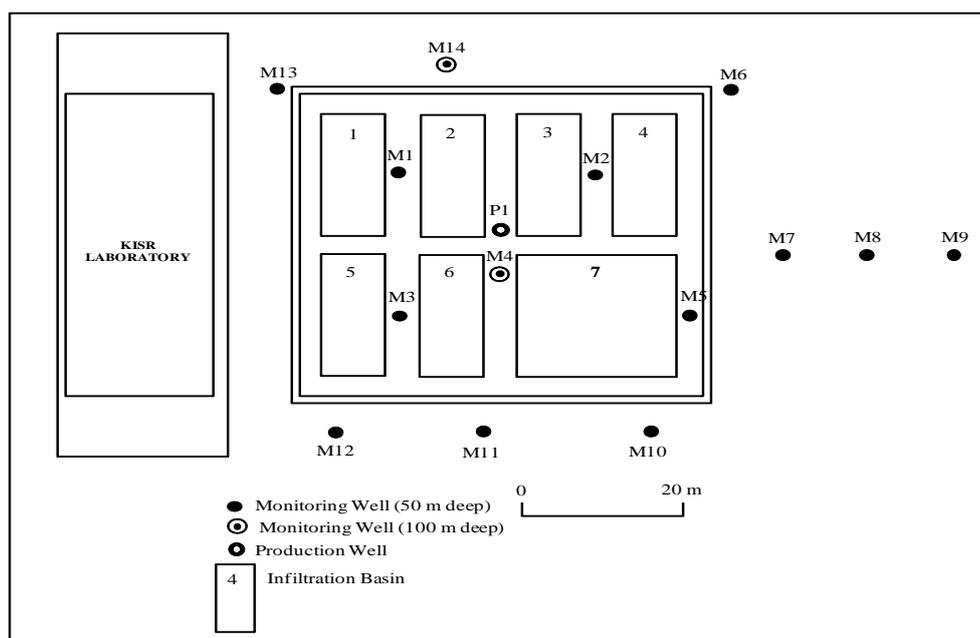


Figure 1. The physical setting of the pilot plant

Prior to the construction of the pilot plant, 20 holes of 100-mm in diameter and 30-m in depth were drilled to study the subsurface lithology of pilot plant site. These holes covered the study area and the spacing between the holes was about 10-m. Drill cuttings were collected at 1 m intervals during drilling. The sediments of unsaturated zone were composed of a sequence of massive, friable grayish to pale brownish fluviatile siliciclastic deposits. Megascopic investigation of drill cuttings, supported by particle size distribution analyses, indicated the occurrence of fine sand, muddy sand, muddy

gravelly sand, gravelly muddy sand and mud sediments types within the unsaturated zone of the study area. These types were identified on the basis of the relative abundance of three grain size classes, i.e., gravel, sand and mud. Table 1 presents the average percentages of the main size classes within the 30-m of the unsaturated zone in the study area.

Table 1. Average Percentages of the Main Size Classes Within the Unsaturated Zone (Al-Otaibi , 2001)

Depth (m)	Gravel (%)	Sand (%)	Mud (%)	Depth (m)	Gravel (%)	Sand (%)	Mud (%)
1	2.00	95.8	2.20	16	2.30	96.6	1.10
2	0.70	97.8	1.50	17	1.40	97.4	1.20
3	0.10	99.4	0.50	18	15.00	55.3	29.70
4	1.10	97.7	1.20	19	4.30	67.1	28.60
5	0.40	97.6	2.00	20	4.30	65.2	30.50
6	0.60	95.6	3.80	21	10.60	71.6	17.80
7	9.80	89.0	1.20	22	14.00	79.0	7.00
8	71.00	26.0	3.00	23	18.40	78.9	2.70
9	12.90	84.1	3.00	24	9.40	72.5	18.10
10	13.50	65.5	21.00	25	4.60	77.8	17.60
11	18.50	75.2	6.30	26	7.60	80.9	11.50
12	11.00	85.5	3.50	27	5.20	89.3	5.50
13	0.90	97.7	1.20	28	15.40	79.8	4.80
14	0.80	98.3	0.90	29	8.50	86.8	4.70
15	2.40	96.0	1.60	30	4.40	89.7	5.90

The clastic sediment deposits in the study area were also characterized by the occurrence of lithological horizons known as calcrete (Gatch). These horizons repeated several times. A muddy horizon, relatively thick encountered between 18 and 21 m below the ground surface. The most dominant deposit in the sequence of the unsaturated zone was fine sand. Table 2 presents the general lithology of the unsaturated zone.

Table 2. General Lithology of the Unsaturated Zone (Al-Otaibi , 2001)

Depth Interval (m)	Lithology
0-1	Soil (muddy sand)
1-6	Fine sand calcretized at bottom
6-7	Gravelly sand
7-8	Gravel
8-12	Calcretized muddy gravelly sand
12-17	Fine sand partially calcretized
17-21	Calcretized gravelly muddy sand
21-23	Muddy gravelly sand partially calcretized
23-27	Gravelly muddy sand calcretized at top
27-30	Muddy gravelly sand partially calcretized

Infiltration basins (1 through 6) were 7 m wide, 15 m long and 2 m deep. Infiltration basin 7 was 18 m wide, 15 m long and 2 m deep. The bottom of all basins were left unlined to allow water infiltration. The sides of the basins were lined with concrete pare of 50-mm thickness. To improve the permeability of infiltration basins' topsoil, 20 holes of 15-mm diameter and 30-m depth were drilled in basin 1 and 2. These holes were backfilled with topsoil. The infiltration basins were provided with

a piping system network to supply treated wastewater. The piping system within the infiltration basins was connected to the supply line of wastewater. Flowmeters were installed on the main and secondary pipes to measure the wastewater flow to each basin. Also A type evaporation pan was installed at the site to measure the actual evaporation rates.

The recharge operation of infiltration basins with wastewater commenced on 10 May 1998, upon the completion of the construction activities, for a duration of 3 years and completed in May 2001. The hydraulic head in the infiltration basins was kept at about 1.0 m. One of the major problems encountered during the operation was the slow infiltration of TTWW. This was presumably due to the clogging and the low vertical value for the hydraulic conductivity of the unsaturated zone. To improve the infiltration of TTWW, 10 holes of 250-mm diameter were drilled in basin 7. These holes were filled with gravel of 5-mm size and the top 2-m of the holes were filled with topsoil. The infiltration rate increased slightly, but not enough to reach practical application requirements. Another trial was made to improve the infiltration of TTWW by the construction of five injection wells with a diameter of 200 mm to depth of 36 m in basin 7. The infiltration rate was higher at the early stage of operation, but it declined again rapidly and reached to its original value (Al-Otaibi, 2001).

The total volume of water that released to recharge basins during the three-year operation period (May 1998 till May 2001) was 16,790 m³. The total water evaporation from the seven infiltration basins throughout operation period was estimated at 9,000 m³. The amount of water that infiltrated to the subsurface was, therefor, 16,790 – 9,000 = 7,790 m³, which is about 46.4% of the total water. Considering a small fraction of this percentage that may had retained with the unsaturated zone, the final volume of water that infiltrated to subsurface was estimated as 45% with an average infiltration rate of 2.885 meter per year (11.8 millimeters per day) (Al-Otaibai, 2001).

During the recharge operation of infiltration basins, the variations in water level and quality were recorded on a monthly basis. The water level rise varied between 1.4 m (M14) and 1.9 m (M2) with an average of 1.7 m from the static groundwater level of about 29 mbgl. Water samples collected from the wastewater and the groundwater were analyzed for various constituents pH, total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD₅), ammonia (NH₃), nitrate (NO₃), phosphate (PO₄) and turbidity (Al-Otaibi and Al-Senafy, 2004). Table 3 presents the removal percentages of these constituents, averaged from February 1999 until May 2001, from tertiary treated wastewater (TTWW) by the SAT system. However, the removal of trace organics represented by polycyclic aromatic hydrocarbons (PAHs), total organic carbon (TOC) and total petroleum hydrocarbon (TPH) from TTWW by SAT was not studied throughout the operation period (May 1998 till May 2001). The PAHs, TOC and TPH are very important parameters to assess the quality of water. TOC is concentration of total organic matter that may be present in water and toxic too. TPH represents the concentration of petroleum hydrocarbons and most of petroleum are toxic. PAHs are high-molecular-weight refractory compounds. Many of the PAHs are highly carcinogenic at low levels e.g., Benzo(a)pyrene, indeno(1,2,3-*cd*) pyrene and benzo(b)fluoranthene and they have been proved carcinogenic for animals in laboratory testing and could also be carcinogenic for human beings (WHO, 2004).

The importance of toxic organics in treated wastewater also come from the fact that treated wastewater is most often used for agricultural purposes and as drinking water for animals such as cows and sheep. The toxins can transfer from the irrigation water to all parts of a plant such as seeds, roots, stems, leaves and fruits. These plant products eaten later either by animals or by human beings could become a health hazard (WHO, 2004). As such, considering the importance of these organics, a separate study was carried out in the year 2002 using the infiltration basins of Sulaiybia. The objectives of the study were the investigation of PAHs, TOC and TPH concentrations in TTWW and the assessment of their removal by SAT under the prevailing conditions at Sulaiybia, Kuwait.

Table 3. Wastewater Quality Parameters Before and After SAT (Al-Otaibi et al., 2001)

Parameter	TTWW	Groundwater	% Removal by SAT	Permissible Levels for Irrigation Water
pH	6.50	7.80	0.00	6.5 – 8.5 (KEPA, 2017)
TDS (mg/l)	1056.00	1874.00	0.00	1500 mg/l (KEPA, 2017)
TSS (mg/l)	2.00	5.00	0.00	15 mg/l (KEPA, 2107)
BOD ₅ (mg/l)	3.00	0.10	97.00	20 mg/l (KEPA, 2017)
NH ₃ (mg/l)	6.00	0.00	100.00	15 mg/l (KEPA, 2017)
NO ₃ (mg/l)	5.00	2.00	60.00	< 5 mg/l as NO ₃ -N mg/l
PO ₄ (mg/l)	10.00	0.10	99.00	30 mg/l (KEPA, 2017)
Turbidity (NTU)	5.00	3.00	40.00	≤ 2 NTU should not exceed < 5 NTU (USEPA, 2012)

Except pH and Turbidity, all other units are in mg/l

TTWW=Tertiary treated wastewater; SAT = Soil aquifer treatment; TDS = Total dissolved solids; TSS = Total suspended solids; BOD₅ = Biochemical oxygen demand;

2 METHODOLOGY

The methodology of the study was composed of the operation of infiltration basins, the collection of soil samples from the infiltration basins, the collection of treated wastewater (influent), the collection of groundwater samples (effluent), the analysis of water samples, and the interpretation of results.

The study commenced on July 2002 and ended in December 2002. The infiltration basins were flooded with TTWW to a depth of approximately 30 cm from the surface of the soil in the basins.

After completing the infiltration of treated wastewater, the basins were dried for one day and the surface of the soils in the basins was ploughed with the help of a metal comb before the re-flooding of the infiltration basins. The groundwater samples were collected from P1. The collection of water samples, both from TTWW and groundwater, was on a monthly basis following the water sampling instructions of the American Public Health Association (APHA, 2005). Since recharge rate and evaporation rate had been estimated in the study conducted by Al-Otaibi (2001) that is why the measurements of volume of TTWW discharged to infiltration basin as well as evaporation rate of TTWW from infiltration basins were not carried out.

The collected TTWW and groundwater samples were analyzed to determine TOC, TPH and PAHs concentrations. The United States Environmental Protection Agency (USEPA) method 418.1, combustion-infrared method 5310B from the Standard Method for the Examination of Water and Wastewater (APHA, 2005) and gaschromatograph/mass spectrometer (GC/MS) method No. KISR/CAL-C16/04 were used to determine the concentration of TOC, TPH and PAHs, respectively. The method (KISR/CAL-C16/04) covers the determination of acenaphthene, acenaphthylene, anthracene, benzo(a)Anthracene, benzo(a)ylene, benzo(b)flouranthene, benzo(ghi)perylene,

benzo(k)flouranthene, chryesene, dibenzo(ah)anthracene, flouranthene, flourene, indeno(1,2,3)pyrene, naphthalene, phenanthrene and pyrene.

The soil samples were collected from the infiltration basins for particle size distribution [gravel, sand and fines (silt and clay)] analysis, determination of total organic matter of the soil, cation exchange capacity (CEC) and calcium carbonate (CaCO_3) content. The grain size analysis was carried out in accordance with the clause 9.3 of part 2 of British Standard Institutions (BSI) BS 1377 (BSI, 1990). The total organic matter was determined in accordance with the clause 3 of part 3 of BS 1377. The CEC of the soil was determined following the methodology of Rhoades (Rhoades, 1982). The CaCO_3 content of the soil was determined following the methodology of Nelson (Nelson, 1982). The organic matter, CEC and CaCO_3 of Sulaiybia soil were found at 0.12%, 3.8 meq/100g and 5%, respectively.

Also jar tests were conducted to comprehend the role of Gatch in removal mechanism of PAHs from the TTWW. Only the Gatch (calcrete) part of the soil samples was used for jar tests. Gatch was collected from drill cuttings. Gatch and TTWW (1:1 w/v ratio) were mixed in screw-capped glass bottles using rotary mixer (Janke & Kunkel, IKA-Werk, KS500) at a rate of 300 cycles per minute for 24 hours at a room temperature of 22°C. After mixing, the Calcrete-TTWW mixture were filtered through filter paper Whatman No. 40 in to glass bottles and analyzed for PAHs. No PAHs was detected in TTWW after jar tests.

3 RESULTS AND DISCUSSION

A common approach to evaluate the performance of SAT is by calculating the removal efficiency of a pollutant from its concentration in the influent (recharge wastewater) and in the effluent (collected water samples) (Al-Otaibi, 2001). As such, the removal of TOC, TPH and PAHs from the TTWW by SAT is described here.

3.1 Total Organic Carbon

Organic matter of water is usually measured as TOC, which represents all the organic compounds that may be present in water. The determination of TOC is important for two main reasons, first it is a convenient way of measuring the overall contamination of water with organic compounds, and second, the level of TOC is very useful in measuring the efficiency of water and wastewater treatment. The analytical data related to the concentration of TOC in TTWW and in the groundwater, and its removal from TTWW by SAT are presented in Table 4. The analytical results indicate that the TOC concentration in TTWW ranges from 5.16 mg/l to 6.72 mg/l with an average of 6.12 mg/l. It ranges from 0.90 mg/l to 1.14 mg/l with an average of 1.01 mg/l in groundwater samples collected from production wells P1. Fig. 2 shows the variation of TOC concentrations in TTWW and groundwater during the study period (July 2002 – December 2002). The removal of TOC from TTWW by SAT ranges from 80.04% to 85.67% with an average of 83.40%. There is a decrease in removal of TOC by SAT over the study period. The removal percentage of TOC and TPH presented in Table 4 and Table 5 were estimated as follow:

$$\text{Removal (\%)} = [(\text{Influent Concentration} - \text{Effluent Concentration}) / (\text{Effluent Concentration})] \times 100$$

Where influent concentration is the concentration of TOC/TPH in TTWW and effluent concentration is the concentration of TOC/TPH in groundwater.

3.2 Total Petroleum Hydrocarbon

TPH is a term used to describe a large family of hundreds of chemical compounds that originally come from petroleum. The analytical data related to the concentrations of TPH in TTWW, in groundwater and its removal from TTWW by SAT is presented in Table 5. The analytical data indicate that the TPH concentration in TTWW varies from 0.44 mg/l to 0.84 mg/l with an average of 0.60 mg/l and from 0.15 mg/ to 0.39 mg/l with an average of 0.25 mg/l in groundwater. Maximum permissible level of TPH in the wastewater to be used for irrigation is 5 mg/l (KEPA, 2017). Fig. 3 shows the variation of TPH concentration in TTWW and groundwater and removal by SAT during the study period (July 2002 – December 2002). The removal of TPH from TTWW by SAT ranges from 45.83% to 70.45%. The average removal of TPH by SAT is found at 59.65%. Fig. 3 presents the variation in TPH removal by SAT during the study period.

Table 4. Concentration of TOC in TTWW, in Groundwater and Removal by the SAT System

	TOC in TTWW (mg/l)	TOC in Groundwater (P1) (mg/l) P1	TOC Removal (%)
August 2002	6.49	1.01	84.44
September 2002	6.28	0.90	85.67
October 2002	5.93	0.96	83.81
November 2002	6.72	1.14	83.04
December 2002	5.16	1.03	80.04

TOC = Total organic carbon; TTWW = Tertiary treated wastewater; SAT = Soil aquifer treatment; P1 = Production well no. 1

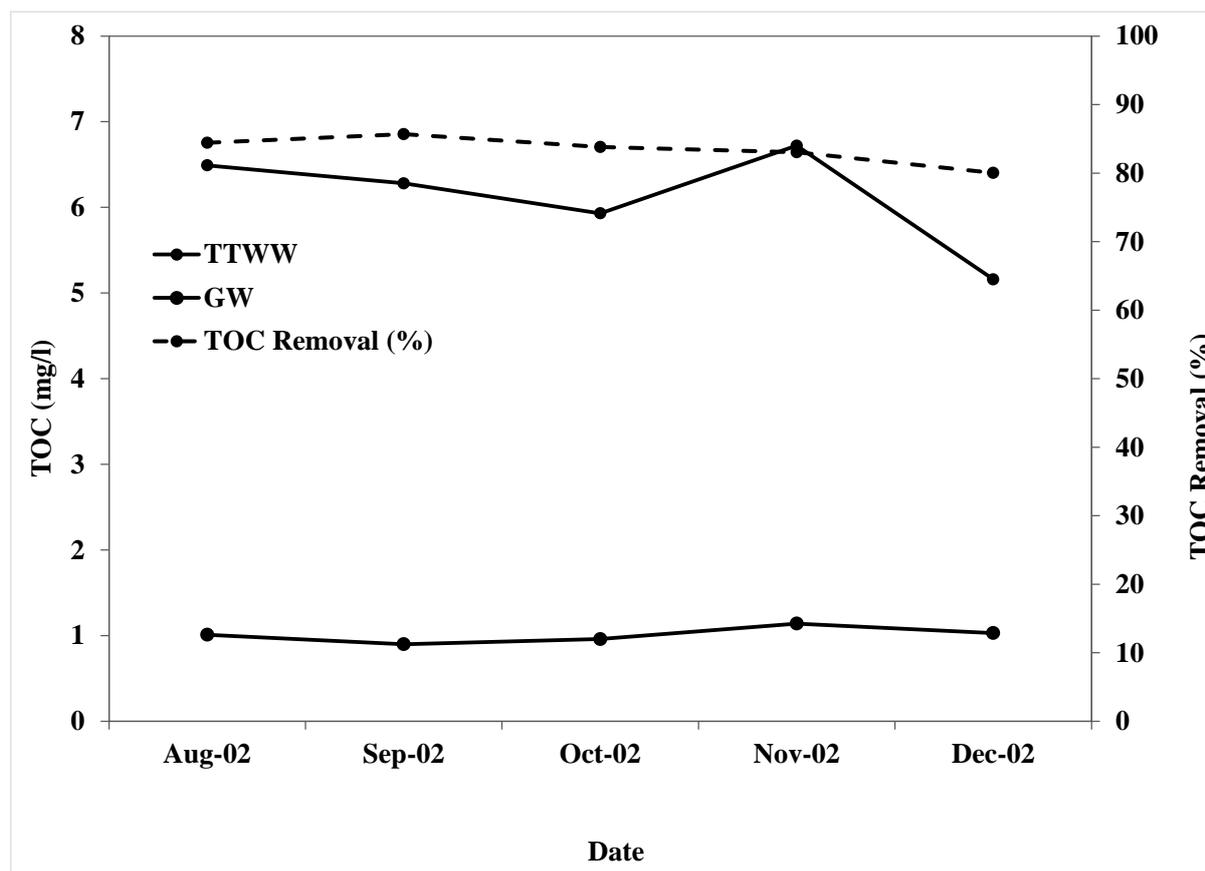


Figure 2. Variation of total organic carbon in tertiary treated wastewater and in groundwater and removal by SAT.

Table 5. Concentration of TPH in TTWW, in Groundwater and their Removal by SAT System

	TPH in TTWW (mg/l)	TPH in Groundwater (P1) (mg/l)	TPH Removal by SAT (%)
July 2002	0.56	0.23	58.93
August 2002	0.46	0.22	52.17
September 2002	0.44	0.15	65.91
October 2002	0.55	0.22	60.00
November 2002	0.72	0.39	45.83
December 2002	0.84	0.29	65.48

TPH = Total petroleum hydrocarbon; TTWW = Tertiary treated wastewater; SAT = Soil aquifer treatment.

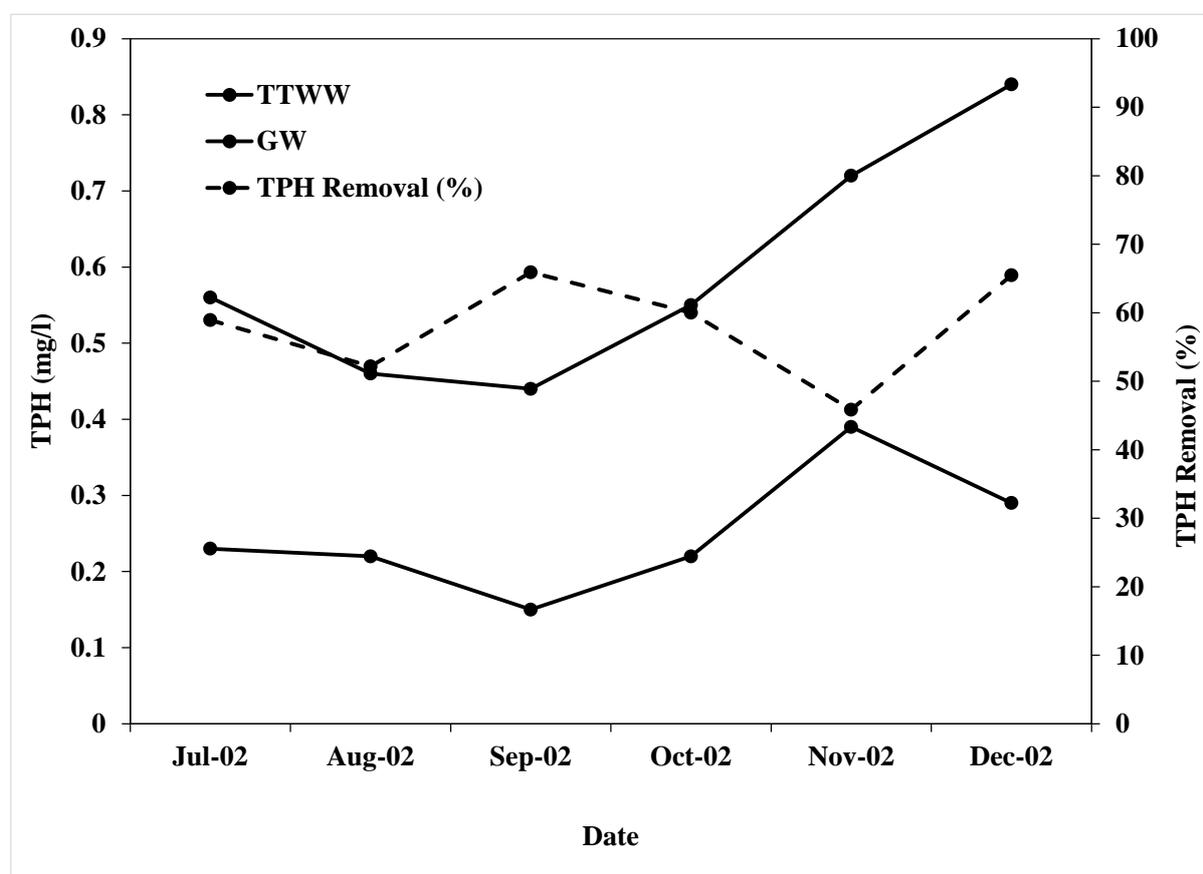


Figure 3. Variation of total petroleum hydrocarbon in tertiary treated wastewater and in groundwater and removal by SAT.

3.3 Polycyclic Aromatic Hydrocarbon

PAHs are potent pollutants that consist of fused aromatic rings and do not contain heteroatoms or carry substituents (Aziz et al., 2003). PAHs occur in oil, coal, and tar deposits, and are produced as by-products of fuel burning (whether fossil fuel or biomass). As pollutant, they are of concern because

some of the PAHs have been identified as carcinogenic, mutagenic, and teratogenic. PAHs known for their carcinogenic, mutagenic, and teratogenic properties are benz[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, benzo[*ghi*]perylene, coronene, dibenz(a,h)anthracene, indeno(1,2,3-*cd*)pyrene and ovalene (Luch, 2005). Permissible level of benzo[*a*]pyrene in the drinking water is 0.01 µg/l (WHO, 1998). Collected groundwater samples were analyzed for 16 PAHs including acenaphthene, acenaphthylene, anthracene, benzo(a)Anthracene, benzo(a)ylene, benzo(b)flouranthene, benzo(ghi)perylene, benzo(k)flouranthene, chryesene, dibenzo(ah)anthracene, flouranthene, flourene, indeno(1,2,3)pyrene, naphthalene, phenanthrene and pyrene. The results indicate the consistent presence of only pyrene in the TTWW samples collected throughout the study period (July 2002 – December 2002). Its concentration varies from 15 ng/l (0.015 mg/l) to 30 ng/l (0.030 mg/l) with an average of 20.83 ng/l (0.021 mg/l), whereas benzo(a)pyrene was detected in TTWW samples collected in month of September 2002; acenaphthalene in November 2002; and fluoranthene in December 2002 (Fig. 4). PAHs were not detected in either of the groundwater samples collected during the study period indicating 100% removal of PAHs from TTWW by SAT. Also, no PAH was detected in filtered water samples of Gatch-TTWW mixture of jar test indicating 100% removal of PAHs from TTWW by Gatch.

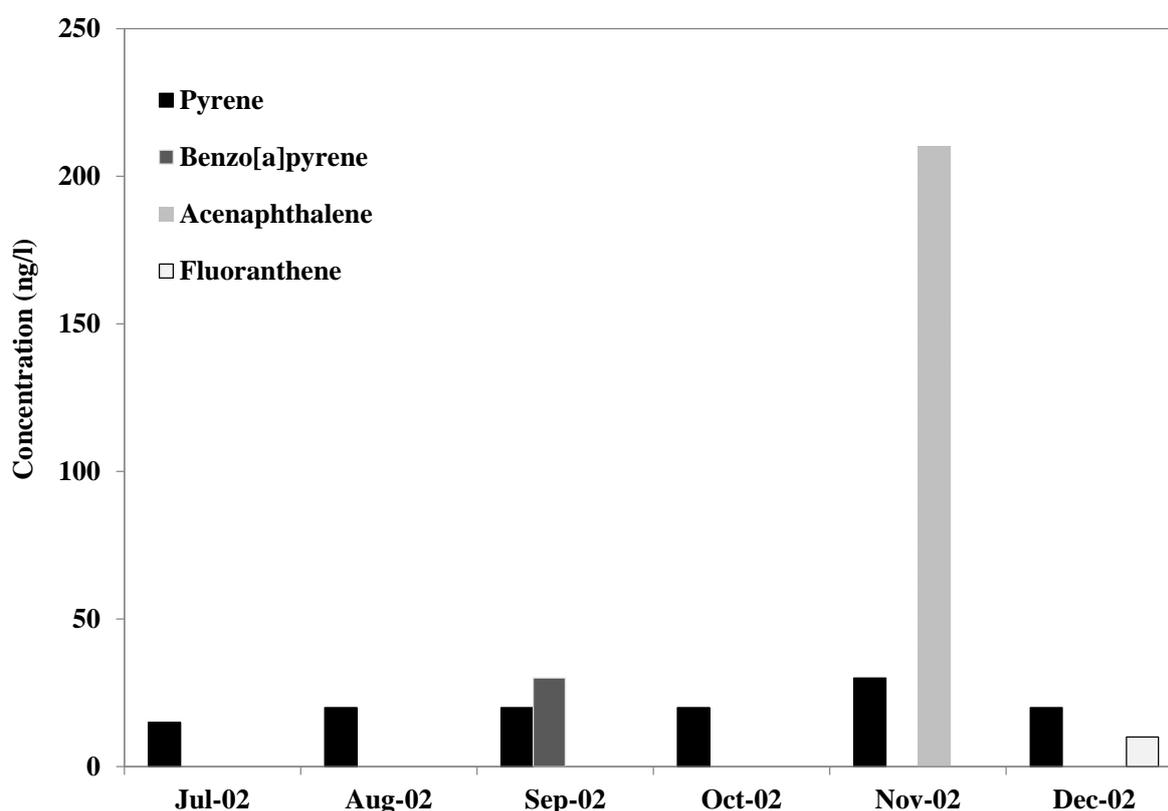


Figure 4. Concentration of polycyclic aromatic hydrocarbons in tertiary treated wastewater

Removal mechanisms for organics during SAT include volatilization, degradation and sorption. The mechanism and extent of removal vary with the type of organic compound. Volatilization can take place both during application and following infiltration from sites in the soil profile where sorption has occurred. The rate of volatilization is controlled by factors such as physical and chemical properties of the organic compound, sorptive characteristics of the soil, organic compound concentration, air movement, temperature, etc. Degradation of organics can be either chemical or biological. However it primarily the result of biological degradation in which microbes transform or alter (through metabolic or enzymatic action) the structure of organics. Although many organic

compounds can be partially or totally degraded, many cannot be metabolized by soil microorganisms (Crites, 1985). Sorption is the interaction of organics to the solids of the soil. Sorption of organics on soil depends on the nature (polar or nonpolar) of the organics (sorbates), the characteristics of the soil including mineralogical composition, organic matter and CEC of the soil. The sorption of nonpolar is almost exclusively associated with organic matter of the soil however, clay minerals, also, can be considered good sorbent of nonpolar ionic compounds (Alessandro, 2000)

The organic matter, CEC and CaCO_3 of Sulaiybia soil were found at 0.12%, 3.8 meq/100g and 5%, respectively. A low percentage (less than 4%) of fines (silt and clay) and organic matter (0.12%) of Sulaiybia soil explain its low CEC. With low percentage of organic matter (0.12%) and low CEC (3.8 meq/100g) of Sulaiybia soil, it can be inferred that the bulk removal of organics being investigated in terms of TOC, TPH and PAHs could be the result of their sorption particularly on reactive surfaces of calcrite (calcite/dolomite) (Bouwer et al., 1981; Crites, 1985). Subsurface investigation found calcrite at different depth intervals of unsaturated zone of the study area. Studies related to calcrite of Kuwait found montmorillonite and vermiculite as major clay minerals of its mineralogical composition (Yamani, 1970). Montmorillonite and vermiculite are among clay minerals that have the highest CEC, 80 to 120 meq/100g and 120 to 150 meq/100g, respectively (Maurizio, 2011). The montmorillonite clay minerals also have an anion exchange capacity (AEC) of less than 5 meq/100g (Vasant et al., 2009) whereas vermiculite has an AEC of about 4.96 meq/100g (Abd-Allah et al., 2005).

Pyrene, benzo(a)pyrene and acenaphthalene (also known as acenaphthylene) with dipole moment 0.35 Debye, 0.02 Debye, and 0.30 Debye are weak polar organic compounds whereas fluoranthene with dipole moment 0.00 Debye is nonpolar organic compound (Yaffe et al., 2001). So, the 100% removal of observed trace organics (Pyrene, benzo(a)pyrene and acenaphthalene) may be attributed to their sorption particularly on montmorillonite and vermiculite clays as well as on reactive surfaces of carbonate (calcite/dolomite). The 100 percent removal of fluoranthene may be attributed to its sorption particularly on organic component of the soil. Results of jar tests confirm this removal of organics from the TTWW by SAT. Removal of TOC and TPH by SAT may also be attributed to sorption of their ingredients (organics). Measurement of TOC of water/wastewater represents all organic compounds that may be present in water whereas TPH represent mixture of hydrocarbons that come from petroleum. Many studies have demonstrated the ability of SAT to decompose or remove organic compounds by biodegradation and/or adsorption (Quanrud et al. 2003)

The role of volatilization in the removal of organics from TTWW, during the flooding period of infiltration basins, under the circumstance of high atmospheric temperature that prevails in Kuwait particularly during summer cannot be ruled out.

4 CONCLUSIONS AND RECOMMENDATIONS

This study investigates removal efficiency of SAT for trace organics in terms of TOC, TPH and organics. Considering this study, conducted from July 2002 till December 2002, as an extension of the previous study conducted by Al-Otaibi (2001) from May 1998 till May 2001, the conclusions and recommendations of Al-Otaibi (2001) can be considered for this study as well, which are as follow:

A pilot project has been constructed in the Sulaiybiya area of Kuwait to assess the suitability of the site, the implemented recharge system and adopted technique. The SAT process at Sulaiybiya performed very well regarding the improvement in quality of the renovated water with respect to the parameters like COD, BOD, ammonia, phosphate, TOC, TPH and PAHs [pyrene, benzo(a)pyrene, acenaphthalene and fluoranthene). Overall, the quality of renovated water after SAT was suitable for unrestricted irrigation use. The efficiency of the SAT depends of the specific conditions of the site and the operational schedule. The total volume of TTWW released to the infiltration basins during the period 10 May 1998 to 1 June 2001 was 17790 m³. Almost 50% of this amount was lost through evaporation. The efficiency of the implemented SAT pilot project was estimated to be at about 45%.

Several factors contributed to this low efficiency including the hydrogeological conditions and implemented operational schedule. Very high evaporation rates during summer also affected the performance of the system.

Comprehensive hydrogeological investigations including drilling of a number of boreholes should be conducted prior to final selection of location of any similar projects in the future. Subsurface investigation of the site must be integrated with bench scale/laboratory scale studies such as jar and column experiments to comprehend the role of different constituents of the soil aquifer in the treatment of wastewater.

The infiltration basins should be shallow and designed in such a manner to allow for transfer of recharged water from one basin to the other under gravity and without pumps, as much as, possible, to reduce the operation costs.

Shorter operation cycles (flooding/drying) should be implemented to allow for proper restoration of the infiltration rate and, hence, increase the average annual infiltration rate (cycles should not exceed one week or so).

Operation of the entire system should be terminated during the summer season (June, July, August and September). During this period, the evaporation rates are very high (more than 15 mm/d), and, thus the loss of water through evaporation will be considerable. Major maintenance work could be made during this inactive recharged period.

The implementation of a large-scale wastewater recharge/SAT project should be implemented in two phases. In the first phase, the field-estimated infiltration rates and actual operation conditions should be studied carefully. The required area of the infiltration basins to be constructed for the large-scale project (second phase) can then be estimated based on the results of the first phase.

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