International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Check for updates

Monitoring of polycyclic aromatic hydrocarbons in wastewater of industrial city, Riyadh region, Saudi Arabia

Thawab M. R. Albuqmi, Marzoq Hadi Al Fahd, Khalid M. Almesfer and Mohamed H. EL-Saeid *

Chromatographic Analysis Unit, Department of Soil Science, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia.

International Journal of Science and Research Archive, 2023, 10(02), 788–797

Publication history: Received on 01 September 2023; revised on 08 December 2023; accepted on 11 December 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.10.2.1043

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are hydrocarbons with more than two benzene rings in their molecules and are a class of harmful organic pollutants widely distributed in nature. This research aims to determine the Polycyclic Aromatic Hydrocarbons (PAHs)Naphthalene, Anthracene, and Chrysene (2, 3, and 4 Rings respectively) in different sources of treated and untreated wastewater collected from different sources during the years of 2021 and 2022. Eleven wastewater sources were collected from different industrial treated wastewater, farms, main treatment plants, tanning factory treated wastewater, tanning factory non-treated wastewater, Carton factories, Factories Lake, and Grease refining plants. PAHs were extracted by QuEChERS methodology and Analyzed by GCMSMS/TQD. The results of PAHs concertation in wastewater ranged from 19.55 -278.29 µg/l for Naphthalene, 21.09 -223.69 µg/l for Anthracene, and 14.05-123.11 for Chrysene. Tanning factory non-treated wastewater had the highest concentration of examined 3 PAHs. Results showed also the highest PAHs concentrations was in tanning factory non-treated wastewater, followed by carton factories, tanning factory treated wastewater, Grease refining plants, Factories Lake, and then the main treatment plant. These outcomes of this study can be used to deliver significant guidelines concerning habitants of the area for possible measures for controlling PAHs contamination in Riyadh industrial city to protect human health and ensure environmental and wastewater sustainability.

Keywords: Organic pollutant; PAHs; Environmental; Wastewater sustainability

1. Introduction

Polycyclic Aromatic Hydrocarbons) PAHs are aromatic chemical compounds that contain more than one benzene ring, and 16 PAHs were found to be listed on the pollutant list by the [1,2]. One of the groups of persistent organic pollutants (POPs), witnessing many global concerns due to its occurrence of genetic mutations and causative agents of conditions as well as its association with heart disease, cancer, and respiratory diseases [3,4]. It results from incomplete combustion of carbon-based fuels such as wood, coal, diesel, grease, tobacco, transportation, and oil spills in industrial and urban areas. [5,6].

The presence of PAHs in treated water as they are very dangerous compounds due to their solubility in fats, and they can easily cross biological membranes and accumulate inside organisms, causing damage to the genetic material and the emergence of some cancer-causing mutations. PAHs have been identified in these waters. [7].

PAHs were studied for different types of sludge for a large wastewater treatment plant in the Lombardy region of Italy, the concentration of pyrene was consistently the highest, while the anthracene was the lowest. The mean concentrations ranged from 2405 ng/ g in the secondary sludge to 2645 ng in the final sludge [8].

* Corresponding author: Mohamed H. EL-Saeid

2. Literature Review

Polycyclic aromatic hydrocarbons (PAHs) have been monitored in various environments around the world, including aquatic environments and ambient air in Riyadh, Saudi Arabia. In aquatic environments, PAH concentrations range widely, from 0.03 ng/L to 8,310,000 ng/L[9]. In Riyadh, PAHs have been detected in carpet dust samples from mosques, with concentrations ranging from 90 to 22,146 ng g−1 [10]. Additionally, ambient air samples collected in Riyadh showed the presence of 16 particle-phase PAHs, with pyrene and fluoranthene being the most abundant [11]. In the largest industrial city in South Korea, Ulsan, PAHs were monitored in semi-rural, urban, and industrial areas, with the mean total cancer risk through inhalation intake and dermal absorption falling within acceptable levels [12].

Polycyclic aromatic hydrocarbons (PAHs) in wastewater of industrial cities pose risks to public health and the environment. Studies have shown that man-made chemicals, including PAHs, present in industrial and household products can leak into the environment and have detrimental effects on human health [13]. Treatment of wastewater using ultrasound systems has been proposed as an effective method for removing toxic PAH compounds [14]. Monitoring of PAHs in industrial areas has revealed that the concentrations of these compounds can vary depending on the season, with higher concentrations observed in winter [15]. Additionally, the treatment of coking wastewater in industrial plants can result in the occurrence of substituted PAHs, which can pose risks to both human health and the ecosystem [16,17].

The sources of water pollution by PAHs, transport, and fate in natural aquatic systems. Then the chemical analysis, how to determine the presence of PAHs in water and wastewater, and the changes in PAHs concentrations during treatment processes using membrane bioreactors, also show the presence of PAHs in conventional wastewater treatment plants, especially in sludge [18].

The U.S. Environmental Protection Agency [19] has established maximum contaminant levels (MCLs) for public water supplies to reduce the chances of adverse health effects from drinking contaminated water. MCLs are enforceable limits that public water supplies must meet. These standards are much lower than levels at which health effects have been observed. USEPA has not established MCLs for individual PAHs but has set an MCL for total PAHs of 0.2 ppb (μg/l) = 0.0002 ppm (mg/l). There are currently no standards for regulating levels of these chemicals in private wells. USEPA requires the reporting of any releases of PAHs into the environment that exceed one pound. There are no regulations for the PAH content of foods.

Benzo(a)pyrene (PAHs) MCLG1 (mg/L)2 zero and MCL or TT1 (mg/L)2 0.0002. The Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term) are reproductive difficulties; increased risk of cancer, and it can be leaching from the linings of water storage tanks and distribution lines [20] .

Long-term health effects of exposure to PAHs may include cataracts, kidney and liver damage, and jaundice. Repeated skin contact with the PAH naphthalene can result in redness and inflammation of the skin. Breathing or swallowing large amounts of naphthalene can cause the breakdown of red blood cells. However, long-term exposure to low levels of some PAHs have caused cancer in laboratory animals. Benzo(a)pyrene is the most common PAH to cause cancer in animals. Studies of workers exposed to mixtures of PAHs and other compounds have noted an increased risk of skin, lung, bladder, and gastrointestinal cancers. The information provided by these studies is limited because the workers were exposed to other potential cancer-causing chemicals besides PAHs. Although animal studies have shown adverse reproductive and developmental effects from PAH exposure, these effects have generally not been seen in humans, [21,22].

The effective removal of polycyclic aromatic hydrocarbons (PAHs) from wastewater before discharging them into the environment is always an urgent requirement [23]. Therefore, the study was designed to identify the concentrations of PAHs in different sources of treated and untreated wastewater collected from different factories in Riyadh Industrial City and farms that used the treated wastewater for irrigation.

3. Materials and Methods

3.1. Wastewater Samples

Treated and untreated wastewater samples were collected from Eleven wastewater sources industrial treated wastewater during the years of 2021 and 2022, farms (F1 to F5), main treatment plants (F6), tanning factory treated wastewater (F7), tanning factory non-treated wastewater (F8), Carton factories (F9), Factories Lake (F10), and Grease refining plants (F11) in 1st industrial city, Riyadh, the capital of Saudi Arabia. One liter of each sample was taken in dark glass continuer in ice books and transferred to the lab on the same day to extract the targeted PAHs using the QuEChERS Methodology.

3.2. Standards and Reagents

Calibration and injection standards of PAHs with declared 99.9% purity, were purchased from Accu-Standard, 153 Inc., New Haven, CT, USA as an individual (50 mg) or mixture standards at a concentration of 100 µg/ml. Internal standards are ^{13}C 12-labelled; the use of the ^{13}C-labelled compound is preferable because the analysis can be quantified without clean-up. All solvents (Methanol, dichloromethane, hexane and acetonitrile) used for the extraction and analysis of PAHs were residue-analysis grade 99.9% purity and obtained from Fisher Scientific (Fair Lawn, NJ, USA). QuEChERS kits were purchased from Phenomenex, Madrid Avenue, Torrance, CA, USA.

3.3. Extraction of PAHs in Wastewater Sample by QuEChERS Method.

To extract the PAHs from treated and untreated wastewater samples, 10 ml of each sample (3 replicates) were added to a 50 mL centrifuge tube and then add 10 mL of acetonitrile solvent to each sample. Shake (manually or mechanically) or vortex samples for 3 minutes to extract the targeted PAHs. Add 1 gm of NaCl and 2 gm of magnesium sulfate then immediately shake samples and vortex for 2 min to complete the extraction of PAHs and then centrifugation for 5 minutes at ≥ 3500 rcf. Transfer a 1.5 mL aliquot of supernatant to a 2 mL CUMPSC18CT (MgSO4, PSA, C18) dSPE tube and Vortex samples for 1 min**.** Centrifuge for 2 min at high rcf. (e.g. ≥ 5000)**.** Transfer 1 ml of the aliquot of supernatant to filter purified supernatant through a 0.2 µm syringe filter directly into a 1.8 ml umber GC vial to be analyzed by GC-MS/MS TQD [24].

3.4. Analysis of PAHs by GC-MS/MSTQD 8000/SRM

All measurements have been carried out using the latest Thermo Scientific™ TSQ 8000™ triple quadrupole GC-MS/MS system equipped with the Thermo Scientific™ TRACE™ 1310 GC with SSL Instant Connect™ SSL module and Thermo Scientific™ TriPlus™ RSH autosampler. Injection mode was spiltless, Spitless Time 1.0 min GC Column DB5 MS, 30 m × 0.25 mm × 0.25 µm.Carrier gas was He99.999%, flow rate 1.2 mL/min, constant flow, temperature program 100°C, 1 min; 10°C/min to 160°C, 4 min and 10°C/min to 250°C, 2 min, transfer line temperature 280°C, total analysis time 31 min, TriPlus RSH Autosampler Injection volume 2 µL. Ionization mode EI, 70 eV, Ion source temperature 250°C, scan mode SRM using timed SRM transition setup automatically build-up by Auto SRM software. GC-MS/MSTQD 8000 SRM Transition conditions are shown in Table 1 [25].

Table 1 GC-MS/MSTQD 8000 / SRM Instrumental conditions of PAHs analysis in wastewater samples

GC Trace Ultra Conditions		TSQ Quantum MS/MS Conditions	
Column	**DB5 30 m × 0.25 mm × 0.25 µm**	**Operating mode**	**Selected Reaction Monitoring (SRM)**
Injector	Splitless	Ionization mode	EI
Injected volume	1 µL	Electron energy	70 eV
Injector temperature	220°C	Emission current	50 µA
Carrier gas	Helium, 1.2mL/min	Q1/Q3 resolution	0.7 u (FWHM)
Oven program	70 °C hold 1 min 15°C/min to 150°C hold 1 min 2.2°C/min to 220°C hold 1 min 5°C/min to 285°C hold 5 min Run Time 30.00 min	Collision gas	Argon
Transfer line temperature	280 °C	Collision gas pressure	1 mTorr
		Polarity	Positive

3.5. Method Performance

Precision and accuracy of the extraction and analysis method were conducted by 3 replicates of blank wastewater samples spiked with the labeled PAHs standards. Limit of detection: Instrument Detection Limit (IDL), Sample Detection Limit (SDL), Method Detection Limit, accuracy and precision.

3.6. QAQC Strategies

Quality control samples were prepared and analyzed the duplicate sample, blank and spiked, and/ or Certified Reference material CRM was prepared for this purpose and processed with every 5 samples. QuEChERS and GC-MS/MS TSQ 8000 method limit of detection (LOD) and Limit of Quantification (LOQ), repeatability, reproducibility, accuracy, and precession also were determined for each PAHs compound.

4. Results and Discussions

4.1. Levels of PAHs in Wastewater

4.1.1. PAHs Concentration in Treated Wastewater Samples Collected in 2022

The levels of all determined PAHs in treated and untreated wastewater samples collected in 2021 are shown in Table 2 and Fig 1. Results depicted that the concentrations of PAHs Naphthalene, Anthracene, and Chrysene were 19.55±1.86, 22.05±1.23, and 14.56±1.67 (µg/l ±SD) in the F1 wastewater sample respectively. Meanwhile, the concentration of Naphthalene, Anthracene, and Chrysene were 21.33±2.18, 21.49±2.22, and 17.22±2.86 (µg/l ±SD) in the F2 wastewater sample respectively. Also, the Naphthalene, Anthracene, and Chrysene levels were 20.49±3.43, 21.09±2.17, and 14.05±2.02 (µg/l ±SD) in the F3 wastewater sample respectively. On the other hand, the Naphthalene, Anthracene, and Chrysene levels were 22.21±1.54, 22.33±2.49, and 16.83±1.77 (µg/l ±SD) in the F4 wastewater sample respectively. Meanwhile, the Naphthalene, Anthracene, and Chrysene levels were 22.83±2.76, 23.18±2.41, and 17.23±1.23 (µg/l ±SD) in the F5 wastewater sample respectively. The main treatment plant (F6) was analyzed and the concentration of Naphthalene, Anthracene, and Chrysene levels were 26.23±3.19, 23.83±1.22, and 15.77±1.81 (µg/l ±SD) respectively.

Tanning factory treated wastewater (F7) and Tanning factory non-treated wastewater (F8) were tested for the levels of Naphthalene, Anthracene, and Chrysene PAHs and the results showed 144.83±4.62, 154.11±3.77, 102.33±1.71 and 278.29±7.39, 223.69±4.05, 123.11±3.55 (µg/l ±SD) respectively. Also, Carton Factories (F9) and Factories Lake (F10) wastewater samples were analyzed for Naphthalene, Anthracene, and Chrysene levels and showed the concentration was 139.92±4.71, 119.88±3.55, 89.03±3.55 and 98.75±3.88, 91.22±3.16, 62.05±2.15 (µg/l ±SD) respectively. Finally the Grease refining plants (F11) were tested to analyze Naphthalene, Anthracene, and Chrysene levels and showed the concentration was 112.89±4.87, 122.34±1.66 and 89.51±3.71 (µg/l ±SD) respectively. The conclusion of the 2021 wastewater samples can revealed that the tanning factory's non-treated wastewater had the highest concentration of examined 3 PAHs. Results showed also the highest PAHs concentrations was in tanning factory non-treated wastewater, followed by carton factories, tanning factory treated wastewater, Grease refining plants, Factories Lake, and then the main treatment plant.

Table 2 Concentration (µg/l ±SD) of PAH in different treated and untreated wastewater during the year 2021

Wastewater	Naphthalene	Anthracene	Chrysene
Farm1 (F1)	19.55±1.86	22.05±1.23	14.56±1.67
Farm2 (F2)	21.33±2.18	21.49±2.22	17.22±2.86
Farm 3 (F3)	20.49±3.43	21.09±2.17	14.05±2.02
Farm 4 (F4)	22.21±1.54	22.33±2.49	16.83±1.77
Farm 5 (F5)	22.83±2.76	23.18±2.41	17.23±1.23
Main treatment plant (F6)	26.23±3.19	23.83±1.22	15.77±1.81
Tanning factory treated wastewater (F7)	144.83±4.62	154.11±3.77	102.33±1.71
Tanning factory non-treated wastewater (F8)	278.29±7.39	223.69±4.05	123.11±3.55
Carton factories (F9)	139.92±4.71	119.88±3.55	89.03±3.55
Factories Lake (F10)	98.75±3.88	91.22±3.16	62.05±2.15
Grease refining plants (F11)	112.89±4.87	122.34±1.66	89.51±3.71

SD: Standards Deviations

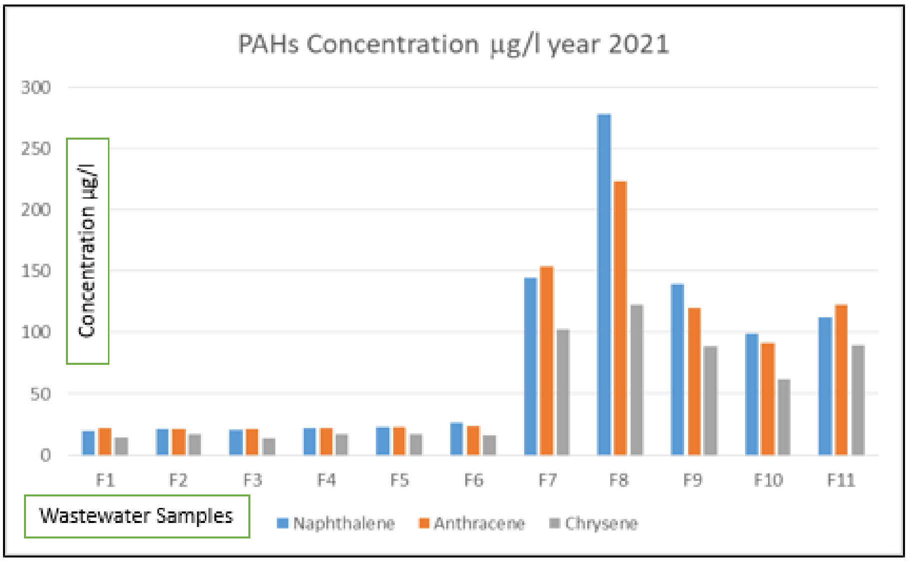

Figure 1 Concentration (µg/l) of Naphthalene, Anthracene, and Chrysene in different treated and untreated wastewater during the year 2021

4.1.2. PAHs Concentration in Treated Wastewater Samples Collected in 2022

The results of determined PAHs in treated and untreated wastewater samples collected in the year 2022 extracted by QuEChERS and analyzed by GCMSMSTQD are shown in Table 3 and Fig 2. The concentrations of PAHs Naphthalene, Anthracene, and Chrysene were 23.92±2.05, 30.11±2.43 and 25.21±3.10 (µg/l ±SD) in the F1 wastewater sample respectively. Meanwhile, the concentration of Naphthalene, Anthracene, and Chrysene were 31.76±2.44, 29.09±2.38 and 23.07±2.41 (µg/l ±SD) in the F2 wastewater sample respectively. Also, the Naphthalene, Anthracene, and Chrysene levels were 27.24±3.51, 28.76±3.22 and 21.60±2.67 (µg/l ±SD) in the F3 wastewater sample respectively. On the other hand, the Naphthalene, Anthracene, and Chrysene levels were 27.88±3.04, 29.11±2.54 and 22.25±3.44 (µg/l ±SD) in the F4 wastewater sample respectively. Meanwhile, the Naphthalene, Anthracene, and Chrysene levels were 31.30±2.21, 30.76±2.66 and 21.49±2.49 (µg/l ±SD) in the F5 wastewater sample respectively. The main treatment plant (F6) was analyzed and the concentration of Naphthalene, Anthracene, and Chrysene levels were 36.69±4.07, 31.43±4.09 and 19.33±2.45 (µg/l ±SD) respectively.

Tanning factory-treated wastewater (F7) and Tanning factory non-treated wastewater (F8) were tested for the levels of Naphthalene, Anthracene, and Chrysene PAHs and the results showed 161.20±4.05, 160.44±7.32,118.93±6.22 and 298.11±6.44, 259.71±8.29, 141.22±4.06 (µg/l ±SD) respectively. Also, Carton Factories (F9) and Factories Lake (F10) wastewater samples were analyzed for Naphthalene, Anthracene, and Chrysene levels and showed the concentration was 141.77±5.22, 133.88±4.19, 93.21±2.69 and 104.33±3.36, 111.73±4.03 and 77.34±4.01 (µg/l ±SD) respectively.

Finally, the Grease refining plants (F11) were tested to analyze Naphthalene, Anthracene, and Chrysene levels and showed the concentration was 123.65±6.03, 141.55±6.17 and 92.33±2.63 (µg/l ±SD) respectively. The results of the year 2022 wastewater samples revealed that the tanning factory's non-treated wastewater had the highest concentration of the examined three PAHs. Results showed also the highest PAHs concentrations were in tanning factory non-treated wastewater, followed by carton factories, tanning factory treated wastewater, Grease refining plants, Factories Lake, and then the main treatment plant.

Table 3 The Maine Concentration (µg/l ±SD) of PAH in different treated and untreated wastewater during the year 2022

Wastewater	Naphthalene	Anthracene	Chrysene
Farm1 (F1)	23.92±2.05	30.11±2.43	25.21±3.10
Farm2 (F2)	31.76±2.44	29.09±2.38	23.07±2.41
Farm 3 (F3)	27.24±3.51	28.76±3.22	21.60±2.67
Farm 4 (F4)	27.88±3.04	29.11±2.54	22.25±3.44
Farm 5 (F5)	31.30±2.21	30.76±2.66	21.49±2.49
Main treatment plant (F6)	36.69±4.07	31.43±4.09	19.33±2.45
Tanning factory treated wastewater (F7)	161.20±4.05	160.44±7.32	118.93±6.22
Tanning factory non-treated wastewater (F8)	298.11±6.44	259.71±8.29	141.22±4.06
Carton factories (F9)	141.77±5.22	133.88±4.19	93.21±2.69
Factories Lake (F10)	104.33±3.36	111.73±4.03	77.34±4.01
Grease refining plants (F11)	123.65±6.03	141.55±6.17	92.33±2.63

SD: Standards Deviations

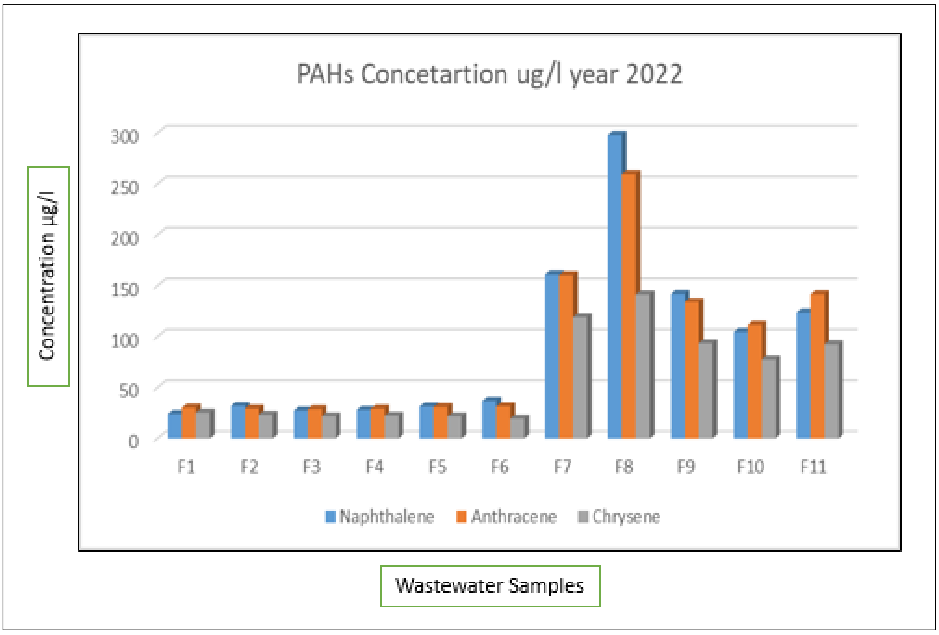

Figure 2 Concentration (µg/l) of Naphthalene, Anthracene, and Chrysene in different treated and untreated wastewater during the year 2022

4.2. Naphthalene Concentration in Wastewater Samples

The values of Naphthalene PAH in the years 2021 and 2022 wastewater samples are shown in Fig 3. The results cleared that the concentration (µg/l ±SD) in tested samples in year 2021 were 19.55±1.86, 21.33±2.18, 20.49±3.43, 22.21±1.54, 22.83±2.76, 26.23±3.19, 144.83±4.62, 278.29±7.39, 139.92±4.71, 98.75±3.88 and 112.89±4.87 (µg/l ±SD) for F1 to F11 respectively. Meanwhile, the concentration in year 2022 were 23.92±2.05, 31.76±2.44, 27.24±3.51, 27.88±3.04, 31.30±2.21, 36.69±4.07, 161.20±4.05, 298.11±6.44, 141.77±5.22, 104.33±3.36 and 123.65±6.03 (µg/l ±SD) for F1 to F11 respectively. Naphthalene results also indicate that the highest concentration was in Tanning factory non-treated wastewater (F8) followed by Tanning factory treated wastewater (F7) for wastewater samples tested in 2021 and 2022.

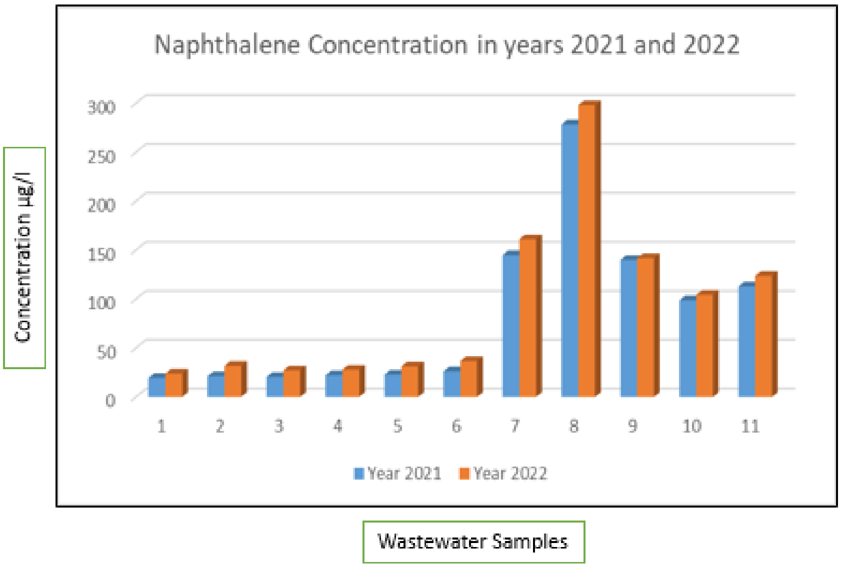

Figure 3 Concentration (µg/l) of Naphthalene in different treated and untreated wastewater during the years of 2021/2022

4.3. Anthracene Concentration in Treated Wastewater Samples

The results of Anthracene PAH in the years 2021 and 2022 wastewater samples are shown in Fig 4. The results revealed that the concentration (µg/l ±SD) in tested samples in the year 2021 were 22.05±1.23, 21.49±2.22

21.09±2.17, 22.33±2.49, 23.18±2.41, 23.83±1.22, 154.11±3.77, 223.69±4.05, 119.88±3.55, 91.22±3.16, and 122.34±1.66 (µg/l ±SD) for F1 to F11 respectively. Meanwhile, the concentration in year 2022 were 30.11±2.43, 29.09±2.38, 28.76±3.22, 29.11±2.54, 30.76±2.66, 31.43±4.09

160.44±7.32, 259.71±8.29, 133.88±4.19, 111.73±4.03, and 141.55±6.17 (µg/l ±SD) for F1 to F11 respectively. Anthracene PAH results also indicate that the highest concentration was in Tanning factory non-treated wastewater (F8) followed by Tanning factory treated wastewater (F7) for wastewater samples tested in 2021 and 2022.

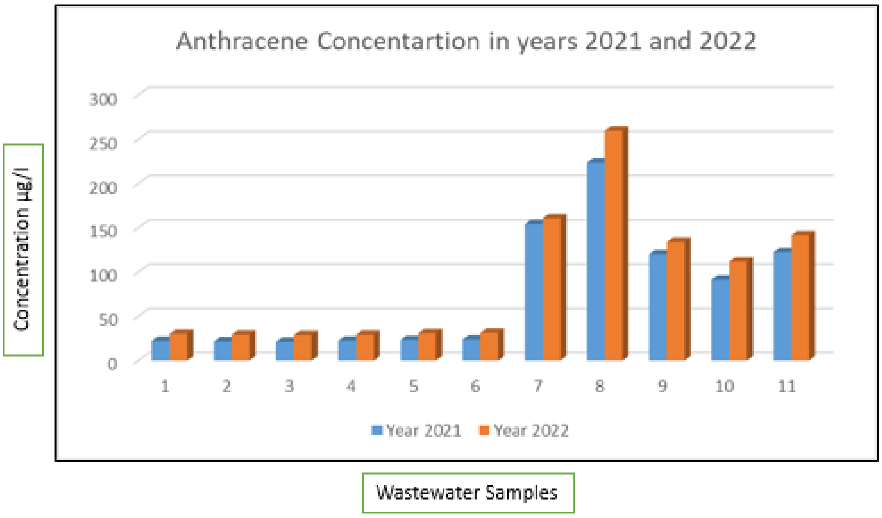

Figure 4 Concentration (µg/l) of Anthracene in different treated and untreated wastewater during the years of 2021/2022

4.4. Crysene Concentration in Treated Wastewater Samples

The results of Crysene PAH tested in the years 2021 and 2022 wastewater samples are shown in Fig 5. The results showed that the concentration (µg/l ±SD) in tested samples in the year 2021 were 14.56±1.67, 17.22±2.86, 14.05±2.02, 16.83±1.77, 17.23±1.23, 15.77±1.81, 102.33±1.71, 123.11±3.55, 89.03±3.55, 62.05±2.15 and 89.51±3.71 (µg/l ±SD) for F1 to F11 respectively. On the other year, the concentration in the year 2022 were 25.21±3.10, 23.07±2.41, 21.60±2.67, 22.25±3.44, 21.49±2.49, 19.33±2.45, 118.93±6.22, 141.22±4.06, 93.21±2.69, 77.34±4.01, and 92.33±2.63 (µg/l ±SD) for F1 to F11 respectively. Crysene PAH results also indicate that the highest concentration was in Tanning factory non-treated wastewater (F8) followed by Tanning factory treated wastewater (F7) for wastewater samples tested in 2021 and 2022.

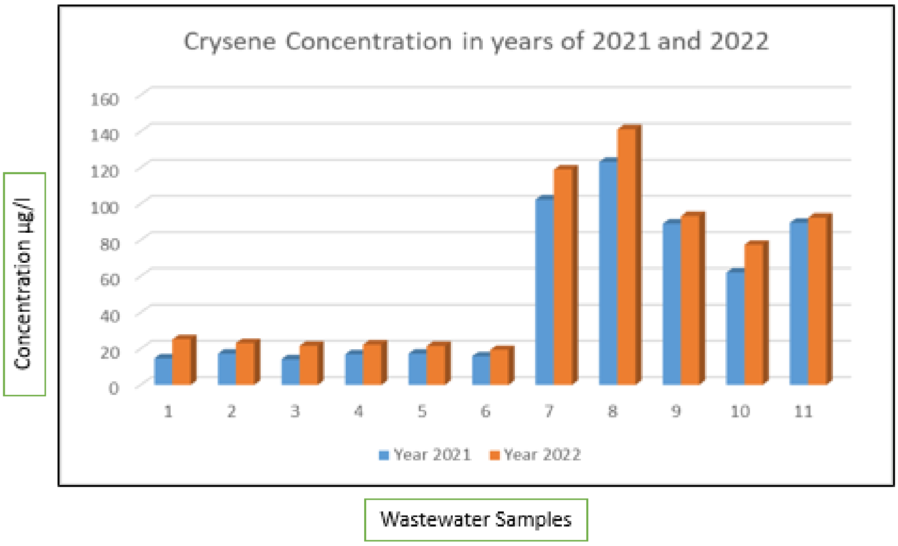

Figure 5 Concentration (µg/l) of Crysene in different treated and untreated wastewater during the years of 2021/2022

Generally, the results obtained in this research were compared with some results by other researchers (Anwar et al 2000 and Qi et al 2013), [26-27] and it was noted that the results of the estimation of the three compounds agree with the results obtained in some research, especially for wastewater tested from factories, specially treated water, as well as wastewater from factories in industrial areas.

5. Conclusion

This study presents a report on the assessment of the concentration of 3 PAHs in treated and untreated wastewater and it was in the highest concentration in treated and untreated Tanning factory non-treated wastewater followed by Tanning factory treated wastewater samples during 2021 and 2022. The Lowest concentration of the tested 3 PAHs was recorded wastewater in collected from the farms (F1 to F5) it was used for irrigation. This study also demonstrated the possibility of estimating the different PAHs using the least techniques of chromatographic, GCMSMSTQD which may be available in most laboratories. This study encourages the future application of this method with extraction by the QuEChERS method to estimate the PAHs in real environmental samples.

Compliance with ethical standards

Acknowledgments

The Authors deeply thank the soil science department and the unit of chromatographic analysis who helped and collaborated with the study.

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Kwon, Hye-Ok, and Sung-Deuk Choi (2014). Polycyclic aromatic hydrocarbons (PAHs) in soils from a multi-industrial city, South Korea. Science of The Total Environment Volumes 470–471, 1 February 2014, Pages 1494-1501

[2] Ma, Jiaman, Eldon R. Rene, Zongyao Chen, Weifang Ma (2022). Fate of PAHs in treated wastewater reused as irrigation water: Environmental risks in water-soil-ryegrass multimedia system. Journal of Hazardous Materials Volume 424, Part B, 15 February 2022, 127500

[3] Gan S., E.V. Lau, H.K. Ng (2009). Remediation of soils contaminated with polycyclic aromatic hydrocarbons (PAHs). Journal of Hazardous Materials Volume 172, Issues 2–3, 30 December 2009, Pages 532-549

[4] Vasconcelos Pedro Hermano M., André Luiz M. Camelo , Ari Clecius A. de Lima, Hélio O. do Nascimento, Carla B. Vidal, Ronaldo F. do Nascimento, Gisele S. Lopes4 and Elisane Longhinotti. (2021). Chemometric tools applied to optimize a fast solid-phase microextraction method for analysis of polycyclic aromatic hydrocarbons in produced water. Environmental Science and Pollution Research (2021) 28:8012–8021.

[5] Baek, S. O., Field, R. A., Goldstone, M. E., Kirk, P. W., Lester, J. N &Perry, R. (1991). A review of atmospheric polycyclic aromatic hydrocarbons: Sources, fate and behavior. Water, Air & Soil Pollution, 60, 279–300.

[6] Gubler, Andreas, Daniel Wachter, Franziska Blumb and Thomas D. Bucheli (2015). Remarkably constant PAH concentrations in Swiss soils over the last 30 years. Environ. Sci.: Processes Impacts, 2015, 17, 1816–1828

[7] Torretta V. (2012) PAHs in wastewater: removal efficiency in a conventional wastewater treatment plant and comparison with model predictions. Environ Technol. 2012 Apr-May;33(7-9):851-5.

[8] Torretta V1, Katsoyiannis A. (2013) Occurrence of polycyclic aromatic hydrocarbons in sludges from different stages of wastewater treatment plant in Italy. Environ Technol. 2013 Mar-Apr;34(5-8):937-43

[9] Amin, Mojiri., John, L., Zhou., Akiyoshi, Ohashi., Noriatsu, Ozaki., Tomonori, Kindaichi. (2019). Comprehensive review of polycyclic aromatic hydrocarbons in water sources, their effects and treatments. Science of The Total Environment, doi: 10.1016/J.SCITOTENV.2019.133971

[10] Élise, Euvrard., Coline, Druart., Nadia, Morin-Crini., Grégorio, Crini. (2019). Monitoring and Origin of Polycyclic Aromatic Hydrocarbons (PAHs) in Effluents from a Surface Treatment Industry. Polycyclic Aromatic Compounds, doi: 10.1080/10406638.2017.1342666

[11] Aarif, H., El-Mubarak., Aarif, H., El-Mubarak., Ahmed, I., Rushdi., Ahmed, I., Rushdi., Ahmed, I., Rushdi., Khalid, F., Al-Mutlaq., Falah, Z., Al, Mdawi., Khalid, Al-Hazmi., Ramil, Dumenden., Rex, A., Pascua. (2016). Polycyclic aromatic hydrocarbons and trace metals in mosque's carpet dust of Riyadh, Saudi Arabia, and their health risk implications. Environmental Science and Pollution Research, doi: 10.1007/S11356-016-7299-4

[12] Qijing, Bian., Badr, H., Alharbi., Jeffrey, L., Collett., Sonia, M., Kreidenweis., Mohammad, J., Pasha. (2016). Measurements and source apportionment of particle-associated polycyclic aromatic hydrocarbons in ambient air in Riyadh, Saudi Arabia. Atmospheric Environment, doi: 10.1016/J.ATMOSENV.2016.04.025

[13] Katarzyna, Styszko., Kai, O'Donnell., Kai, O'Donnell., Muddassar, Sarfraz. (2023). Occurence of selected hydroxy derivatives of polycyclic aromatic hydrocarbons in wastewater treatment plant. doi: 10.5194/egusphere-egu23-3691

[14] Negareh, Ghasemi., Negareh, Ghasemi., Gustav, Gbeddy., Prasanna, Egodawatta., Firuz, Zare., Ashantha, Goonetilleke. (2020). Removal of polycyclic aromatic hydrocarbons from wastewater using dual-mode ultrasound system. Water and Environment Journal, doi: 10.1111/WEJ.12540

[15] M., B., Alao., E., A., Adebayo. (2022). Fungi as veritable tool in bioremediation of polycyclic aromatic hydrocarbons-polluted wastewater. Journal of Basic Microbiology, doi: 10.1002/jobm.202100376

[16] Tuyet, Nam, Thi, Nguyen., Hye-Ok, Kwon., Gerhard, Lammel., Gerhard, Lammel., Kun-Sik, Jung., Sang, Jin, Lee., Sung-Deuk, Choi. (2020). Spatially high-resolved monitoring and risk assessment of polycyclic aromatic hydrocarbons in an industrial city. Journal of Hazardous Materials, doi: 10.1016/J.JHAZMAT.2020.122409

[17] Ayman, N., Saber., Haifeng, Zhang., Ashraful, Islam., Min, Yang. (2021). Occurrence, fates, and carcinogenic risks of substituted polycyclic aromatic hydrocarbons in two coking wastewater treatment systems. Science of The Total Environment, doi: 10.1016/J.SCITOTENV.2021.147808

[18] Amy J. Forsgren (2017) Wastewater Treatment: Occurrence and Fate of Polycyclic Aromatic Hydrocarbons (PAHs). CRC Press, Published July 26, 2017 , ISBN 9781138893900

[19] US.EPA, 2022 – Method 610: Polynuclear aromatic hydrocarbons – Available from: https://www.epa.gov›files›method6101984

[20] ATSDR. Agency for Toxic Substances and Disease Registry (2023). National Primary Drinking Water Regulations. https://www.atsdr.cdc.gov

[21] Nene, Anyahara Jessica (2021). Effects of Polycyclic Aromatic Hydrocarbons (PAHs) on the Environment: A Systematic Review. International Journal of Advanced Academic Research | ISSN: 2488-9849 Vol. 7, Issue 3 www.ijaar.org

[22] Mallah, Manthar Ali, Li Changxing, Mukhtiar Ali Mallah, Sobia Noreen, Yang Liu, Muhammad Saeed, He Xi, Bilal Ahmed, Feifei Feng, Ali Asghar Mirjat , Wei Wang, Abdul Jabar, Muhammad Naveed, Jian-Hua Li and Qiao Zhang (2022). Polycyclic aromatic hydrocarbon and its effects on human health: An overeview. Chemosphere Volume 296, June 2022, 133948

[23] Yang, Xiaolong,; Haoyuan Cai,; Mutai Bao,; Jianqiang Yu,; Jinren Lu and Yiming Li (2017) Highly Efficient Photocatalytic Remediation of Simulated Polycyclic Aromatic Hydrocarbons (PAHs) Contaminated Wastewater under Visible Light Irradiation by Graphene Oxide Enwrapped Ag3PO4 Composite. Chin. J. Chem. 2017, 35, 1549—1558.

[24] El-Saeid, Mohamed H., Marzoq Hadi Al Fahd and Mohamed S. Al-Sewailem (2020). Studies on the Impact of Forest Combustion on Soil Contamination by PAHs Using QuEChERS and GCMS/ MSTQD. Book Chapter 9, Current Research and Development in Chemistry Vol. 3. Book Publisher International. Print ISBN: 978-93-90149-44-5, eBook ISBN: 978-93-90149-43-8. DOI: 10.9734/bpi/crdc/v3

[25] EL-Saeid, Mohamed H., Abdulaziz G. Alghamdi and Abdulhakim Jari Alzahrani (2023). Impact of Atmospheric Polycyclic Aromatic Hydrocarbons (PAHs) of Falling Dust in Urban Area Settings: Status, Chemical Composition, Sources and Potential Human Health Risks. Int. J. Environ. Res. Public Health, 20, 1216. 2-15. https://doi.org/10.3390/ijerph20021216

[26] Anwar Jiries; Helmi Hussain and Jutta Lintelmann (2000) Determination of Polycyclic Aromatic Hydrocarbons in Wastewater, Sediments, Sludge and Plants in Karak Province, Jordan Water, Air, and Soil Pollution July 2000, Volume 121, Issue 1–4, pp 217–228

[27] Qi W1, Liu H, Pernet-Coudrier B, Qu J. (2013) Polycyclic aromatic hydrocarbons in wastewater, WWTPs effluents and in the recipient waters of Beijing, China. Environ Sci Pollut Res Int. 2013 Jun;20(6):4254-60. doi: 10.1007/s11356-012-1435-6. Epub 2013 Jan 6. https://www.atsdr.cdc.gov/