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Passer Journal

Passer 6 (Issue 1) (2024) 161-170

http://passer.garmian.edu.krd/

Evaluation of Polycyclic Aromatic Hydrocarbons in Water from Dukan Lake to Main Distributor Stations in Sulaimani City, Iraq

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Received 09 October 2023; revised 22 December 2023;
accepted 23 December 2023; available online 27 February 2024

DOI: 10.24271/PSR.2023.419952.1406

ABSTRACT

This study investigated polycyclic aromatic hydrocarbon (PAH) contamination in Sulaimani City, Iraq. A longitudinal study was conducted from May 2022 to February 2023 to analyze PAH concentrations in water samples collected across three seasons using a GC-MC6890 Agilent gas chromatograph. Samples were collected from Dukan Lake, the City's primary water source, to the last distribution stations within the city. The study focused on four prevalent PAHs: naphthalene, acenaphthylene, acenaphthene, and pyrene. Their concentrations were meticulously compared against established drinking water standards to assess potential health risks. Additionally, the influence of seasons on PAH levels and the impact of PAH concentration on the water's pH were investigated.

The results revealed noteworthy seasonal variations in PAH concentrations, with higher levels observed during summer. Naphthalene concentrations were 20% higher in the summer compared to autumn/winter. Acenaphthylene and acenaphthene exhibited statistically significant differences in mean concentrations across the seasons ($p\text{-value} < 0.0001$), with naphthalene also showing significant differences between summer and autumn/winter. All PAH parameters exceeded standard limits in drinking water, posing potential risks to human health and aquatic organisms. Pyrene and other variables did not significantly affect pH ($p\text{-value} = 0.9360$).

These findings emphasize the need for continuous monitoring and treatment strategies to mitigate PAH contamination and ensure the safety of the City's drinking water supply. This study provides valuable baseline data for future efforts and management of drinking water resources in Sulaimani City.

Keywords: Water pollution, Drinking water, PAHs, Dukan Lake, Sulaimani City.

1. Introduction

The Earth is currently facing myriad environmental challenges, such as global warming, the clearing of forests, and the loss of biodiversity[1]. Of these, water pollution, particularly in freshwater sources, is one of the most serious[2]. The contamination of water resources has been a global concern for decades, and its negative impact on human health, the natural world, and economic activity is well established[3]. The adverse effects of water pollution are extensive and profound, ranging from human health risks to environmental degradation and economic losses[4]. Water pollution can cause a diverse range of health problems, including cancer, reproductive issues, neurological disorders, and renal disease[5].

Scientists have conducted extensive research on polycyclic aromatic hydrocarbons (PAH) due to their ubiquity in the marine environment and their detrimental effects on both aquatic life and human health[6]. Polycyclic aromatic hydrocarbons (PAH) are xenobiotic compounds composed of carbon and hydrogen. They are a class of nonpolar, hydrophobic pollutants with low water solubility, high melting and boiling points, and low vapor pressure[7]. PAH are typically formed through the incomplete combustion of organic matter, such as fossil fuels and wood. They can enter the environment through industrial activities, waste disposal, and natural events like volcanic eruptions and wildfires[8]. Additional sources of PAHs include vehicle emissions, catalytic cracking units, and related petroleum refinery processes[9]. PAHs can also be released into the environment through biological processes. As a result, PAHs are commonly found in the air, soil, and water, making them ubiquitous environmental contaminants[10].

PAHs binds to sediments or bioaccumulate in aquatic organisms instead of dissolving in water. PAHs can be transported with suspended sediment. Improperly disposed of ash, tar, or creosote in landfills can leach PAHs into groundwater[11]. The accumulation of pollutants can have adverse effects on exposed organisms, including cancer and other health problems. Additionally, several PAHs are potential

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Peer-reviewed under the responsibility of the University of Garmian.

human carcinogens, raising serious public health concerns[12]. Given the growing environmental challenges and the pressing need for sustainable practices, it is imperative to assess the water quality of vital resources and comprehend the potential risks of pollution[13]. This issue is particularly important in regions like Sulaimani City, where the unique environmental and socioeconomic context makes water pollution a complex problem. The city, located in the Iraqi Kurdistan mountains, faces the potential threat of water pollution[14].

Dukan Lake is a vital drinking water source for Sulaimani City and the surrounding region, and water contamination could gravely endanger public health[15]. The presence of polycyclic aromatic hydrocarbons (PAH) in drinking water poses a significant threat to human health due to their carcinogenic and mutagenic properties. However, there is a paucity of data on PAH levels in Sulaimani City's drinking water, particularly about potential sources and seasonal variations. This study aims to characterize the occurrence and concentration of PAH in Dukan Lake, the primary drinking water source for Sulaimani City and its surrounding region. Additionally, the study will identify potential sources of PAH contamination, assess the impact of PAHs on drinking water pH, and evaluate seasonal variations in PAH levels. The findings of this study will contribute to a comprehensive understanding of PAH contamination in Sulaimani City's drinking water and provide valuable insights for policymakers and stakeholders to safeguard public health and enhance drinking water quality.

2. Methods and Materials

The analysis employed a GC-MC6890 Agilent gas chromatograph using electron ionization (EI) at 70 eV (Table 1). A Select PAH column (30 m x 0.25 mm, df = 0.15 µm, Agilent)[16] facilitated the separation. Detection was performed in single-ion monitoring (SIM) mode, and Mass Lynx software calibrated the standards. To optimize the separation, different temperature programs were investigated[17].

A longitudinal study conducted from May 2022 to February 2023 constituted the research methodology. Water samples collected throughout three distinct seasons (summer, autumn, and winter) represented the variability across the year. Two samples were collected during each of the six sampling campaigns, resulting in a total of 72 samples.

Table 1: Conditions of the GC/MS method for PAH: PAH method.

Condition	
Technique	*GC/MC*
Column	Select PAH, 30 m x 0.25 mm df = 0.15 µm (Part number CP7462).
Sample concentration	0.008-4.0 ng/µl
Injection volume	1 µl
Carrier gas	Helium, constant flow 2 ml/min
Injector	250 °C, Spitless mode, 1 min @ 50 ml/min
Director	Triple Quad, EI in SIM mode, ion source 230 °C, transfer line 300 °C

3. Statistical analysis

Collected data were subjected to a two-way analysis of variance (ANOVA) using a factorial design, with location and season as factors. Tukey's range tests were used to determine the variances between the means. The data were analyzed using two statistical packages for social sciences: SPSS (version 26) and JMP-Pro (version 16). Data were expressed as mean ± standard error. Relationships among PAH levels found in different seasons[18] were evaluated using two-way analysis of variance (ANOVA) multiple comparison tests at the 95% confidence level ($P < 0.05$) to identify significant differences between the stations.

The following equation is used to determine the comparison of each value between two seasons

$$\frac{result\ in\ sesson\ N1 - result\ in\ season\ N2}{result\ season\ N1} * 100 = Compare\ between\ each\ value, Between\ two\ seasons\ \% \quad \text{.....1}$$

4. Study Area

The primary study area was Dukan Lake, a critical water source. This dam provides drinking water to several areas, including Sulaimani City, Kirkuk City, Tasluja area, Bazyan area, Duzkhurmatu City, and Chamchamal City. The Dukan Lake is the largest reservoir in Kurdistan[19].

Dukan Lake is located on the Lower Zab River, about 295 km northeast of Baghdad and 65 km northwest of Sulaimani City. Its boundaries extend between 34°17'N – 36°33'N latitude and 43°17'E – 46°24'E longitude[19]. The Lake's capacity is 6.8 billion cubic meters, and its surface area at high and low tides would be approximately 270 and 48 km2, respectively. Sulaimani City relied on Dukan Lake utterly for its entire existence. This reliance made it the most crucial Lake in the Kurdistan region.

For this study, the first sample was taken from the Lake, the second and third from the river, and three other samples were taken from the center of Sulaimani at the main water distribution point. Samples were collected from the studied sites during an extension period from May 2022 to February 2023. The exact sample's locations were determined using the Global Positioning System (GPS). (Table 2) (Figure 1) and show a map of sampling locations and the recorded coordinates for sampling stations.

Table 2: Sample sites and their geographical coordinates.

Sites	Coordinates		Site description
	North (N)	East(E)	
S1	35°31'6.352"N	45°27'17.762"E	Top Zawa
S2	35°53'27.792"N	44°58'53.964"E	Inside the Lake near the Dam
S3	35°55'38.518"N	44°58'18.360"E	Perqwrban
S4	36°12'48.528"N	44°59'18.150"E	Sarchinar main water station
S5	35°34'56.406"N	45°26'6.353"E	Westgay Dabashan 1
S6	35°35'4.308"N	45°53'53.162"E	Westgay Dabashan 2

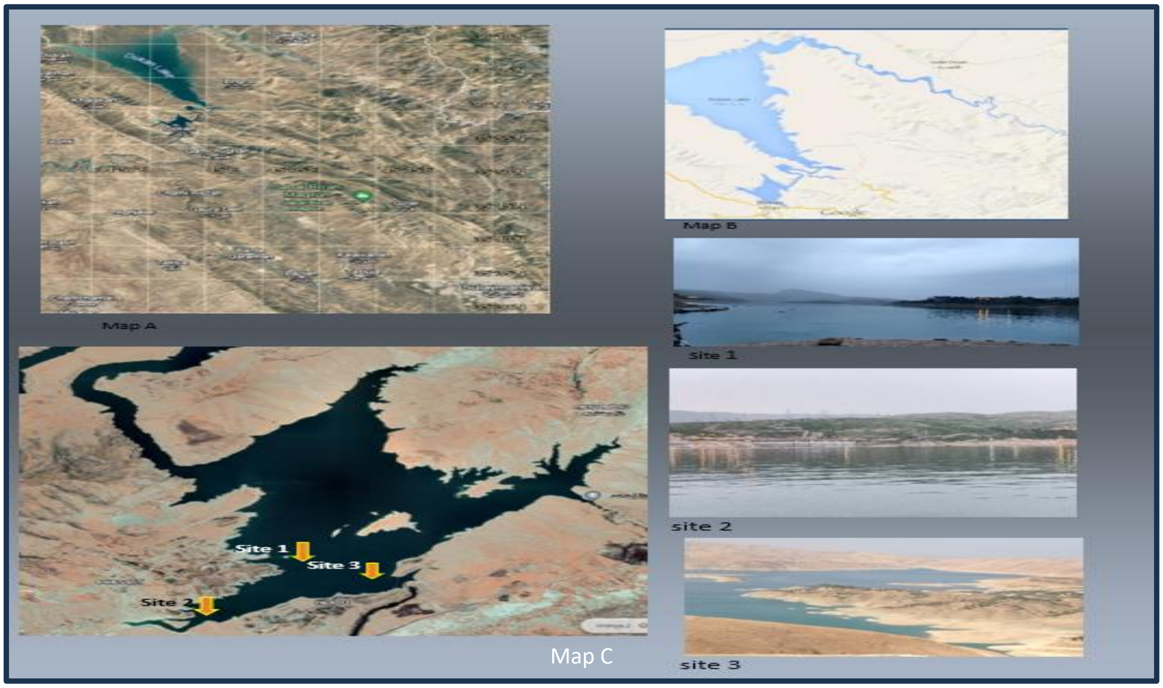

Figure 1: Map shows: (A) Sulaimani governorate map ;(B) Dukan lake; (C) location of the studied area (S1-S3) water.

5. Results and Discussions

The mean concentration of the (naphthalene, acenaphthene, and pyrene) moved toward a higher level in the summer than in the autumn and winter, which are (5.0348, 174.8959, and 10.7724) µg/ml respectively (Table 3). In such a way, the mean concentration of naphthalene increased by 49.92% compared to its mean concentration in autumn and increased by 50.45% compared to its mean concentration in winter. Likewise, the mean concentration of acenaphthene in summer increased by 14.58% compared to its mean concentration in the autumn and increased by 43.69% compared to its mean concentration in the winter. Furthermore, the mean concentration of pyrene in summer increased by 43.90% compared to its mean concentration in autumn and increased by 16.99% compared to its mean concentration in winter. Besides, in contrast, the mean concentration of (acenaphthylene) moved toward a higher level in the winter than in the summer and autumn, which is 15.0578, so the mean concentration of acenaphthylene in winter increased by 79.72% compared to its mean concentration in the autumn and increased 69.55% compared to its mean concentration in the summer.

Table 3: Overall Mean Concentration of the naphthalene, acenaphthylene, acenaphthene, and pyrene between the Seasons. Data represented as (mean ± Standard division).

Seasons	Naphthalene µg/ml	Acenaphthylene µg/ml	Acenaphthene µg/ml	Pyrene µg/ml
Autumn	2.5213 ± 1.886	3.0527 ± 2.3783	149.3924 ± 36.6069	6.0433 ± 4.6517
Summer	5.0348 ± 0.826	4.5852 ± 0.4132	174.8959 ± 12.2884	10.7724 ± 1.0991
Winter	2.4947 ± 1.430	15.0578 ± 4.5420	98.4867 ± 10.2196	8.9416 ± 2.8716

Results show that the concentration of naphthalene was 25.5418 µg/ml (Table 4) shows a p-value of 0.0001, there were significant differences between at least two mean concentrations of naphthalene during different seasons. A post hoc multiple comparison technique can also clarify and emphasize the previous result.

Table 4: The statistical analysis of naphthalene concentrations (µg/ml) among different seasons, representing the sum of squares and the mean square.

Source	DF	Sum of Squares	Mean Square	F Ratio	p-value
Seasons	2	51.08363	25.5418		
Error	33	69.16141	2.0958		
C. Total	35	120.24505		12.1871	0.0001*

The significant difference between the two pairs of means is shown in (Figure 2). The selected mean will have a bold red circle and a variable label. The mean significantly different from the selected mean will have a grey circle and grey italicized variable labels. In contrast, the circle's red color and variable label indicate no difference. Thus, the mean naphthalene in summer is statistically and significantly different (P < 0.01) from the mean naphthalene in autumn and winter. On the other hand, the mean concentration of naphthalene in autumn is not different in winter.

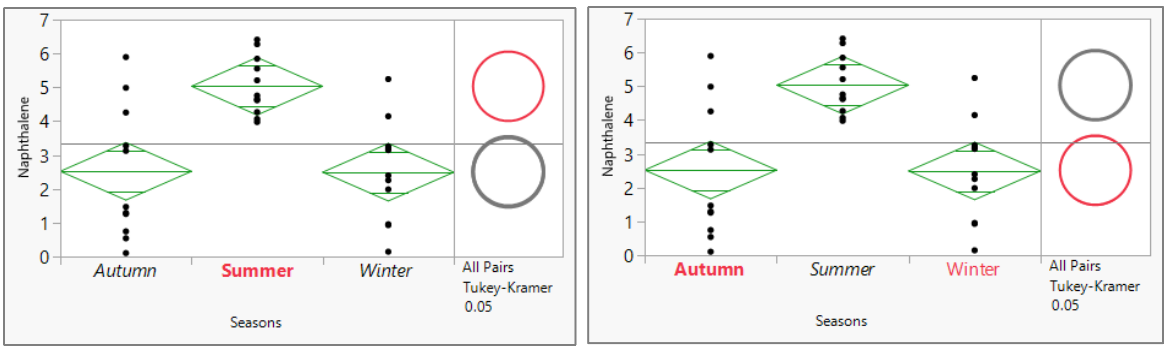

Figure 2: Post hoc of Means Comparisons for the naphthalene that showed the difference between naphthalene levels among different seasons.

Results show that the concentration of acenaphthylene was 512.294 [µg /ml]. (Table 5) shows that the p-value of 0.0001 is less than the significant level of 0.05. In other words, there are significant differences between at least two mean concentrations of acenaphthylene during different seasons. A post hoc multiple comparison technique can also clarify and emphasize the previous result.

Table 5: The statistical analysis of acenaphthylene concentrations (µg/ml) among the seasons (summer, autumn, winter) was presented, representing the sum of squares and mean squares for acenaphthylene.

Source	DF	Sum of Squares	Mean Square	F Ratio	p-value
Seasons	2	1024.5874	512.294		
Error	33	291.0283	8.819		
C. Total	35	1315.6156		58.0895	0.0001*

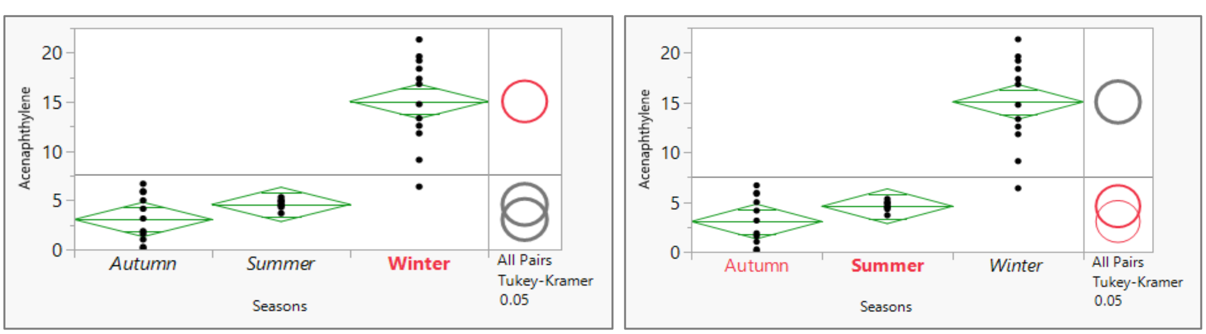

Figure 3: Post hoc of Means Comparisons for acenaphthylene. That showed a change in the level of acenaphthylene among different seasons.

(Figure 3) shows the significant difference between the two pairs of means. The selected mean will have a bold red circle and a variable label. The mean concentration significantly different from the selected mean will have a grey circle and grey italicized variable labels. In contrast, the circle's red color and variable label indicate no difference. Consequently, the mean acenaphthylene in winter is statistically significantly different from the mean acenaphthylene in autumn and summer. On the other hand, the mean concentrations of acenaphthylene in summer are not different in autumn.

Results show that the concentration of acenaphthene was 18160.4[µg /ml]. (Table 6) shows that the p-value of 0.0001 is less than the significant level of 0.05. there are significant differences between at least two mean concentrations of acenaphthene during different seasons. A post hoc multiple comparison technique can also clarify and emphasize the previous result.

Table 6: The statistical analysis of acenaphthene concentrations (µg/ml), represented as the sum of squares and mean squares of acenaphthene among the seasons (summer, autumn, winter).

Source	DF	Sum of Squares	Mean Square	F Ratio	p-value
Seasons	2	36320.776	18160.4		
Error	33	17550.624	531.8		
C. Total	35	53871.400		34.1465	0.0001*

(Figure 4) shows the significant difference between the two pairs of means. The selected mean will have a bold red circle and a variable label. The mean concentrations were significantly different from the selected mean and will have grey circles and grey italicized variable labels. In contrast, the circle's red color and variable label indicate no difference. As a result, the mean acenaphthene in winter significantly differs from the mean acenaphthene in autumn and summer. Likewise, the mean concentrations of acenaphthene in summer significantly differ from autumn.

Results show that the concentration of pyrene was 68.2325 µg/ml. (Table 7) shows that the p-value of 0.0039 is less than the significant level of 0.05., there are significant differences between at least two mean concentrations of Pyrene during different seasons. A post hoc multiple comparison technique can also clarify and emphasize the previous result.

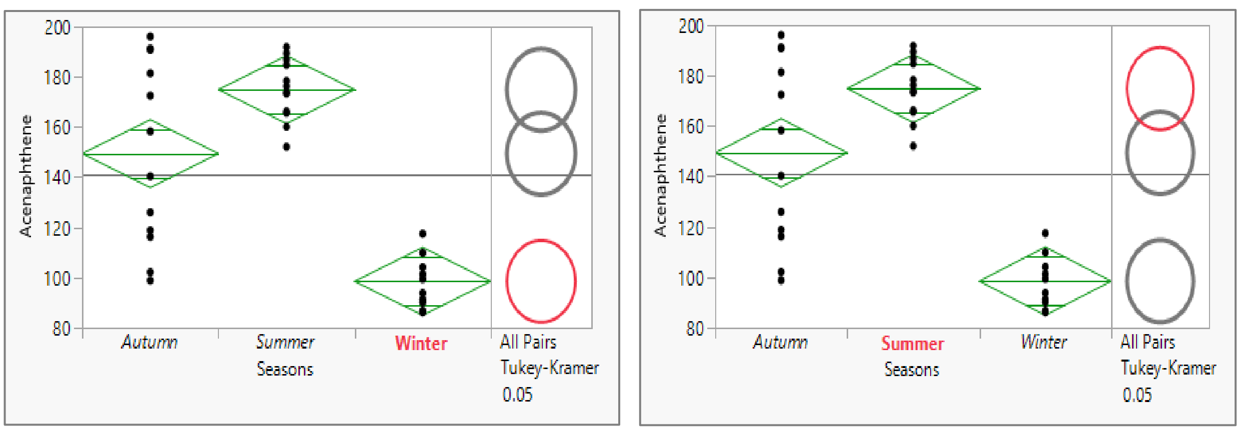

Figure 4 : Post hoc of Means Comparisons for Acenaphthene. That showed the change in the level of acenaphthene among different seasons.

Table 7: presents the statistical analysis of Pyrene concentrations (µg/ml), represented as the sum of squares and mean squares of pyrene among different seasons.

Source	DF	Sum of Squares	Mean Square	F Ratio	p-value
Seasons	2	136.46498	68.2325		
Error	33	342.01623	10.3641		
C. Total	35	478.48120		6.5835	0.0039*

Figure 5 shows the significant difference between the two pairs of means. The selected mean will have a bold red circle and a variable label. The mean concentration significantly different from the selected mean will have a grey circle and grey italicized variable labels. In contrast, the circle's red color and variable label indicate no difference. As a result, the mean pyrene in summer significantly differs from the mean pyrene in autumn. Furthermore, the mean concentration of pyrene in autumn is not significantly different from winter. But the range between winter and autumn has significant differences.

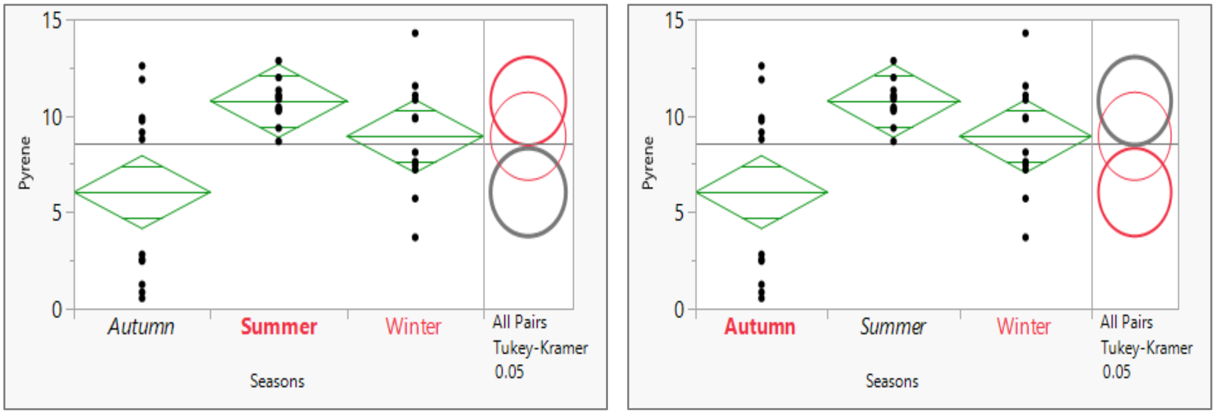

Figure 5: Post hoc Means Comparisons for pyrene that showed the change level of pyrene among the seasons.

To determine a correlation between the paired variables (Table 8) displays the pairwise correlation values and a hypothesis test based on the following hypothesis testing:

The correlation is statistically significant (P ≤0.05) so we can say that there is a linear correlation between these pairwise variables in the population.

Table 8: displays the correlations among PAH and the correlation between PAH and pH across different seasons.

Variable	by Variable	Correlation	p-values	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
Acenaphthylene	Naphthalene	-0.1684	0.3261	
Acenaphthene	Naphthalene	0.6689	0.0001*	
Acenaphthene	Acenaphthylene	-0.5919	0.0001*	
Pyrene	Naphthalene	0.5540	0.0005*	
Pyrene	Acenaphthylene	0.2719	0.1087	
Pyrene	Acenaphthene	0.4277	0.0093*	
pH	Naphthalene	0.0533	0.7574	
pH	Acenaphthylene	-0.0783	0.6497	
pH	Acenaphthene	0.1090	0.5269	
pH	Pyrene	0.0417	0.8092	

To determine if the factors of (naphthalene, acenaphthylene, acenaphthene, and pyrene) influence the (pH), we will utilize the Multiple Linear Regression Model since we are dealing with more than one factor.

Table (9) shows the analysis of variance, which it uses to test whether the means of the predicted variables (naphthalene, acenaphthylene, acenaphthene, and pyrene) are equal to zero. The null hypothesis for an ANOVA shows no difference between the independent or predicted variables. The alternative hypothesis says that at least one predicted Variable is not zero or has affected the pH.

Table 9: Analysis of Variance (ANOVA) and Parameter Estimates for the Effect of PAHs on pH.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.309955	0.077489	0.1008
Error	31	23.828745	0.768669	Prob > F (p-value)
C. Total	35	24.138700		0.9814

Since the P-value is 0.9814, which was more than the significant value, we conclude there is no evidence to reject the null hypothesis. In other words, the mean concentrations of the variables are equal and all equal to zero, which indicates that none of the variables has affected pH. We can see the parameter estimates in the following table for further clarification. In (Table 10), the P-values of all the independent variables (naphthalene, acenaphthylene, acenaphthene, and pyrene) are not statistically significant because of their large p-values of 0.8946, 0.9316, 0.7847, and 0.9360, which are more than 0.05. It suggests that (naphthalene, acenaphthylene, acenaphthene, and pyrene) do not affect the response variable of pH. However, we can only be sure of the above conclusions once we check the residuals for the model to see if they are normal.

Table 10: displays the parameter estimates of PAH among the seasons, representing the standard error and p-value for each one-off of them.

Term	Estimate	Std Error	t Ratio	p-value
Intercept	6.8049491	0.991621	6.86	<.0001*
Naphthalene	-0.015832	0.118538	-0.13	0.8946
Acenaphthylene	-0.00378	0.043707	-0.09	0.9316
Acenaphthene	0.002245	0.008145	0.28	0.7847
Pyrene	0.0052782	0.065198	0.08	0.9360

Based on both tests in (Table 11), the p-value of the Shapiro-Wilk test is 0.1701, and the p-value of the Anderson-Darling test is 0.0676. Since the p-values are more than $\alpha = 0.05$ $\alpha = 0.05$, there is no evidence to reject the null hypothesis, which says that the data are normal.

While the sample data is normally distributed, the parameter estimates in Table 10 can be concentrated, and the (naphthalene, acenaphthylene, acenaphthene, and pyrene) do not affect the response variable of pH.

Table 11: Goodness-of-Fit Test that contains Normality Tests and Parameter Estimates for pH Response in the Presence of naphthalene, acenaphthylene, acenaphthene, and pyrene.

Shapiro-Wilk	**W**	**P-value**
	0.9567261	0.1701
Anderson-Darling	A2	P-value
	0.6794555	0.0676

All four PAH (naphthalene, acenaphthylene, acenaphthene, and pyrene) were detected in the water samples, according to Table 12, The overall mean concentration of (naphthalene, acenaphthene, and pyrene) exceeded the standard level. However, the overall mean concentration of acenaphthylene was below the standard level.

Table 12: compares the overall mean concentrations of naphthalene, acenaphthene, and pyrene with their respective standard levels.

Variables	Overall Mean concentrations	Standard
Naphthalene	3.42896833	2
Acenaphthylene	0.00851222	0.1
Acenaphthene	0.1096	0.1
Pyrene	0.00848333	0.0002

In a typical environment, bacteria biodegrade organic pollutants and convert them into a form that is beneficial to aquatic life. Inorganic pollutants, on the other hand, are generally less hazardous because they are widely dispersed and have little impact on the ecosystems into which they are released. However, when the concentration of organic compounds increases, they can become pollutants, harming aquatic ecosystems, organisms, and human health when consumed[21].

Polycyclic aromatic hydrocarbons (PAH) are the most common type of organic compound, and this study provides a statistical analysis of acenaphthylene and acenaphthene levels in a particular body of water across different seasons (summer, autumn, and winter).

The study found that mean naphthalene levels varied significantly (P≤0.05) across the three seasons: autumn (2.5213µg/mL), summer (5.0348 µg/mL), and winter (2.4947 µg/mL). These differences suggest that naphthalene levels are significantly higher in the summer than in the autumn and winter, but there is no significant difference between autumn and winter. It may be related to several reasons.

The warmer temperatures in the summer cause more naphthalene to evaporate from various sources, including industrial operations, vehicle emissions, and even naphthalene-containing products like mothballs. These increases the amount of naphthalene in the atmosphere. In addition, the use of some naphthalene-containing products, such as outdoor pesticides, may also increase during the summer, contributing to higher naphthalene levels in the atmosphere. Atmospheric conditions are also often less stable in the summer due to increased convection and turbulence, which can spread pollutants like naphthalene over larger areas[22].

The relationship between high temperatures and increased naphthalene volatilization is due to increased molecular agitation, which allows for a larger release of naphthalene into the environment. The seasonal increase in the use of naphthalene-containing products intensifies the compound's introduction into the environment[23].

Naphthalene dispersion is a complex process influenced by meteorological conditions, anthropogenic activities, and environmental influences. Warmer temperatures enhance naphthalene volatilization and release, while atmospheric instability facilitates its transport over wider areas. The use of naphthalene-containing products, particularly during summer months, intensifies naphthalene emissions, while industrial activities and vehicle emissions also contribute to its atmospheric presence. Elevated naphthalene levels in the atmosphere can lead to the formation of ground-level ozone, a harmful air pollutant[24].

The average levels of acenaphthylene varied across seasons. The most substantial difference was observed in winter, which was considerably higher than those in both autumn and summer, as described in (Table 1). Statistically, a significant difference ($P \leq 0.05$) was observed between the winter, autumn, and summer seasons.

The mean levels of acenaphthene also differed across seasons. The findings suggest that the quantity of acenaphthene in the examined setting changes depending on the season. In autumn, the mean level of acenaphthene is quite high, and the summer mean level of acenaphthene is even higher. This suggests a slightly elevated presence of acenaphthene during the summer months compared to autumn. In stark contrast to autumn and summer, the winter mean level of acenaphthene is significantly lower. Indicating a substantial decrease in acenaphthene levels during Winter. As Figure 3 explains, the post hoc multiple comparison test shows that the mean acenaphthene concentration in winter significantly differs from the mean acenaphthene concentration in autumn and summer, and the mean acenaphthene concentration in summer significantly differs from the mean acenaphthene concentration in autumn.

Results showed a p-value of 0.0001, which is less than the significant level of 0.05, providing evidence to reject the null hypothesis (i.e., that there is no significant difference between the mean concentrations across the seasons).

The presence of acenaphthylene and acenaphthene in drinking water may not exhibit significant seasonal variations due to several reasons, acenaphthylene and acenaphthene are (PAH), which can be relatively stable in aquatic environments. They may not undergo rapid degradation, leading to consistent levels in the water. The primary source of acenaphthylene and acenaphthene in drinking water is often from pollutants or contamination in the environment, such as industrial runoff or agricultural chemicals. These sources don't usually fluctuate significantly with the season[25].

However, due to their low solubility in drinking water, they may exist in the water as solid particles or suspended solids rather than being fully dissolved. That may eventually settle or be removed during water treatment[26].

The Results indicate that the correlation between pyrene and other variables was examined. A positive correlation between pyrene and naphthalene (0.5540, p-value = 0.0005) and pyrene and acenaphthene (0.4277, p-value = 0.0093) was found, suggesting that these pairs of variables tend to increase or decrease together[27].

In contrast, the correlation between pyrene and pH was found to be not statistically significant (0.0417, p-value = 0.8092), suggesting that changes in pyrene levels do not significantly impact the PH.

A Multiple Linear Regression Model was utilized to check if pyrene, alongside other factors, influences pH. However, the results indicated that pyrene, among other variables, does not significantly affect the pH, as the P-value is 0.9360, which is greater than 0.05.

Polycyclic aromatic hydrocarbons (PAH) are responses to varying pH conditions. Naphthalene, acenaphthene, and pyrene, three prominent PAHs, display contrasting trends in concentration with increasing pH[28].

Naphthalene's concentration exhibits a slight decrease with rising pH due to increased ionization. As pH rises, hydrogen ions (H^+) decrease, leading to the deprotonation of naphthalene molecules. These deprotonated naphthalene molecules become more water-soluble, enhancing their adsorption onto suspended particles and sediments. This adsorption effectively removes naphthalene from the aqueous phase, reducing its concentration in the water column[29].

In contrast, acenaphthene and pyrene display a subtle increase in concentration with increasing pH due to deprotonation-induced enhanced lipophilic. As pH rises, deprotonation occurs, increasing the electron density of the PAH molecules. This enhanced electron density makes acenaphthene and pyrene more lipophilic, meaning they have a greater affinity for organic matter. As a result, this PAH partitions more readily into organic matter and less into water, reducing its solubility in water[30].

Naphthalene and pyrene levels were higher than expected, increasing the risk of cancer, as PAHs were recognized as potential human carcinogens, especially for bladder, liver, and lung cancer[31]. Although excessive PAH in drinking water may cause stomach aches, nausea, or vomiting, these symptoms are generally temporary[32]. Long-term exposure to PAH-contaminated water was linked to chronic health problems, including cardiovascular diseases[33].

Acenaphthylene and acenaphthene may be present in lower-than-expected concentrations due to their low solubility in water and tendency to form solids. However, this does not necessarily mean that they are not pollutants or pose a risk to human health and water systems. Further scientific research and measurement of these compounds in specific environments is needed to determine their impact[34].

Conclusion

The study concludes that the primary issue with drinking water in Sulaimani City is the contamination of Dukan Lake, the principal water source, with polycyclic aromatic hydrocarbons (PAH). Physicochemical analysis revealed that PAH concentrations exceeded the permissible limits for drinking water established by the World Health Organization (WHO). Consequently, the elevated PAH concentrations in drinking water warrant their classification as a pollutant posing significant health risks to humans through direct consumption and indirect exposure via the food chain.

Naphthalene levels exhibited significant seasonal variations, with higher concentrations observed during summer compared to autumn and winter. However, no significant differences were detected between autumn and winter. The ratios of acenaphthylene and acenaphthene remained stable throughout the seasons. Positive correlations between pyrene and naphthalene, as well as pyrene and acenaphthene, suggest that these variables tend to fluctuate in tandem.

While PAHs do not directly impact pH, certain organic molecules, including PAH, can indirectly affect pH by altering the water's buffering capacity. Further research is warranted to elucidate the precise mechanisms underlying these indirect effects and their potential implications for human health.

Conflict of interests

None

Author Contribution

In a testament to collaborative spirit, all authors played equally crucial roles. They meticulously designed the research framework and implemented it with precision, then delved deep into the data, integrating their insights into a cohesive manuscript. Their combined expertise and seamless teamwork fueled every step of this journey, making this work a true testament to shared dedication.

Funding

This research and the subsequent authorship and publication of this article were conducted independently, without financial support from any external source.

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