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Ecological and human health risk assessment of total petroleum hydrocarbons in surface water and sediments from the northern part of the Gulf of Suez, Egypt

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ABSTRACT

Total petroleum hydrocarbons (TPHs) in coastal seawater and marine sediments have attracted much interest because of their potential danger to aquatic ecosystems and human health. This research evaluated seasonal variations and ecological and human health concerns associated with total petroleum hydrocarbon (THPs) in surface water and sediment samples from the northern Gulf of Suez in 2019. Spectrophotometric detection was used to determine the concentration of TPHs in water and sediment samples that had been extracted using liquid-liquid and sonication extraction techniques, respectively. TPHs seasonal means in the water and sediment samples collected from the studied area showed that summer has the lowest levels of this pollutant, and ordered by winter (20.35) > autumn (17.51) > spring (11.55) > summer (17.88 µg/l), and winter (77.64) > summer (64.54 µg/g) for water and sediment samples, respectively. There was a highly significant correlation between physical parameters and TPHs in water and sediments. Evaluation of ecological risk using the pollution index (PI) and Nemerow pollution index (NPI) recorded moderate and low pollution, respectively. The non-carcinogenic risk of TPHs calculated in the water column and sediments by dermal absorption were lower than the target value (< 1) for adults and children. For human health risk, the carcinogenic dermal risk of TPHs was more than the acceptable limits (1 x10^{-4} - 1 x 10^{-6}) for adults. In contrast, the carcinogenic dermal risk of TPHs was lower than the acceptable limits (1 x10^{-4} - 1 x 10^{-6}) for children. Therefore, it follows that the body of water is contaminated and that the necessary measures should be taken to rein in all the sources of pollution there.

Keywords: Total petroleum hydrocarbon, Ecological risk, Human risk, Seawater, Sediments, Gulf of Suez, Egypt

INTRODUCTION

There was a release of several anthropogenic contaminants into the aquatic environment including polycyclic aromatic hydrocarbons (PAHs) since rapid industrialization and urbanization (Brusseau *et al*., 2019). Carbon and hydrogen, with trace quantities of other elements, including sulfur, nitrogen, and oxygen, are the primary building blocks of petroleum, which is found in nature (Dembicki Harry, 2017). Anthropogenic activities, such as petroleum extraction and burning fossil fuels, also release hydrocarbons into the environment (Zeneli *et al*., 2019; Brusseau *et al*., 2019). Ukpaka *et al*. (2020) pointed out how this devastatingly impacts marine ecosystems, fisheries resources, and the diversity of biological communities. In recent years, oil spills have become a major hazard to marine life and human health. Depending on the organism's metabolism, they may be acutely or chronically hazardous (Quintana-Rizzo *et al*., 2015; Bo *et al*., 2017). They have limited biodegradability, are carcinogenic, teratogenic, and mutagenic, and cause considerable damage to organisms. As a result of swallowing small amounts or because of direct contact, petroleum hydrocarbons may bio-accumulate in bigger animals through trophic transfer (Kuppusamy *et al*., 2020). As a result, they cause disorder in food webs, destroy ecosystems, and threaten human health (Muniz *et al*. 2015; Ukpaka *et al*. 2020). Various studies have confirmed the presence of total petroleum hydrocarbon in surface waters and sediments, emphasizing their toxicity and the risks they pose to human health in various regions around the world (Adeniji *et al*., 2019 a; Du, 2019; Akinola *et al*., 2019; Anyanwu *et al*., 2020). Depending on the goals of protection, management, and mitigation, a risk assessment may be conducted in the context of an ecological risk assessment or a human health risk assessment (Pinedo *et al*., 2012; Tian *et al*., 2020). These substances' potential carcinogenicity or non-carcinogenicity is assumed mechanically in the risk evaluation of human exposure to contaminants (Chiesa *et al*., 2019).

The primary source of pollution in Egypt's Red Sea is oil, making the Gulf of Suez the most contaminated location in the country (El-Agroudy *et al*., 2017). It is a key international trade route and a strategic site near the mouth of the Suez Canal. In addition, the Gulf of Suez's distinctive maritime environment makes it valuable for fishing stocks and tourism (Mahmoud *et al*., 2020). Oil terminals and oil refineries, ships, petroleum industries, and other ports that serve as (transit zone, loading/unloading, and fishing operations) are all possible causes of oil pollution. It is thus of local concern that the waters of the Gulf of Suez have a deleterious effect on marine habitats and human health (Abdelmongy & El-Moselhy, 2015; Ibrahim *et al*., 2019).

This research aimed to assess and identify the concentrations and sources of total petroleum hydrocarbon in surface water and sediments in the northern part of the Gulf of Suez in 2019. In addition, assessment the ecological dangers of TPHs in the investigated locations by using the pollution index approach and the risk assessment method. Also, to investigate the possible hazardous impacts of TPHs on the dermal health of children and adults.

MATERIALS AND METHODS

1. Study area:

The investigated area is located at the northern part of the Gulf of Suez and at the south entrance of the Suez Canal, which extends from Port-Tawfik to El-Sokhna with an average length of nearly about 54 km, and a mean depth is (10-18 m). The northern part of the Gulf of Suez has been subjected to different industrial and human activities covering the coastline (Hamed, 1992**)**. Seven stations were selected depending on the main activities (I: Port-Tawfik; II: El-Zaiytia: III: El-Kabanon; IV: Attaka; V: El-Adabyia: VI: Tourist villages and VII: El-Sokhna) (Fig., 1).

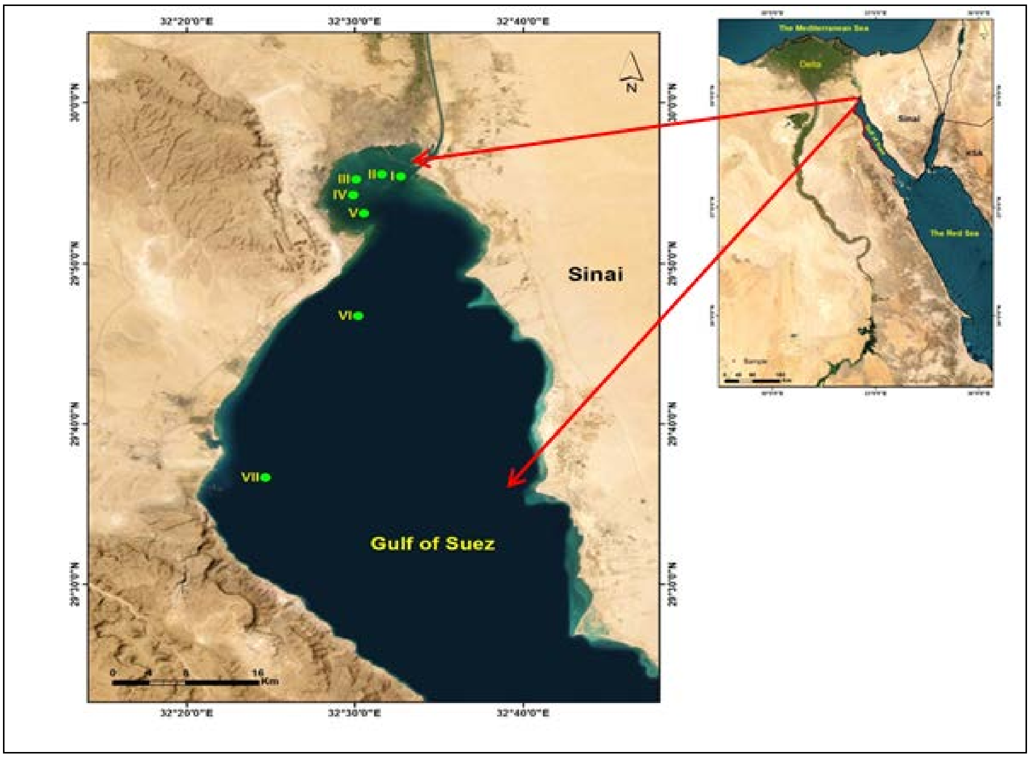

Fig. (1). Map of the northern part of the Gulf of Suez showing the sampling stations.

2. Sampling collection and preparation:

Seven monitoring stations were set up to reflect the varying environmental conditions of the offshore regions of the northern part of the Gulf of Suez in 2019. A total of 84 samples of seawater and 42 samples of surface sediments were collected. According to (UNEP and PERSGA, 1997), subsurface water samples were taken at 50 centimeters; the seawater was acidified to pH 2 using 10% HCl to protect against bacterial activity in dark bottles. The sediment samples were taken using a grab and wrapped in pre-cleaned aluminum foil. The samples were kept at 4ºC until they could be sent to the lab for examination.

3. Sampling Analysis:

After adding dichloromethane to a water sample of known volume in a separator funnel, we gave it a good shake for 2 minutes. After letting the organic layer settle to the bottom of the vial, the water was filtered through 5 g of sodium sulfate-coated filter paper. The sediment sample weighed 10 g, and 30 mL of dichloromethane (the extraction solvent) was added before the vial was sonicated for 15 minutes. The extracted mixture is filtered into the vial when the solid phase has settled, using filter paper with 5 g of sodium sulfate already on it. The water and sediment samples yielded findings in µg/L and µg/g, respectively.

4. Reagents, Solvents, and Standards:

The high-performance liquid chromatography grade solvents (dichloromethane, acetone, and hexane) utilized in sample preparation and analysis were purchased from Merck. Absorbent silica gel (100-200 mesh) made from reagent-grade anhydrous sodium sulfate (Merck).

5. Quality control:

All stages of production were subjected to stringent quality checks. Before taking any samples, we cleaned the equipment with sterile water and laboratory-grade detergent. The accuracy of all instruments was checked. The calibration of the system was checked and confirmed. Ensure there are at least three linear concentration points in the calibration range. Samples were prepared for colorimetric analysis by evaporating oil from produced water; the concentration of samples was determined by the density of crude oil in the range of 100-250 mg/L, and the method was validated by comparing it to other methods for determining oil in water, such as gas chromatography and flame ionization detection. Light crude oil extracted with a low relative error of 31.504 and heavy crude oil extracted with a high relative error of 7.025 was studied. Oil in generated water was successfully quantified using the suggested approach.

6. Pollution assessment

6.1. Ecological Risk

The northern part of the Gulf of Suez water and sediments quality was evaluated using the standard index of single-factor assessment. The pollution index (PI) approach is often used for assessing the pollution status of petroleum hydrocarbons (Zhu *et al*., 2020; Cao *et al*., 2020), with the formula for doing so being:

$$Pi = Ci/Ci_o \qquad (1)$$

Pi, Ci, and Ci_o represent the evaluated results, the actual measured data, and the evaluation standard of petroleum hydrocarbon, respectively. TPH is measured at 0.05 mg/L in surface seawater and 500 mg/kg in surface sediments (Pawar *et al*., 2002; Kwak *et al*., 2018). PI class is the environment and aquatic products into three categories: The non-polluted type when PI<0.5; the moderately polluted environment and aquatic products when it varies between 0.5-1; and the highly polluted environment and aquatic products when PI is >1.

6.2. Nemerow pollution index (NPI)

The NPI approach considers both the mean and the maximum PI value, provides a more nuanced response to the pollution level, and can emphasize the influence of pollutants using TPH. According to the formula (Nemerow, 1974):

$$NPI = \frac{\sqrt{(Pi)^2+(Pimax)2}}{2} \qquad (2)$$

Where, Pi is pollution concentration for each station; Pimax is the maximum pollution concentration, NPI, pollution levels are high when NPI > 3, pollution levels are moderate when 2 < NPI ≤ 3.0; pollution levels are low when 1< NPI ≤ 2.0; NPI pollution levels are low when 0.7 < NPI ≤ 1.0, and finally safe when NPI ≤ 0.7.

7. Evaluation of potential human health

Human health risk assessment is all about assessing the risks that carcinogenic and non-carcinogenic chemicals pose to human health. The risk assessment procedure consists of four steps: calculating toxicity (dose-response), measuring exposure, describing risks, and identifying hazards (USEPA, 2015).

7.1. Non-carcinogenic hazard (THQ)

The possible carcinogenic and non-carcinogenic effects of exposure to the TPHs over a particular time were calculated to determine the human health risk (USEPA, 2015; Titilawo *et al*., 2018). Since this body of water is intended for recreational use, the study was focused only on dermal contact with the contaminants (EOH CES, 2016). The target hazard quotient (THQ) is the ratio of the exposure dose to the reference dose (RfD) (Table 1); THQ was calculated using the formula of Eqs. (3 & 4) in mg/kg/day.

$$(THQ) Demal - water \text{ (mg/kg/day)} = \frac{CsxSAxCFx\ ET\ x\ EFx\ E_D}{Bw\ x\ T_A x\ RfD} \dots\dots\dots\dots\dots\dots (3)$$

$$(THQ)\ Dermal\ \text{-}Sediment \text{ (mg/kg/day)} = \frac{CxCFx\ SAx\ AFx\ ABSx\ EFxETx\ ED}{BwxATx\ RfD} \dots\dots\dots (4)$$

Where THQ (Target Hazard Quotients) ingestion and dermal of TPHs (mg/kg/day); Cs stands for the concentration of TPHs in the water sample (mg/L); EF is the exposure frequency both ingestion and dermal absorption; ED is the exposure duration; BW represents the average body weight; AT means the average time; SA stands for the exposed skin area; ET is the exposure time of shower and bathing; and CF represents the unit conversion factor and RfD, which represents dermal reference dose (Table 1). Guidelines values provided by the Department of Environmental Affairs and USEPA were used for the estimations (USEPA, 2015; DTSC, 2014; Feng *et al*., 2016; Wang *et al*., 2018). Hazard quotient (HQ) ≥1 is high risk; 0.1≤ (HQ)<1 is medium risk, and (HQ) < 0.1 is low risk.

7.2. Cancer risk assessment

The cancer slope factor (CSF) is used to convert the ratio of the exposure dose of TPHs over a lifetime of exposure to the risk of an individual developing cancer (USEPA, 2015). Potential carcinogen exposure is part of a carcinogenic risk assessment that estimates a person developing cancer over a lifetime. The incidence of cancer was estimated using Eq (5) according to USEPA guidelines (Wei *et al*., 2015; USEPA, 2015).

$$\text{CSR} = ADDx\ CSR \quad \dots\dots\dots\dots \quad (5)$$

Where CSF represents the cancer slope factor for Benzo (a) Pyrene is 7.3 mg/kg/day (USEPA, 2015). A risk value > 1.0×10^{-4} indicates carcinogenic effects, according to the US Environmental Protection Agency (USEPA, 2015) (Table 1).

Table (1). Exposure parameters used for the health risk assessment through different exposure pathways (Adeniji *et al*., 2019a; USEPA, 2015)

Parameters	Values		
	Unit	Child	Adult
Body weight (B_W)	Kg	15	70
Exposure frequency (E_F)	Days/year	365	
Exposure Duration (E_D)	Years	6	30
Stands for the exposed skin area (SA)	Cm^2	18000	6600
The exposure time of shower and bathing (ET)	h/day	0.58	1
RfD (USEPA, 2009)	mg/kg/day	Dermal = 0.04	
Cancer Slop Factor CSF	mg/kg/day	7.3	
Conversion factor (CF)	mg/ng	10^{-6}	
Dermal Absorption from Sediment ABS		0.13	
Adherence Factor from Sediment to Skin AF	mg/cm^2	0.07	0.2
Average Time	Days/year		
For Carcinogenic	365 x 70 = 25550		
For non-Carcinogenic	365 x E_D	365 x E_D	

8. Data Analysis

The statistical analysis of the collected dataset was performed using XL-state, 2020. Pearson's correlation coefficient (CM) analysis was performed to identify the relationship between total petroleum hydrocarbons in seawater and sediments and physical parameters. In addition, TPH content in seawater and sediment samples and physical parameters were subjected to one-way ANOVA. A probability of 0.05 was considered a significance level (Stephan *et al*., 2019).

RESULTS AND DISCUSSION

1. Physical parameters:

Table (2) shows the physical characteristics measured in this work for water samples taken from 7 locations in the northern part of the Gulf of Suez in 2019. Water temperature, pH, and salinity varied between (18.33 - 30.22 °C), (7.78 - 8.20), and (39.93 – 42.33 ‰), respectively. The present results matched the previous study by Khedr *et al*. (2019).

The seasonal water temperature distribution showed summer > autumn > spring > winter. Various factors could affect the water temperature, such as variations in climatic conditions, latitude, height, season, wind, depth, and waves (Abdelmongy & El-Moselhy, 2015). The pH value declined more in the summer than in the other seasons. In which the volume of sewage released into urbanized regions and the photosynthetic activity of algal biomass significantly impact the pH value (Abdel-Halim & Aly-Eldeen, 2016). The lowest annual pH level (7.87) was observed at station (III) El-Kabanon. This might be related to high sewage discharges and increased microbial activity in the maritime environment (Abo El-Khair *et al*., 2016; Mahmoud *et al*., 2020). The annual mean of salinity ranged between (40.02 – 42.14 ‰) for Tourist villages and El-Zaityia stations, respectively. Salinity variations were affected by temperature and wastewater discharge (Mahmoud *et al*., 2020). The current results agreed within acceptable limits with coastal water quality guidelines tailored to the marine environment (DSME, 2004),

Table (2): Seasonal and annual means of physical parameters measured in water samples collected from the northern part of the Gulf of Suez during (2019).

Stations		Seasons	Temp °C	pH	Salinity ‰
I	Port-Tawfik	Winter	18.69	8.14	41.33
		Spring	23.74	8.10	41.35
		Summer	29.88	8.00	41.89
		Autumn	23.87	8.11	41.54
Annual Mean			**24.05 ± 4.58**	**8.09 ± 0.06**	**41.53 ± 0.26**
II	El-Ziaytia	Winter	18.33	8.19	41.89
		Spring	23.34	8.13	42.15
		Summer	29.27	8.01	42.33
		Autumn	23.55	8.15	42.20
Annual Mean			**23.62 ± 4.47**	**8.12 ± 0.08**	**42.14 ± 0.18**
III	El-Kabanon	Winter	18.39	7.99	39.93
		Spring	23.86	7.84	39.95
		Summer	29.55	7.78	40.35
		Autumn	23.85	7.88	40.09
Annual Mean			**23.91 ± 4.56**	**7.87 ± 0.09**	**40.08 ± 0.19**
IV	Attaka	Winter	19.09	8.18	40.17
		Spring	24.50	8.10	40.18
		Summer	30.22	8.06	40.16
		Autumn	24.35	8.13	40.21
Annual Mean			**24.54 ± 4.55**	**8.12 ± 0.05**	**40.18 ± 0.02**
V	El-Adabyia	Winter	18.22	8.20	40.29
		Spring	24.78	8.17	40.33
		Summer	29.88	8.11	40.31
		Autumn	25.50	8.18	40.33
Annual Mean			**24.60 ± 4.81**	**8.17 ± 0.04**	**40.32 ± 0.02**
VI	Tourist villages	Winter	18.50	8.20	39.97
		Spring	24.80	8.16	40.01
		Summer	30.10	8.10	40.07
		Autumn	24.22	8.13	40.02
Annual Mean			**24.41 ± 4.74**	**8.15 ± 0.04**	**40.02 ± 0.04**
VII	El-Sokhna	Winter	18.90	8.10	40.89
		Spring	25.26	8.01	41.23
		Summer	29.70	7.95	41.27
		Autumn	24.10	8.00	41.11
Annual Mean			**24.49 ± 4.44**	**8.02 ± 0.06**	**41.13 ± 0.17**

2. Total petroleum hydrocarbons in water and sediments:

The presence of petroleum hydrocarbons in marine ecosystems is rapidly rising to the top of the world's most environmental concerns. It helped us recognize the human impacts on marine ecosystems and shed light on the dramatic shifts that have occurred in recent years (Beiras, 2018). The quantity, origin of pollutants, the temporal and spatial patterns of TPHs in water may be assumed from monitoring (Ahmed *et al*., 2015). Marine sediments act as a reservoir for petroleum hydrocarbon components. Therefore, surface sediment may provide insight into the contamination level of sediments today (Angela *et al*., 2012). The present study analyzed all samples from the northern Gulf of Suez for total petroleum hydrocarbons (TPH) in the sediments and surface water (Table 3 and Figs. 2 – 4).

TPH concentration recorded the highest annual mean (28.53 µg/l and 122.04 µg/g) at El-Zaiytia station (II) for water and sediments, respectively. It can be attributed to its proximity to numerous oil pollution sources, including loading and unloading activities at El-Zaiytia harbor and the effluents of oil refineries owned by El- Nasr and Suez petroleum companies (Diab, 2017). TPHs level observed in sediments is higher than in water, which may be attributed to TPHs being less affected by biological or photochemical oxidation in bottom sediments. Also, TPHs may stay long and build up to dangerous levels in sediments (Guzzella & Paolis, 1994). According to these findings, Neff (1985) stated that the petroleum hydrocarbons in sediments are more than those observed in the water column by a factor of 1000 or more.

The present results showed the spatial pattern of TPHs mean concentrations in water samples in the investigated area fall in the following order El-Zaiytia > El-Sokhna > Attaka > El-Adabyia > Port-Tawfik> Tourist villages > El-Kabanon (28.53, 21.40, 17.21, 15.39, 14.19, 13.56 and 7.50 µg/l, respectively). While, in sediment samples was El-Zaiytia > Port-Tawfik > Attaka > El-Adabyia > El-Sokhna > Tourist villages > El-Kabanon (122.04, 97.76, 85.22, 55.11, 41.63 and 23.36 µg/g, respectively). Ports activities highly contribute to the TPH's value in the marine ecosystem. This conclusion was consistent with the previous results of (Eed & Kaiser, 2016), which suggested that marine-based activities may be the most effective variables in the distribution patterns and concentrations of TPHs at severely contaminated stations. According to Adeniji *et al*. (2017), all stations had TPH concentrations below the EU's maximum allowable level for hydrocarbons in harbor basin water of 300 µg/L. In comparison, our data showed that the sediments of the present study revealed slightly to moderately polluted (Table 3).

Seasonally, TPHs in water varied from (8.90 – 35.46), (7.22 – 30.19), (5.52 – 19.03), and (8.35 – 29.43) µg/L throughout the winter, spring, summer, and autumn seasons, respectively, and from (26.36 – 138.98) and (20.35 – 105.11) µg/g during the winter and summer, respectively, in the sediments. In particular, the TPHs distribution confirmed that summer has the lowest level of these pollutants in the studied area, with average means of (20.39 > 17.87 > 17.49 > 11.55 µg/l) and (77.64 > 64.54 µg/g) for water and sediments, respectively. High temperatures accelerate the breakdown of petroleum hydrocarbons due to increased microbial activity (El-Agroudy *et al.*, 2017; Kottb *et al.*, 2019).

Table (3). Seasonal and annual mean for TPHs in water and sediment samples collected from the northern part of the Gulf of Suez during 2019.

		Surface water samples µg/l						MAC for TPHs for Seawater = 0.05 m (ATSDR 2013) (Omayma *et al.*, 2015), wastewater = 0.5 mg/l; DPR (2015) = 10 mg/l
	Stations		Winter	Spring	Summer	Autumn	Annual Mean	
Water	I	Port-Tawfik	17.47	14.03	10.02	15.22	14.19	
Water	II	El-Zaiytia	35.46	30.19	19.03	29.43	28.53	
Water	III	El-Kabanon	8.90	7.22	5.52	8.35	7.50	
Water	IV	Attaka	20.78	19.15	10.71	18.19	17.21	
Water	V	El-Adabyia	18.56	15.05	11.32	16.61	15.39	
Water	VI	Tourist villages	16.21	13.95	9.97	14.09	13.56	
Water	VII	El-Sokhna	25.08	22.99	14.29	23.24	21.40	
Water	Seasonal Mean		**20.35 ± 8.27**	**17.51 ± 7.42**	**11.55 ± 4.19**	**17.88 ± 6.78**	**16.82 ± 6.64**	
Sediment samples µg/g								
	Station		**Winter**		**Summer**		**Annual Mean**	
Sediment	I	Port-Tawfik	101.97		93.55		97.76	
Sediment	II	El-Zaiytia	138.98		105.11		122.04	
Sediment	III	El-Kabanon	26.36		20.35		23.36	
Sediment	IV	Attaka	92.50		77.93		85.22	
Sediment	V	El-Adabyia	59.61		50.62		55.11	
Sediment	VI	Tourist villages	45.98		37.29		41.63	
Sediment	VII	El-Sokhna	78.06		66.96		72.51	
Sediment	Seasonal Mean		**77.64 ± 37.71**		**64.54 ± 30.45**		**71.09 ± 33.94**	
Guideline for sediment	Unpolluted				10 – 15 mg/kg		(Adeniji *et al.*, 2017)	
Guideline for sediment	Slightly polluted				15 – 50 mg/kg			
Guideline for sediment	Moderately polluted				50 – 200 mg/kg			
Guideline for sediment	Heavily polluted				> 200 mg/kg			

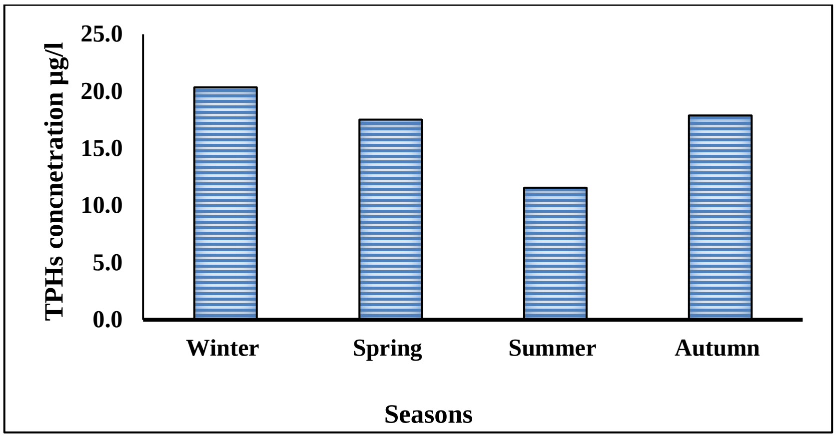

Fig. (2). Seasonal mean for TPHs in the water samples from the investigated area during 2019

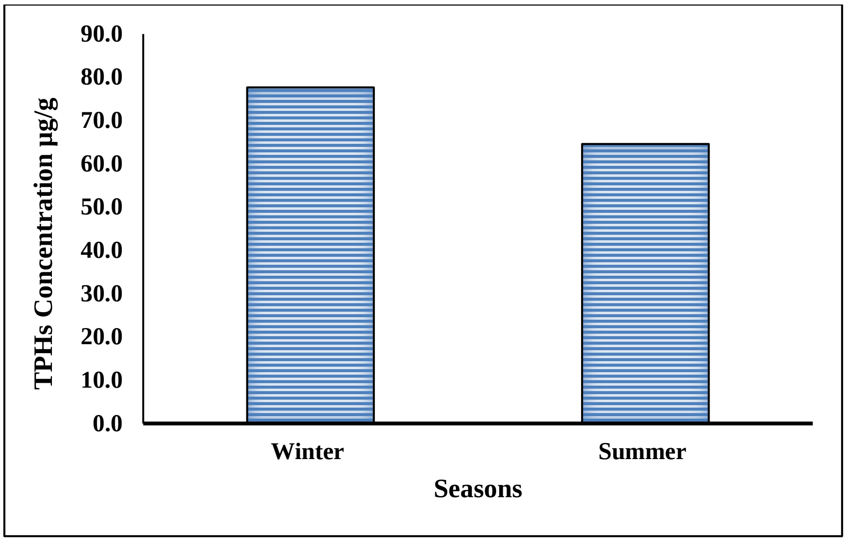

Fig. (3). Seasonal mean for TPHs in the sediment samples from the investigated area during 2019

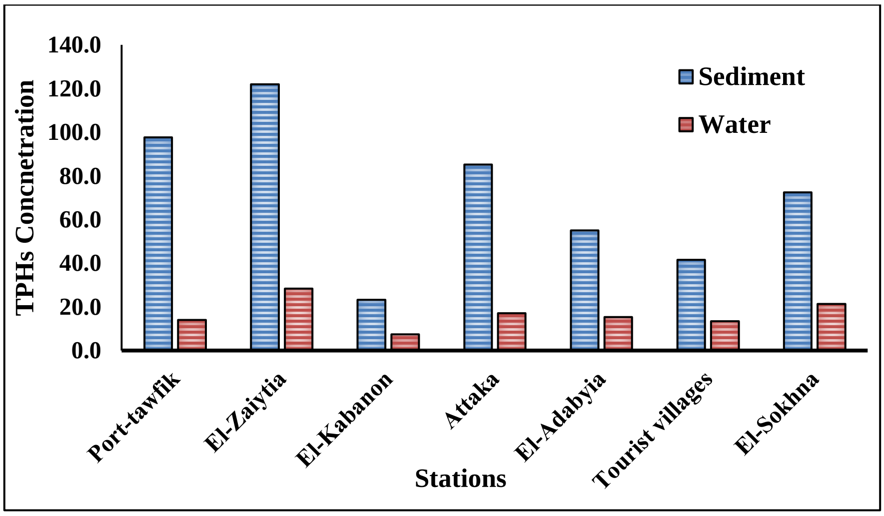

Fig. (4). Annual mean for TPHs in water and sediment samples from the investigated area during 2019

3. Ecological risk assessment:

Coastal ecosystem health may be estimated by assessing pollutants such as petroleum contaminates in seawater and sediments (Khudur *et al.*, 2018). Each sample's PI was used to determine how much pollution was present in the area of investigation and the results are shown in Table (4) and Figure (5). Seasonal PI for TPHs in water and sediments ranged between (0.18 – 0.71), (0.14 – 0.60), (0.11 – 0.38) and (0.17 – 0.59) for winter, spring, summer, and autumn, respectively, and from (0.053 – 0.278) and (0.041 – 0.201) for winter and summer, respectively. The order of the mean values of PI for water showed winter (0.41) > autumn (0.36) > spring (0.35) > summer (0.23), whereas in sediment samples was winter (0.155) > summer (0.129). Seasonal PI was classified as a non-polluted type (<0.5) for water and sediment samples. Regionally, the annual mean values ranged (0.15 – 0.57) with an average (0.34 ± 0.13) and (0.047 – 0.244) with an average (0.142 ± 0.07) for water and sediments, respectively. Only El-Zaiytia station recorded PI (0.57) higher than the lower pollution limit in water, and was classified as a moderately polluted station.

Whereas, NPI values ranged from 0.51 to 0.64 with an average of 0.56 ± 0.04 and 0.199 – 0.262 with an average of 0.224 ±0.022 for water and sediments, respectively. The seven water monitoring stations revealed the following geographical distribution trend: El-Zaiytia (II) > El-Sokhna (VII) > Attaka (IV) > El-Adabyia > Port-Tawfik (I) = Tourist villages (VI) > El-Kabanon (III). While in sediments was El-Zaiytia (II) > Port-Tawfik (I) > Attaka (IV) > El-Sokhna (VII) > El-Adabyia > Tourist villages (VI) > El-Kabanon (III). According to the NPI values, the current investigated stations were classified as a safe pollution area. Consequently, the northern part of the Gulf of Suez is classified as non-polluted and safe even though shipping operations and land-based wastewater discharges are the primary causes of oil pollution in the present study area (Liu *et al*., 2019).

Table (4). Pollution indices of the measured TPHs in water and sediment samples collected from the northern part of the Gulf of Suez for aquatic life utilizations.

			Pi= Ci/Ci_o					**NPI**
Stations			Winter	Spring	Summer	Autumn	Annual Mean	
Water	I	Port-Tawfik	0.35	0.28	0.20	0.30	0.28	**0.54**
	II	El-Zaiytia	0.71	0.60	0.38	0.59	**0.57**	**0.64**
	III	El-Kabanon	0.18	0.14	0.11	0.17	0.15	**0.51**
	IV	Attaka	0.42	0.38	0.21	0.36	**0.34**	**0.56**
	V	El-Adabyia	0.37	0.30	0.23	0.33	0.31	**0.55**
	VI	Tourist villages	0.32	0.28	0.20	0.28	0.27	**0.54**
	VII	El-Sokhna	0.50	0.46	0.29	0.46	**0.43**	**0.59**
	Average		**0.41 ±0.17**	**0.35 ±0.15**	**0.23 ±0.08**	**0.36 ±0.14**	**0.34 ±0.13**	**0.65 ±0.04**
Sediment	Stations		Winter		Spring		Annual Mean	**NPI**
	I	Port-Tawfik	0.204		0.187		**0.196**	**0.240**
	II	El-Zaiytia	0.278		0.210		**0.244**	**0.262**
	III	El-Kabanon	0.053		0.041		0.047	**0.199**
	IV	Attaka	0.185		0.156		**0.170**	**0.231**
	V	El-Adabyia	0.119		0.101		0.110	**0.211**
	VI	Tourist villages	0.092		0.075		0.083	**0.205**
	VII	El-Sokhna	0.156		0.134		**0.145**	**0.222**
	Average		**0.155± 0.08**		**0.129 ± 0.06**		**0.142 ±0.07**	**0.224± 0.05**

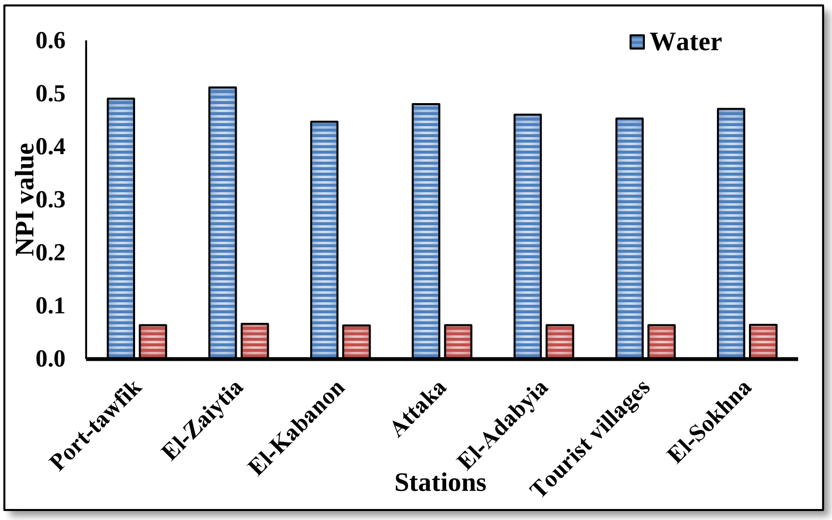

Fig. (4). Annual mean for NPI in water and sediment samples from the area of investigation during 2019

4. Human health risk assessment:

TPHs directly threaten humans in the aquatic environment because of their toxic properties and negative impact on the food chain (ITRC, 2018). In light of the above, the following are the most typical forms of serious risk assessment that include assessing the impact of water bodies on human health risks:

4.1. Non-Carcinogenic risk (THQ)

Exposure to carcinogenic compounds during a certain period was considered in human health risk assessments (USEPA, 2015). The danger to human health from dermal TPHs-contaminated water was calculated in this research using equations (3 and 4). In water, TPHs in the studied area were calculated to have target hazard quotients (THQ) ranging from (4.8×10^{-5} - 1.8×10^{-4}) and (3.1×10^{-7} - 1.2×10^{-6}) for adults and children, respectively, for dermal absorption (Table 5). In sediments, the THQ for TPHs ranged from (3.9×10^{-6} – 2.0×10^{-5}) and (2.3×10^{-10} - 1.2×10^{-9}), respectively. The findings show that the THQ in the water column and sediments for both age groups was lower than the USEPA's threshold (<1). Therefore, recreational use is unlikely to expose people to non-carcinogenic diseases or other health problems (ATSDR, 2013; Wei *et al.*, 2015; Benson *et al.*, 2017). Consequently, adults are highly susceptible to non-carcinogenic risk than a child.

4.2. Carcinogenic Risk

Using equation (5), the effect of each particular hydrocarbon in water across all exposure routes was calculated independently for children and adults, yielding unique cancer risk assessments. Results from an analysis of the carcinogenic hazards posed by TPHs showed that these compounds have a low risk of causing cancer (Table 5). Therefore, the US Environmental Protection Agency (USEPA, 2015) accepts a cancer risk range of 1×10^{-6} - 1×10^{-4}. According to Adeniji *et al.* (2019 a, b), who stated that if the CSR is $\leq 1 \times 10^{-6}$, the risk is considered acceptable by the USEPA, and if it is between $1 \times 10^{-5} < CSR < 1 \times 10^{-4}$, the risk is considered unacceptable. If CSR ≥ 1 × 10 $^{-4}$, it can cause serious health effects.

Table (5) shows that the water content of CSRs ranged from (1.3 x 10^{-5} – 3.5 x10 $^{-5}$) and (2.1 x 10^{-9} – 5.6 x 10^{-10}) for dermal in both adults and children, respectively. In comparison, CSR for sediments content varied between (2.6 x 10^{-6} – 4.7 x10^{-7}) and (3.17 x 10^{-12} – 7.1 x 10^{-13}) for dermal in both adults and children, respectively. Adult group risk indices were higher than the limit value of (1 x10^{-4} – 1 x10^{-6}), which is considered unacceptable. At the same time, child group risk indices were lower than the limit value (acceptable limit) (Wei *et al*., 2015; Wang *et al*., 2018).

Table (5). THQ $_{Dermal}$ of non-carcinogenic and Cancer Slop Risk (CSR) for adults and children in the area of investigation.

	Stations		Adult	Child	Adult	Child
			THQ $_{Dermal}$	**THQ $_{Dermal}$**	**CSR**	**CSR**
Water	I	Port-Tawfik	9.1E-05	5.8E-07	**6.6E-06**	1.1E-09
	II	El-Zaiytia	1.8E-04	1.2E-06	1.3E-05	2.1E-09
	III	El-Kabanon	4.8E-05	3.1E-07	**3.5E-06**	5.6E-10
	IV	Attaka	1.1E-04	7.1E-07	**8.0E-06**	1.3E-09
	V	El-Adabyia	9.9E-05	6.3E-07	**7.2E-06**	1.1E-09
	VI	Tourist villages	8.7E-05	5.6E-07	**6.3E-06**	1.0E-09
	VII	El-Sokhna	1.4E-04	8.8E-07	1.0E-05	1.6E-09
Sediment	I	Port-Tawfik	1.6E-05	9.5E-10	**2.0E-06**	3.0E-12
	II	El-Zaiytia	2.0E-05	1.2E-09	**2.6E-06**	3.7E-12
	III	El-Kabanon	3.9E-06	2.3E-10	4.9E-07	7.1E-13
	IV	Attaka	1.4E-05	8.3E-10	**1.8E-06**	2.6E-12
	V	El-Adabyia	9.2E-06	5.3E-10	**1.2E-06**	1.7E-12
	VI	Tourist villages	7.0E-06	4.0E-10	8.7E-07	1.3E-12
	VII	El-Sokhna	1.2E-05	7.0E-10	**1.5E-06**	2.2E-12
					CSR= 1x 10^{-6} - 1 x10^{-4}	

5. Data analysis

According to the ANOVA analysis, the studied physical parameters and TPHs showed significant spatial and temporal variations (p-value < 0.05). Table (6) displays the correlation matrix of numerous variables in water and sediments across stations. Salinity and total petroleum hydrocarbons in water and sediments were shown to have very positive associations (0.89 and 0.77, respectively). The correlation between total petroleum hydrocarbons in water and sediments was (0.82). In contrast, there were strong to moderate inverse associations between pH and total petroleum hydrocarbons in water and sediments (- 0.79 and - 0.58).

Table (6). Correlation matrix with different variables in water and sediment samples.

	Salinity	pH	Temp.	TPHs S	TPHs W
Salinity	1				
pH	-0.695	1			
Temp.	-0.272	-0.263	1		
TPHs S	**0.885**	-0.582	-0.355	1	
TPHs W	**0.766**	-0.789	-0.234	**0.815**	1

Conclusion

This study evaluated the spatial and temporal distribution patterns of the total petroleum hydrocarbons in water and sediment samples from the northern part of the Gulf of Suez, Egypt. Overall, TPHs were observed to be modest, and the principal sources of TPHs in the studied area were likely to be different intensive shipping activities associated with the main harbors and effluents discharged from petroleum oil refineries and petroleum production and industry companies. The PI and NPI pollution levels were classified as moderate and low, respectively, for ecological risk. For human health risk, the non-carcinogenic risk of TPHs calculated in the water column and sediments by dermal absorption was lower compared to the target value (< 1) for both adults and children. For adults, the carcinogenic dermal risk of TPHs was more than the acceptable limits (1×10^{-4} - 1×10^{-6}). In contrast, the carcinogenic dermal risk of TPHs was less than the acceptable limits (1×10^{-4} - 1×10^{-6}) for children. Therefore, more precautions have to be followed to protect the body of water from contamination with TPH from different sources.

REFERENCES

Abdel-Halim, A.M. and Aly-Eldeen, M.A. (2016). Characteristics of Mediterranean Sea water in the vicinity of Sidikerir Region, west of Alexandria, Egypt. Egypt. J. Aquat. Res., 42: 133–140.

Abdelmongy, A.S. and El-Moselhy, K.M. (2015). Seasonal variations of the physical and chemical properties of seawater at the Northern Red Sea, Egypt. Open J. Oceanogr. Environ. Develop., 6 (1):49-73.

Abo El-Khair, A.M.; Abdel Fattah, L.M.; Abdel-Halim, A.M.; Abd-Elnaby, M.A. Fahmy, M.A. and Ahdy, H.H. (2016). Assessment of the Hydro-chemical Characteristics of the Suez Gulf Coastal Waters during 2011-2013. J. Environ. Protection, 7: 1497-1521. https://doi.org/10.4236/jep.2016.711126

Adeniji, A.O.; Okoh, O.O. and Okoh, A.I. (2019b). Distribution pattern and health risk assessment of polycyclic aromatic hydrocarbons in the water and sediment of Algoa Bay, South Africa. Environ. Geochem. Health, 41: 1303–1320

Adeniji, A.O.; Okoh, O.O. and Okoh, A.I. (2017). Petroleum hydrocarbon fingerprints of water and sediment samples of Buffalo River Estuary in the Eastern Cape Province, South Africa. J. Analytical Methods in Chemistry.

Adeniji, A.O.; Okoh, O.O. and Okoh, A.I. (2019 a). Levels of polycyclic aromatic hydrocarbons in the water and sediment of Buffalo River Estuary, South Africa and their health risk assessment. Arch. Environ. Contamination Toxicol., 76: 657-669.

Ahmed, O.E.; Mahmoud, S.A. and Mousa, A.M. (2015). Aliphatic and polyaromatic hydrocarbon pollution at the drainage basin of Suez Oil Refinery Company. Curr. Sci. Int.: 4: 27-44.

Akinola, J.O.; Olawusi-Peters, O.O. and Akpambang, V.O. (2019). Ecological hazards of total petroleum hydrocarbon in brackish water white shrimp *Nematopalaemon hastatus* (AURIVILLUS 1898). Egypt. J. Aquat. Res., 45(3): 205-210.

Angela, de.L.; R.W.; Maria, de.F.G.G.; Meniconi, C.; Hamacher, I.C.O.; Farias, Gilson, C.D.S.; Irene, T.G. and Arthur, de.L.S. (2012). Hydrocarbons in sediments of a chronically contaminated bay: The challenge of source assignment. Mar. Poll. Bull., 64: 284–29.

Anyanwu, I.N.; Sikoki, F.D. and Semple, K.T. (2020). Risk assessment of PAHs and N-PAH analogs in sediment cores from the Niger Delta, Marine Pollution Bulletin, 161: 111684.

ATSDR (Agency for Toxic Substances and Disease Registry) (2013). Polycyclic aromatic hydrocarbons (PAHs): What health effects are associated with PAH Exposure; https://www.atsdr.cdc.gov/csem/csem.asp?csem=13&po=11.

Beiras, R. (2018). Basic concepts. In: Beiras, R.B.T.-M.P. (Ed.), Marine Pollution Sources, Fate and Effects of Pollutants in Coastal Ecosystems. Elsevier, pp. 3–20.

Benson, N.U.; Anake, A.E.; Adedapo, W.U.; Fred-Ahmadu, O.H. and Eke, K.P. (2017). Polycyclic aromatic hydrocarbons in imported Sardinops sagax: levels and health risk assessments through dietary exposure in Nigeria. J. Food Composition and Analysis, 57: 109–116.

Bo, J.; Zheng, R.; Kuang, W.; Hong, F.; Xie, Q. and Zhang, Y. (2017). The use of rockfish *Sebastiscus marmoratus a*s a sentinel species to assess petroleum hydrocarbons pollution: a case study in Quanzhou Bay, China. Mar. Poll., 124(2): 984-992.

Brusseau, M.L.; Matthias, A.D.; Comrie, A.C. and Musil, S.A. (2019). Atmospheric pollution. PS (Third E). In: Brusseau, Mark, L., Pepper, I.L., Gerba, C.P.B.T.-E. (Eds.), Environ. Poll. Sci. Academic Press, pp. 293–309.

Cao, Z.Q.; Wang, L.; Yang, L.S.; Yu, J.P.; Lv, J.; Meng, M. and Li, G.S. (2020). Heavy metal pollution and the risk from tidal reclamation in coastal areas of Jiangsu, China. Mar Pollut Bull., 158: 111427.

Chiesa, L.M.; Zanardi, E.; Nobile, M.; Panseri, S.; Ferretti, E.; Ghidini, S.; Foschini, S.; Ianieri, A. and Arioli, F. (2019). Food risk characterization from exposure to persistent organic pollutants and metals contaminating eels from an Italian lake. Food Addit. Contam. Part A, Chem. Analys. Contr. Exposur. Risk Assessment. 36: 779788.

Dembicki Harry, J. (2017). Introduction. In: Dembicki Harry BT - Practical Petroleum Geochemistry for Exploration and Production, J. (Ed.), Practical Petroleum Geochemistry for Exploration and Production. Elsevier, pp. 117.

DPR (2015). Department of Petroleum Resources; Oil and Gas Annual Report. pp.1–91.

Diab, H.M. (2017). Petroleum Hydrocarbons Assessment in water, sediment and some biota in the Gulf of Suez. Ph.D. Thesis, Marine Science Department, Faculty of Scienec, Suez Canal University.

DSME (2004). Decree of the State Minister of the Environment No. SI Annex III.

DTSC (California Department of Toxic Substances Control) (2014) Human health risk assessment (HHRA) Note. Hero HHRA Note Number 1, p 4.

Du, H. (2019). Occurrence and health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in water resources of the typical plain river network area. In IOP Conference Series: Earth Environ. Sci., 332 (2):. 022041. IOP Publishing.

Eed, M.A. and Kaiser, M., F. (2016). Monitoring of Oil Spills along Suez-Ain Sokhna Coastal Zone, Using Remote Sensing Techniques. IOSR Journal of Environmental Science, 10: 6–16. DOI:10.9790/2402-10210616.

El-Agroudy, N.; Soliman, Y.; Hamed, M. and Zaghloul, G. (2017). Distribution of PAHs in water and sediments samples of Suez Canal during 2011. J. Aquat. Poll. Toxicol., 1(3): 1–9.

EOH Coastal and Environmental Services (EOHCES) (2016). Buffalo River Estuary, East London. Draft Situation Assessment Report, pp 31–49.

Feng, J.; Hu, P.; Li, X.; Liu, S. and Sun, J. (2016). Ecological and health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in surface water from the middle and lower reaches of the Yellow River. Polycyclic Aromatic Compund, 36(5):656–670. https://doi.org/ 10.1080/10406 638.2015.10425 52.

Guzzella, L. and Paolis, A. (1994). Polycyclic aromatic hydrocarbons in sediments of the Adriatic Sea. Mar. Poll. Bull., 28: 159-165.

Hamed, M.A. (1992). Seawater quality at the northern part of the Gulf of Suez and the nearby area of the Suez Canal, M.Sc. Thesis, Faculty of Science, Mansoura University, Egypt.

Ibrahim, M.I.; Mohamed, L.A.; Mahmoud, M.G.; Shaban, K.S.; Fahmy, M.A. and Ebeid, M.H., (2019). Potential ecological hazards assessment and prediction of sediment heavy metals pollution along the Gulf of Suez, Egypt. Egypt. J. Aquat. Res., 45: 329-335.

ITRC (2018). Human health risk assessment. In: TPH Risk Evaluation at petroleum-contaminated sites. Interstate Technology & Regulatory Council (ITRC), pp. 1–14.

Khedr, A.I.; Soliman, Y.A.; El-Sherbeny, E.F.; Hamed, M.A.; Ahmed, M.A. and Goher, M.E. (2019). Water quality assessment of the Northern part of Suez Gulf (Red Sea, Egypt), using principal component Analysis. Egypt. J. Aquat. Biol. Fish., 23: 527–

538. https://doi.org/10.21608/ejabf.2019.58410

Khudur, L.S. Gleeson, D.B. and Ryan, M.H. (2018). Implications of co-contamination with aged heavy metals and total petroleum hydrocarbons on natural attenuation and ecotoxicity in Australian soils. Environ. Poll., 243: 94–102.

Kottb, M.R.; El-Agroudy, N.A.; Ali, A.E.; Hamed, M.A. and Ezz El-Din, H.M. (2019). Biodegradation of some petroleum hydrocarbons by fungi isolated from Gulf of Suez. CATRINA, 18(1): 169-175.

Kuppusamy, S.; Maddela, N.R.; Megharaj, M. and Venkateswarlu, K. (2020). Ecological impacts of total petroleum hydrocarbons. In: Total Petroleum Hydrocarbons book, (pp.95-138). DOI: 10.1007/978-3-030-24035-6_5

Kwak, J.I.; Nam, S.H. and An, Y.J. (2018). Water quality standards for the protection of human health and aquatic ecosystems in Korea: current state and future perspective. Environ. Sci .Pollut. Res., 25: 3108-3119.

Liu, J.F.; Ma, I.I.; Zhang, H.W.; Ye, S. and Lu, R.M. (2019). Assessment and Analysis on the Marine Ecosystem Health in the Yueqing Bay. Chinese Science Bullutin, 35 (1): 42-48 (in Chinese).

Mahmoud, M.G.; El-Khir, E.A.; Ebeid, M.H.; Mohamed, L.A.; Fahmy, M.A. and Shaban, K.S. (2020). An assessment on the coastal seawater quality of the Gulf of Suez, Egypt. J. Environ. Protection, 11: 34-47.

Muniz, P.; Venturini, N.; Martins, C.C.; Munshi, A.B.; Garcia-Rodriguez, F.; Brugnoli, E.; Dauner, A.L.; Bícego, M.C. and Garcia-Alonso, J. (2015). Integrated assessment of contaminants and monitoring of an urbanized temperate harbor (Montevideo, Uruguay): a 12-year comparison. Brazilian J. Oceanogr., 63: 311–330.

Neff, J.M. (1985). Polycyclic aromatic hydrocarbons in the aquatic environment: sources, fates and biological effects. Appl. Sci., London.

Nemerow, N.L. (1974). Scientist stream pollution Analysis. McGraw-Hill, New York.

Omayma, E.A.; Sawsan, A.M., and Abd El Rahman, M. (2015). Monitoring and assessment of petroleum hydrocarbons in surface seawater along Alexandria Coasts, Egypt. Int. J. Environ., 4(01): 70-8.

Pawar, V.; Matsuda, O. and Fujisaki, N. (2002). Relationship between feed input and sediment quality of the fish cage farms. Fish. Sci., 68(4):894-903.

Pinedo, J.; Ibáñez, R. and Irabien, A. (2012). Risk Assessment of total petroleum hydrocarbons (TPHs) Fractions. Chemical Engineering Transactions, 28: 61-66. DOI: 10.3303/CET1228011

Quintana-Rizzo, E.; Torres, J.J.; Ross, S.W.; Romero, I.; Watson, K.; Goddard, E. and Hollander, D. (2015). δ13C and δ15N in deep-living fishes and shrimps after the Deepwater Horizon oil spill, Gulf of Mexico. Mar. Poll. Bull., 94: 241–250.

Stephan, C.; Lubrina, P.; Sinske, J.; Govers, Y. and Lastère, N. (2019).

AIRBUS Beluga XL state-of-the-art techniques to perform a Ground Vibration Test campaign of a large aircraft. In: IFASD. SAVANNAH, United States.

Tian, Y.; Zeng, Y.; Li, C.; Wang, X.; Liu, Q. and Zhao, Y. (2020). Ecological risk assessment of petroleum hydrocarbons on aquatic organisms based on multisource data. Ecotoxicol. Environ. Safety, 192: 110262.

Titilawo, Y.; Adeniji, A.; Adeniyi, M. and Okoh, A. (2018). Determination of levels of some metal contaminants in the freshwater environments of Osun State, Southwest Nigeria: a risk assessment approach to predict health threat. Chemosphere, 211: 834–843. https://doi.org/10.1016/ j.chemospher, e.2018.07.203

Ukpaka, C.P.; Lezorghia, S.B. and Nwosu, H. (2020). Crude oil degradation in loamy soil using Neem root extracts: an experimental study. Chem. Int., 6(3): 160–167.

UNEP and PERSGA (1997). Assessment of Land-Based Sources and Activities Affecting the Marine Environment in the Red Sea and Gulf of Aden. UNEP Regional Seas Reports and Studies.

USEPA (United States Environmental Protection Agency) (2009). RAGS: part F, supplemental guidance for inhalation risk assessment. EPA/540/R/070/002

USEPA (United States Environmental Protection Agency), (2015). Regional Screening Table. Updated, p. 176. https ://semsp ub.epa.gov/work/10/500011899

Wang, L.; Zhang, S.; Wang, L.; Zhang, W.; Shi, X.; Lu, X. and Li, X. (2018). Concentration and risk evaluation of polycyclic aromatic hydrocarbons in urban soil in the typical semi-arid city of Xi'an in Northwest China. Int. J. Environ. Res. Public Health, 15: 607. https://doi. org/10.3390/ijerp h1504 0607

Wei, H.; Le, Z.; Shuxian, L.; Dan, W.; Xiaojun, L.; Lan, J. and Xiping, M. (2015). Health risk assessment of heavy metals and polycyclic aromatic hydrocarbons in soil at Coke Oven Gas Plants. Environ. Eng. Manag. J., 14(2): 487–496.

Zeneli, A.; Kastanaki, E.; Simantiraki, F. and Gidarakos, E. (2019). Monitoring the biodegradation of TPH and PAHs in refinery solid waste by biostimulation and bioaugmentation. J. environ. Chem. Engin., 7(3): 103054.

Zhu, G.; Noman, M.A.; Narale, D.D.; Feng, W.; Pujari, L. and Sun, J. (2020). Evaluation of ecosystem health and potential human health hazards in the Hangzhou Bay and Qiantang estuary region through multiple assessment approaches. Environ. Pollut., 264: 114791.

Ecological and human health risk assessment of total petroleum hydrocarbons in surface water and sediments from the northern part of the Gulf of Suez, Egypt

تقييم المخاطر البيئية والصحية للإنسان للمواد الهيدروكربونية البترولية الكلية في المياه السطحية والرسوبيات من الجزء الشمالي لخليج السويس، مصر

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المستخلص

اجتذبت المواد الهيدروكربونية البترولية الكلية (TPHs) في المياه الساحلية والرسوبيات البحرية اهتمامًا كبيرًا نظرًا لخطرها المحتمل على النظم البيئية المائية وكذلك على صحة الإنسان. وقد هدفت الدراسة الحالية إلى تقييم الاختلافات الموسمية والمخاطر البيئية والصحية المرتبطة بالمواد الهيدروكربونية البترولية الكلية في عينات من المياه السطحية والرسوبيات من شمال خليج السويس خلال عام ٢٠١٩. حيث تم استخدام الكشف الطيفي لتقدير تركيز المواد الهيدروكربونية البترولية الكلية في عينات المياه والروسوبيات التي تم استخلاصها باستخدام تقنيات الاستخلاص السائل وتقنيات الاستخلاص بالذبذبات الصوتية، على التوالي. أظهرت نتائج المتوسطات الموسمية لـ TPHs في عينات المياه والرسوبيات التي تم جمعها من منطقة الدراسة أن الصيف احتوي على أقل المستويات، وكان ترتيبها كالتالي: الشتاء (٢٠.٣٥) > الخريف (١٧.٥١) > الربيع (١١.٥٥) > الصيف (١٧.٨٨ ميكروجرام/ لتر) للمياه، والشتاء (٧٧.٦٤) > الصيف (٦٤.٥٤ ميكروجرام/جرام) للرسوبيات. كما كانت هناك علاقة طردية عالية بين الخواص الفيزيائية والمواد الهيدروكربونية البترولية الكلية في الماء والرسوبيات. سجل تقييم المخاطر البيئية باستخدام مؤشر التلوث (PI) ومؤشر التلوث Nemerow (NPI) تلوثًا متوسطًا ومنخفضًا، على التوالي. كانت المخاطر غير المسرطنة لـلمواد الهيدروكربونية البترولية الكلية في عمود الماء والرسوبيات عن طريق امتصاص الجلد أقل من القيمة المستهدفة (< ١) للبالغين والأطفال. بالنسبة للمخاطر على صحة الإنسان، كان خطر الإصابة بالسرطان الجلدي من المواد الهيدروكربونية البترولية الكلية أكثر من الحدود المقبولة (١ × ١٠$^{-٤}$ – ١ × ١٠$^{-٦}$) للبالغين. على النقيض من ذلك، كان خطر الإصابة بالسرطان الجلدي من المواد الهيدروكربونية البترولية الكلية أقل من الحدود المقبولة (١ × ١٠$^{-٤}$ – ١ × ١٠$^{-٦}$) للأطفال. وعلى ذلك فإن منطقة الدراسة تتعرض لمخاطر التلوث بالمواد الهيدروكربونية البترولية الكلية خاصة في عمود المياه ويجب اتخاذ الاجراء اللازمة لمعرفة مصادر تلك الملوثات والعمل على الحد من أثارها.