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### Seasonal fluctuations of aliphatic petroleum hydrocarbons in soil and vegetation: A case study near Al-Qurna oil field, Basrah, Iraq

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#### *Abstract*

**Background.** Petroleum hydrocarbons have detrimental effects on plant development and growth and there are substantial seasonal changes in the levels of petroleum hydrocarbons.

**Purpose.** Investigate the seasonal pattern of contamination in soil and plants of petroleum hydrocarbons, paying special attention to the possibility of focusing on the species that may be instrumental in the process of remediation.

**Methodology.** The sampling of soil and plant matter took place monthly during 3 different stations within the north area of the Basra Governorate between October of 2023 and May of 2024. Samples were collected and taken to the laboratory to be processed instantly. Content of petroleum hydrocarbons was specified through extraction, concentration, division and analytical assessment of the soil/plant samples.

**Results.** The maximum levels were seen in spring and this was explained by the fact that the inputs of the hydrocarbons were higher due to the high oil extraction activities. On the other hand, the smallest concentration of hydrocarbons was found during summer, perhaps due to the activity of more favourable microbial degradation and volatilization activities. The inter-station comparison showed that the levels of hydrocarbons in spring were always rather high, indicating that there were local or seasonal contamination sources. The results were a clear indication that soil is the most important storage of the hydrocarbons and the concentration in the soil was far much higher than in the tissue of plants.

**Conclusion.** Petroleum hydrocarbons as monitored seasonally are important in enhancing remediation processes and environmental management measures at oil fields.

**Keywords:** hydrocarbons; sustainability; soil contamination; plant accumulation; phytoremediation

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## Introduction

Environmental pollution can be defined as the alteration of an element or a compound that causes harm to life or destruction of ecological systems. The causes of pollutants are chemical products and energy, which can be light or heat, and noise, which is usually dangerous material that causes significant environmental issues [1]. The oil hydrocarbons are unique from the rest of the pollutants due to their widespread presence in nature, and their adverse effects on the survival of the ecosystem. As shown by Al-Hisnawi et al., crude oil consists of hydrocarbons blended with multiple chemical elements, which represent a significant source of environmental contamination [2]. Petroleum hydrocarbons entering ecosystems create ecological disruption while negatively impacting all forms of life, including plants, animals, and humans. As the concentration of petroleum hydrocarbons in plants increases, their toxicity results in significant physiological harm. Plants absorb organic compounds from crude oil through their roots and leaves, which leads to cellular and tissue destruction that negatively affects their growth and development [3]. Industrial activities related to oil extraction and processing also contribute to soil pollution. Such activities include diesel, gasoline, and other petroleum derivatives that cause changes in the physical and chemical properties of the soil. Through an example, the soil PH might be lowered and the amounts of heavy elements like lead and zinc might be provoked. These pollutants are then used up by plants causing their stunted growth and interference with physiological processes [4]. The interactions between the petroleum hydrocarbon pollutants and soil microorganisms as well as plants are critical aspects of study in relation to the effects they cause and designing strategies to reduce these negative effects.

The seasonal changes contribute much to the occurrence and maintenance of the petroleum hydrocarbon in the environment. The seasonal factors like temperature, microbial activity and volatilization rates vary and they affect the levels of hydrocarbons in the soil and plants. Indicatively, a rise in the temperature during summer might increase the amount of microbial activity in degrading and volatilization to lower the level of hydrocarbons, but low temperatures during the colder seasons may promote their formation. Research on these seasonal patterns is critical in the evaluation of the level of contamination and

establishing the best timings in the remediation process [5]. In addition, some of the plant species have shown impressive ability to absorb the hydrocarbons; hence, providing a long-term remedy to the oil pollution. Phytoremediation involving the use of plants to either eliminate or break down contaminants has become an affordable and environmentally friendly method. Alhagi plants have demonstrated a significant potential of hydrocarbon accumulation among these, and are hence, good candidates in phytoremediation remediation [6].

The existence of petroleum hydrocarbon in soil and vegetation has been widely reported by previous research, but the current study is the sole attempt to establish the gap in knowledge on seasonal and spatial changes around oil fields especially in Al-Qurna District of Basra, Iraq [7]. The novelty of such study is that a method of considering the soil and the vegetation together in several seasons and regions will disclose detailed process of contamination. The research questions that are used as the main focus of this paper are: how seasonally and spatially do petroleum hydrocarbon concentrations change in soil and vegetation around oil fields? and which plant species illustrates high hydrocarbon accumulation potential as a phytoremediation alternative?. This study has attempted to examine dynamics of seasonal variation in petroleum hydrocarbon pollution of soils and plants with emphasis placed on the identification of those species that may be significant in the component of remediation i.e. Alhagi.

## **Materials and methods**

### ***Study Area***

This study was carried out in Al-Qurna District which is in the north of the Basra Governorate, Iraq. Three distinct sampling stations were selected to represent the environmental diversity of the area, station 1 was located adjacent to the Al-Ezz River, station 2 was situated within the Ezz Al-Din Salim District, and station 3 was in the Al-Sharsh region of Al-Qurna District (Figure 1).

### ***Preparation and Collection of Samples***

Samples of plants and soil that had been monthly sampled at each of the stations occurred between October 2023 and May 2024. The samples were collected and taken to the laboratory to process them immediately. The samples were dried at an electric oven of 105 °C to eliminate moisture and ground in a ceramic mortar and dried using a 63-micron mesh sieve to get homogeneous particle sizes that are analyzable.

### ***Petroleum Hydrocarbon Content Determination***

The petroleum hydrocarbons determination is a sequential process which is provisioned by extraction, concentration, separation and analytical evalu-

ation. The samples were first placed in extraction thimbles: samples of plant weighing about 1 g. and soil weighing about 5 g. were placed separately as samples in extraction thimbles. A 150 mL blended mixture of methanol and benzene (1:1 proportions) was filled in 250 mL volumetric flasks connected to a continuous extraction set up. Each of the flasks contained glass beads that ensured that they did not boil too much during extraction. The extraction time was maintained at 24h.



**Fig. 1.** Map of the study area

The extraction was then followed by cooling, and concentrating the extracts in a rotary evaporator. Then 25 mL hexane of each concentrated sample were introduced and passed through columns of chromatographic separation filled with silica gel and covered with a layer of alumina to isolate aliphatic fraction. Aromatic fractions were then collected by pouring 25 mL of benzene to all the chromatographic columns. The aromatic and aliphatic fractions were separated and dried by evaporation and re-dissolved in 5 mL of hexane. The amount of petroleum hydrocarbon of each fraction was quantified by gas chromatography (GC) [8].

### ***Statistical Analysis***

The results from the gas chromatography analysis were evaluated using descriptive and inferential statistical methods. Data were summarized to identify the patterns and concentrations of petroleum hydrocarbons in both soil and plant samples across sampling stations and seasons. One-way Analysis of Variance (ANOVA) was conducted to ascertain statistically significant variations in hydrocarbon concentrations among different stations and seasonal intervals. To compare the groups pairwise, the post hoc test provided by Tukey was used,

and the level of the significance was taken to  $p < 0.05$ . Also, the correlation coefficient of Pearson was used to test the correlation between the hydrocarbon levels of soil and the plant samples. The statistical tests were done with the SPSS statistical package.

## Results

(Table 1) details the seasonal and spatial distribution of normal alkanes in *Alhagi graecorum*. during autumn, CPI values ranged from 1.393 (Station 3) to 2.810 (Station 1), corresponding to total alkane loads of 86.30–176.42  $\mu\text{g g}^{-1}$ . Winter showed a drop in CPI (0.771–1.339) with moderate alkane concentrations in station 2 (107.54–121.65  $\mu\text{g g}^{-1}$ ). Spring exhibited the greatest accumulation (CPI 1.221–1.757; total alkanes 492.92–1,087.84  $\mu\text{g g}^{-1}$ ), while summer CPI (0.775–1.791) and total alkanes (258.09–606.68  $\mu\text{g g}^{-1}$ ) declined.

(Table 2) presents the corresponding profile of *Suaeda aegyptiaca*. Autumn CPI values of 2.688–1.409 were associated with 125.69–154.51  $\mu\text{g g}^{-1}$  of alkanes. Winter CPI decreased to 1.180–1.757, even as total alkanes rose markedly (414.70–939.35  $\mu\text{g g}^{-1}$ ). Spring concentrations moderated (CPI 0.775–1.812; total 229.70–551.96  $\mu\text{g g}^{-1}$ ), and summer values fell sharply (CPI 0.672–1.324; total 74.52–107.21  $\mu\text{g g}^{-1}$ ).

(Table 3) shows that *Tamarix aucheriana* exhibited a similar seasonal shift in alkane composition, with autumn CPI and total alkane content intermediate between those of *A. graecorum* and *S. aegyptiaca*, peaking in spring and diminishing in summer.

(Table 4) summarizes *Cressa cretica*, where autumn CPI (1.281–2.875) corresponded to 123.47–146.30  $\mu\text{g g}^{-1}$  of alkanes, winter loads rose to 389.32–852.33  $\mu\text{g g}^{-1}$  (CPI 1.176–1.609), spring totals reached 221.30–505.88  $\mu\text{g g}^{-1}$  (CPI 0.812–1.811), and summer concentrations dropped to 92.94–96.47  $\mu\text{g g}^{-1}$  (CPI 0.801–1.324).

Table 1.

Seasonal and spatial variation of normal alkanes in plants *A. agracorum*

| N- alkanes | Study stations |        |         |
|------------|----------------|--------|---------|
|            | 1              | 2      | 3       |
| Autumn     |                |        |         |
| CPI        | 2.810          | 1.489  | 1.393   |
| even       | 37.049         | 34.667 | 73.720  |
| odd        | 104.098        | 51.636 | 102.700 |
| Phytane    | 2.856          | 1.415  | 2.959   |

|                         |          |         |         |
|-------------------------|----------|---------|---------|
| <b>Pristane</b>         | 2.310    | 2.387   | 2.811   |
| <b>Pristane:Phytane</b> | 0.809    | 1.687   | 0.950   |
| <b>Total</b>            | 141.146  | 86.303  | 176.420 |
| <b>Winter</b>           |          |         |         |
| <b>CPI</b>              | 1.339    | 1.233   | 0.771   |
| <b>even</b>             | 45.973   | 39.021  | 68.672  |
| <b>odd</b>              | 61.562   | 48.112  | 52.973  |
| <b>Phytane</b>          | 2.548    | 4.377   | 2.771   |
| <b>Pristane</b>         | 1.758    | 2.632   | 1.762   |
| <b>Pristane:Phytane</b> | 0.690    | 0.601   | 0.636   |
| <b>Total</b>            | 107.535  | 87.133  | 121.645 |
| <b>Spring</b>           |          |         |         |
| <b>CPI</b>              | 1.221    | 1.347   | 1.757   |
| <b>even</b>             | 489.690  | 210.032 | 214.246 |
| <b>odd</b>              | 598.147  | 282.887 | 376.439 |
| <b>Phytane</b>          | 2.829    | 3.996   | 15.468  |
| <b>Pristane</b>         | 3.485    | 4.761   | 13.116  |
| <b>Pristane:Phytane</b> | 1.232    | 1.191   | 0.848   |
| <b>Total</b>            | 1087.837 | 492.919 | 590.684 |
| <b>Summer</b>           |          |         |         |
| <b>CPI</b>              | 1.476    | 1.791   | 0.775   |
| <b>even</b>             | 244.990  | 116.395 | 145.427 |
| <b>odd</b>              | 361.689  | 208.457 | 112.662 |
| <b>Phytane</b>          | 14.115   | 13.992  | 32.992  |
| <b>Pristane</b>         | 17.084   | 15.426  | 39.141  |
| <b>Pristane:Phytane</b> | 1.210    | 0.907   | 1.186   |
| <b>Total</b>            | 606.679  | 384.852 | 258.089 |

Table 2.

Seasonal and spatial variation of normal alkanes in plants *S. aegyptiaca*

| N- alkanes              | Study stations | N- alkanes | Study stations |
|-------------------------|----------------|------------|----------------|
|                         | 1              | 2          | 3              |
| <b>Autumn</b>           |                |            |                |
| <b>CPI</b>              | 2.688          | 1.489      | 1.409          |
| <b>even</b>             | 34.085         | 31.894     | 64.136         |
| <b>Odd</b>              | 91.606         | 47.505     | 90.376         |
| <b>Phytane</b>          | 2.570          | 1.217      | 2.811          |
| <b>Pristane</b>         | 1.987          | 2.196      | 2.446          |
| <b>Pristane:Phytane</b> | 0.773          | 1.805      | 0.870          |

|                         |         |         |         |
|-------------------------|---------|---------|---------|
| <b>Total</b>            | 125.691 | 79.399  | 154.512 |
| <b>Winter</b>           |         |         |         |
| <b>CPI</b>              | 1.180   | 1.269   | 1.757   |
| <b>even</b>             | 430.928 | 182.727 | 184.251 |
| <b>Odd</b>              | 508.425 | 231.968 | 323.737 |
| <b>Phytane</b>          | 2.546   | 3.357   | 13.457  |
| <b>Pristane</b>         | 3.241   | 4.237   | 12.329  |
| <b>Pristane:Phytane</b> | 1.273   | 1.262   | 0.916   |
| <b>Total</b>            | 939.352 | 414.695 | 507.988 |
| <b>Spring</b>           |         |         |         |
| <b>CPI</b>              | 1.560   | 1.812   | 0.775   |
| <b>even</b>             | 215.591 | 97.772  | 129.430 |
| <b>Odd</b>              | 336.371 | 177.189 | 100.269 |
| <b>Phytane</b>          | 13.409  | 12.873  | 28.043  |
| <b>Pristane</b>         | 15.888  | 12.958  | 35.227  |
| <b>Pristane:Phytane</b> | 1.185   | 1.007   | 1.256   |
| <b>Total</b>            | 551.962 | 274.961 | 229.699 |
| <b>Summer</b>           |         |         |         |
| <b>CPI</b>              | 1.324   | 1.387   | 0.754   |
| <b>even</b>             | 40.916  | 31.217  | 61.118  |
| <b>odd</b>              | 54.174  | 43.301  | 46.086  |
| <b>Phytane</b>          | 2.140   | 3.851   | 2.410   |
| <b>Pristane</b>         | 1.565   | 2.289   | 1.621   |
| <b>Pristane:Phytane</b> | 0.731   | 0.594   | 0.672   |
| <b>Total</b>            | 95.091  | 74.518  | 107.205 |

Table 3.

Seasonal and site variation of normal alkanes in plants *C. cretica*

| Normal alkane           | Study stations |        |         |
|-------------------------|----------------|--------|---------|
|                         | 1              | 2      | 3       |
| <b>Autum</b>            |                |        |         |
| <b>CPI</b>              | 2.875          | 1.716  | 1.281   |
| <b>Even</b>             | 31.862         | 27.387 | 64.136  |
| <b>Odd</b>              | 91.606         | 46.988 | 82.160  |
| <b>Phytane</b>          | 2.456          | 1.203  | 2.220   |
| <b>Pristane</b>         | 2.148          | 1.790  | 2.614   |
| <b>Pristane:Phytane</b> | 0.875          | 1.489  | 1.178   |
| <b>Total</b>            | 123.468        | 74.376 | 146.296 |

| <b>Winter</b>           |         |         |         |
|-------------------------|---------|---------|---------|
| <b>CPI</b>              | 1.176   | 1.233   | 1.609   |
| <b>Even</b>             | 391.752 | 174.326 | 177.824 |
| <b>Odd</b>              | 460.573 | 214.994 | 286.093 |
| <b>Phytane</b>          | 2.150   | 3.357   | 13.148  |
| <b>Pristane</b>         | 2.788   | 3.713   | 10.624  |
| <b>Pristane:Phytane</b> | 1.297   | 1.106   | 0.808   |
| <b>Total</b>            | 852.325 | 389.320 | 463.917 |
| <b>Spring</b>           |         |         |         |
| <b>CPI</b>              | 1.549   | 1.811   | 0.812   |
| <b>Even</b>             | 198.442 | 102.428 | 122.159 |
| <b>Odd</b>              | 307.436 | 185.527 | 99.142  |
| <b>Phytane</b>          | 11.715  | 12.873  | 30.352  |
| <b>Pristane</b>         | 14.180  | 12.804  | 36.401  |
| <b>Pristane:Phytane</b> | 1.210   | 0.995   | 1.199   |
| <b>Total</b>            | 505.878 | 287.955 | 221.301 |
| <b>Summer</b>           |         |         |         |
| <b>CPI</b>              | 1.324   | 1.314   | 0.801   |
| <b>Even</b>             | 39.997  | 29.656  | 53.564  |
| <b>Odd</b>              | 52.943  | 38.971  | 42.908  |
| <b>Phytane</b>          | 2.293   | 4.070   | 2.438   |
| <b>Pristane</b>         | 1.495   | 2.263   | 1.586   |
| <b>Pristane:Phytane</b> | 0.652   | 0.556   | 0.650   |
| <b>Total</b>            | 92.940  | 68.627  | 96.472  |

Table 4.

Seasonal and spatial variation of normal alkanes in *T. aucheriana*

| <b>N- alkanes</b>       | <b>Study stations</b> | <b>N- alkanes</b> | <b>Study stations</b> |
|-------------------------|-----------------------|-------------------|-----------------------|
|                         | <b>1</b>              | <b>2</b>          | <b>3</b>              |
| <b>Autumn</b>           |                       |                   |                       |
| <b>CPI</b>              | 2.613                 | 1.660             | 1.472                 |
| <b>Even</b>             | 21.118                | 21.147            | 52.341                |
| <b>Odd</b>              | 55.172                | 35.112            | 77.025                |
| <b>Phytane</b>          | 1.828                 | 1.104             | 2.131                 |
| <b>Pristane</b>         | 1.571                 | 1.790             | 2.136                 |
| <b>Pristane:Phytane</b> | 0.859                 | 1.622             | 1.003                 |
| <b>Total</b>            | 76.290                | 56.259            | 129.366               |
| <b>Winter</b>           |                       |                   |                       |
| <b>CPI</b>              | 1.190                 | 1.259             | 1.783                 |

|                         |         |         |         |
|-------------------------|---------|---------|---------|
| <b>Even</b>             | 381.959 | 96.614  | 143.545 |
| <b>Odd</b>              | 454.591 | 121.642 | 255.978 |
| <b>Phytane</b>          | 1.245   | 2.717   | 8.972   |
| <b>Pristane</b>         | 1.463   | 3.523   | 8.394   |
| <b>Pristane:Phytane</b> | 1.176   | 1.297   | 0.936   |
| <b>Total</b>            | 836.550 | 218.256 | 399.523 |
| <b>Spring</b>           |         |         |         |
| <b>CPI</b>              | 1.541   | 2.798   | 0.968   |
| <b>Even</b>             | 169.043 | 55.870  | 63.988  |
| <b>Odd</b>              | 260.416 | 156.343 | 61.964  |
| <b>Phytane</b>          | 10.868  | 9.935   | 13.197  |
| <b>Pristane</b>         | 7.859   | 6.325   | 15.657  |
| <b>Pristane:Phytane</b> | 0.723   | 0.637   | 1.186   |
| <b>Total</b>            | 429.459 | 212.213 | 125.952 |
| <b>Summer</b>           |         |         |         |
| <b>CPI</b>              | 1.509   | 1.270   | 1.149   |
| <b>Even</b>             | 32.641  | 26.144  | 32.276  |
| <b>Odd</b>              | 49.249  | 33.198  | 37.081  |
| <b>Phytane</b>          | 1.911   | 2.845   | 1.967   |
| <b>Pristane</b>         | 0.774   | 1.500   | 1.233   |
| <b>Pristane:Phytane</b> | 0.405   | 0.527   | 0.627   |
| <b>Total</b>            | 81.891  | 59.342  | 69.357  |

(Tables 5–8) compile the total hydrocarbon concentrations by season and station for each species. In *A. graecorum* (Table 5), autumn levels of 94.86–163.29  $\mu\text{g g}^{-1}$  gave way to winter (45.33–105.95  $\mu\text{g g}^{-1}$ ), spring (57.42–265.44  $\mu\text{g g}^{-1}$ ), and low summer values (4.88–24.05  $\mu\text{g g}^{-1}$ ). *S. aegyptiaca* (Table 6) peaked in autumn (76.43–128.66  $\mu\text{g g}^{-1}$ ) and spring (46.40–194.43  $\mu\text{g g}^{-1}$ ), with minimal summer uptake (4.56–20.18  $\mu\text{g g}^{-1}$ ). *T. aucheriana* (Table 7) showed autumn totals of 51.41–86.21  $\mu\text{g g}^{-1}$ , a spring maximum of 130.27  $\mu\text{g g}^{-1}$  at station 3, and summer lows (3.05–13.72  $\mu\text{g g}^{-1}$ ). *C. cretica* (Table 8) recorded autumn concentrations of 46.62–76.49  $\mu\text{g g}^{-1}$ , a spring peak at station 2 (98.60  $\mu\text{g g}^{-1}$ ), and summer minima (2.78–12.32  $\mu\text{g g}^{-1}$ ).

Lastly, (Table 9) confirms the fact that soil TPH follows the same pattern as plant trends, with high loads in the autumn (166.51–290.76  $\mu\text{g g}^{-1}$ ), a sharp increase in the spring at station 2 (407.86  $\mu\text{g g}^{-1}$ ), and very low summer residues (10.55–43.81  $\mu\text{g g}^{-1}$ ), which underlines the fact that vegetation and soil hydrocarbon are strongly correlated.

Table 5.

**Variation in total hydrocarbon concentration Seasonal and spatial in *A. agracorum***

| Seasonal | Station 1 | Station 2 | Station 3 |
|----------|-----------|-----------|-----------|
| Autumn   | 94.86     | 103.25    | 163.29    |
| Winter   | 105.95    | 67.23     | 45.33     |
| Spring   | 57.42     | 265.44    | 87.32     |
| Summer   | 4.88      | 17.87     | 24.05     |

Table 6.

**Variation in total hydrocarbon concentration Seasonal and spatial in *S. aegyptiaca***

| Seasonal | Station 1 | Station 2 | Station 3 |
|----------|-----------|-----------|-----------|
| Autumn   | 128.66    | 80.52     | 76.43     |
| Winter   | 41.33     | 53.45     | 84.32     |
| Spring   | 72.56     | 194.43    | 46.40     |
| Summer   | 20.18     | 16.96     | 4.56      |

Table 7.

**Variation in total hydrocarbon concentration Seasonal and spatial in *T. aucheriana***

| Seasonal | Station 1 | Station 2 | Station 3 |
|----------|-----------|-----------|-----------|
| Autumn   | 86.21     | 51.41     | 53.95     |
| Winter   | 27.69     | 56.50     | 35.81     |
| Spring   | 48.62     | 31.09     | 130.27    |
| Summer   | 13.72     | 3.05      | 11.37     |

Table 8.

**Variation in total hydrocarbon concentration Seasonal and spatial in *C. cretica***

| Seasonal | Station 1 | Station 2 | Station 3 |
|----------|-----------|-----------|-----------|
| Autumn   | 46.62     | 49.12     | 76.49     |
| winter   | 44.45     | 30.61     | 23.21     |
| Spring   | 23.30     | 98.60     | 41.26     |
| Summer   | 2.78      | 11.35     | 12.32     |

Table 9.

**Variation in total hydrocarbon concentration Seasonal and spatial in Soil**

| Seasonal | Station 1 | Station 2 | Station 3 |
|----------|-----------|-----------|-----------|
| Autumn   | 178.30    | 166.51    | 290.76    |
| winter   | 189.84    | 120.12    | 91.11     |
| Spring   | 105.30    | 407.86    | 151.59    |
| Summer   | 10.55     | 33.94     | 43.81     |

(Figure 2) illustrates the annual mean TPH concentrations at stations 1–3, revealing a clear seasonal pattern: autumn values ( $115.27 \pm 36.86 \mu\text{g g}^{-1}$ ) were substantially higher than those in other seasons and peaked at station 3 ( $290.76 \mu\text{g g}^{-1}$ ), declined through winter ( $120.12\text{--}189.84 \mu\text{g g}^{-1}$ ), rebounded in spring – with a maximum of  $407.86 \mu\text{g g}^{-1}$  at station 2 – and reached a minimum plateau in summer ( $10.55\text{--}43.81 \mu\text{g g}^{-1}$ ). (Figure 3) overlays these trends for both plant and soil matrices, demonstrating a strong concordance between vegetative uptake and substrate contamination in all seasons. The plant *A. agracorum* showed the highest values of petroleum hydrocarbons ( $113.447 \mu\text{g g}^{-1}$ ) in station 2. While the lowest value recorded in the plant *C. cretica* ( $29.287 \mu\text{g g}^{-1}$ ) in station 1.

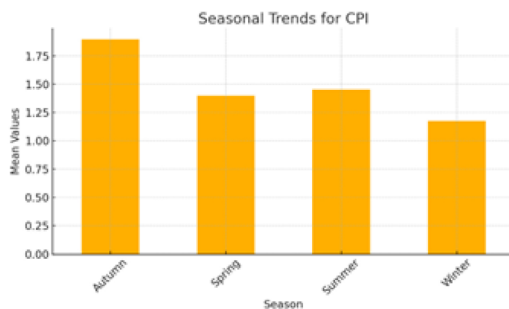


Fig. 2. Annual average of total hydrocarbons at study stations

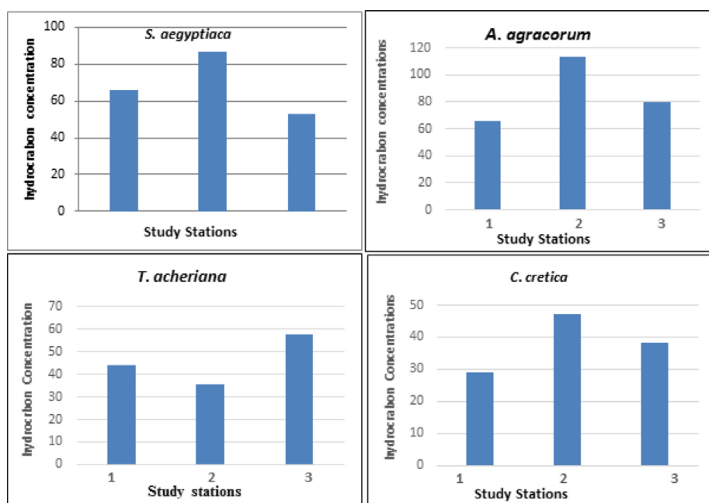


Fig. 3. Total concentrations of petroleum hydrocarbons at study stations

### Discussion

The significant peak observed in the autumn season in both the TPHs of the plants and soils is most likely associated with the increased precipitation during this time, which facilitates the accumulation of hydrocarbons, thus being transported into the biotic and abiotic matrices, and lesser microbial decomposition due to the declining temperatures [9]. Seasonal accumulation patterns similar to those observed here have been noted in temperate and subtropical ecosystems, with autumnal precipitation concurrent with leaf senescence and a greater influx of both biogenic and fossil-derived hydrocarbons [10].

The high pristane and phytane levels and CPI values close to unity support a multi-source origin, both plant (waxes during senescence) and anthropogenic (such as fossil fuel residues) [11; 12]. Species-specific trends (*C. cretica*, especially high in spring) are a consequence of metabolic and growth dynamics, including variations in the maximum growth [13].

The agreement of plant biomarker profiles with soil hydrocarbon distributions supports the utility of vegetation as a soil pollution proxy and is consistent with earlier work that identified plant tissues as good bioindicators of meteoric input among terrestrial hydrocarbon pollution [14; 15].

These findings not only point to the importance of the combination of environmental forcing (rainfall and temperature), biological processes (growth, senescence and microbial activity) and human interference that ensures the destiny of hydrocarbons in terrestrial systems but also shows that these factors are not directly related. To further separate these processes, it is advised to perform long-term seasonal monitoring on a longer time scale coupled with more detailed chemical fingerprinting of the sources using a procedure known as compound-specific isotope analysis (CSIA) both to separate source and degradation processes.

### Conclusion

According to this research, there was a considerable degree of seasonal and spatial differences in the contamination of petroleum hydrocarbons, the highest levels of contamination were during the fall and spring. The findings were able to confirm that soil was the main reservoir of the hydrocarbons and that some plant species have significant phytoremediation, especially *Cressa cretica*. This highlights the need to conduct constant environmental tests, focus remedial measures and adoption of modern type of bioremediation technology to counter the effect of oil hydrocarbon pollution in the oil producing areas in the long-run.

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