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Concentration, Dissolved-Particulate Phase Distribution and Source Identification of Semi-Volatile Organic Compounds (SVOCs) in Surface Water

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Abstract In this study, surface water samples were collected simultaneously from seven different sampling sites over a 12-month period in Bursa, Türkiye, and analyzed for polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) to determine their levels, dissolved/particulate phase distributions, and potential pollutant sources. Throughout the sampling period, the concentrations of 16 PAHs ($\sum_{16}$PAHs) and 41 PCBs ($\sum_{41}$PCBs) in the dissolved and particulate phases were found to be 365.3 ± 302.3 µg/L (average ± SD) and 116.7 ± 92.0 µg/L, and 53.8 ± 54.7 ng/L and 92.8 ± 59.3 ng/L, respectively. For both pollutant groups, the lowest concentrations were measured at background and semi-urban sampling sites, while the highest ones were observed in industrial and agricultural areas. Regression analysis was performed to examine the correlation between $\log K_D$ and $\log K_{OW}$ for 16 PAHs and 7 indicator PCBs congeners. Weak correlations were observed for both chemical groups, indicating that $\log K_{OW}$ alone may not accurately predict partitioning behaviors. Phase distributions are likely influenced by other factors such as organic fraction of particle matter, water temperatures, surface flow rates and physical and chemical properties. Ring distributions and molecular diagnostic ratios (MDRs) were employed to determine the source of PAHs, while homolog group distributions were utilized to identify the sources of PCBs for both dissolved and particulate phases. According to these analyses, the primary sources of PAHs were pyrogenic, coal and biomass combustion and traffic emissions, whereas industrial and agricultural activities were identified as the main sources of PCBs for both phases.

Keywords Dissolved and particulate phase · Surface water · Organic pollutants · Phase partitioning · Source Identification · PAH · PCB

1 Introduction

With increasing urbanization and industrialization, aquatic environments are continuously exposed to pollution from various discharges (i.e., hospital, municipal, industrial and agricultural wastes).

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Streams, lakes, and seas have been contaminated by numerous organic pollutants (Rabodonirina et al., 2015). Among them, semi-volatile organic compounds (SVOCs) such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are of global concern due to their persistence, toxicity, long range transport, and bioaccumulation (Rabodonirina et al., 2015; Yang et al., 2019). PAHs are chemicals formed by the combination of two or more benzene rings and have natural and anthropogenic sources (Mojiri et al., 2019; Premnath et al., 2021). On the other hand, PCBs, are chlorinated compounds with flame-retardant properties consisting of 209 congeners differing according to the number of chlorine atoms and their bonding positions and generally have low electrical conductivity (Sari et al., 2023; Zhu et al., 2022). Most SVOCs are not susceptible to biodegradation, which increases their persistence in the environmental cycle, and their solubility in water generally decreases with increasing molecular weight. Due to these properties, PAHs and PCBs are continuously transported from air and land to aquatic environments (Mojiri et al., 2019; Urbaniak, 2007; Yin et al., 2019). PAHs and PCBs are characterized by high persistence and low solubility in water and are typical organic pollutants for aquatic environment (Luo et al., 2023; Urbaniak, 2007). Our results indicate that PAHs and PCBs contribute to environmental pollution of the Bursa region.

The partition coefficient is commonly used to evaluate the tendency of a chemical to adsorb on the solid phase from the liquid phase (Chen et al., 2019). The environmental fate of organic pollutants in aquatic environments is controlled by their partitioning between dissolved and particulate phase. This partitioning varies depending on total suspended solids, organic matter content, and various physical and chemical factors (Nellier et al., 2015). Mathematical models have been extensively used for over three decades to determine the behavior and fate of SVOC compounds among multiple environmental media (Bates et al., 2019; Sari et al., 2023; Wania & Mackay, 1999).

Nilüfer Stream is the most important stream of Bursa (Türkiye) with a length of 168 km and a basin area of 411.3 km^2 (Summak et al., 2010). With an annual total flow of 743.77 hm^3/year and average flow of 23.58 m^3/s (Sari et al., 2023), Nilüfer Stream receives discharges from wastewater treatment plants as well as numerous agricultural and industrial activities (Ersöz et al., 2022). Although limited studies have investigated pollution loads in the Nilüfer Stream, none of them have evaluated dissolved–particulate phase partitioning (Ersöz et al., 2022; Sari et al., 2023). Therefore, the main goals of this study are 1) to determine the concentrations of PAHs and PCBs in dissolved and particulate phases of surface water, 2) to determine their dissolved/particulate phase distributions, and 3) to identify potential pollutant sources.

2 Materials and Methods

2.1 Sampling Strategy

Water samples were systematically collected on a monthly basis between October 2020 and September 2021 at seven different sampling sites along the 168 km route of the Nilüfer Stream in Bursa (Fig. 1). Detailed information about seven sampling sites can be found in the Supplementary Material (SM, Table S1). Briefly, the sampling sites were strategically selected to represent different environmental settings, including background, semi-urban, urban, industrial and agricultural areas. This selection enables a comprehensive assessment of PAHs and PCBs distribution patterns across sites with varying pollutant concentrations as well as areas with minimal pollutant sources.

2.2 Water Samples Collection and Analysis

Detailed descriptions of water sample collection and analysis are provided in the Supplementary Material (SM). Briefly, approximately 10L of water samples were collected in dark bottles and the temperature was measured immediately. Samples were then transported to the laboratory and stored at 4 °C until analysis.

Solid phase extraction (SPE) cartridges (C18) were used to determine the concentrations of PAHs and PCBs in the water samples. Prior to sample application, 10–15 mL of hexane (HEX) was passed through the cartridges to eliminate potential contaminants. The samples, previously reduced to 2 mL, were then added to the cartridges, and eluted sequentially with adding 20 mL HEX and 30 mL acetone (ACE). The

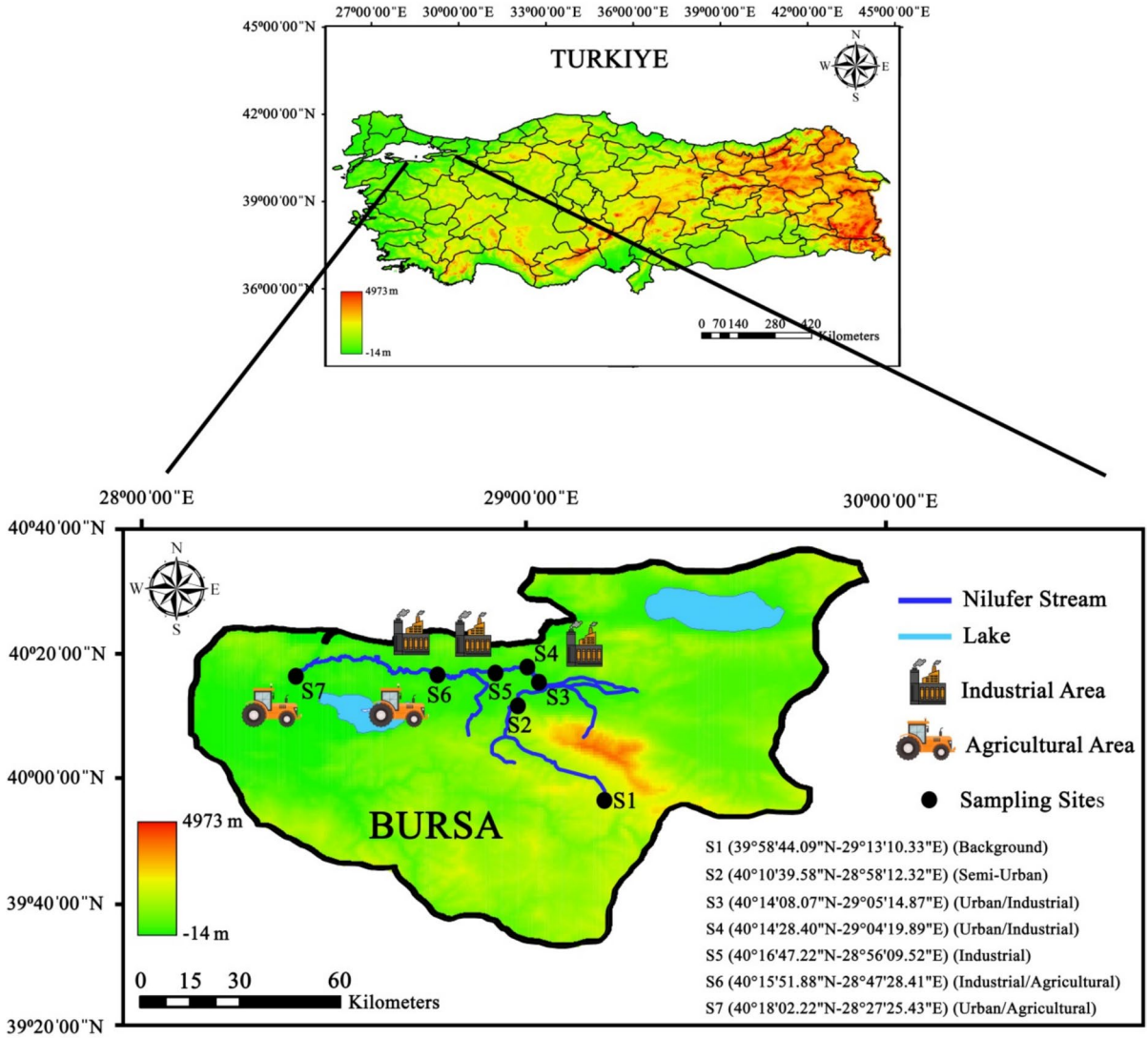

Fig. 1 The location of the sampling sites from Nilufer Stream

combined eluates were dried over anhydrous sodium sulfate (Na_2SO_4) to remove residual moisture prior to concentration. Afterwards, the sample volumes were further reduced to 1 mL using a rotary evaporator with the same solvent exchange steps and transferred to vials for GC–MS analysis.

2.3 Instrumental Analysis

Analyses of PAHs and PCBs were performed using an Agilent GC/MS (6890 N/5975 inert MSD) coupled with an HP5-MS column (30 m length × 0.25 mm inner diameter × 0.25 μm film thickness). The GS/MS was operated in Electron Impact (EI) ionization mode. The injector, ion source, and quadrupole temperatures were set to 295, 300, and 180 ^{0}C, respectively. A single GC–MS oven temperature program was applied for the analysis of both PAHs and PCBs. For PCBs, the oven temperature was initially set to 50 °C and held for 1 min, followed by a ramp of 25 °C min^{-1} to 200 °C and then increased at 8 °C min^{-1} to 300 °C, where it was held for 5.5 min. The same temperature program was used for PAHs, except for the initial holding step at 50 °C. All water samples were analyzed in splitless

mode with an injection volume of 1 µL. In this study, 16 PAHs and 41 PCBs congeners were determined, namely; Naphthalene (Nap), Acenaphthylene (Ace), Acenaphthene (Act), Fluorene (Fln), Phenanthrene (Phe), Anthracene (Ant), Fluoranthene (Fl), Pyrene (Pyr), Benz(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Indeno(1,2,3-c,d)pyrene (IcdP), Dibenz(a,h)anthracene (DahA), and Benzo[ghi] perylene (BghiP) for PAHs; and congeners #17, 18, 28, 31, 33, 44, 49, 52, 70, 74, 82, 87, 95, 99, 101, 105, 110, 118, 128, 132, 138, 149, 151, 153, 156, 158, 169, 170, 171, 177, 180, 183, 187, 191, 194, 195, 199, 205, 206, 208, and 209 for PCBs.

2.4 Quality Control/Quality Assurance

Detailed descriptions of the Quality Control/Quality Assurance procedures are provided in the SM. Briefly, the limit of detection (LOD) values were determined by adding 3 times the standard deviations to the average mass values (ng) of the blank water samples (LOD = mean blank masses + 3 × SD). The LOD values were then compared with the masses in real samples, compounds with masses below the LOD were excluded from calculations. The LOD values obtained in this study are summarized in Table S2.

A surrogate standard (1 mL) was added to each water sample prior to extraction to determine recovery efficiencies. Only samples with recovery efficiencies between 60 and 120% were included in the calculations. The recovery values for each compound are presented in Table S3. The quantifiable amounts of the PCBs and PAHs were found to be 0.10 and 0.15 pg for 1 ml injection, respectively. Finally, blank masses were subtracted from the sample masses to apply blank correction.

2.5 Dissolved-Particulate Phase Distribution

Dissolved-particulate phase distributions of PAHs and PCBs in surface waters are calculated using the dissolved-particulate phase partitioning coefficient (K_D) (Eq. 1).

$$K_D = \frac{\frac{C_P}{TSM}}{C_D} \quad (1)$$

where, K_D is the dissolved-particulate phase partitioning coefficient (kg/L), C_P and C_D are the particulate and dissolved phase concentrations (ng/L) in surface waters, respectively. TSM refers to the total suspended solids concentration (kg/L). The TSM values obtained in this study are summarized in Table S4.

3 Results and Discussion

3.1 Dissolved and Particulate Phase PAH and PCB Concentrations in Surface Water

The concentrations of total 16 PAHs ($\sum_{16}$PAHs) in all sites varied between 3.2 µg/L and 1176.9 µg/L (365.3 ± 302.3 µg/L) for the dissolved phase. The lowest PAHs concentrations in the dissolved phase were measured at the background sampling site (7.0 ± 3.0 µg/L), while the highest were measured at the urban/agricultural site (743.1 ± 221.7 µg/L). Similarly, $\sum_{16}$PAHs concentrations in the particulate phase ranged from 0.3 µg/L to 433.1 µg/L (116.7 ± 92.0 µg/L). The lowest particulate phase PAH concentrations were measured at the background sampling site (1.3 ± 0.7 µg/L), while the highest were observed at the urban/agricultural sampling site (222.5 ± 88.9 µg/L) (Fig. 2).

The highest total concentrations (dissolved + particulate phases) of $\sum_{16}$PAHs were observed at the urban/agricultural sampling site (S7) (965.6 ± 219.8 µg/L), followed by the industrial (787.4 ± 188.8 µg/L), the industrial/agricultural (S6) (448.0 ± 131.0 µg/L) and the urban/industrial site (S4) (390.4 ± 48.7 µg/L). In a study conducted by Guigue et al. (2014), it was stated that anthropogenic sources, in particular, can significantly increase dissolved phase PAH concentrations in surface waters. Hence, the highest PAH concentrations in both dissolved and particulate phases were measured at the urban/agricultural sampling sites. This site, which represents the most heavily polluted region, is the final point where the Nilüfer Stream flows into the Marmara Sea. Compared to concentration at the origins of the Nilüfer Stream (background sampling site), the total PAHs concentrations were found to be 2 times higher at the semi-urban sampling site (S2), 86 times higher at the urban/industrial sampling site (S4), 46 times higher at the urban/industrial sampling site (S3), and 94 times higher at the industrial sampling site (S5). Moreover, the concentrations were 51 times higher at the industrial/agricultural (S6) and finally 100 times higher at

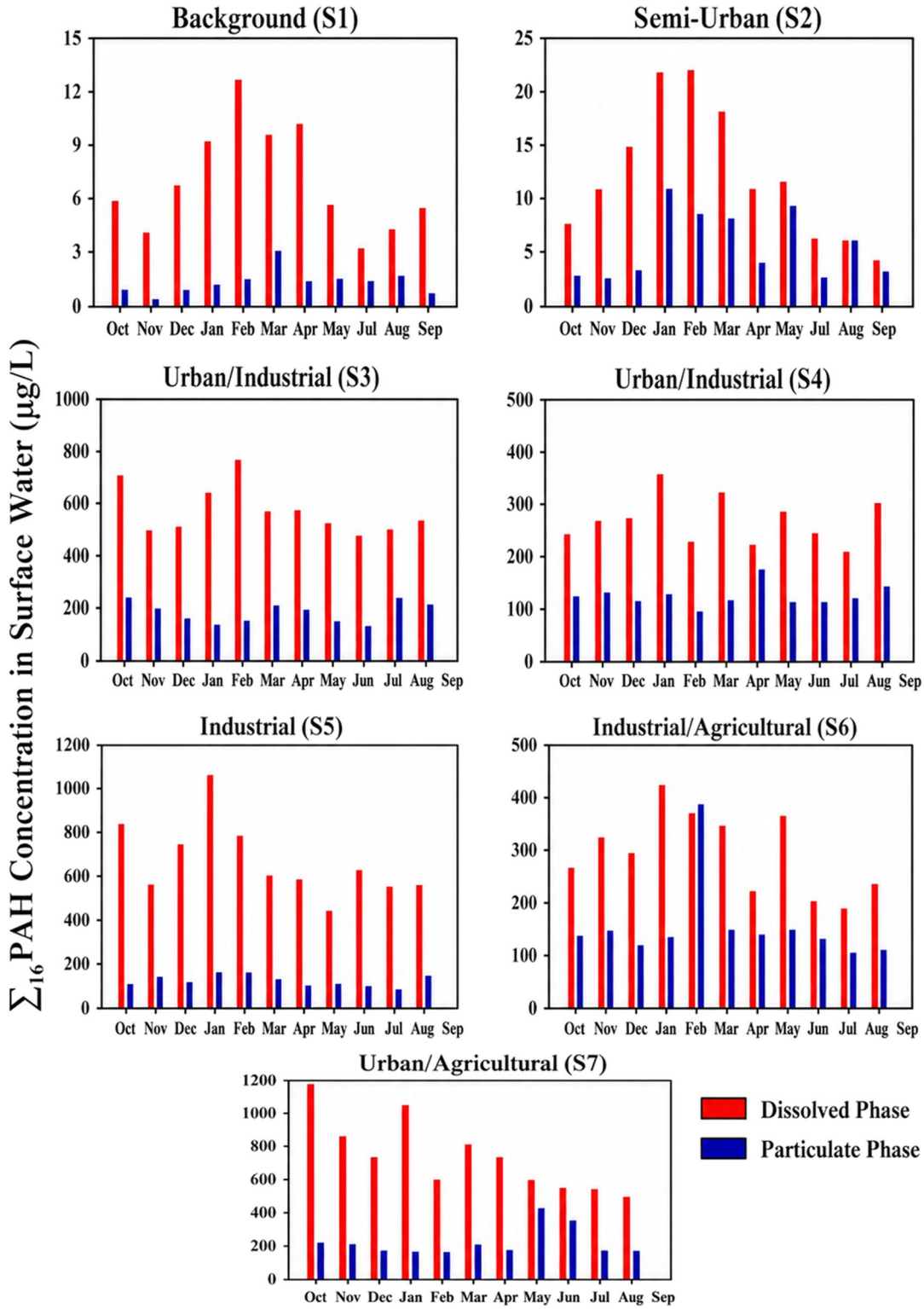

Fig. 2 PAH concentration in dissolved and particulate phases

urban/agricultural sampling site (S7). These results indicate a consistent increase in pollution along the entire route of the Nilüfer Stream.

In comparison with other surface waters worldwide, the average concentrations of $\sum_{16}$PAHs in the dissolved phase from Nilüfer Stream (365.3 ± 302.3 µg/L) were notably higher than those reported for the Daliao River Estuary in China (0.49 µg/L) by Men et al. (2009), Weihe River in Northwest China (0.84 µg/L) by Chen et al. (2015), and Sarno River in Italy (0.734 µg/L) by Montuori and Triassi (2012). In the study conducted by Li et al. (2021), contamination levels in the dissolved phase PAHs in surface waters were classified into 4 classes: micro (10–50 ng/L), lightly (50–250 ng/L), moderately (250–1000 ng/L) and heavily (> 1000 ng/L). Based on these criteria, all sampling sites in this study exhibit extremely high PAHs contamination in the dissolved phase. Anthropogenic sources are likely influential even at the background sampling site near the stream's origin. The average concentrations of $\sum_{16}$PAHs in particulate phase from Nilüfer Stream (116.7 ± 92.0 µg/L) were notably higher than those found in Sarno River in Italy (255.0 ng/L) by Montuori and Triassi (2012), in Yellow River Delta in China (209.1 ng/L) by Wang et al. (2009) and Weihe River in Northwest China (20,780 ng/L) by Chen et al. (2015). These findings suggest that Nilüfer Stream is significantly more polluted than many other surface waters worldwide.

The maximum concentration levels were predominantly measured during winter months, while the minimum ones for PAHs were recorded during the summer months. This seasonal variation can be attributed to photodegradation of pollutants under sunlight, particularly at higher temperatures, and to microbial degradation of PAHs. Additionally, elevated temperatures and lower atmospheric pressure in summer facilitate PAHs evaporation from surface waters, leading to decreased concentrations in the aquatic environment (Lin et al., 2023; Srinivasa Reddy et al., 2005). On the other hand, during winter, reduced microbial degradation and lower light intensity, combined with anthropogenic activities such as fuel combustion heating, contribute to increased PAH concentrations (Koudryashova et al., 2019).

Dissolved phase PAH concentrations accounted for 48.8—91.7% (74.5 ± 9.9%) of total PAHs. In a study conducted by Ya et al. (2014) in China, it was reported that the percentage of PAHs in the dissolved phase in surface waters exceeds 72%. Many researchers have observed variations in the dissolved and particulate phase distributions of PAHs in surface waters, depending on physical and chemical properties such as organic matter content, salinity and size distribution (Chen et al., 2015; Gustafson & Dickhut, 1997). In this study, the highest percentages in the dissolved phase were observed at the background sampling site (average, 83.7%), whereas the lowest were observed at the industrial/agricultural site (average, 68.5%). This pattern is likely due to lower particulate phase PAHs inputs at background sampling sites compared to other sites.

Total PCBs concentrations ($\sum_{41}$PCBs) varied between 3.8 ng/L and 209.9 ng/L (53.8 ± 54.7 ng/L) for the dissolved phase. The lowest dissolved phase PCB concentrations were measured at the background sampling site (8.3 ± 3.7 ng/L), while the highest were observed at the urban/agricultural site (163.8 ± 27.0 ng/L). Similarly, particulate phase $\sum_{41}$PCB concentrations in all sampling sites ranged from 6.3 ng/L to 206.7 ng/L (92.8 ± 59.3 ng/L). The lowest particulate phase PCB concentrations were measured at the background sampling site (10.8 ± 2.9 ng/L), while the highest were observed at the industrial/agricultural site (168.7 ± 21.2 ng/L) (Fig. 3).

Since there is no known discharge to the background sampling site, the lowest concentrations of PCBs were measured at this site. However, this site is located in an area characterized by intensive agricultural activities. During rainy months, increased runoff enhances pollutant transport, leading to higher concentrations. The urban/agricultural sampling site represents an area where both urban population and agricultural activities are concentrated. Bettinetti et al. (2011) stated that PCBs can be transported to surface waters from extensive agricultural areas and densely populated regions. Similarly, Montuori et al. (2016) identified large agricultural areas and direct discharge of untreated wastewater as major sources of PCBs in surface waters. Also in our study, the highest PCB concentrations were measured at the urban/agricultural sampling site, followed by the industrial/agricultural sampling site, where both industrial and agricultural activities are intense. Wastewater discharged from facilities, particularly in industrial areas, is considered the

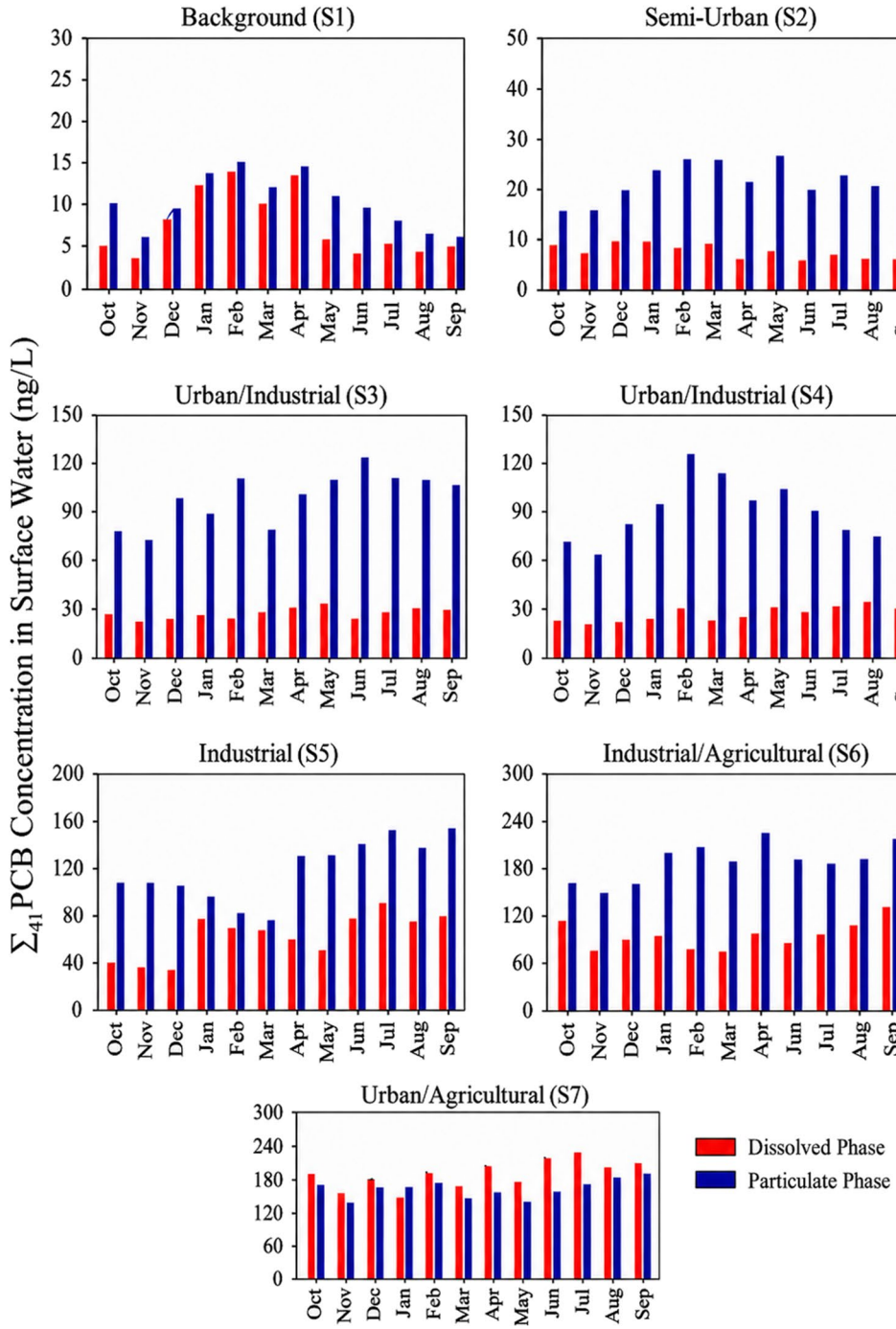

Fig. 3 PCB concentration in dissolved and particulate phases

most significant source of PCBs in the aquatic environment (Balasubramani et al., 2014).

In terms of seasonal variations, the highest PCB concentrations were measured at industrial/agricultural and urban/agricultural sampling sites during spring and summer, whereas the lowest were found at the background and semi-urban sampling sites in autumn and winter. The distribution of PCB

concentrations in surface waters varies depending on physical and chemical properties such as surface flow rates, temperature, hydrophobicity and solubility of PCBs (Wolska et al., 1999). In addition, water temperatures, sedimentation, air–water and water–sediment exchanges seasonally affect both PCB concentrations in surface waters and their dissolved-particulate phase distributions (Smith & McLachlan, 2006).

Particulate-phase PCBs were dominant in surface waters (66.8 ± 12.1%) at all sampling sites except urban/agricultural one, indicating a different phenomenon. This predominance of particulate phase PCBs has been associated with the turbulence of water. As the turbulence increases, PCBs accumulated in sediments are resuspended into surface waters, resulting in higher particulate phase concentrations (Zhang et al., 2011). PCBs exhibit physicochemical properties such as hydrophobicity and low solubility, which favor adsorption onto particulate matter (Wolska et al., 1999). In addition, the fate of PCBs in dissolved and particulate phases in water varies with multiple factors such as air–water exchange, chemical and biological transformation, sedimentation and water temperature (Smith & McLachlan, 2006). Proximity to industrial areas and associated wastewater discharges are also key factors affecting the seasonal distribution of PCBs in surface waters (Balasubramani et al., 2014).

3.2 Dissolved and Particulate Phase Partition in Surface Water

The general phase distributions of PAHs and PCBs may vary depending on many factors, including the hydrophobic properties of each molecule and the specific characteristics of the sampling sites (Smith & McLachlan, 2006; Wolska et al., 1999; Ya et al., 2014). Additionally, parameters such as water temperature, octanol–water partition coefficient (K_{OW}) and total suspended matters (TSM) affect the dissolved-particulate phase partitioning in surface waters (Nellier et al., 2015). The regression analysis was conducted to examine the relationship between the dissolved/particulate phase distribution coefficient ($\log K_D$) and $\log K_{OW}$ values for 16 PAHs and seven indicator PCBs congeners, and the results are presented in Figs. 4 and 5, respectively.

A positive correlation was observed between $\log K_D$ and $\log K_{OW}$ at semi-urban, industrial/agricultural and urban/agricultural sampling sites, whereas a negative correlation was found at other sites for PAHs. However, it's important to note that these correlations were weak, with low r^2 values (< 0.39), suggesting that $\log K_{OW}$ alone may not be a reliable predictor of PAHs partitioning behavior. Previously, it was reported that particulate matter rich in organic content may pass through glass fiber filter (GFF), contributing to dissolved phase concentrations (Vilanova et al., 2001). Additionally, different water temperatures were recorded among the sampling sites. The lowest at background (13.6 ± 5.9 ^{0}C) and semi-urban (17.4 ± 5.1 ^{0}C) sampling sites, while other sites were approximately 5 °C warmer. Furthermore, atmospheric deposition (dry—wet) also influences PAHs concentrations in surface water (Sari et al., 2023). At background and semi-urban sampling sites, PAHs sources were attributed to incomplete combustion of organic materials, while industrial emissions, traffic and agricultural activities predominated at other sites. These discrepancies in dissolved-particulate phase distributions among the sampling sites are likely due to site-specific characteristics and varying PAHs sources.

For PCBs, a positive relationship was observed between $\log K_D$ and $\log K_{OW}$ at all sites except the semi-urban sampling site, with low r^2 values similar to PAHs (< 0.34). Pearson et al. (1996) noted that the negative and/or positive slope values between $\log K_D$ and $\log K_{OW}$ may vary depending on factors such as site-specific differences, organic matter content of the water, and regional source variations. Additionally, parameters including water temperatures, river flow velocity, turbulence and atmospheric deposition mechanisms affect PCBs concentrations and their dissolved-particulate phase distributions in water. According to Nellier et al. (2015), PCB partitioning tends toward equilibrium during ice cover, whereas deviations occur during open-water periods, indicating non-equilibrium dynamics. Similarly, results from this study suggest a non-equilibrium state in PCB partitioning, where environmental factors beyond Kow likely govern PCBs distribution in aquatic systems. These complex interactions underscore the need for comprehensive analyses that incorporate multiple variables to better understand the partitioning dynamics of PCBs in surface waters.

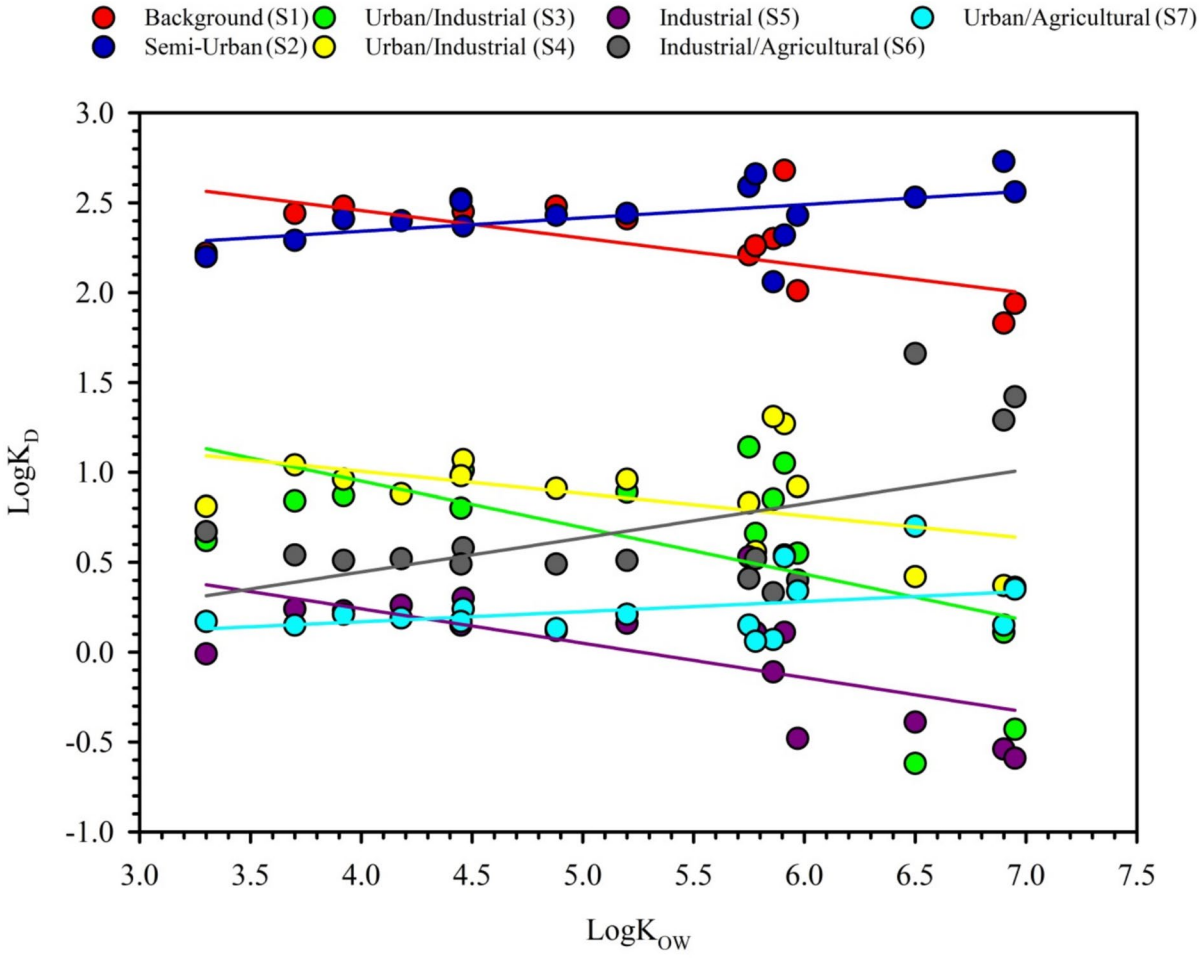

Fig. 4 $LogK_D$ versus $LogK_{OW}$ for PAHs

3.3 Sources Identification of PAHs and PCBs in Surface Water

Various methods exist for identifying the sources of PAHs, and molecular diagnostic ratios (MDRs) are among the most commonly utilized approaches due to their simplicity and widespread use in previous studies (Ravindra et al., 2008; Tobiszewski & Namieśnik, 2012; Wu et al., 2021). In this study, ring distributions and MDRs (Ant/(Ant + Phe)), Fl/(Fl + Pyr), BaP/BghiP and CPAHs (combustion PAHs (sum of Fl, Pyr, BaA, CHR, BaP, BbF, BkF, IcdP and BghiP)) and TPAHs (total PAHs) ratios were employed to identify sources. Descriptions of the MDRs used in this study are provided in Table S5, while the resulting ring distributions and MDRs are shown in Fig. 6.

According to the ring distribution analysis, 4-ring PAHs were predominantly observed in both dissolved and particulate phases. This prevalence, suggests the emissions resulting from incomplete combustion of carbon-rich fuels (Sari et al., 2020). The Ant/(Ant + Phe) ratios for PAHs in both phases were found to be higher than 0.1 for almost all sampling sites, indicating a common source for PAHs in surface waters regardless of phase. Similarly, a high percentage (> 90.2%) of Fl/(Fl + Pyr) ratios were higher than 0.4, and significant portion (> 60%) were found to be higher than 0.5 in both dissolved phase and particulate phases. Moreover, the majority of (> 91%) the BaP/BghiP ratios were found to be higher than 0.6 for both phases, and high CPAH/TPAH ratios were obtained. In a study conducted by Lakhani (2012), it

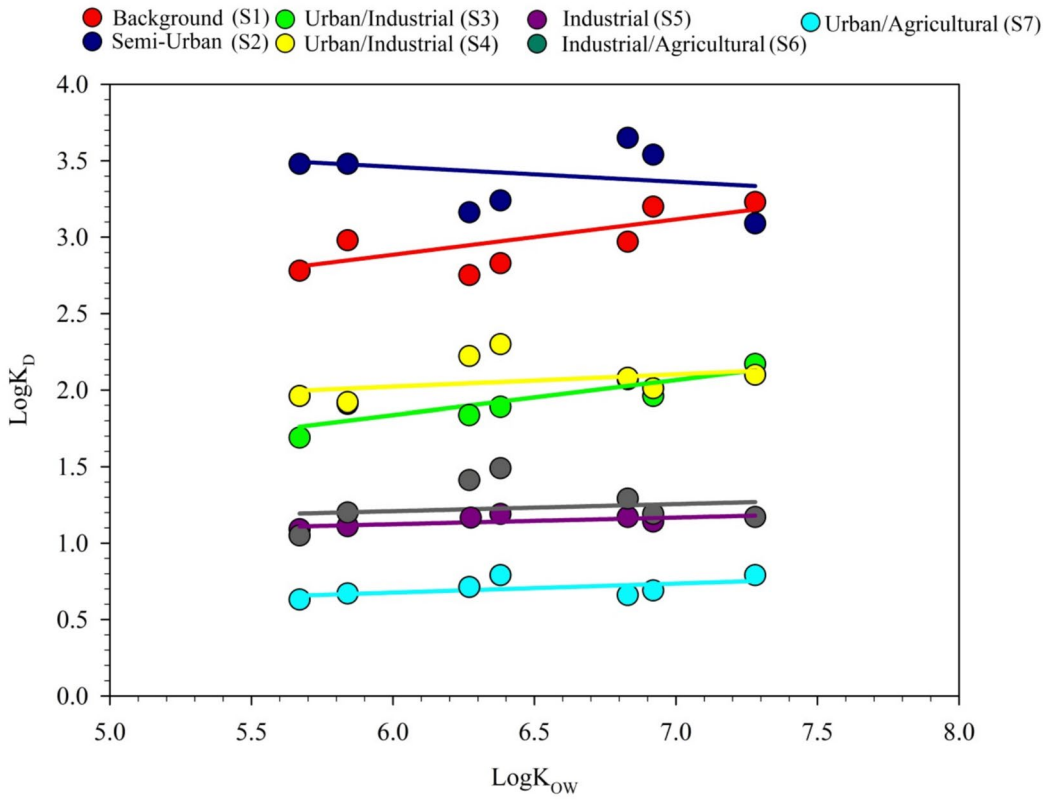

Fig. 5 LogKD versus LogKOW for PCBs

was noted that high CPAH/TPAH ratios were attributed to less efficient emission control systems in vehicles, leading to increased combustion activities. Overall, the main sources of PAHs in both phases were pyrogenic, coal and biomass combustion and traffic emissions. Despite differences in site characteristics, similar sources likely influence all sampling sites, probably due to the significant impact of atmospheric deposition on surface waters.

Identification of homologous groups of PCBs provides valuable insights into their sources and environmental fate (Jiang et al., 2011; Sari et al., 2020). The distributions homologous group in both dissolved and particulate phases are depicted in Fig. 7. This study revealed a predominance of highly chlorined PCBs (5-Cl, 6-Cl, 7-Cl and 8-Cl) in both phases. Vecchiato et al. (2015) and Devi et al. (2014) reported that the presence of high chlorinated PCBs in surface waters is strongly influenced by local sources. However, for dissolved phase PCBs at the urban/industrial sampling site (S4), 2-Cl PCBs were the dominant homolog group, suggesting potential input from nearby wastewater treatment plant effluents. In contrast, the predominance of 6-Cl PCBs at the background sampling site can be attributed to local emission sources where meteorological parameters play an important role in their transport. Agricultural and industrial activities were identified as the primary sources of 6-Cl PCBs at the industrial/agricultural sampling site, consistent with previous findings (Di Guardo et al., 2020). Moreover, the predominance of 6-Cls PCBs at the urban/agricultural sampling site points to agricultural activities as potential sources, where both human and agricultural activities are intense.

4 Conclusions

In this study, the concentration levels, dissolved-particulate phases partitioning and source identification of PAHs and PCBs in surface water were investigated at sampling sites with different

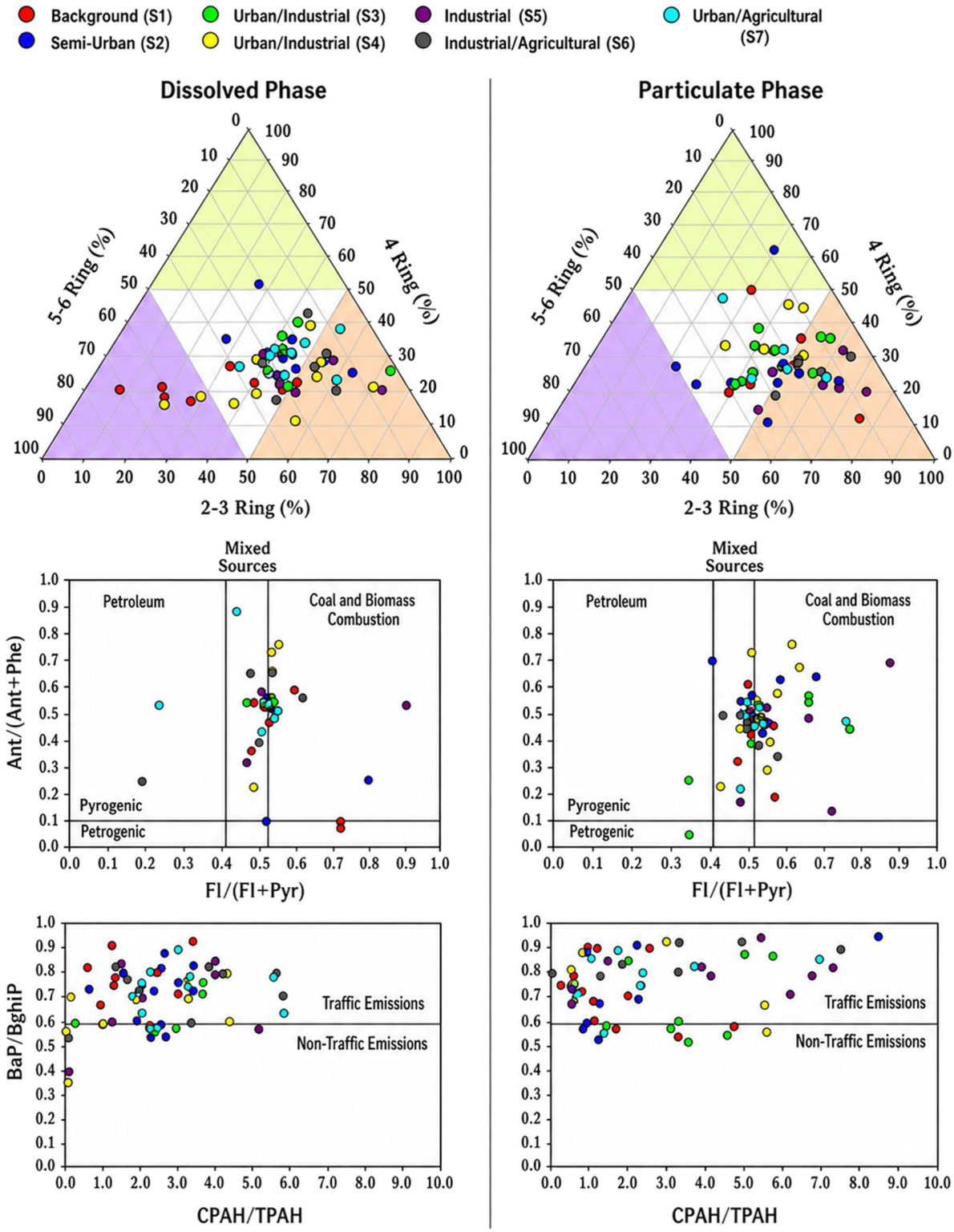

Fig. 6 Ring distributions and MDR ratios for PAHs

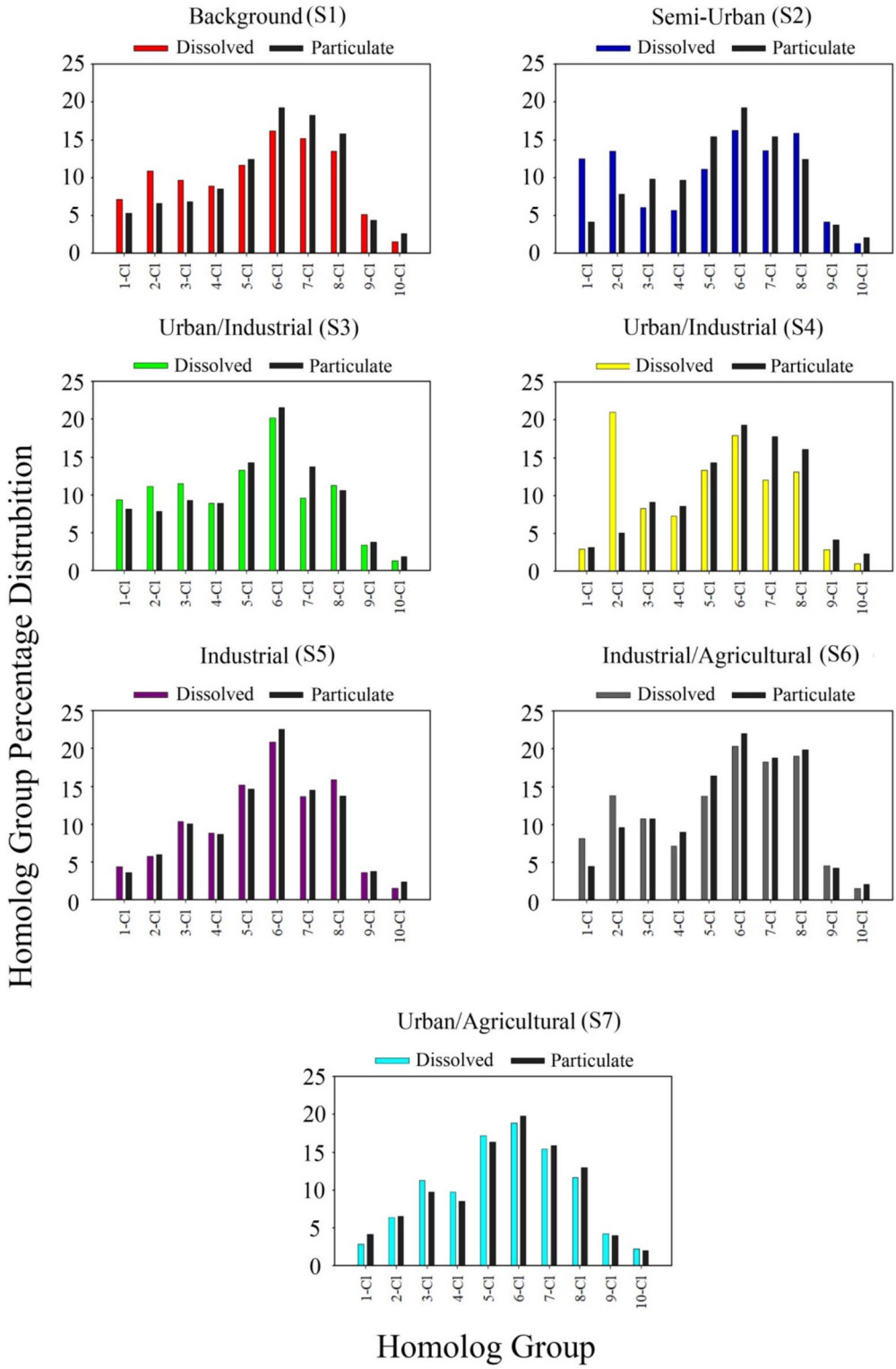

Fig. 7 Homolog group distribution of dissolved and particulate phases

characteristics in Bursa, Türkiye. The lowest concentrations were observed in background and semi-urban sampling sites, while the highest were detected in urban and industrial sampling sites for both dissolved and particulate phases of PAHs and PCBs. A concerning trend of increasing concentrations of PAHs and PCBs for both phases has emerged, particularly in industrial and agricultural areas, reflecting the growing impact of anthropogenic sources on surface water quality. Regression analyses were conducted to examine the relationship between $\log K_D$ and $\log K_{OW}$ and weak correlations were observed for both PAHs and PCBs, suggesting that $\log K_{OW}$ alone may not be a reliable predictor of the partitioning behaviors. Instead, phase distributions are likely influenced by various factors such as the organic matter content of the particle matter, water temperatures, surface flow rates, and physicochemical properties. These complex interactions emphasize the necessity for comprehensive, multivariate approaches to better understand the partitioning dynamics of PAHs and PCBs in aquatic environments. Furthermore, source identification of PAHs and PCBs was provided through molecular diagnostic ratios and homolog group distributions. It was found that both dissolved and particulate phases of PAHs were influenced by similar sources, notably petroleum and traffic emission. Similarly, industrial and agricultural activities were identified as significant contributors to PCBs sources in surface waters. Consequently, the findings underscore the urgent need for comprehensive management strategies to protect the environment quality and public health by mitigating the increasing contamination of surface waters with PAHs and PCBs in the region.

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Author Contributions All the authors listed on the title page contributed to the study's conception and design.

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Data Availability All data generated and analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing interests The authors declare no competing interests.

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