POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN INDRAMAYU COASTAL, WEST JAVA: DISTRIBUTION, SOURCE, AND ECOLOGICAL RISK ASSESSMENT

POLISIKLIK AROMATIK HIDROKARBON (PAH) DI PESISIR INDRAMAYU, JAWA BARAT: DISTRIBUSI, SUMBER, DAN KAJIAN RISIKO EKOLOGI

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ABSTRACT: PAH pollutants from anthropogenic activities were released into Indramayu Coast and could potentially have negative effects on the environment. This study aimed to determine the distribution, source, and ecological risks of PAHs in the area. Seawater and sediment samples were collected and stored in glass bottles at 4 °C and then further processed in the laboratory. The samples were extracted with dichloromethane and n-hexane and then fractionated using a silica gel column, and finally injected into a Gas Chromatography-Mass Spectrometer (GCMS). The distribution of PAH compounds was detected in all sampling stations in varying amounts. PAH with low molecular weight (two to three rings) was predominant in seawater samples, while high molecular weight (four rings) was predominant in sediments. In addition, by using the molecular diagnostic ratio, the PAH source in Indramayu Coast was detected to be pyrogenic and petrogenic processes that come from anthropogenic activities. Exposure to PAH concentrations in this study posed a lower risk to sediment-dwelling organisms. However, further awareness and periodic monitoring are required to detect carcinogenic PAHs.

Keywords: polycyclic aromatic hydrocarbons (PAHs), pollutants, Indramayu Coast, ecological risk

ABSTRAK: *Polutan PAH yang berasal dari kegiatan antropogenik dilepaskan ke Pesisir Indramayu dan berpotensi menimbulkan dampak negatif terhadap lingkungan. Penelitian ini bertujuan untuk mengetahui distribusi, sumber, dan risiko ekologi PAH di pesisir Indramayu. Sampel air laut dan sedimen diambil dan disimpan dalam botol kaca pada suhu 4°C untuk kemudian dianalisis lebih lanjut di laboratorium. Sampel diekstraksi dengan diklorometana dan n-heksana kemudian difraksinasi menggunakan kolom silika gel, lalu diinjeksikan ke alat Gas Chromatography-Mass Spectrometer (GCMS). Konsentrasi PAH terdeteksi dalam air laut dan sedimen masing-masing sebesar 190-400 ng/L dan 8,3-45 ng/g. PAH dengan berat molekul rendah (dua sampai tiga cincin) dominan dalam sampel air laut, sedangkan PAH dengan berat molekul sedang (empat cincin) dominan dalam sedimen. Selain itu, dengan menggunakan rasio diagnostik molekuler, sumber PAH di Pesisir Indramayu terdeteksi dari proses pirogenik dan petrogenik serta berasal dari aktivitas antropogenik. Paparan konsentrasi PAH dalam penelitian ini mempunyai risiko lebih rendah terhadap organisme penghuni sedimen. Namun, kesadaran lebih lanjut dan pemantauan berkala diperlukan untuk mendeteksi PAH yang bersifat karsinogenik.*

Kata Kunci: *Polisiklik Aromatik Hidrokarbon (PAH), Polutan, Pesisir Indramayu, Risiko Ekologi*

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are the most abundant and widespread persistent organic pollutants in aquatic environments (Neşer et al., 2012; Mehdinia et al., 2015). Attention to these pollutants is increasing due to their toxic, mutagenic, and carcinogenic effects on organisms and human health (Ravindra et al., 2008). Unlike other organic hydrophobic contaminants (Charles et al., 2012), PAHs are continuously produced and released into the environment by the pyrolysis of fossil fuels (UNEP 2001; Mastral et al., 2003). Coastal and marine ecosystems are particularly vulnerable to PAHs (Glad et al., 2017), which mostly come from terrestrial area and the ocean itself. Furthermore, seasonal variations might affect hydrodynamic processes in Indramayu Coast and hence the transportation of PAHs in ecosystems and accumulate PAHs in seawaters, sediments (Liu et al., 2016), and marine biota (Farrington 2020; Yogaswara et al., 2021).

In aquatic ecosystems, low molecular weight PAHs are found in the dissolved phase; however, those of heavier molecules (having four or more aromatic rings) are mostly adsorbed onto sediment particles (Veerasingam et al., 2016). PAHs evaporate into the atmosphere and incorporate into aerosol particles and then can be deposited on the sea surface, where they aggregate with marine particulate organic matter (POM) (Akyüz and Çabuk 2010). Once in the water column, biogeochemical processes play a role in the transfer of contaminants bound in suspended particles to the sediment surface (Portet-Koltalo et al., 2013). Therefore, sediment is the main receptor and reservoir of PAH (Chen et al., 2020).

Indramayu coastal is a neritic sea in the northern Java (Widhiarno and Muliati 2016) and is influenced by several factors, including population growth, industrialization, and rapid economic development (Sodikin 2011; Wulandari et al., 2019). These anthropogenic activities have a detrimental effects and have become a potential source of PAHs (Tong et al., 2019; Zhao et al., 2021) for which the Cimanuk River might carry PAHs to the estuary through surface runoff (Paryono et al., 2017; Sholeh et al., 2018). Therefore, Indramayu CoastIndramayu Coast requires intensive environmental quality monitoring.

This study was conducted to analyze the levels, sources, and potential ecological risks of PAHs in the environment of Indramayu Coast. Furthermore, it provides information to understand PAHs levels as an environmental database, the management of organic pollution in the Indramayu coastal area, the sources of risk, and the mapping of exposure to PAHs to the coastal environment.

METHODS AND MATERIALS

Sampling site

Seawater and sediments were collected using an acrylic glass Van Dorn water sampler and a stainless steel Van Veen grab, respectively, from 18 stations in the Estuary of Cimanuk River and Indramayu Coast, West Java Province, in April 2017 (Figure 1). All samples were kept in an ice box at a temperature of 4 °C, for further analysis in the laboratory.

Sediment characteristics

The granulometric method was used to analyze the particle size of the sediments. Briefly, 50 g of wet sediment was weighed, dried in an oven at 80 °C for 12 h, homogenized with distilled water, and filtered through stratified sieves with mesh sizes of 4, 2, 1, 0.5, 0.25, 0.125, and 0.063 mm (Wentworth, 1922; Blair and McPherson, 1999).

Sample analysis

One liter of seawater was collected and filtered using Whatman Grade GF/C Glass Microfiber Filter Papers (pore size: 0.45 µm; diameter: 47 mm). The filtrate was extracted three times using a liquid-liquid extraction method and shaken using a vertical shaker at 150 rpm for 5 min with dichloromethane (30 mL), n-hexane (30 mL), and a dichloromethane-n-hexane mixture (1:1 v/v, 30 mL). The mixture was then fractionated using sodium sulfate and silica gel-60, with 15 mL of n-pentane-dichloromethane (40:60) and then it was evaporated and injected into the Gas Chromatography-Mass Spectrometer (GCMS) ISQ-LT 1310 Thermo Scientific (Khozanah et al., 2019).

Furthermore, 10 g of sediment was extracted using a solvent similar to the seawater samples, in an ultrasonic water bath for 30 min at 30 °C (Yamaguchi and Lee 2010). Subsequently, activated copper was added to remove the sulfur containing material. Moreover, the sample was fractionated by silica gel-60 with 15 mL of n-pentane:dichloromethane mixture (2:3, v/v). Finally, it was evaporated and injected into a GCMS ISQ-LT 1310 Thermo Scientific (Khozanah et al., 2019).

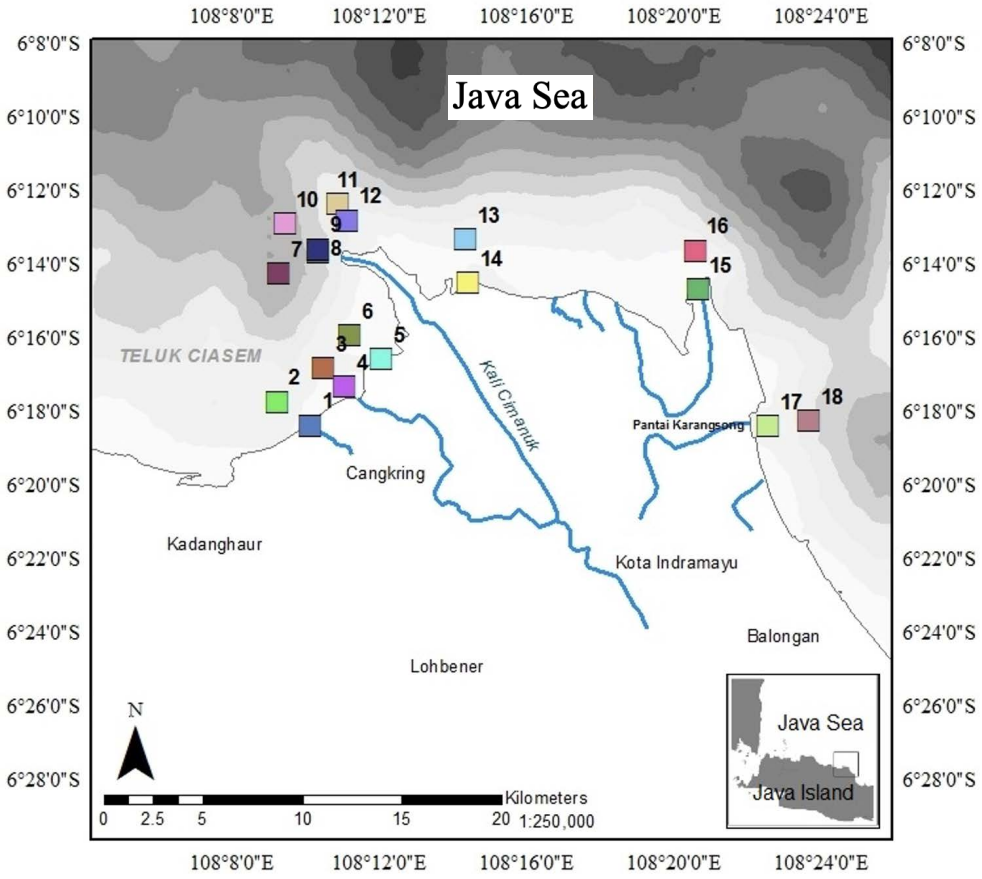

Figure 1. Field sampling of seawater and sediment samples at 18 stations in Indramayu Coast, West Java.

GCMS condition

PAHs were determined using a GCMS ISQ-LT 1310 Thermo with a column TG5-SilMs (30 m length, 0.25 mm ID). The GC oven was set at 50 °C (hold for 0.5 minutes), and then it was set with an initial temperature of 160 °C for 15 minutes, which increased the temperature to 290 ^{o}C with a gas rate of 10 ^{o}C/min (hold for 13 minutes). Finally, the temperature was raised to 300 ^{o}C and held for 4 minutes. The gas system used helium gas at a rate of 1.2 mL/min (with constant flow), with a splitless time mode of 0.5 minutes. The MS detector was set at an ionization potential/electron energy of +70 eV with ion sources and interface temperature of 230 ^{o}C and 250 ^{o}C respectively. Ion mass data (m/z) was recorded between 50-750 scans per second. PAH compounds were identified based on the mass spectra and retention times using the full scan method.

The average recovery of the blank spiked standard was 60% and it was performed separately. The GCMS performance was carried out separately against external standards QTM PAH mix CRM47930 immediately before injecting the sample. A blank sample procedure was performed to identify contaminants during PAH analysis in the laboratory.

Identification of pollution source

Diagnostic ratios were used to identify the potential sources of PAHs in seawater and sediments (Table 1) (Yunker et al., 2002; Ke et al., 2017). In general, PAHs can be classified into three groups based on differences in the number of rings: low molecular weight PAHs (2-3 rings), medium molecular weight PAHs (4 rings), and high molecular weight PAHs (5-6 rings). Different distributions of the number of rings may indicate different PAH sources (Baumard et al., 1998). In this method, the diagnostic ratios fluoranthene (Flt)/(fluoranthene (Flt) + pyrene (Pyr)), Anthracene (Ant)/(Anthracene (Ant) + Phenenathrene (Phe)), Benzo [a] Anthracene (BaA)/(Bezo [a] Anthracene (BaA) + Chrysene (Chry)), Indeno (123-cd) pyreine (Ind)/(Indeno (1,2,3-cd) pyrene (Ind) + Benzo (g,h,i) perylene (B(ghi)P)), and Benzo (a) pyrene (BaP)/Benzo (ghi) Perylene (B(ghi)P) were used as indicators in the study of PAH compounds (Yang et al., 2020).

Table 1. Molecular diagnostic ratio of PAHs to determine pollution source

PAH Ratio	Range	Source	Reference
∑LMW/∑HMW	< 1	Pyrogenic	(Tobiszewski and Namieśnik 2012)
	> 1	Petrogenic	
Ant/(Ant+Phe)	< 0.1	Petrogenic	(Ravindra et al., 2008)
	> 0.1	Pyrogenic	
Flt/(Flt+Pyr)	< 0.4	Petrogenic	(De La Torre-Roche et al., 2009)
	0.4-0.5	Fossil fuel combustion	
	> 0.5	Grass, wood, coal combustion	
BaA/(BaA+Chry)	0.2-0.35	Coal combustion	(Yunker et al., 2011)
	> 0.35	Vehicle emission	
	< 0.2	Petrogenic	
Ind/(Ind+B(g,h,i)P)	< 0.2	Petrogenic	
	0.2-0.5	Petroleum combustion	
	> 0.5	Grass, wood, coal combustion	
BaP/B(ghi)P	< 0.6	Non-traffic emission	(Katsoyiannis et al., 2007)
	> 0.6	Traffic emission	

Distribution of PAH

PAH distribution is determined based on the distribution of the types of PAH compounds detected at each sampling station. Typically, PAH levels will decrease or degrade as they move farther from the mainland or coastline and towards the open sea.

Environmental ecological risk evaluation

The ecological risk assessment of PAHs in sediments was evaluated using sediment quality guidelines, such as the effect range level (ERL), effect range medium (ERM), threshold effects level (TEL), and probable effects level (PEL) (MacDonald et al., 1996; CCME 1999). The adverse biological effects of PAHs in sediment were predicted to occur infrequently (<ERL/TEL), occasionally (ERL/TEL > concentrations < ERM/PEL), and frequently (>ERM/PEL) (Yang et al., 2020). In addition, it is significant to examine the sediment particles as organic contaminants. Therefore, sediment quality guidelines (ISQG value) were necessary to evaluate the effect of contaminated sediment in the marine environment (ANZECC 2000). For four carcinogenic PAHs, e.g., chrysene, benzo (a) pyrene, benzo (a) anthracene, and benzo (k) fluoranthene (PAH_4), were calculated based on the total number of carcinogenic PAH detected in seawater and sediment samples.

Statistical Analysis

For statistical analysis of the significance level (p) of PAH distribution among sampling stations, a one-way ANOVA was applied. To gain a better understanding of the relationship between PAH concentration and the characteristics of sediment from each station investigated, the obtained results were subjected to principal component analysis (PCA) by using the Paleontological Statistics software package for education and data analysis (Past) 4.13.

RESULTS

PAHs level in seawater and sediment

The PAHs levels in seawater ranged from 190 ng/L to 400 ng/L, with a mean value of 279.4 ng/L. The highest PAH concentration was found at Station 1, whereas the lowest total PAH level was detected at Station 12. PAH concentrations in sediments ranged from 8.3-45 ng/g wet weight (ww) with a mean value of 18.5 ng/g, and the highest PAHs level was detected at station 1 and the lowest at station 2 (Figure 2).

Characteristics and distribution of PAHs

PAHs with three rings were more prevalent than those with two or more rings in seawater, meanwhile, PAHs with four rings were more prevalent in sediment. Anthracene was detected massively in seawater, followed by fluorene, fluoranthene, and pyrene. In sediment, anthracene was also predominant, followed by fluoranthene, pyrene, and benzo (a) anthracene (Figure 3).

The composition of PAHs in seawater and sediment samples varied at each sampling station. A large number of PAH compounds were detected in seawater and sediment samples at station 1 (Figure 4).

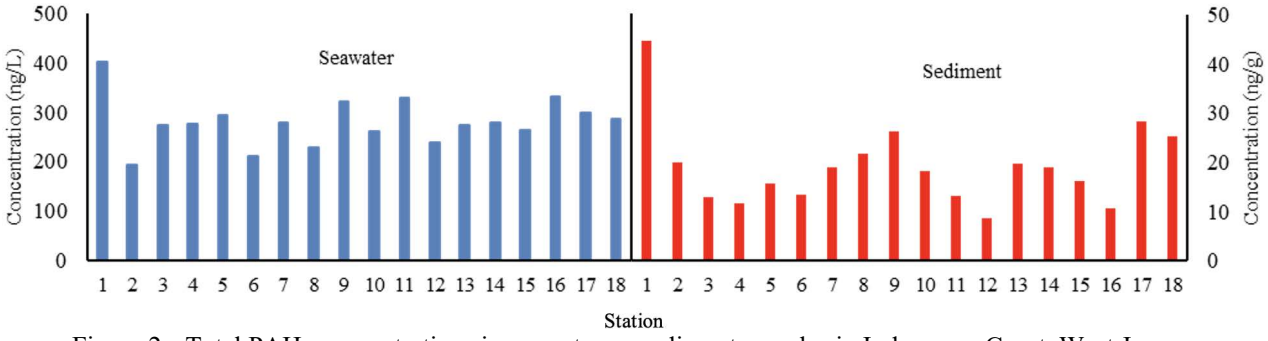

Figure 2. Total PAHs concentrations in seawater an sediment samples in Indramayu Coast, West Java.

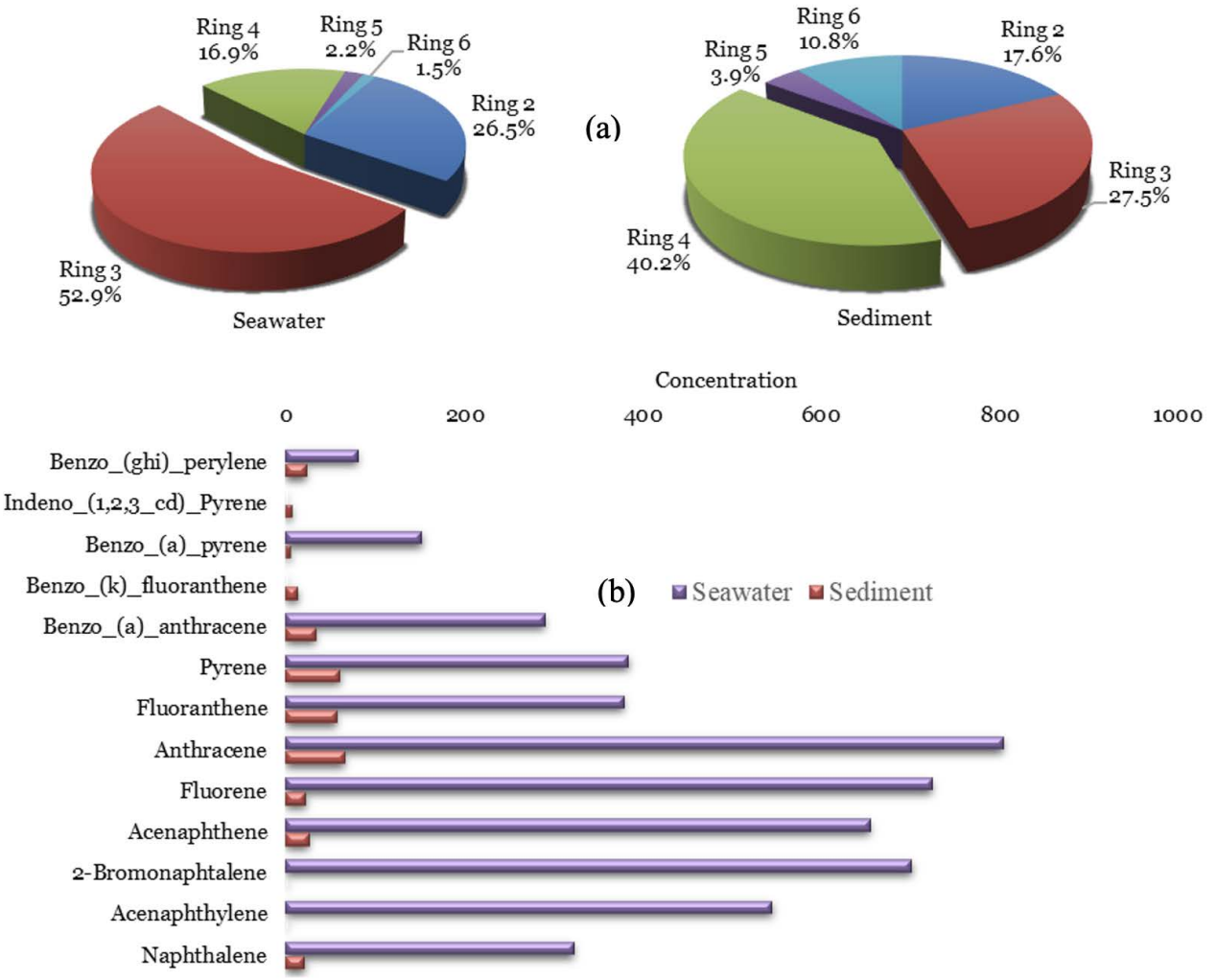

Figure 3. Ring composition (a) and distribution of PAH congeners (b) in seawater (ng/L) and sediment (ng/g) samples in Indramayu Coast, West Java.

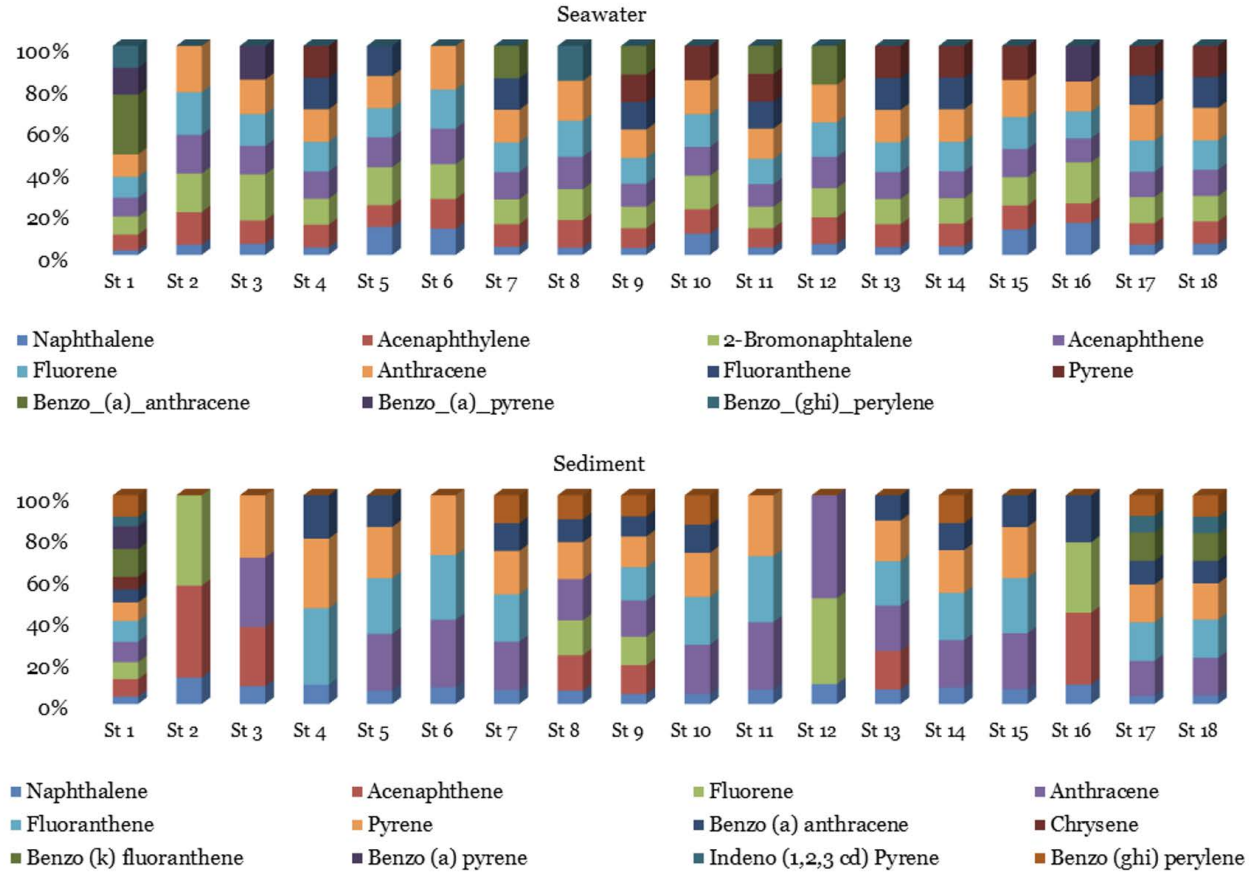

Figure 4. PAH congeners composition in seawater and sediment samples from each station in Indramayu Coast, West Java.

DISCUSSIONS

PAHs in seawater and sediment

In general, the Indramayu waters can be described as unpolluted by PAH substances, given that their concentration levels are below the threshold limit set by the sediment quality guidelines of CCME (1999) and ANZECC (2000). The highest PAH concentrations in seawater were observed at station 1, located near the harbor and crossed by the ship line. Ship dock activities and fishing boat traffic are sources of PAH in water (Chen et al., 2020; Yogaswara et al., 2020). In addition, the deposition of particulate matter from the atmosphere can be a potential source of PAHs (Tong et al., 2019). The Indramayu Coast is located in the Java Sea and is influenced by two monsoon regimes, the northwest and southeast monsoons, which affect the variability of rainfall, riverine input, winds, waves, and sea currents (Koropitan et al., 2009). According to several previous studies, these physical oceanographic parameters can affect the distribution of organic pollutants in water (Zhao et al., 2021).

The PAHs levels in seawater are higher than in other sites on Java, such as Cilincing Waters, Jakarta Bay (Yogaswara et al., 2020). Moreover, these levels are still higher in comparison to those observed in several other countries, such as the Xiamen Coast - China, the Mediterranean Sea - France (Guigue et al., 2014), the Tyyhenian Sea - Italy (Cincinelli et al., 2001), and the Pier Estuary, New Jersey - USA (Gigliotti et al., 2002). The high PAHs was detected in this study could be due to the nearby crude oil refinery of PT Pertamina and the potential for crude oil leakage from the loading and unloading of tankers via single-point mooring (SPM) (Sinurat et al., 2016).

The highest level of polycyclic aromatic hydrocarbons (PAHs) was found in the sediment samples at Station 1 due to its location near a shipping port in an estuary area. The lower level at Station 2 could be attributed to the hydrophobic nature of organic pollutants and the hydrodynamic conditions in the coastal area. Several factors contribute to the accumulation of these pollutants in the sediment samples, such as the dramatic increase in shipping activity over the last two decades. In addition, offshore or onshore gas and oil exploration and production activities are potentially due to oil spills, which contribute to increasing chemical

pollution in coastal and ocean areas (Tornero and Hanke 2016). Their low solubility and hydrophobic nature cause them to be adsorbed onto suspended particulates and carried by rivers, which eventually spread and sunk into the sediment in estuaries and coastal waters (Duan et al., 2015). This leads to their persistent accumulation in high concentrations (Li and Li 2017). In addition, the deposition of organic pollutants can be affected by the hydrodynamic conditions in the area (Kang et al., 2017) and potentially occur in the various PAHs distributions in each sampling in Indramayu Coast.

The average PAHs levels in the sediment samples were lower than those along the Java Sea, such as Banten Bay (Khozanah and Yogaswara 2017), Jakarta Bay (Yogaswara et al., 2020), and Cirebon Waters (Khozanah et al., 2019). This is likely due to the lower industrial activity in Indramayu than the other four sites. Additionally, PAH levels decreased with an increasing distance from the estuary, suggesting that human activities have less of an impact on the open sea (Yang et al., 2020). In estuaries, PAH compounds generally originate from river discharges. However, hydrodynamic conditions such as currents, tides, winds, and waves influences high PAH levels in rivers (Mehdinia et al., 2015). Furthermore, the ANOVA test showed statistical significance ($p < 0.05$) of PAH distribution in seawater and sediment samples among sampling stations, particularly sampling stations close to the mainland, as the main sources of anthropogenic activities and riverine input.

PAHs with four or more rings tend to be detected in sediment samples because they are persistent and accumulate in sediment particulates. In contrast, PAHs with lower rings (two to three rings) are more commonly detected in seawater samples because of their hydrophobicity, meaning they stay in seawater (Tong et al., 2019). Furthermore, based on the classification of contaminated water proposed by Maliszewska-Kordybach (1996), the PAH concentrations in sediments can be divided into four categories: (a) uncontaminated (<200 ng/g), (b) weakly contaminated (200-600 ng/g), (c) contaminated (600-1000 ng/g), and (d) heavily contaminated (>1000 ng/g). Consequently, according to this category, sediments from the Estuary of Cimanuk River and Indramayu Coast are uncontaminated by PAHs. Anthracene was the predominant compound detected in seawater and sediment samples, while benzo (ghi) perylene and chrysene were the less detected compounds in seawater and sediment samples (Figure 3). Generally, anthracene originates from the petrochemical and manufacturing industries, while benzo (ghi) perylene originates from motor vehicle emissions (Abdel-Shafy and Mansour, 2016). Several PAHs congeners that were not detected in seawater or sediment samples had concentrations below the detection limit of 1 ng/L.

PAHs Distribution

The distribution of PAHs was significant at station 1, indicating that during seawater sampling, PAHs were distributed around this site. As hydrophobic compounds, PAHs tend to float and spread on the surface of the air, and due to hydrodynamical processes, PAH compounds sank into the water column and being accumulated in sediment over a long period of time (Tong et al., 2019). Therefore, the concentration of PAH compounds at the seawater surface is higher in general than at the sediment surface. Furthermore, the accumulation of PAHs generally occurred in the estuary, while at the station 1, it was detected to be a significant location for the distribution of these pollutants because it is located in the estuary area. Hence, an estuary is often used as a long-term monitoring site due to its ability to accumulate and deposit organic pollutants over a long period of time (Wang et al., 2017). Furthermore, degradation of PAHs in sediments is low for high molecular weight (HMW) group PAH compounds and under anaerobic conditions. PAH levels near the coastal sampling stations (e.g., station 1, 5, 8, 9, 15, and 17) are consistently higher in comparison to sampling stations in the open sea, indicating a decline in PAH concentrations as they move away from the coast. The distribution of PAHs in coastal waters is strongly influenced by hydrodynamic conditions and the aggregation of organic pollutants with particulate matter (Mehdinia et al., 2015).

The distribution of pollutants in coastal and marine environments is impacted by the size of particles and the amount of clay in sediment (Yang et al., 2020). This research uncovered that at each sampling station, there were varying dominant sediment characteristics. Generally, silt particles were predominant sediment characteristic for the whole sampling station, and followed by clayish silt, silty sand, and sand (Table 2). In addition, PCA analysis was figure out for 85.5% of the total variances in profile of PAH rings in particle size of sediment samples (Figure 5). About 56.4% of total variances on the first principal components is characterized by clayish silt, sand, silty

sand, and silt. Furthermore, about 29.1% of total variances on the second principal (PC2) is dominated by silt, clayish silt, sand, and silty sand. The PCA analysis in correlation between particle size of sediment and PAH ring depicted a minor significant correlation in each sampling station. Each particle size of sediment has a various accumulation of type of PAH ring and is not related to each other. This indicates that the dominant sediment characteristics were not necessarily associated with high levels and ring molecules of PAHs. This is a normal occurrence in the changing aquatic ecosystems of estuarine and coastal areas (Timoney and Lee 2011). According to a study by Duan et al. (2015), Gu et al. (2017), and Lohmann et al. (2005), have demonstrated that sediment characteristics have less effect on the accumulation of organic contaminants in sediments.

Identification and source of PAHs

The molecular weight ratio (low and high) and molecular diagnostic ratio (MDR) indicated that the source of PAH pollutants came from pyrogenic and petrogenic processes (Table 2). Pyrogenic sources were predominantly derived from seawater samples, whereas petrogenic sources were predominantly derived from sediment samples. In addition, particulate organic pollutants can also come from atmospheric deposition, thereby contributing to the

Table 2. Sediment characteristics at each sampling station in Indramayu Coast, West Java

Station	Sediment Characteristic	Station	Sediment Characteristic	Station	Sediment Characteristic
St 1	Clayish silt	St 7	Silt	St 13	Clayish silt
St 2	Silt	St 8	Silt	St 14	Sand
St 3	Silt	St 9	Silt	St 15	Silt
St 4	Silty sand	St 10	Silt	St 16	Silt
St 5	Silty sand	St 11	Clayish silt	St 17	Silt
St 6	Clayish silt	St 12	Silt	St 18	Silt

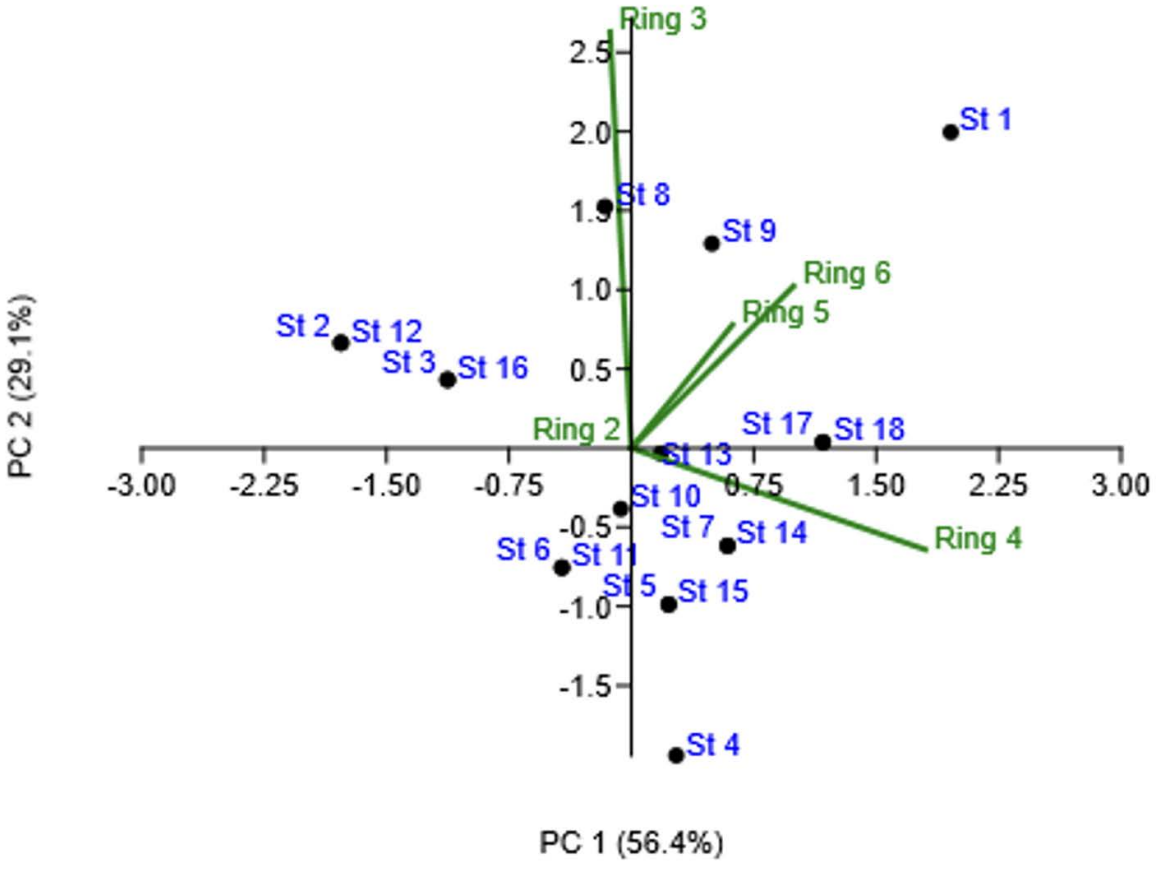

Figure 5. PCA analysis to identify the correlation between ring of PAHs and sampling stations in Indramayu Coast, West Java.

accumulation of pollutants in the marine environment as well (Galarneau, 2008). In this study, it suggests that the PAH pollutants come from both sources, petrogenic sources potentially come from oil spills and oil seeps from Kilang Balongan Pertamina Indramayu, shipping and boat discharge, as well as input from riverine and municipal waste water. Meanwhile, pyrogenic source potentially come from the atmospheric deposition of particulate matter and the combustion emission of vehicles from mainland and boat activities in Eretan and Karangsong fishing ports, Indramayu.

PAHs potentially originate from both pyrogenic and petrogenic sources. Pyrogenic sources generally originate from industrial emissions or fuel combustion from ships or automobile discharge, transport through the atmosphere, and dispersion through water periods of time (Li et al., 2015).

Environmental ecological risk

Based on sediment quality guidelines, the relationship between PAHs levels and ERL and ERM criteria can reveal whether PAHs adversely affect benthic communities and organisms (Han et al., 2019). The results showed that the selected individual PAH level below the sediment quality threshold did not negatively affect the biota in the sediment (CCME, 1999; ANZECC, 2000). However, it is still necessary to be more aware of the potential ecological risks posed by sedimentary PAHs over the long term, particularly in estuaries.

For carcinogenic risk evaluation, the risks for seven carcinogenic PAHs, benzo (k) fluoranthene (BkF), benzo (a) anthracene (BaA), benzo (a) pyrene

Table 3. Identification of PAHs source in Indramayu Coast, West Java

Station	∑LMW/∑HMW		Ant/(Ant+Phe)		Flt/(Flt+Pyr)		BaA/(BaA+Chry)	
	Sdm	Swt	Sdm	Swt	Sdm	Swt	Sdm	Swt
St 1	0.42	0.93	1.00	1.00	0.53	nc	0.51	1.00
St 2	nc	nc	nc	1.00	nc	nc	nc	nc
St 3	2.35	5.20	1.00	1.00	nc	nc	nc	nc
St 4	0.10	2.29	nc	1.00	0.52	0.50	1.00	nc
St 5	0.51	5.95	1.00	1.00	0.52	1.00	1.00	nc
St 6	0.68	nc	1.00	1.00	0.52	nc	nc	nc
St 7	0.43	2.27	1.00	1.00	0.52	1.00	1.00	1.00
St 8	1.49	4.98	1.00	1.00	nc	nc	1.00	nc
St 9	0.98	1.50	1.00	1.00	0.52	0.50	1.00	1.00
St 10	0.40	5.09	1.00	1.00	0.52	nc	1.00	nc
St 11	0.64	1.53	1.00	1.00	0.52	0.49	nc	1.00
St 12	nc	4.39	1.00	1.00	nc	nc	nc	1.00
St 13	0.89	2.27	1.00	1.00	0.52	0.50	1.00	nc
St 14	0.44	2.30	1.00	1.00	0.52	0.50	1.00	nc
St 15	0.51	5.14	1.00	1.00	0.52	nc	1.00	nc
St 16	3.43	4.84	nc	1.00	nc	nc	1.00	nc
St 17	0.26	2.54	1.00	1.00	0.50	0.50	1.00	nc
St 18	0.28	2.38	1.00	1.00	0.51	0.50	1.00	nc

Note: nc = not calculated, Sdm = Sediment, Swt = Seawater

hydrodynamic processes (Castro-Jiménez et al., 2012). In addition, pyrogenic sources can originate from river flow inputs carried from estuaries to the high seas (Chen et al., 2020). Petrogenic sources usually originate from the contamination of crude oil or petroleum fuel products that are spilled to the ocean, directly spread in the water, and aggregated by organic particulates (Tobiszewski and Namieśnik 2012). Furthermore, they sink and gradually accumulate in sediments over long

(BaP), benzo (b) fluoranthene (BbF), indeno (cd - 1,2,3) perylene (IND), chrysene (Chr), and dibenzo (a,h) anthracene (DBahA), in the aquatic environment have the potential to occur, especially the type of BaP, which is carcinogenic (Mu et al., 2014; Li and Li 2017). The four carcinogenic PAHs (PAH_4) based on regulation of EU-Commission (2011) were detected from a total of seven types of PAH congeners that were categorized as

Table 4. Sediment analysis of ecological risk (ng/g) in Indramayu Coast, West Java

PAHs	ERL	ERM	TEL	PEL	ISQG-Low	ISQG-High	This study (average)
Naphthalene	160	2100	34.6	391	-	-	1.1
Acenaphthene	16	500	6.7	88.9	16	500	3.7
Fluorene	19	540	21.2	144	19	540	3.6
Anthracene	85.3	1100	46.9	245	85	1100	4.4
LMW	**280.3**	**4240**	**109.4**	**868.9**	**120**	**2140**	**12.8**
Fluoranthene	600	5100	113	1494	600	5100	4.3
Pyrene	665	2600	153	1398	665	2600	4
Benzo (a) anthracene	261	1600	74.8	693	261	1600	2.4
Chrysene	384	2800	108	846	384	2800	2.7
Benzo (a) pyrene	430	1600	88.8	763	430	1600	4.9
HMW	**2340**	**13700**	**537.6**	**5194**	**2340**	**13700**	**18.3**
Total	**2620.3**	**17940**	**647**	**6062.9**	**2460**	**15840**	**31.2**

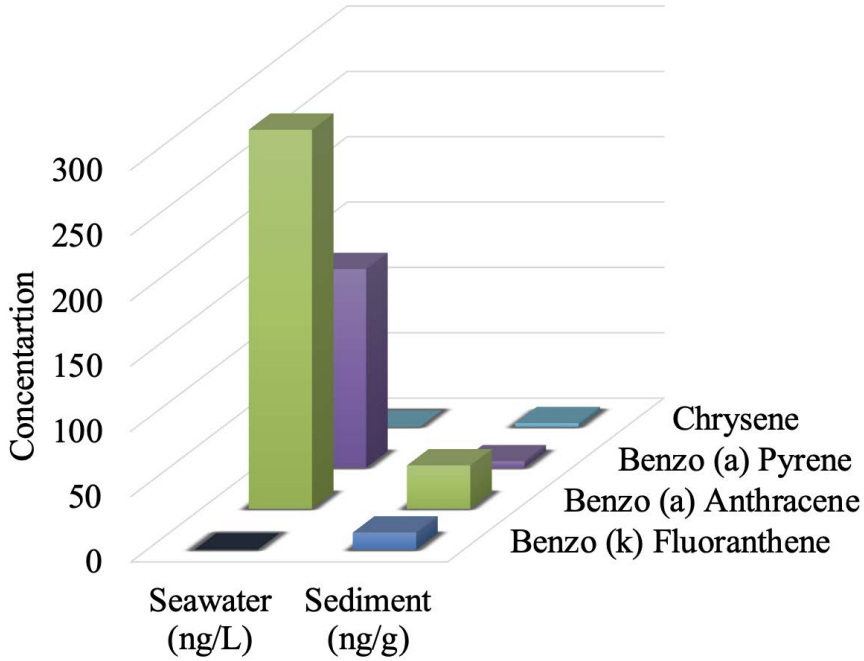

Figure 6. Identification of carcinogenic PAHs in Indramayu Coast, West Java

carcinogenic, such as chrysene, benzo (a) pyrene, benzo (a) anthracene, and benzo (k) fluoranthene (Figure 6). Two carcinogenic PAHs were detected in the seawater samples, whereas four were detected in the sediment samples. The carcinogenic PAHs benzo (a) anthracene had the highest levels in both the seawater and sediment samples. With the presence of four carcinogenic PAHs in this area, it is important to be concerned about the health risks both marine organisms and humans. In particular, the carcinogen BaP can disrupt the reproductive system and trigger the occurrence of cancer cells (Zhao et al., 2021).

CONCLUSSIONS

This study figured out that the low molecular weight PAHs (two to three rings) are the main PAHs profile in seawater, while medium molecular weight (four rings) PAHs are most detected in sediments. As they move towards the open sea, PAH concentrations will generally decrease or undergo degradation, away

from the land or coast. It is assumed that input from anthropogenic and industrial activities on land is a possible source of PAH pollutants in this coastal environment, both from pyrogenic and petrogenic. The ecological risk posed by the levels of PAHs in the sediments was observed to be relatively low. Nevertheless, further investigation is required, as carcinogenic PAHs have been noticed at some field stations along Indramayu coastal. The existence of four carcinogenic PAHs in this vicinity warrants attention towards potential health risks for both marine organisms and humans.

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