MDPI

Article

Health Risk Assessment of PAHs from Estuarine Sediments in the South of Italy

Fabiana Di Duca [1], Paolo Montuori [1,*], Ugo Trama [2], Armando Masucci [1], Gennaro Maria Borrelli [1] and Maria Triassi [1]

[1] Department of Public Health, University "Federico II", Via Sergio Pansini n° 5, 80131 Naples, Italy
[2] General Directorate of Health, Campania Region, Centro Direzionale Is. C3, 80143 Naples, Italy
* Correspondence: pmontuor@unina.it

Abstract: Increased concerns about the toxicities of Polycyclic Aromatic Hydrocarbons (PAHs), ubiquitous and persistent compounds, as well as the associated ecotoxicology issue in estuarine sediments, have drawn attention worldwide in the last few years. The levels of PAHs in the Sele, Sarno, and Volturno Rivers sediments were evaluated. Moreover, the cancerogenic risk resulting from dermal and ingestion exposure to PAHs was estimated using the incremental lifetime cancer risk (ILCR) assessment and the toxic equivalent concentration (TEQ$_{BaP}$). For Sele River, the results showed that the total PAH concentration ranged from 632.42 to 844.93 ng g^{-1} dw, with an average value of 738.68 ng g^{-1} dw. ∑PAHs were in the range of 5.2–678.6 ng g^{-1} dw and 434.8–872.1 ng g^{-1} dw for the Sarno and Volturno River sediments, respectively. The cancerogenic risk from the accidental ingestion of PAHs in estuarine sediments was low at all sampling sites. However, based on the ILCR$_{dermal}$ values obtained, the risk of cancer associated with exposure by dermal contact with the PAHs present in the sediments was moderate, with a mean ILCR$_{dermal}$ value of 2.77×10^{-6}. This study revealed the pollution levels of PAHs across the South of Italy and provided a scientific basis for PAH pollution control and environmental protection.

Keywords: polycyclic aromatic hydrocarbons (PAHs); river sediment; occurrence; incremental lifetime cancer risk; carcinogenic risk

1. Introduction

Estuaries are the main deposits for the disposal of industrial and domestic effluents, sewage sludge, and dredged material with a significant load of contaminants, including PAHs, from pipeline discharges, vehicular emissions, atmospheric deposition, surface runoff, as well as oil spills in aquatic environments [1]. Due to their low water solubility and high lipophilicity, PAHs tend to accumulate in the sediments of aquatic systems for long periods due to their high degradation resistance and high organic carbon content [2]. In soil and sediment compartments, PAHs can undergo biodegradation processes by microorganisms. However, due to their stable physic–chemical characteristics, hydrophobicity, and a strong tendency to absorb into the soil matrix, their biodegradation rate is low. Consequently, PAHs do not degrade easily, and they can accumulate in the solid phase of the terrestrial and aquatic environment, where they persist for a long time [3,4]. Thus, sediments constitute a natural reserve of PAHs in the aquatic system [5,6]. Moreover, they can be released into the surrounding environment by means of resuspension phenomena, thus giving rise to "secondary pollution". Consequently, since high concentrations of PAHs in sediments may reveal a potential pollution risk for the environment and human health, it is essential to monitor these compounds in sediment to protect and preserve the aquatic environment and human health [7].

PAHs, as persistent organic pollutants (POPs), are widely present in the ecosystem [8–10]. Their spread to the environment has raised many concerns for human health, as some of them

have been identified as carcinogens, mutagens, and teratogens. Indeed, PAHs released into the environment may enter the food chain, and exposure to them may result in a risk of cancer or other adverse effects on human health [11–13]. The International Agency for Research on Cancer (IARC) has classified PAHs according to their carcinogenicity as carcinogenic (Group 1), probable carcinogenic (Group 2A), possible carcinogenic (Group 2B), and non-carcinogenic (Group 3) [14]. In general, high molecular weight PAHs (4–6 rings) are more toxic than low molecular weight PAHs (2–3 rings) [15]. The greater toxicity of the former is due to the greater number of aromatic rings from which dihydrodioloepoxides are formed [16]. In particular, the fat solubility of PAHs makes them dangerous because they can cross cell membranes, penetrate, and deposit in tissues. In tissues, PAHs can be oxidized to epoxide (where an oxygen atom replaces one of the double bonds C=C) by a monooxygenase associated with cytochrome P 450 present in the endoplasmic reticulum of cells. The epoxide thus formed can attack macromolecules such as DNA, hence the mutagenic and carcinogenic action of the PAHs, or be transformed into diol by enzymatic systems such as epoxide hydrolase (EH). This reaction of detoxification allows the formed diol, with two hydrophilic alcohol groups, to be more soluble than the starting compound and then to be expelled from the body more easily [17]. In fact, Lee et al. reported that cytochrome P450 enzymes can metabolize BaP and activate it into a carcinogenic reactive intermediate or metabolite. Consequently, these substances can bind to DNA, resulting in DNA adducts that interfere with DNA replication, causing cytotoxicity, teratogenicity, genotoxicity, immunotoxicity, mutagenesis, and carcinogenesis [18].

Mainly, Benzo[a]pyrene (BaP) has been classified as genotoxic using in vitro tests and in vivo studies. In laboratory animals, oral administration of BaP induced tumors of the stomach and mammary gland and skin cancer [19,20]. According to the WHO, BaP is the compound with the greatest negative consequences for human health and has been included in Group 1, which includes all those substances for which there is sufficient evidence of carcinogenicity in humans [20]. BaP has been classified as genotoxic [10], and it has been involved in tumor development in all test animal species tested, regardless of the route of exposure (oral, cutaneous, subcutaneous, inhalator, intratracheal, intrabronchial, intraperitoneal, or intravenous) [21]. Furthermore, dibenz[a,h]anthracene (DahA) has been classified as a probable carcinogen and/or mutagen for humans, and it is included in Group 2A unlike Benzo[a]anthracene (BaA), Benzo[b]fluoranthrene (BbF), Benzo[k]fluoranthrene (BkF), Chrysene (Chr), and Indeno [123-cd]pyrene (IcdP), which have been included in Group 2B as possible carcinogens in humans [22].

The main routes of exposure to PAHs in the general population are inhalation from breathing ambient and indoor air or smoking cigarettes, ingesting food containing PAHs, and breathing smoke from open fireplaces [10,23,24]. According to Adeniji et al., exposure via inhalation, ingestion, or skin contact may lead to human health problems resulting from short- and long-term effects, including some serious respiratory and cardiovascular diseases [13].

The acute effects of PAHs on human health mainly depend on the duration of exposure, PAH concentration during exposure, and the toxicity of the compounds to which one is exposed, as well as the route of exposure. Short-term exposure to PAHs has been reported to cause impaired lung function such as asthma and thrombotic effects in people with coronary heart disease [24]. However, there is currently no full understanding of the effects of short-term exposure to PAHs, but it is well-known that occupational exposure to high levels of PAH-containing mixtures causes symptoms such as eye irritation, nausea, and vomiting [25]. Moreover, PAHs mixtures are also known to cause skin irritation and inflammation, as Anthracene (Ant), Benzo[a]Pyrene (BaP), and Naphthalene (NaP) are skin irritants [26]. In addition, PAHs interfere with hormonal systems and, as a result, can have harmful effects on reproduction and immune function [27]. The adverse effects of exposure to PAHs have been extensively investigated, but the information currently available on human exposure to individual PAHs is scattered and incomplete, except for some accidental contact with NaP and BaP [28–30]. Srogi et al. stated that prolonged dermal contact with NaP may cause redness and inflammation of the skin [31]. In addition, Diggs et al. reported that

long-term exposure to low levels of Pyr and BaP has been identified as the cause of cancer in laboratory animals [32]. Animal studies have also shown adverse effects on reproduction and development due to exposure to PAHs, whereas these effects were not commonly detected in humans [33,34]. Moreover, Anyahara stated that exposure to PAHs can induce cataracts and cause kidney and liver damage and jaundice [35].

Estuaries are important aquatic systems largely affected by PAH pollution. In fact, due to their chemical properties, PAHs can persist in water where they are readily adsorbed onto particulate matter, settling in river sediments and soils. Thus, river sediments behave as the primary sink and reservoir for PAHs in the aquatic environment [36,37]. Consequently, sediments are important indicators since they can reflect the pollution status of the environment [38].

To date, no previous studies have evaluated the carcinogenic risk to human health associated with dermal and accidental ingestion exposure to PAHs from surface sediments in the South of Italy. Therefore, the main aim of this study was to assess the risk to human health from exposure to PAHs present in the sediments of surface waters in a large coastal area of the Campania Region, in the South of Italy. Specifically, the purpose of this study was to evaluate the distribution patterns of PAHs and to assess the carcinogenic risk to human health from dermal and ingestion exposure to these contaminants from the estuarine sediments of the Sarno, Volturno, and Sele Rivers, which are the main surface water streams of the Campania Region, in the South of Italy.

2. Materials and Methods

2.1. Study Area

This assessment of the human health risk from exposure to PAHs was carried out in a study area of approximately 3100 km^2 and included the three largest plains in the Campania Region, in the South of Italy. Particularly, the research area was close to the estuaries of the Sele, Volturno, and Sarno Rivers, which traverse the same-named plains. Figure 1 shows the three plains of interest and the respective estuaries of the rivers that cross them.
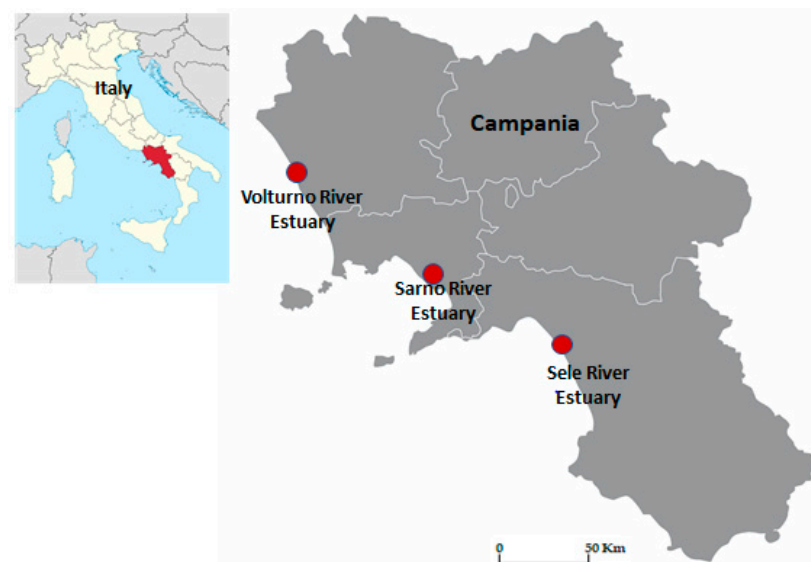

Figure 1. Study area.

2.2. Sampling

A sampling campaign was carried out during the spring season (April 2021) at 10 sampling sites near the Sele River Estuary. In detail, sediment samples were taken from the mouth of the river (Site 1) at different distances, 500 m, 1000 m, and 1500 m from the mouth, and directions, to the north, west, and south of the estuary (Figure 2). During sampling, a global positioning system (GPS) was used to locate all sampling sites.

Information on the identification number (ID), characteristics, and coordinates of each sampling location are shown in Table 1. The samples were collected at a depth of 0 to 5 cm using a scraping sampler (Van Veen Grab) and placed in aluminum containers. Then, they were transferred under refrigeration to the laboratory and stored at −20 °C until analysis.
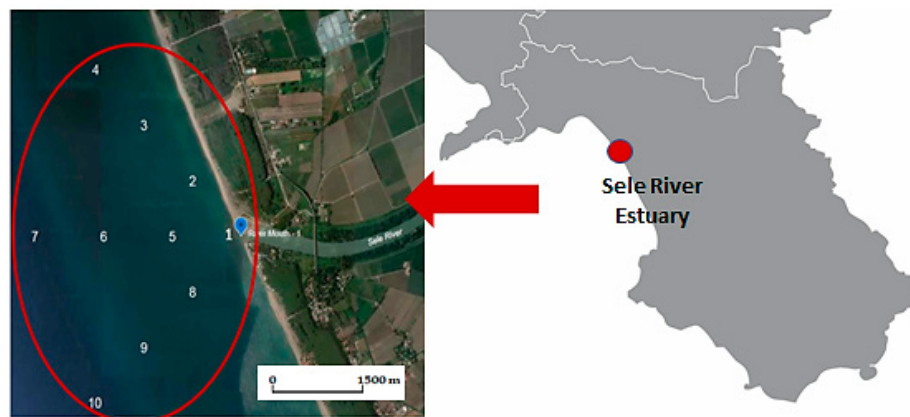

Figure 2. Hydrographic network and sampling sites near the Sele River.

Table 1. Sampling sites with their identification number (ID), location name, and coordinates from the Sele River.

ID	Location	Coordinates	ID	Location	Coordinates
1	Sele River mouth	40°28′55″ N 14°56′33″ E	6	1000 m west	40°28′55″ N 14°55′50″ E
2	500 m north	40°29′04″ N 14°56′14″ E	7	1000 m south	40°28′39″ N 14°55′56″ E
3	500 m west	40°28′55″ N 14°56′12″ E	8	1500 m north	40°29′20″ N 14°55′38″ E
4	500 m south	40°28′47″ N 14°56′16″ E	9	1500 m west	40°28′55″ N 14°55′28″ E
5	1000 m north	40°29′12″ N 14°55′56″ E	10	1500 m south	40°28′30″ N 14°55′38″ E

The PAHs levels in sediment samples from the Sarno and Volturno Rivers were evaluated previously [39,40]. Briefly, for the Sarno River, a sampling campaign was carried out during the spring of 2008 at the source of the river (site 1), just before and after the junction with Alveo Comune, at the river mouth (site 4), and in 9 sites located at different distances from the estuary (Figure 3). More detailed information about the sediment sampling in the Sarno River is given in Table 2.

Figure 3. Hydrographic network and sampling sites near the Sarno River.

Table 2. Sampling sites with their identification number (ID), location name, and coordinates from the Sarno River.

ID	Location	Coordinates	ID	Location	Coordinates
1	Source of Sarno River	40°48′54.03″ N 14°36′45.36″ E	8	150 m south	40°43′35.68″ N 14°28′02.94″ E
2	Before junction with Alveo Comune	40°46′42.73″ N 14°34′00.48″ E	9	150 m west	40°43′42.25″ N 14°27′59.97″ E
3	After junction with Alveo Comune	40°46′00.34″ N 14°33′10.68″ E	10	150 m north	40°43′49.26″ N 14°27′30.31″ E
4	Sarno River mouth	40°46′10.68″ N 14°28′07.89″ E	11	500 m south	40°43′30.31″ N 14°27′58.94″ E
5	50 m south	40°43′40.11″ N 14°28′06.45″ E	12	500 m west	40°43′42.29″ N 14°27′46.41″ E
6	50 m west	40°43′42.46″ N 14°28′05.03″ E	13	500 m north	40°43′57.85″ N 14°27′48.68″ E
7	50 m north	40°43′45.09″ N 14°28′05.17″ E			

For the Volturno River, the sampling campaign was carried out in April 2018 near the mouth of the Volturno River and in 9 sites located at different distances from it (Figure 4). The specific details are provided in Table 3.

Figure 4. Hydrographic network and sampling sites near the Volturno River.

Table 3. Sampling sites with their identification number (ID), location name, and coordinates from the Volturno River.

ID	Location	Coordinates	ID	Location	Coordinates
1	Volturno River mouth	40°48′54.03″ N 14°36′45.36″ E	6	1000 m west	40°43′42.46″ N 14°28′05.03″ E
2	500 m north	40°46′42.73″ N 14°34′00.48″ E	7	1000 m south	40°43′45.09″ N 14°28′05.17″ E
3	500 m west	40°46′00.34″ N 14°33′10.68″ E	8	1500 m north	40°43′35.68″ N 14°28′02.94″ E
4	500 m south	40°43′42.62″ N 14°28′07.89″ E	9	1500 m west	40°43′42.25″ N 14°27′59.97″ E
5	1000 m north	40°43′40.11″ N 14°28′06.45″ E	10	1500 m south	40°43′49.26″ N 14°27′59.82″ E

2.3. Extraction Procedure and Clean-Up

The analyses were performed as described previously [41]. Briefly, for PAH extraction, the sediment samples were air-dried, crushed, sieved in 250 μm particles, and then divided into portions of 5 g. The PAH concentrations were indicated as dry weight (ng/g dw) [42,43].

The PAH extraction was performed with a Soxhlet extractor using methylene chloride as solvent. Subsequently, the extracts, first purified using a column composed of sodium sulfate/silica gel and then eluted with 70 mL of a hexane:methylene chloride (7:3, *v/v*) solution, were evaporated to dryness and reduced to a final volume (500 µL) with the aid of a weak current of nitrogen. Finally, the extracts were analyzed using gas chromatography coupled with mass spectrometry (GC-MS). A TOC analyzer was used to evaluate the total organic carbon (TOC) content in the sediment samples (TOC-VCPH, Shimadzu Corp., Kyoto, Japan).

### 2.4. Instrumental Analysis, Quality Assurance, and Quality Control
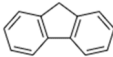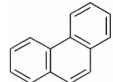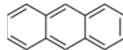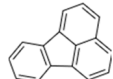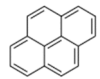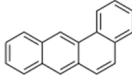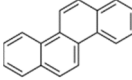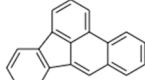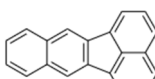
A TRACE^{TM}1310 gas chromatograph coupled to an ISQ^{TM}7000 single quadrupole mass spectrometer (GC-MS, Thermo Scientific, Waltham, MA, USA) was used, equipped with a capillary column TG-5MS (length 30 mm, inner diameter 0.25 mm, film thickness 0.25 µm) and helium as a gas carrier (constant flow of 1 mL/min), operating in the electronic ionization mode (EI) set to 70 eV. The injector operated at 280 °C, and the temperature of the detector was set to 300 °C. The acquisition was performed with the Selected Ion Monitoring (SIM) mode using two characteristic fragments for each selected analyte. A splitless injection mode was adopted with an injection volume of 1 µL. The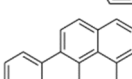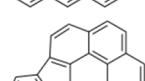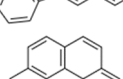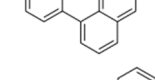 quantification of PAHs was carried out using response factors related to the respective internal standards based on a six-point calibration curve for individual PAHs (Dr. Ehrenstorfer GmbH, Augsburg, Germany) ($R^2 > 0.97$). Chrysene-d$_{12}$ was used as an internal standard for sample quantification. Before the analysis, all the glassware to be used was thoroughly washed with methanol, acetone, and dichloromethane and placed in the oven at 200 °C to minimize possible sources of contamination. The column temperature was set with different gradients: from 60 °C to 200 °C with an increase of 25 °C/min (kept for 2 min), to 270 °C increasing at 10 °C min^{-1} (kept for 6 min), and to 310 °C with a rise of 25 °C min^{-1} (kept for 10 min). The single ion monitoring mode (SIM) was used for the acquisition using characteristic ions for each target analyte. The 16 priority IPA, according to the WHO and USEPA, were evaluated (Table 4) [20,44].

Six-point calibration curves (5–10–50–250–500–1000 ng/L), procedural blanks, and sample triplicates were carried out for every set of samples. The PAH concentrations were calculated as dry weight (ng/g dw). The limits of detection (LOD) and quantification (LOQ) were evaluated as three and ten times the noise in blank samples, respectively. They were in the range of 1.5–1.9 ng g^{-1} and 5.1–6.3 ng g^{-1}, respectively. In the procedural blanks, analyzed as the samples, the PAHs showed a concentration below the LOD. Moreover, for individual PAHs, the recovery test values ranged from 80% to 97%, meeting the quality control criteria (70–130%). For the effective and reproducible detection and quantification of low concentrations of PAHs in sediments, the linear range, precision, limits of detection, and limits of quantification were performed. The precision of the method was determined using repeatability tests and was expressed as standard deviation (SD) (Tables S1–S3). The average of the results was used to estimate the precision of the method.

2.5. Human Health Risk Assessment

The human health risk assessment is useful in determining whether exposure to a chemical in a specific dose may cause an increase in the frequency of adverse effects on human health [39,42,45–47]. For the population, PAH exposure represents a health and hygiene risk, which is assessed as a carcinogenic risk. Therefore, the USEPA defined carcinogenic risk as the probability that an individual may develop cancer over a lifetime from exposure to a specific substance classified as mutagenic or carcinogenic. Thus, this risk assessment consists of two phases, which are the estimation of the probability of an event occurring and the study of the likely magnitude of its adverse effect over a specific time frame [48].

Table 4. The 16 Priority PAHs according to the United States Environmental Protection Agency (US EPA) and the World Health Organization (WHO) [20,44].

Name	Abbreviation	Molecular Formula	Number of Rings	Chemical Structure	Molecular Weight
Naphthalene	Nap	$C_{10}H_8$	2		128.2 g mol^{-1}
Acenaphthylene	Acy	$C_{12}H_8$	3		152.2 g mol^{-1}
Acenaphthalene	Ace	$C_{12}H_{10}$	3		154.2 g mol^{-1}
Fluorene	Flu	$C_{13}H_{10}$	3		166.2 g mol^{-1}
Phenanthrene	Phe	$C_{14}H_{10}$	3		178.2 g mol^{-1}
Anthracene	Ant	$C_{14}H_{10}$	3		178.2 g mol^{-1}
Fluoranthene	Fla	$C_{16}H_{10}$	4		202.3 g mol^{-1}
Pyrene	Pyr	$C_{16}H_{10}$	4		202.3 g mol^{-1}
Benzo[a]anthracene	BaA	$C_{18}H_{12}$	4		228.3 g mol^{-1}
Crysene	Chr	$C_{18}H_{12}$	4		228.3 g mol^{-1}
Benzo[b]fluoranthene	BbF	$C_{20}H_{12}$	5		252.3 g mol^{-1}
Benzo[k]fluoranthene	BkF	$C_{20}H_{12}$	5		252.3 g mol^{-1}
Benzo[a]pyrene	BaP	$C_{20}H_{12}$	5		252.3 g mol^{-1}
Indeno [123-cd]pyrene	IcdP	$C_{22}H_{12}$	6		276.3 g mol^{-1}
Benzo[ghi]perylene	BghiP	$C_{22}H_{12}$	6		276.3 g mol^{-1}
Dibenzo[a,h]anthracene	DahA	$C_{22}H_{14}$	5		278.3 g mol^{-1}

The incremental lifetime cancer risk (ILCR) due to exposure by direct ingestion and skin contact to PAHs present in the sediment was evaluated [49]. First, the doses of

contaminants taken up by human receptors through the two different exposure pathways considered were calculated according to Equations (1) and (2) [50]:

$$\text{Dose}_{\text{ing}} = \frac{C_s \times IR_s \times RAF_{\text{oral}} \times D_{\text{hours}} \times D_{\text{days}} \times D_{\text{weeks}} \times ED_{\text{years}}}{BW \times LE} \tag{1}$$

$$\text{Dose}_{\text{derm}} = \frac{C_s \times SA_h \times SL_h \times RAF_{\text{derm}} \times EF \times D_{\text{days}} \times D_{\text{weeks}} \times ED_{\text{years}}}{BW \times LE} \tag{2}$$

where:

Dose$_{\text{ingestion}}$ (mg/kg-day) indicates the dose from accidental sediment ingestion; Dose$_{\text{dermal}}$ (mg/kg-day) is the dose from skin contact with sediment; C_s (mg/kg) represents the concentration of the contaminant in the sediment; IR_s (kg/day) is the rate of accidental sediment ingestion; RAF$_{\text{oral}}$ indicates the relative absorption factor for the gastrointestinal tract; RAF$_{\text{derm}}$ (dimensionless) expresses the relative absorption factor for the skin. Moreover, the dose was evaluated based on the hours per day with exposure: 0–16/16 h for accidental ingestion of sediment (D$_{\text{hours}}$); days in a week with exposure [(0–7)/7 days] (D$_{\text{days}}$); weeks in a year with exposure [(0–52)/52 weeks] (D$_{\text{weeks}}$); total years with exposure (ED$_{\text{years}}$); surface of hands (assuming only hands are exposed) (SA$_h$ (cm^2); SL$_h$ (kg/cm^2-event) = Sediment load rate on exposed skin; EF (event/day) = Number of skin exposures per day; BW (kg) = receptor body weight; LE = life expectancy/average life expectancy expressed in years; CF (conversion coefficient) = 1 × 10^{-6} kg/mg.

Additionally, since Benzo(a)pyrene (BaP) is the most carcinogenic compound among the PAHs considered [10], all individual analyte concentrations were converted to the corresponding toxic equivalent concentrations of BaP. These concentrations are referred to as TEQ$_{\text{BaP}}$ or BaP$_{\text{eq}}$ and were obtained using the concentration product for toxic equivalence factor (TEF). The TEF factors for the 16 US EPA priority PAHs are shown in Table 5 [51].

Table 5. Equivalent toxicity factors (TEF) of the 16 PAHs [51].

Compound	TEF
Acenaphthalene (Ace)	0.001
Acenaphthylene (Acy)	0.001
Anthracene (Ant)	0.01
Benzo[a]anthracene (BaA)	0.1
Benzo[a]pyrene (BaP)	1
Benzo[b]fluoranthene (BbF)	0.1
Benzo[g,h,i]perylene (BghiP)	0.01
Benzo[k]fluoranthene (BkF)	0.1
Crysene (Chr)	0.01
Dibenzo[a,h]anthracene (DahA)	1
Fluoranthene (Fla)	0.001
Fluorene (Flu)	0.001
Indeno [1,2,3-cd] pyrene (IcdP)	0.1
Naphtalene (Nap)	0.001
Fenanthrene (Phe)	0.001
Pyrene (Pyr)	0.001

The total concentrations of PAHs were obtained using the sum of the calculated toxic equivalents for each compound in relation to BaP. BaPeq were calculated according to Equation (3) [52]:

$$\text{BaP}_{\text{eq}} = \Sigma C_s \times TEF_i \tag{3}$$

where C_s represents the average concentration of an individual PAH.

Humans can encounter the PAHs present in estuarine sediments by oral ingestion and dermal contact. As a result, in addition to calculating the doses of contaminants taken up

by human receptors, the incremental lifetime cancer risk by oral ingestion (ILCR$_{ingestion}$) and dermal contact (ILCR$_{dermal}$) was evaluated according to Equations (4) and (5) [49]:

$$\text{ILCR}_{ingestion} = \frac{C_s \times SF_{ingestion} \times \sqrt[3]{\frac{BW}{70}} \times IR_{ingestion} \times EF \times D_{years}}{BW \times AT \times 10^6} \tag{4}$$

$$\text{ILCR}_{dermal} = \frac{C_s \times SF_{dermal} \times \sqrt[3]{\frac{BW}{70}} \times AS \times AF \times ABS \times EF \times D_{years}}{BW \times AT \times 10^6} \tag{5}$$

where:

SF$_{ingestion}$ (Kg-day/mg) indicates the oral slope factor.
SF$_{dermal}$ (Kg-day/mg) is the dermal slope factor.
SA (cm^2/kg) represents the area of dermal contact with the sediment.
AF (mg/cm^2) is the skin absorption coefficient for the sediment.
ABS is the skin absorption coefficient for contaminants.
AT (years) is the average lifespan.

The parameters used for the calculation of the carcinogenic risk are shown in Table 6.

Table 6. Parameters used for the calculation of doses taken up by human receptors through different routes of exposure.

Parameter	Unit of Measure	Value	References
BW	Kg	70.7	[53]
IR$_{ingestion}$	Kg/days	2.00×10^{-5}	[54,55]
AT	Years	80	[56,57]
SA$_h$	cm^2	890	[53]
SL$_h$	Kg/cm^2-event	1.00×10^{-7}	[58]
D$_{hours}$	Hours	0–16/16 h	[59]
D$_{days}$	Days	0–7/7 days	[59]
D$_{weeks}$	Weeks	0–52/52 weeks	[59]
RAF$_{oral}$	-	1	[60]
ED$_{years}$	Years	60	[60]
RAF$_{derm}$ [a]	-	0.148	[61]
SF$_{ingestion}$ [a]	Kg-day/mg	2.3	[60]
SF$_{dermal}$ [a]	Kg-day/mg	25	[62]
EF	(event/day)	1	[63]
SA	cm^2/kg	5000	[64]
AF	mg/cm^2	0.04	[64]
ABS	/	0.1	[64]

[a] expressed in relation to BaP.

3. Results

3.1. PAH Concentrations in Sediment from the Sele River

The concentrations of the 16 USEPA priority PAHs obtained from instrumental analyses of sediment samples taken near the mouth of the Sele River are given in Table S1. In particular, the total concentration of the PAHs ranged from 632.42 ng g^{-1} dw (site 10) to 844.93 ng g^{-1} dw (at site 1), with an average value of 738.68 ng g^{-1} dw. Specifically, the concentrations ranged from 2.23 to 70.64 ng g^{-1} dw with an average value of 36.43 ng g^{-1} dw for PAHs with 2 rings (NaP), from 5.45 to 51.03 ng g^{-1} dw for 3-ring PAHs (Acy, Ace, Flu, Phe, Ant), from 0.70 to 74.6 ng g^{-1} dw for 4-ring PAHs (Flu, Pyr, BaA, Chr), from 39.12 to 154.99 ng g^{-1} dw for 5-ring PAHs (BbF, BkF, BaP, DahA), and from 3.01 to 75.13 ng g^{-1} dw for 6-ring PAHs (BghiP, IcdP). Figure 5 shows the individual concentrations of PAHs detected in sediment samples from different sampling sites. The figure reveals that the highest concentrations of PAHs were found at the mouth of the Sele River (site 1) and 500 m from the mouth in the southerly direction (site 8). The composition profile of PAHs in the

sediment is shown in Figure 6. PAHs with 5 rings were found in most test sites at 57.4% of the total PAHs in the sediment.
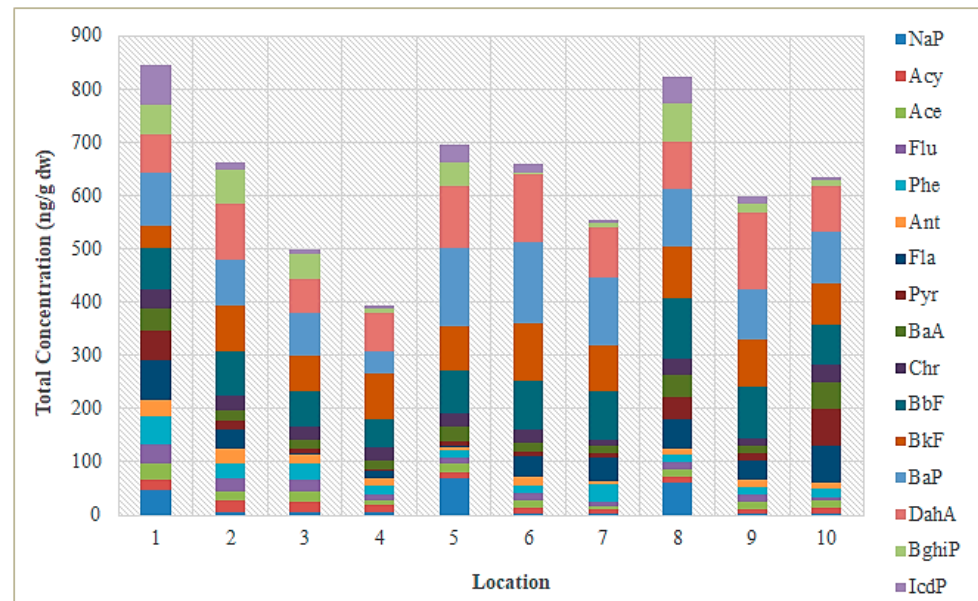

Figure 5. Concentrations of the 16 priority PAHs (ng/g dw) found in sediment samples from the Sele River at 10 sampling locations (April 2021).
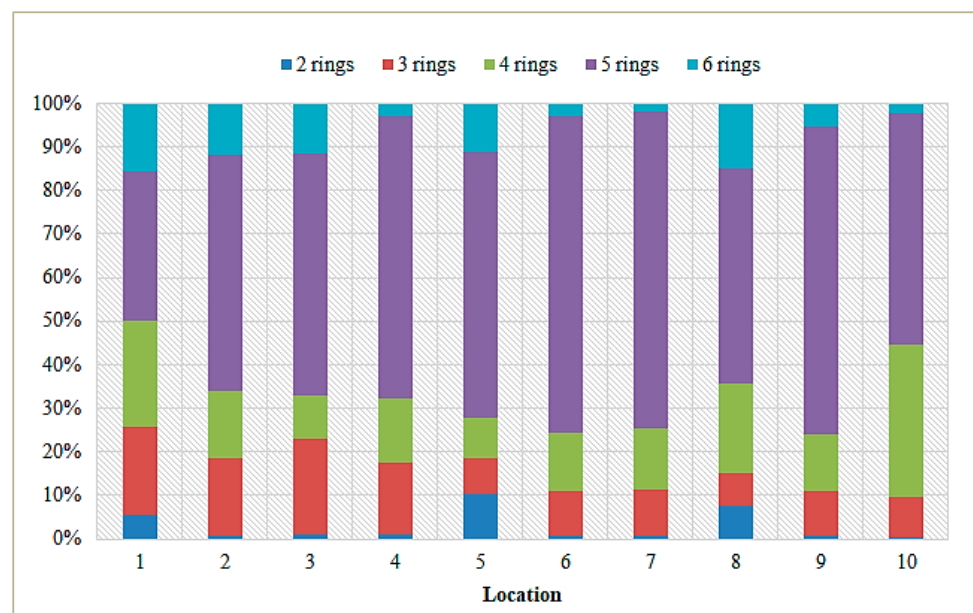

Figure 6. Composition profile of total PAHs in sediment samples from the Sele River.

3.2. PAH Concentrations in Sediment from the Sarno River

Data on PAH concentrations found in the Sarno River are indicated in Table S2 [39]. The total concentration of PAHs in the sediment ranged from 5.2 ng g^{-1} dw at the source of the river (site 1) to 678.6 ng g^{-1} dw at the point 150 m to the west of the mouth (site 9), with an average value of 266.9 ng g^{-1} dw. The measured PAH concentrations ranged from 0.2 to 31.6 ng g^{-1} dw with an average of 9.7 ng g^{-1} dw for 2-ring PAHs (Nap), from 0.2 to 46.3 ng g^{-1} dw for 3-ring PAHs (Acy, Ace, Flu, Phe, Ant), from 0.3 to 47.2 ng g^{-1} dw for 4-ring PAHs (Fla, Pyr, BaA, Chr), from 0.2 to 46.6 ng g^{-1} dw for 5-ring PAHs (BbF, BkF, BaP, DahA), and from 0.5 to 46.7 ng g^{-1} dw for 6-ring PAHs (BghiP, IcdP). Figure 7 shows the individual and total concentrations of PAHs found in the sediment samples taken from the

different sampling sites located near the mouth of the Sarno River. The figure indicates an increase in total PAH levels at the sampling point 150 m west of the river mouth (site 8). The composition profile of PAHs in the sediment is shown in Figure 8. Three-ring PAHs were found in most test sites, at a percentage of 47.3% of the total PAH amount in the sediment, followed by 5-ring PAHs at a percentage of 20.6%.
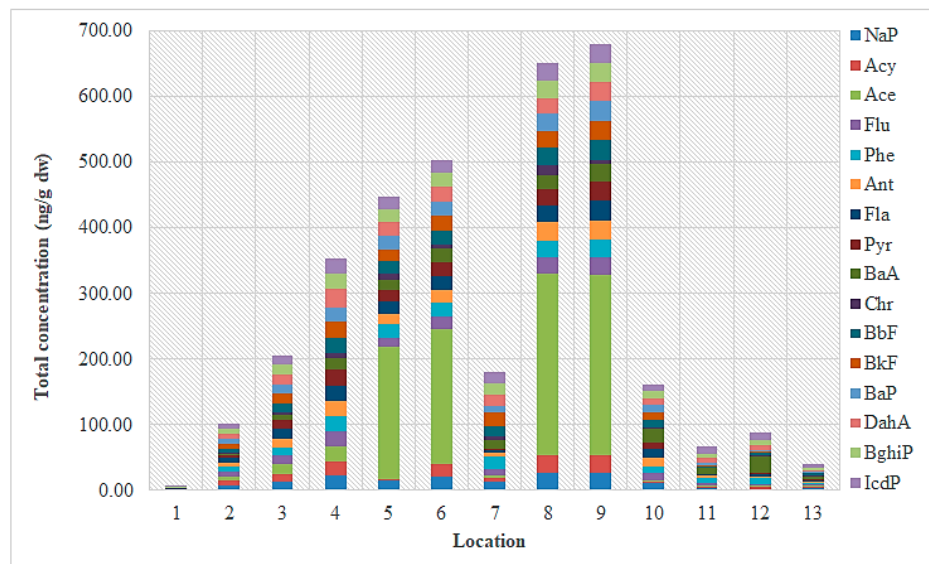

Figure 7. Concentrations of the 16 priority PAHs (ng/g dw) found in sediment samples from the Sarno River at the 13 sampling sites (April 2008).
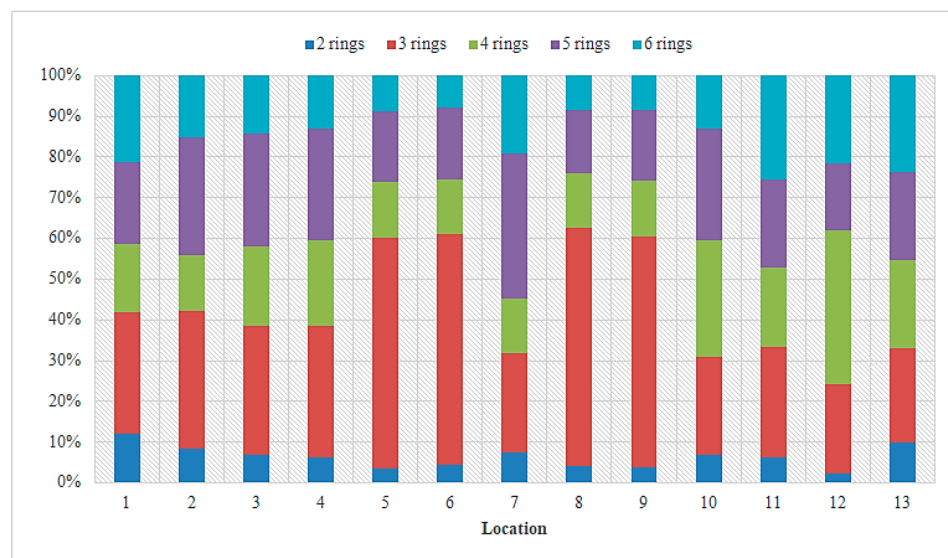

Figure 8. Composition profile of total PAHs in sediment samples from the Sarno River.

3.3. PAH Concentrations in Sediment from the Volturno River

Data on individual PAH concentrations found in the Volturno River are given in Table S3, while total concentrations were previously reported [40]. In detail, total concentrations were between 434.8 ng g^{-1} dw (site 8) and 872.1 ng g^{-1} dw (site 1), with an average value of 659.1 ng g^{-1} dw. For 2-ring PAHs (NaP), the levels ranged from 5.3 to 73.8 ng g^{-1} dw with an average value of 24.1 ng g^{-1} dw; for 3-ring PAHs (Acy, Ace, Flu, Phe, Ant), from 42.9 to 186.3 ng g^{-1} dw; for 4-ring PAHs (Fla, Pyr, BaA, Chr), from 61.7 ng g^{-1} dw to 199.7 ng g^{-1} dw; for 5-ring PAHs (BbF, BkF, BaP, DahA), from 262.7 to 507.1 ng g^{-1} dw; and for 6-ring PAHs (BghiP, IcdP), from 17.5 to 133.2 ng g^{-1} dw. Figure 9 shows the individual and total concentrations of PAHs found in the sediment samples taken at the different sampling sites

near the mouth of the Volturno River. The figure shows that the highest concentrations of PAHs were found at the mouth of the river (site 1) and 500 m from the mouth in the southerly direction (site 4). The composition profile of PAHs in sediment is shown in Figure 10. Five-ring PAHs were found in most of the test sites at 57,4% of the total PAHs in the sediment.
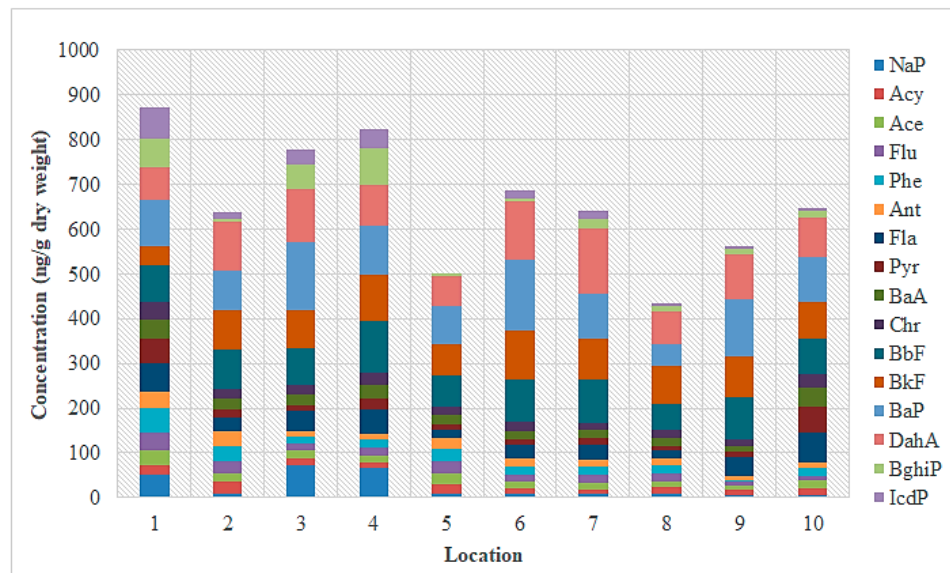

Figure 9. Concentrations of the 16 priority PAHs (ng/g dry weight) found in sediment samples from the Volturno River at 10 sampling locations (April 2018).
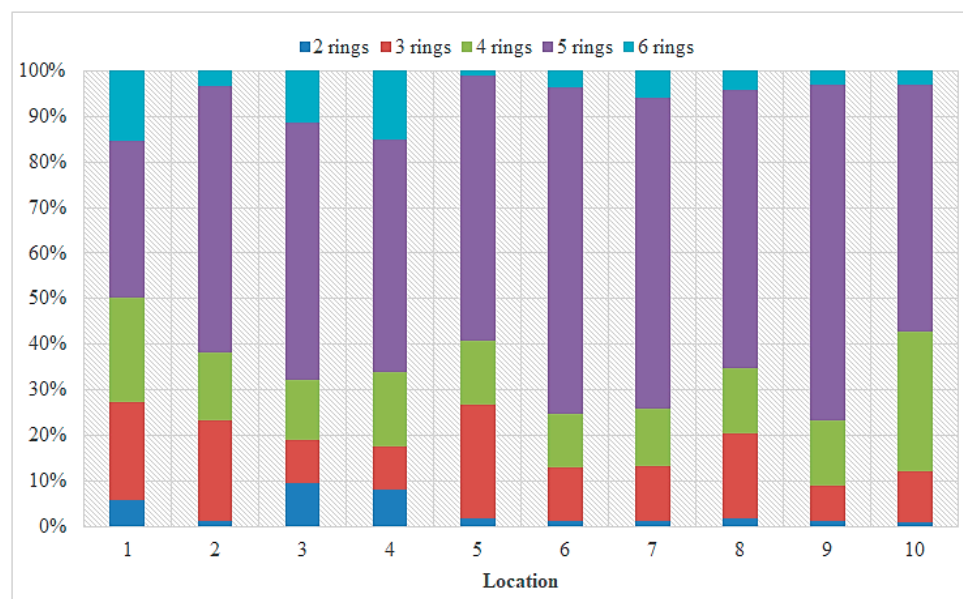

Figure 10. Composition profile of total PAHs in sediment samples from the Volturno River.

3.4. Evaluation of the Carcinogenic Risk for Human Health from Dermal and Accidental Ingestion Exposure to the PAHs Present in the Sediments of the Surface Waters

To assess the Carcinogenic Risk from exposure to PAHs present in estuarine sediments of the Sele, Volturno, and Sarno Rivers, doses of contaminants taken up by human receptors through the different routes of exposure were evaluated, and the results obtained are reported in Table 7. Particularly, for all three rivers, the doses of each individual PAH and the total doses relating to the entire class of compounds taken up by human receptors through dermal and oral exposure were calculated. The doses from accidental ingestion of PAHs from sediments (Dose$_{ingestion}$) were 7.86×10^{-4} mg Kg^{-1}/day for the Sele River, 8.13×10^{-4} mg Kg^{-1}/day

for the Volturno River, and 3.31×10^{-4} mg Kg^{-1}/day for the Sarno River. On the other hand, in relation to the doses of PAHs taken up by skin contact with sediment (Dose$_{dermal}$), the results were 3.23×10^{-5}, 1.36×10^{-5}, and 3.35×10^{-5} mg Kg^{-1}/day for the Sele, Sarno, and Volturno Rivers, respectively.

Table 7. Average total PAH concentrations (C$_s$), intakes by accidental ingestion (Dose$_{ingestion}$), and dermal contact (Dose$_{dermal}$) of PAH present in estuarine sediments of the Sele, Volturno, and Sarno Rivers and equivalent toxic concentrations (BaP$_{eq}$).

River	C$_s$ (mg Kg^{-1} dw)	Dose$_{ingestion}$ (mg Kg^{-1}/day)	Dose$_{dermal}$ (mg Kg^{-1}/day)	BaP$_{eq}$ (mg Kg^{-1} dw)
Sele	0.6360	7.86×10^{-4}	3.23×10^{-5}	2.23×10^{-1}
Sarno	0.2677	3.31×10^{-4}	1.36×10^{-5}	3.38×10^{-2}
Volturno	0.6577	8.13×10^{-4}	3.35×10^{-5}	2.30×10^{-1}

Moreover, to assess the carcinogenic and mutagenic potencies of PAHs in relation to BaP, the most carcinogenic compound among the PAH considered [10], the average concentrations of individual analytes were converted to the corresponding toxic equivalent concentrations (BaP$_{eq}$). The equivalent toxic concentrations (BaP$_{eq}$) obtained for the Sele, Volturno, and Sarno Rivers are given in Table 7.

Furthermore, the incremental risk of developing lifelong cancer expressed as ILCR was assessed for the exposure to PAHs by ingestion (ILCR$_{ingestion}$) and dermal contact (ILCR$_{dermal}$) [65]. The ILCR$_{ingestion}$ and ILCR$_{dermal}$ values obtained for Sele, Volturno, and Sarno Rivers are shown in Table 8.

Table 8. Incremental lifetime cancer risk values (ILCR$_{ingestion}$ and ILCR$_{dermal}$) due to exposure by ingestion and dermal contact from PAHs present in the estuarine sediments of the Sele, Volturno, and Sarno Rivers.

River	ILCR$_{ingestion}$ (mg Kg^{-1} dw)	ILCR$_{dermal}$ (mg Kg^{-1} dw)	ILCR$_{ingestion/dermal}$ [66] Cancerogenic Risk
Sele	3.11×10^{-13}	3.38×10^{-6}	If ILCR $< 1 \times 10^{-6}$ Low or Zero Risk
Sarno	1.31×10^{-13}	1.42×10^{-6}	If $1 \times 10^{-6} <$ ILCR $< 1 \times 10^{-4}$ Medium Risk
Volturno	3.22×10^{-13}	3.50×10^{-6}	If ILCR $>1 \times 10^{-4}$ High Risk

The values obtained for carcinogenic risk due to exposure to PAHs by ingestion (ILCR$_{ingestion}$) and dermal contact (ILCR$_{dermal}$) were found to be comparable for the three rivers. According to the USEPA, the ILCR values were interpreted by reference to three ranges, each of which is associated with a risk of carcinogenicity: an ILCR value $< 1 \times 10^{-6}$ is associated with a low or zero carcinogenic risk; ILCR values between 1×10^{-4} and 1×10^{-6} are indicators of a moderate carcinogenic risk; and an ILCR value higher than 1×10^{-4} corresponds to a high carcinogenic risk associated with exposure to PAHs in sediment [66,67]. The ILCR$_{ingestion}$ values obtained for the three rivers were found to be much lower than the ILCR$_{dermal}$, indicating that the risk of cancer associated with dermal contact exposure to PAHs present in estuarine sediments may be higher than that associated with accidental ingestion exposure. Specifically, the ILCR$_{ingestion}$ and ILCR$_{dermal}$ values obtained for all sediment samples taken near the mouth of the Sele River ranged between 6.69×10^{-15} and 3.11×10^{-13} and 7.27×10^{-8} and 3.38×10^{-6}, respectively. The ILCR$_{ingestion}$ and ILCR$_{dermal}$ values obtained for the Sarno River ranged between 2.45×10^{-15} and 1.31×10^{-13} and 2.66×10^{-8} and 1.42×10^{-6}, respectively. For the Volturno River, the ILCR$_{ingestion}$ values were between 8.23×10^{-15} and 3.22×10^{-13}, while those of ILCR$_{dermal}$ were between 8.95×10^{-8} and 3.50×10^{-6}. Thus, the risk of cancer associated with exposure to PAHs by ingestion of estuarine sediments of the Sele, Sarno, and Volturno Rivers was found to be low at all sampling sites. However, based on the ILCR$_{dermal}$ values obtained, the risk of cancer associated with exposure by dermal contact with the PAHs present in the sediments

was found to be moderate (average $ILCR_{dermal}$ for the three rivers of 2.77×10^{-6}). In addition, the values of the $ILCR_{ingestion}$ and $ILCR_{dermal}$ indices for sediment samples taken at sites with the highest concentrations of PAHs were evaluated. For the Sele and Volturno Rivers, the assessment was carried out at the mouth (site 1), for which total PAH concentrations of 0.8449 and 0.8721 mg Kg^{-1} dw were found, respectively. For the Sarno River, the assessment was carried out at the sampling site 150 m to the west of the estuary (site 9), where a total concentration of PAHs of 0.6792 mg Kg^{-1} dw was found. The results obtained for the three rivers are shown in Table 9.

Table 9. Incremental lifetime cancer risk values ($ILCR_{ingestion}$ and $ILCR_{dermal}$) due to exposure by ingestion and dermal contact to the highest PAHs levels found in the sediment samples of the Sele, Volturno, and Sarno Rivers.

River	$ILCR_{ingestion}$ (mg Kg^{-1} dw)	$ILCR_{dermal}$ (mg Kg^{-1} dw)	$ILCR_{ingestion/dermal}$ [66] Cancerogenic Risk
Sele	4.14×10^{-13}	4.50×10^{-6}	If ILCR < 1×10^{-6} Low or Zero Risk
Sarno	3.33×10^{-13}	3.61×10^{-6}	If 1×10^{-6} < ILCR < 1×10^{-4} Medium Risk
Volturno	4.27×10^{-13}	4.64×10^{-6}	If ILCR > 1×10^{-4} High Risk

The $ILCR_{ingestion}$ values obtained for the three rivers at the sampling sites with the highest PAH concentrations were $<1 \times 10^{-6}$ (order of 10^{-13}), suggesting that the risk of cancer associated with exposure by ingestion of PAHs present in estuarine sediments was low or zero. On the other hand, the $ILCR_{dermal}$ values obtained for the three rivers at the sampling sites with the highest PAH concentrations were in the order of 10^{-6}, suggesting that the risk of cancer associated with dermal contact exposure to PAHs present in estuarine sediments was moderate. In fact, as stated also by Cheng et al., ILCR values between 1×10^{-4} and 1×10^{-6} are associated with a moderate carcinogenic risk [66,67]. Thus, on the basis of the ILCR values obtained by taking into account total PAH concentrations at all sites or considering only the total concentrations recorded at the most polluted sites, the risk of cancer associated with exposure by ingestion was found to be low or zero, but the risk associated with dermal contact exposure of PAHs present in estuarine sediments of the Sele, Volturno, and Sarno Rivers is moderate. Thus, since these areas were previously considered potentially contaminated according to Italian environmental law (D. Lgs. 152/2006), and as stated by Albanese et al., who assessed an incremental lifetime cancer risk higher than 1×10^{-5} for the city of Naples [9], a continuous monitoring of potentially hazardous substances is necessary to ensure the protection of public health.

4. Conclusions

This paper presents for the first time an assessment of the carcinogenic risk to human health from dermal and ingestion exposure to PAHs present in sediments of the main surface water streams of the Campania Region, southern Italy. The paper also provides information on the concentrations, spatial distribution, and composition profiles of the PAHs detected in sediments collected near the Sele, Sarno, and Volturno River estuaries. The results obtained indicate that the risk of cancer following oral exposure to PAHs in estuarine sediments, expressed as incremental lifetime cancer risk ($ILCR_{ingestion}$), is low, unlike the risk from accidental skin exposure, which was moderate with $ILCR_{dermal}$ values between 1×10^{-4} and 1×10^{-6}. This calls for ongoing assessment of the carcinogenic risk to human health posed by cutaneous and oral exposure to PAHs, as well as constant monitoring of PAH concentrations in surface water sediments in the Campania Region. In conclusion, this study represents a starting point for future studies aimed at assessing the risk of carcinogenicity to human health due to exposure to the PAHs in order to provide support for pollution prevention measures and ecological restoration strategies for rivers, as well as for the preservation of the general well-being.

References

1. Huang, Y.; Zhang, W.; Pang, S.; Chen, J.; Bhatt, P.; Mishra, S.; Chen, S. Insights into the microbial degradation and catalytic mechanisms of chlorpyrifos. *Environ. Res.* **2021**, *194*, 110660. [CrossRef]
2. Zhang, A.; Zhao, S.; Wang, L.; Yang, X.; Zhao, Q.; Fan, J.; Yuan, X. Polycyclic aromatic hydrocarbons (PAHs) in seawater and sediments from the northern Liaodong Bay, China. *Mar. Pollut. Bull.* **2016**, *113*, 592–599. [CrossRef] [PubMed]
3. Brion, D.; Pelletier, É. Modelling PAHs adsorption and sequestration in freshwater and marine sediments. *Chemosphere* **2005**, *61*, 867–876. [CrossRef]
4. Shahsavari, E.; Schwarz, A.; Aburto-Medina, A.; Ball, A.S. Biological degradation of polycyclic aromatic compounds (PAHs) in soil: A current perspective. *Curr. Pollut. Rep.* **2019**, *5*, 84–92. [CrossRef]
5. Guo, W.; He, M.; Yang, Z.; Lin, C.; Quan, X.; Wang, H. Distribution of polycyclic aromatic hydrocarbons in water, suspended particulate matter and sediment from Daliao River watershed, China. *Chemosphere* **2007**, *68*, 93–104. [CrossRef]
6. Awe, A.A.; Opeolu, B.O.; Olatunji, O.S.; Fatoki, O.S.; Jackson, V.A.; Snyman, R. Occurrence and probabilistic risk assessment of PAHs in water and sediment samples of the Diep River, South Africa. *Heliyon* **2020**, *6*, e04306. [CrossRef]
7. Lin, Y.; Ma, Y.; Qiu, X.; Li, R.; Fang, Y.; Wang, J.; Hu, D. Sources, transformation, and health implications of PAHs and their nitrated, hydroxylated, and oxygenated derivatives in PM2.5 in Beijing. *J. Geophys. Res. Atmos.* **2015**, *120*, 7219–7228. [CrossRef]
8. CCME (Canadian Council of Ministers of the Environment). *Canadian Soil Quality Guidelines for Carcinogenic and Other Polycyclic Aromatic Hydrocarbons (Environmental and Human Health Effects)*; Canadian Council of Ministers of the Environment: Winnipeg, MB, Canada, 2008.
9. Albanese, S.; Fontaine, B.; Chen, W.; Lima, A.; Cannatelli, C.; Piccolo, A.; De Vivo, B. Polycyclic aromatic hydrocarbons in the soils of a densely populated region and associated human health risks: The Campania Plain (Southern Italy) case study. *Environ. Geochem. Health* **2015**, *37*, 1–20. [CrossRef] [PubMed]
10. Wang, Y.; Liu, M.; Dai, Y.; Luo, Y.; Zhang, S. Health and ecotoxicological risk assessment for human and aquatic organism exposure to polycyclic aromatic hydrocarbons in the Baiyangdian Lake. *Environ. Sci. Pollut. Res.* **2021**, *28*, 574–586. [CrossRef]
11. Omar, W.A.M.; Mahmoud, H.M. Risk assessment of polycyclic aromatic hydrocarbons (PAHs) in River Nile up-and downstream of a densely populated area. *J. Environ. Sci. Health A* **2017**, *52*, 166–173. [CrossRef]
12. Zhu, Y.; Liang, B.; Xia, W.; Gao, M.; Zheng, H.; Chen, J.; Tian, M. Assessing potential risks of aquatic polycyclic aromatic compounds via multiple approaches: A case study in Jialing and Yangtze Rivers in downtown Chongqing, China. *Environ. Pollut.* **2022**, *294*, 118620. [CrossRef] [PubMed]
13. Adeniji, A.O.; Okoh, O.O.; Okoh, A.I. Levels of polycyclic aromatic hydrocarbons in the water and sediment of Buffalo River Estuary, South Africa and their health risk assessment. *Arch. Environ. Contam. Toxicol.* **2019**, *76*, 657–669. [CrossRef]
14. Regional Office for Europe. *Air Quality Guidelines for Europe*, 2nd ed.; World Health Organization, Regional Office for Europe: Geneva, Switzerland, 2000; Available online: https://apps.who.int/iris/handle/10665/107335 (accessed on 16 September 2022).
15. Rocha, M.J.; Dores-Sousa, J.L.; Cruzeiro, C.; Rocha, E. PAHs in water and surface sediments from Douro River estuary and Porto Atlantic coast (Portugal)-impacts on human health. *Environ. Monit. Assess.* **2017**, *189*, 1–14. [CrossRef] [PubMed]
16. Khan, A.; Ahsan, A.; Farooq, M.A.; Naveed, M.; Li, H. Role of polycyclic aromatic hydrocarbons as EDCs in metabolic disorders. In *Endocrine Disrupting Chemicals-induced Metabolic Disorders and Treatment Strategies*; Springer: Cham, Switzerland, 2021; pp. 323–341.

17.　Gaber, M.; Sequely, A.A.; Monem, N.A.; Balbaa, M. Effect of polyaromatic hydrocarbons on cellular cytochrome P450 1A induction. *Ocean Coast Manag.* **2021**, *69*, 21026. [CrossRef]

18.　Lee, T.Y.; Tseng, Y.H. The potential of phytochemicals in oral cancer prevention and therapy: A review of the evidence. *Biomolecules* **2020**, *10*, 1150. [CrossRef]

19.　Kobets, T.; Smith, B.P.; Williams, G.M. Food-Borne Chemical Carcinogens and the Evidence for Human Cancer Risk. *Foods* **2022**, *11*, 2828. [CrossRef] [PubMed]

20.　Joint WHO/Convention Task Force on the Health Aspects of Air Pollution; World Health Organization. *Health Risks of Persistent Organic Pollutants from Long-Range Transboundary Air Pollution*; WHO Regional Office for Europe: Copenhagen, Denmark, 2003; Available online: https://apps.who.int/iris/handle/10665/107471 (accessed on 16 September 2022).

21.　IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Air pollution, Part 1, some non-heterocyclic polycyclic aromatic hydrocarbons and some related industrial exposure. *IARC Monogr. Eval. Carcinog. Risks Hum.* **2010**, *92*, 1–853. Available online: https://pubmed.ncbi.nlm.nih.gov/21141735/ (accessed on 3 October 2022).

22.　Tay, C.K.; Doamekpor, L.K.; Mohammed, S.; Dartey, G.; Kuddy, R.; Fianyaglo, E.; Mawuena, M. Health risk assessment and source identification of Polycyclic Aromatic Hydrocarbons (PAHs) in commercially available singed cowhide within the Greater Accra Region, Ghana. *West Afr. J. Appl. Ecol.* **2022**, *30*, 13–34.

23.　Ravindra, K.; Sokhi, R.; Van Grieken, R. Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmos. Environ.* **2008**, *42*, 2895–2921. [CrossRef]

24.　Campling, B.G.; El-Deiry, W.S. Clinical implications of p53 mutations in lung cancer. *Lung Cancer* **2003**, *75*, 53–78.

25.　Unwin, J.; Cocker, J.; Scobbie, E.; Chambers, H. An assessment of occupational exposure to polycyclic aromatic hydrocarbons in the UK. *Ann. Occup. Hyg.* **2006**, *50*, 395–403. [CrossRef]

26.　Kim, K.H.; Jahan, S.A.; Kabir, E.; Brown, R.J. A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. *Environ. Int.* **2013**, *60*, 71–80. [CrossRef] [PubMed]

27.　Sun, K.; Song, Y.; He, F.; Jing, M.; Tang, J.; Liu, R. A review of human and animals exposure to polycyclic aromatic hydrocarbons: Health risk and adverse effects, photo-induced toxicity and regulating effect of microplastics. *Sci. Total Environ.* **2021**, *773*, 145403. [CrossRef] [PubMed]

28.　Gunter, M.J.; Divi, R.L.; Kulldorff, M.; Vermeulen, R.; Haverkos, K.J.; Kuo, M.M.; Sinha, R. Leukocyte polycyclic aromatic hydrocarbon–DNA adduct formation and colorectal adenoma. *Carcinogenesis* **2007**, *28*, 1426–1429. [CrossRef] [PubMed]

29.　John, K.; Ragavan, N.; Pratt, M.M.; Singh, P.B.; Al-Buheissi, S.; Matanhelia, S.S.; Martin, F.L. Quantification of phase I/II metabolizing enzyme gene expression and polycyclic aromatic hydrocarbon–DNA adduct levels in human prostate. *The Prostate* **2009**, *69*, 505–519. [CrossRef]

30.　Garcia-Suastegui, W.A.; Huerta-Chagoya, A.; Carrasco-Colín, K.L.; Pratt, M.M.; John, K.; Petrosyan, P.; Gonsebatt, M.E. Seasonal variations in the levels of PAH–DNA adducts in young adults living in Mexico City. *Mutagenesis* **2010**, *26*, 385–391. [CrossRef] [PubMed]

31.　Srogi, K. Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: A review. *Environ. Chem. Lett.* **2007**, *5*, 169–195. [CrossRef]

32.　Diggs, D.L.; Harris, K.L.; Rekhadevi, P.V.; Ramesh, A. *Tumor.* microsomal metabolism of the food toxicant, benzo (a) pyrene, in Apc Min mouse model of colon cancer. *Tumor. Biol.* **2012**, *33*, 1255–1260. [CrossRef]

33.　Wells, P.G.; Lee, C.J.; McCallum, G.P.; Perstin, J.; Harper, P.A. Receptor-and reactive intermediate-mediated mechanisms of teratogenesis. In *Adverse Drug Reactions*; Springer: Berlin/Heidelberg, Germany, 2010; Volume 43, pp. 221–242. [CrossRef]

34.　Drwal, E.; Rak, A.; Gregoraszczuk, E.L. Polycyclic aromatic hydrocarbons (PAHs)—Action on placental function and health risks in future life of newborns. *Toxicology* **2019**, *411*, 133–142. [CrossRef]

35.　Anyahara, J.N. Effects of Polycyclic Aromatic Hydrocarbons (PAHs) on the environment: A systematic review. *Int. J. Adv. Acad. Res.* **2021**, *7*, e7303. [CrossRef]

36.　Ambade, B.; Sethi, S.S.; Giri, B.; Biswas, J.K.; Bauddh, K. Characterization, behavior, and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in the estuary sediments. *Bull. Environ. Contam. Toxicol.* **2022**, *108*, 243–252. [CrossRef]

37.　Li, Y.; Liu, M.; Hou, L.; Li, X.; Yin, G.; Sun, P.; Zheng, D. Geographical distribution of polycyclic aromatic hydrocarbons in estuarine sediments over China: Human impacts and source apportionment. *Sci. Total Environ.* **2021**, *768*, 145279. [CrossRef]

38.　Du, J.; Jing, C. Anthropogenic PAHs in lake sediments: A literature review (2002–2018). *Environ. Sci. Process. Impacts* **2018**, *20*, 1649–1666. [CrossRef] [PubMed]

39.　Montuori, P.; Triassi, M. Polycyclic aromatic hydrocarbons loads into the Mediterranean Sea: Estimate of Sarno River inputs. *Mar. Pollut. Bull.* **2012**, *64*, 512–520. [CrossRef]

40.　Montuori, P.; De Rosa, E.; Di Duca, F.; Provvisiero, D.P.; Sarnacchiaro, P.; Nardone, A.; Triassi, M. Estimation of Polycyclic Aromatic Hydrocarbons Pollution in Mediterranean Sea from Volturno River, Southern Italy: Distribution, Risk Assessment and Loads. *Int. J. Environ. Res. Public Health.* **2021**, *18*, 1383. [CrossRef]

41.　Montuori, P.; De Rosa, E.; Di Duca, F.; De Simone, B.; Scippa, S.; Russo, I.; Triassi, M. Polycyclic Aromatic Hydrocarbons (PAHs) in the Dissolved Phase, Particulate Matter, and Sediment of the Sele River, Southern Italy: A Focus on Distribution, Risk Assessment, and Sources. *Toxics* **2022**, *10*, 401. [CrossRef] [PubMed]

42. Lin, L.; Dong, L.; Meng, X.; Li, Q.; Huang, Z.; Li, C.; Li, R.; Yang, W.; Crittenden, J. Distribution and sources of polycyclic aromatic hydrocarbons and phthalic acid esters in water and surface sediment from the Three Gorges Reservoir. *J. Environ. Sci.* **2018**, *69*, 271–280. [CrossRef] [PubMed]

43. USEPA (United States Environmental Protection Agency). *Method 3540C. Soxhlet Extraction*; USEPA: Washington, DC, USA, 1996.

44. US Environmental Protection Agency. *Protocol for Equipment Leak Emission Estimates*; EPA-453/R-95—17; US Environmental Protection Agency: Washington, DC, USA, 1995.

45. Wcisło, E.; Ioven, D.; Kucharski, R.; Szdzuj, J. Human health risk assessment case study: An abandoned metal smelter site in Poland. *Chemosphere* **2002**, *47*, 507–515. [CrossRef] [PubMed]

46. Li, Y.L.; Liu, Y.G.; Liu, J.L.; Zeng, G.M.; Li, X. Effects of EDTA on lead uptake by Typha oreentalis Presl: A new lead-accumulating species in southern China. *Bull. Environ. Contam. Toxicol.* **2008**, *81*, 36–41. [CrossRef]

47. Li, Y.; Liu, J.; Cao, Z.; Lin, C.; Yang, Z. Spatial distribution and health risk of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in the water of the Luanhe River basin, China. *Environ. Monit. Assess.* **2010**, *163*, 1–13. [CrossRef]

48. Gerba, C.P.; Pepper, I.L.; Gerb, C.P.; Brusseau, M. *Risk Assessment. Environmental and Pollution Science*; Academic Press, Elsevier: San Diego, CA, California, 2006.

49. Han, J.; Liang, Y.; Zhao, B.; Wang, Y.; Xing, F.; Qin, L. Polycyclic aromatic hydrocarbon (PAHs) geographical distribution in China and their source, risk assessment analysis. *Environ. Pollut.* **2019**, *251*, 312–327. [CrossRef]

50. Akpan, A.D.; Okori, B.S.U.; Ekpechi, D.C. Human Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Water Samples around Eket Metropolis, Akwa Ibom State, Nigeria. *Asian J. Environ. Sci.* **2022**, *19*, 58–71. [CrossRef]

51. Nisbet, I.C.T.; LaGoy, P.K. Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). *Regul. Toxicol. Pharmacol.* **1992**, *16*, 290–300. [CrossRef]

52. Deelaman, W.; Choochuay, C.; Pongpiachan, S.; Han, Y. Ecological and health risks of polycyclic aromatic hydrocarbons in the sediment core of Phayao Lake, Thailand. *J. Exp. Sci. Environ. Epidemiol.* **2023**, *2*, 3. [CrossRef]

53. Richardson, G.M. *Compendium of Canadian Human Exposure Factors for Risk Assessment*; O'Connor Associates Environmental Incorporated: Ottawa, ON, Canada, 1997.

54. Khiari, N.; Charef, A.; Atoui, A.; Azouzi, R.; Khalil, N.; Khadhar, S. Southern Mediterranean coast pollution: Long-term assessment and evolution of PAH pollutants in Monastir Bay (Tunisia). *Mar. Pollut. Bull.* **2021**, *167*, 112268. [CrossRef] [PubMed]

55. MassDEP. *Technical Update: Calculation of Enhanced Soil Ingestion Rate*; MassDEP: Boston, MA, USA, 2002.

56. Health Canada. *Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals (DQRAChem.)*; Health Canada: Ottawa, ON, Canada, 2010.

57. Haney Jr, J.T.; Forsberg, N.D.; Hoeger, G.C.; Magee, B.H.; Meyer, A.K. Risk assessment implications of site-specific oral relative bioavailability factors and dermal absorption fractions for polycyclic aromatic hydrocarbons in surface soils impacted by clay skeet target fragments. *Regul. Toxicol. Pharmacol.* **2020**, *113*, 104649. [CrossRef]

58. Kissel, J.C.; Richter, K.Y.; Fenske, R.A. Field measurement of dermal soil loading attributable to various activities: Implications for exposure assessment. *Risk Anal.* **1996**, *16*, 115–125. [CrossRef]

59. Albanese, S.; Taiani, M.V.E.; De Vivo, B.; Lima, A. An environmental epidemiological study based on the stream sediment geochemistry of the Salerno province (Campania region, Southern Italy). *J. Geochem. Explor.* **2013**, *131*, 59–66. [CrossRef]

60. Alberico, I.; Amato, V.; Aucelli, P.P.C.; D'Argenio, B.; Di Paola, G.; Pappone, G. Historical shoreline change of the Sele Plain (Southern Italy): The 1870–2009 time window. *J. Coast. Res.* **2012**, *28*, 1638–1647. [CrossRef]

61. Moody, R.P.; Joncasa, J.; Richardsonb, M.; Chua, I. Contaminated soils (I): In vitro dermal absorption of benzo[a]pyrene in human skin. *J. Toxicol. Environ. Health Part A* **2007**, *70*, 1858–1865. [CrossRef]

62. Knafla, A.; Phillipps, K.A.; Brecher, R.W.; Petrovic, S.; Richardson, M. Development of a dermal cancer slope factor for benzo[a]pyrene. *Regul. Toxicol. Pharmacol.* **2006**, *45*, 159–168. [CrossRef]

63. Grmasha, R.A.; Al-sareji, O.J.; Salman, J.M.; Hashim, K.S. Polycyclic aromatic hydrocarbons (PAHs) in urban street dust within three land-uses of Babylon governorate, Iraq: Distribution, sources, and health risk assessment. *J. King Saud Univ. Eng. Sci.* **2020**, *34*, 231–239. [CrossRef]

64. Huang, B.; Liu, M.; Bi, X.; Chaemfa, C.; Ren, Z.; Wang, X.; Fu, J. Phase distribution, sources and risk assessment of PAHs, NPAHs and OPAHs in a rural site of Pearl River Delta region, China. *Atmos. Pollut. Res.* **2014**, *5*, 210–218. [CrossRef]

65. Srivastava, P.; Sreekrishnan, T.R.; Nema, A.K. Human health risk assessment and PAHs in a stretch of river Ganges near Kanpur. *Environ. Monit. Assess.* **2017**, *189*, 445. [CrossRef] [PubMed]

66. USEPA (US Environmental Protection Agency). *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final*; EPA/540/R/99/005 OSWER 9285.7-02EP PB99-963312 July 2004; Office of Superfund Remediation and Technology Innovation: Washington, DC, USA, 2004.

67. Cheng, J.; Wang, X.; Zheng, B.; Zhang, X.; Han, J. Evaluation of distribution characteristics and health risk of polycyclic aromatic hydrocarbons in sediments: From the perspective of land-ocean coordination. *J. Hydrol* **2022**, *607*, 127514. [CrossRef]