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TRACING PESTICIDES AND PHARMACEUTICALS IN WATER AND SEDIMENTS OF THE DANUBE DELTA

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Abstract

The Danube Delta is listed on UNESCO's World Heritage List for its exceptional value, attributed to the numerous natural ecosystems with remarkable characteristics and high biodiversity that have been preserved in an almost original state. Despite the significant environmental initiatives implemented in recent years, this place remains at risk from both natural and human-made stresses that could alter its ecosystems. This study focuses on determining the contamination degree with emerging and persistent pollutants in the deltaic and pre-deltaic Danube zone. In the present investigation, the pharmaceutical compounds in water samples and pesticides in sediment samples were assessed by considering the physicochemical properties of the targeted contaminants and their interactions with ecosystem matrices. Among the analysed water samples, the compound caffeine recorded the highest concentration (17.33 ng/L), while the compound carbamazepine registered the lowest value, 0.31 ng/L. The sediment samples were freeze-dried and analysed in terms of organochlorine and organophosphorus pesticides. The highest pesticide concentrations were identified in the terminal sampling point, including 3.45 ng/g of dichlorodiphenyltrichloroethane (DDT). The presence of both persistent and emerging pollutants in the Danube Delta imposes permanent monitoring to maintain biodiversity and the best possible environmental conditions.

Key words*: Danube Delta, pesticides, pharmaceuticals, sediments, water.*

INTRODUCTION

The Danube Delta is a biodiversity sanctuary, providing habitat to numerous unique, exotic, and important species with considerable conservation and commercial importance (Bănăduc et al., 2016). It is one of the most important wetland ecosystems for animals on the continent, as it is the second biggest river delta in Europe and the largest natural wetland still in existence (ICPDR, n.d.). Over 300 bird species and 45 freshwater fish species may be found in the Danube Delta's various lakes and marshes (UNESCO World Heritage, n.d.). This area of rich biodiversity is greatly impacted by upstream pollution and discharge modification (ICPDR, n.d.). Water quality has undergone significant changes in the second half of the 20th century as a result of increased pressure from industrial and hydrotechnical activities, urban development, and agriculture. These changes have affected the Danube's physical conditions (suspended sediment, bedload transport, temperature), chemical (emerging pollutants, nitrite, nitrate, phosphorous, and ammonium), and biological (faecals, species loss, and biological community alterations caused by invasive organisms) (Mănoiu & Crăciun, 2021). Additionally, monitoring the quality of water by assessing the concentration of pollutants in surface and ground water has an immediate connection to human health (Iticescu et al., 2014). Surface river systems are contaminated by industrial sites and agricultural operations that are situated close to bodies of water, endangering aquatic life (Zlati et al., 2023). Pesticides, pharmaceuticals, microbiological contaminants, endocrine disruptors, heavy metals, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls have all been identified by many monitoring studies (Chiţescu et al., 2021). The Danube is particularly susceptible to agricultural chemical contamination, which has an impact on regional

biodiversity as well as the quality of drinking water. Because of their environmental persistence, accumulation in biological organisms, and concerns about ecosystems and human health, a considerable number of pesticides are identified as persistent organic pollutants (Matei et al., 2025). Persistent organic pollutants are nonpolar organic chemicals that are potentially hazardous at threshold levels and have strong bioaccumulation and stability characteristics (Chiţescu et al., 2021). Because of their strong hydrophobicity, they tend to absorb into solid particles (Katsoyiannis & Samara, 2005). Numerous types of human and veterinary antibiotics, as well as human prescription and over-the-counter medications, such as antiepileptics, NSAIDs, blood lipid regulators, antidepressants, β-blockers, and analgesics, are among the pharmaceutical chemicals most frequently found in aquatic systems (Chitescu et al., 2015). The Danube Delta is a topical hotspot for assessing the combined presence of contaminants since it is the last accumulation area of the Danube River basin and is constantly impacted by incoming agricultural, local, and industrial discharges. In the context of the Water Framework Directive (WFD) which emphasizes maintaining both qualitative and quantitative status of water bodies, it is now essential to evaluate the ecological status in terms of chemical pollution. This study aims to perform an evaluation of both pesticides and pharmaceuticals in the Danube Delta area. The monitoring of these emerging and persistent organic pollutants is essential for many reasons: a) the protection and preservation of a unique ecosystem, b) the possibility of entering the food chain through drinking water and biota, c) the impact on organisms' health, and d) the need to establish concentration limits. Moreover, this paper fills a scientific gap in understanding the combined impact of contaminants on the aquatic ecosystem, with particular focus on a highly vulnerable and understudied area.

MATERIALS AND METHODS

In order to characterize the pesticides from the sediment and pharmaceuticals from the water, the samples were collected according to the specificity of each class of compound to ensure their representativeness. A total of 6 water samples and 6 sediment samples were taken from the Sulina branch in May 2026, and these were chronologically coded according to the distance to the spillway (1 meaning the farthest to the spillway and 6 meaning the closest point to the spillway: Partizani, Maliuc, Gorgova, Crișan, Sulina Intermediar, and Sulina). Water samples were collected from a depth of 20 cm in prewashed containers and sediment samples were collected using a dredge and transferred to different specific containers for each target analysis. In Table 1, the coordinates of the samples are presented.

Table 1. Geographical coordinates of the samples

Sample codes	Sampling stations	Geographical coordinates
1	Partizani	45.19330, 28.95869
2	Maliuc	45.17459, 29.11427
3	Gorgova	45.18153, 29.17888
4	Crișan	45.17358, 29.42541
5	Intermediate Sulina	45.18125, 29.51804
6	Sulina	45.16208, 29.68527

Water samples for pharmaceutical analysis were filtered, and then the collected samples were carefully stored and preserved until further analysis. For the pesticide analysis, the sediment was freeze-dried to ensure the compounds' stability with the Table Top Freeze Dryer BioBase BK-FD10PT (BioBase, Shandong, China) equipment

Analytical standards

- Organochlorine pesticide mix containing α-BHC; β-BHC; δ-BHC; γ-BHC (Lindane); α-Chlordane; γ-Chlordane; p,p′-DDD; p,p′-DDE; p,p′-DDT; Aldrin; Dieldrin; Endosulfan I; Endosulfan II; Endosulfan sulfate; Endrin aldehyde; Endrin; Endrin ketone; Heptachlor epoxide (Isomer B); Heptachlor; Methoxychlor.
- Organophosphorus pesticides mix containing Disulfoton, Dimethoate, Parathion-methyl, Famphur, Triethyl thiophosphate, Parathion, Sulfotep, Phorate, Thionazin.

- ***Internal standards***

4,4` - DDT-D8, 4,4` - DDD-D8, 4,4` - DDE-D8, γ-BHC-D6, PCB-143.

- Pharmaceutical residues in the examined water samples were identified and quantified using analytical standards for the following compounds: Caffeine, Carbamazepine, Ketoprofen, Metformin, Diclofenac, Clindamycin, Trimethoprim, Sulfamethoxazole, and Clarithromycin.

QuEChERS extraction of pesticides

The pesticides belonging to the organochlorine and organophosphorus classes were extracted from freeze-dried sediments using an optimized QuEChERS protocol. The sample was weighed and well hydrated with ultrapure water to better simulate the matrix composition. First, the internal standard was added, and the samples were allowed to rest for 30 minutes. The extraction procedure started with the addition of acetonitrile as solvent extraction, and after 15 minutes of sonication at 150 W, using an Elmasonic S60 H 100 2238 (Elma Schmidbauer GmbH, Singen, Germany) and homogenization, the extraction salts (6 grams of magnesium sulfate with 1.5 grams of sodium acetate) were added to the sample. The samples were vortexed for 5 minutes each and centrifuged at 4500 rpm for 10 minutes (OHAUS FC5916R Centrifuge) for 10 minutes in order to collect the resulting supernatant. A known aliquot of the sample was then mixed with the clean-up (150 mg magnesium sulfate, 25 mg C18, and 25 mg Primary-Secondary Amine), and the liquid was again centrifuged. The resulting supernatant was carefully evaporated under nitrogen stirring (Reacti-Therm™ Heating and Stirring Module - TS-18823 from Thermo Fisher Scientific, Waltham, MA, USA), redissolved in toluene, and filtered to be prepared for chromatographic analysis.

Automatic SPE extraction of pharmaceuticals from liquid samples

Sample preparation for the analysis of pharmaceutical compounds in water samples involved the use of an automated solid-phase extraction with a dedicated instrument Dionex AutoTrace 280 (Thermo Fisher Scientific, Waltham, MA, USA). The extraction was made using C18 cartridges, methanol, and water, and methanol as the elution solvent. An evaporator that allowed the concentration of analytes in a nitrogen atmosphere was also used to evaporate the samples, and 10% methanol for re-dissolution.

The analysis of pesticides from sediment by GC-MS/MS

The toluene extracts of sediment samples were analyzed using a TSQ 9000 Triple quadrupole GC-MS/MS instrument, a Thermo Scientific™ TRACE™ 1310 GC, and a Thermo Scientific™ TriPlus™ RSH autosampler (Waltham, Massachusetts, USA), 2 µL of extract was injected into a Thermo Scientific™ TraceGOLD TG-PAH 30 m × 0.25 mm I.D. × 0.10 µm film capillary column, which was used for the chromatographic separation. The ramped temperature within the GC oven was set up as follows: initial temperature 60°C - 2 min hold time, from 60°C to 120°C at a rate of 30°C/min, from 120°C to 320°C at a rate of 10°C/min, and the final step, 320°C with a hold time of 16 min. The total program run is 40 minutes.

Each targeted compound was identified and quantified using three SRM transitions, and the final results were processed using Chromeleon 7.3. The pesticides were quantified using an internal-standard calibration curve constructed from six concentration levels, with a concentration range between 2 and 80 ng/g.

The analysis of pharmaceuticals from water by UHPLC-HRMS

Qualitative and quantitative analysis of the identified pharmaceutical compounds was performed using liquid chromatography with high-resolution mass spectrometry, Vanquish Flex UHPLC - Orbitrap Exploris 120, and a mass spectrometer from Thermo Fisher Scientific (Waltham, Massachusetts, USA). The analysis method involved the use of two mobile phases represented by ultrapure water with 0.1% formic acid and methanol with 0.1% formic acid in a gradient with a flow rate of 0.4 mL/min. The separation of the compounds was done using an Accucore C18 column (100 x 2.1 mm, 2.6 µm) at a temperature of 40 °C. The analysis time was 20 minutes and the sample injection volume was 10 µL. The calibration

curve was performed in 6 points over the range 0.1 ng/L - 25 ng/L. Quantification of the compounds was performed based on the following internal standards: dihydrocarbamazepine for carbamazepine; phenacetin for metformin, caffeine and diclofenac and enrofloxacin for sulfamethoxazole.
The results obtained for both pesticides and pharmaceuticals were validated using the spiking method on 3 different levels.

RESULTS AND DISCUSSIONS

Due to extensive development, inadequate pollution control, and inflows from severely polluted tributaries, the Middle and Lower Danube River's water quality quickly declined after the 1970s (Gati et al., 2019). The quality of the Danube Delta waters as well as the Black Sea's coastline region is impacted by the Danube River, which serves as the primary collector and emissary of all urban and industrial effluent from the whole river basin (Ene et al., 2025).
The sediment samples were analyzed in terms of pesticide content, and the results showed the presence of DDTs in all target points (Figure 1).
Generally, the organochlorine and organophosphorus pesticides were not detected in the samples, except for DDT and its metabolites. DDT levels in our samples varied between 0.90 and 3.45 ng/g DW with the highest concentration in the terminal sampling point. As expected, the highest abundance and concentration of DDTs were recorded in the closest point to the mouth of the Sulina branch (Figure 1 and Figure 2). The presence of the metabolite 4,4`-DDE could only be quantified in the final point of sampling, and for 4,4`-DDD in two of the collected points (Figure 1). The presence of both metabolites was confirmed in all points, but the concentrations were below the limit of quantification. The highest content within the DDTs metabolites was recorded also in the last point, 1.09 ng DDD/g DW. Sediment samples were also scanned for the presence/absence of organophosphorus pesticides, and no compounds from this category were identified. The absence of these compounds could be a reason for their rapid biodegradability, compared to organochlorines (Saad et al., 2025). It is clear that from the OCP category only DDTs have been identified. First of all, these compounds are indicators of historical pollution, being particularly persistent compounds with a high potential for bioaccumulation. The fact that other compounds from the pesticide category have not been identified does not necessarily indicate their absence, but the possibility of their degradation over time. Also, another argument could be given by the volatility of the substances. While DDTs are strongly persistent and hydrophobic, therefore almost immobile in solid matrices, pesticides such as lindane are more volatile and slightly more soluble.
In agreement with previous reports, the predominance of DDTs in environmental samples from the Danube Delta was observed by Covaci et al. (2006), who found concentrations of DDTs in Danube Delta sediments varying between 0.7 and 33 ng/g.
Belháčová-Minaříkova et al. (2020) reported DDT and its breakdown products in high amounts in the lower Danube, with the river delta containing the highest levels.
Sediments act as storage spaces for non-polar contaminants and sources for living organisms from the aquatic ecosystem. For example, Stancheva et al., 2013, reported in freshwater fish from the Danube river concentrations of DDTs from 19.2 to 30.3 ng/g WW. Despite the global initiative to minimize the use of pesticides, the risk of pesticide pollution is still present due to their high degree of bioaccumulation (Sharma et al., 2019). ICPDR (2005) reported that 71% of the samples from the Danube and 54% from the tributaries exceeded 0.01 µg/L 4,4`-DDT. DDT was banned in Europe in the 1970s due to its toxicity and environmental persistence and is now listed as a priority substance under European Directive 2013/39/EU and as a persistent organic pollutant under the Stockholm Convention (2001) (van den Berg et al., 2025). Since its use is prohibited, current contamination most likely reflects historical inputs and long-term environmental persistence. DDT is nevertheless utilized in many underdeveloped nations. This chemical is widely distributed throughout the environment

because of its persistence and long-distance atmospheric transport, causing high bioaccumulation and biomagnification potential (Tasselli et al., 2023).

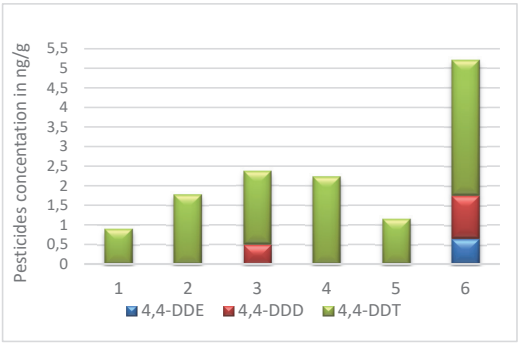


Figure 1. The concentrations of pesticides in sediments from the Danube Delta

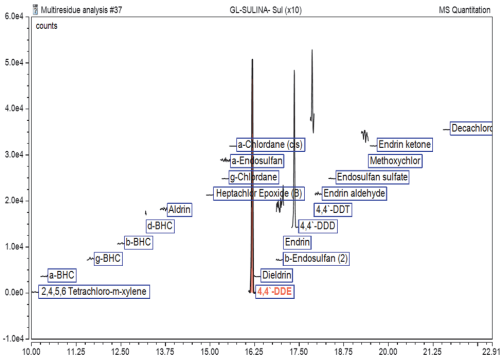


Figure 2. Chromatogram example (sample 6) of pesticide in a sediment sample analyzed from Danube Sulina branch

Following the investigation into the presence of pharmaceutical residues in water samples taken from the Danube Sulina branch, five compounds were detected at trace levels (Table 2; Figure 3): metformin, caffeine, sulfamethoxazole, carbamazepine, and diclofenac. In Figure 4, an example of chromatogram highlighting the presence of pharmaceuticals in water can be observed.

In Table 2, the concentrations of the identified pharmaceuticals are presented. One of the compounds identified in all 6 sampling stations is metformin, for which minimal variations in concentrations were obtained from one station to another, ranging between 1.7 ng/L (sample 1) and 1.93 ng/L (sample 6). Carbamazepine is another compound frequently identified in surface water; low values within the range 0.31 to 0.49 ng/L were measured on the Danube Sulina branch.

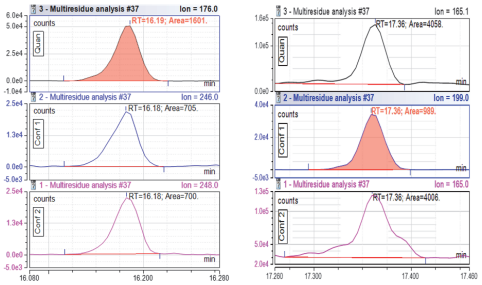


Figure 3. MS Components for 4,4`-DDE and 4,4`-DDD

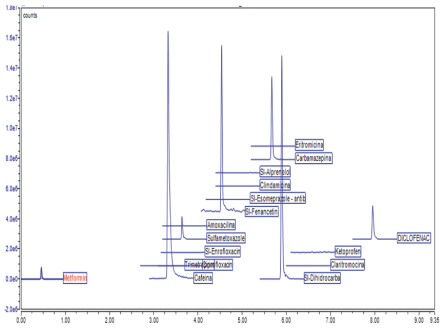


Figure 4. Chromatogram example of compounds in a water sample analyzed from Danube Sulina branch

Table 2. Concentration of pharmaceutical compounds identified in water samples taken from the Danube Sulina branch

Pharmaceuticals concentration (ng/L)	1	2	3	4	5	6
Metformin	1.7	1.77	1.9	1.86	1.86	1.93
Caffeine	14.06	13.31	17.33	8.92	8.79	9.56
Sulfamethoxazole	1.02	1.07	1.08	0.96	0.95	0.98
Carbamazepine	0.38	0.47	0.49	0.35	0.31	0.33
Diclofenac	4.42	2.37	3.3	3.34	2.23	3.97

The antibiotic sulfamethoxazole was also quantified in the analyzed samples, the highest value was 1.08 ng/L and the lowest measured 0.95 ng/L. The highest concentrations were obtained for the psychoactive substance caffeine, with values ranging from 8.79 ng/L to 17.33 ng/L. For the nonsteroidal anti-inflammatory drug diclofenac, concentration variations were recorded from 2.23 ng/L to 4.42 ng/L. Other studies have also reported that sulfamethoxazole, carbamazepine, and diclofenac were detected in the Sulina branch (Ene et al., 2025). Loos et al. (2017) reported

that on the Danube River, diclofenac values were recorded from upstream to the mouth in the range of 20 ng/L - 2 ng/L. Significant concentrations of metformin were also recorded in the Prut, a main tributary of the Danube, with values ranging from 100 ng/L to 240 ng/L (Moldovan et al., 2018). In a study conducted by Chitescu et al. (2015), values of carbamazepine identified in water samples taken from the Danube River basin in Romania territory were reported to be in the range of 4 ng/L - 40 ng/L. In other studies conducted on the Danube River, sulfamethoxazole values ranging from 3.7 ng/L to 141 ng/L were also reported (Loos et al., 2017).

All analytical results were validated using a spiking approach at three concentration levels. For pesticide analysis, limits of detection (LOD) and quantification (LOQ) ranged from 0.12 to 0.19 ng/g and from 0.26 to 0.57 ng/g, respectively. Recovery rates for DDT and its metabolites ranged between 96.62% and 115.07%. For pharmaceuticals, LOD and LOQ values ranged from 0.17 to 0.69 ng/L and from 0.30 to 0.98 ng/L, respectively, while recovery rates varied between 90.11% and 98.80%. Linearity was assessed based on calibration curves, with correlation coefficients (R^2) higher than 0.99 for all target pesticides and pharmaceuticals.

Correlation analysis between pesticides from sediments and pharmaceuticals from water

The pesticides were analysed from sediments and the pharmaceuticals from water according to the compound's chemical affinity from the matrices. Generally, the pesticides are hydrophobic while pharmaceuticals are more hydrophilic substances.

In Figure 5, the correlation between both classes is represented. First, the presence of DDE and DDD correlates strongly with the presence of DDT because they are metabolic breakdown products of the dichlorodiphenyltrichloroethane. This confirms again the persistence and also the historical pollution with DDT.

An interesting observation is that metformin tends to correlate with DDTs, especially DDT. This could suggest almost a possible common source of pollution or some specific conditions that facilitates the existence of both classes.

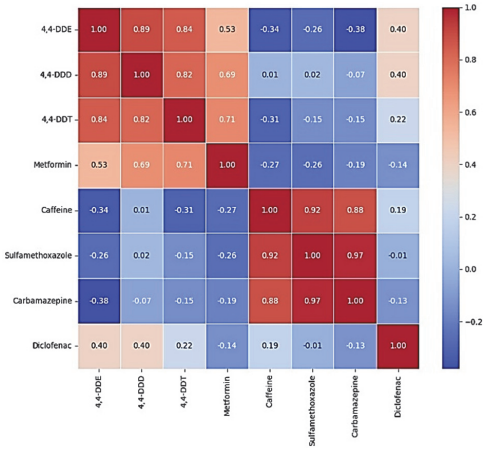


Figure 5. Correlation analysis between pesticides from sediments and pharmaceuticals from water

On the other hand, a negative correlation may be observed between pesticides and carbamazepine, sulfamethoxazole or caffeine, which may highlight different source of pollution (agriculture vs urban waste).

CONCLUSIONS

This research provides an evaluation of emerging and persistent pollutants in water and sediment samples from a valuable, unique ecosystem in Europe. The present study detected DDTs, caffeine, metformin, sulfamethoxazole, diclofenac, and carbamazepine in the Danube Delta samples. While the pesticides analysis revealed only the presence of a restricted profile of OCPs suggesting both historical pollution and a dominated persistent pollutants profile, the pharmaceutical profile highlighted an actual anthropogenic pollution and a continuous pressure to the Danube ecosystem. However, some limitations regarding the present study should be considered.

Although the present study is relevant from the perspective of the presence of two categories of persistent and emerging pollutants, future studies could be expanded with additional surveys campaigns and a larger number of collected samples. Beyond this, the level of pollution could be underestimate because only two classes of pollutants were analysed. Future studies may include more sample, more sampling campaigns, and a wider spectrum of

compounds to analyze. The presence of these compounds in the aquatic environment of the Danube Delta, which is part of an UNESCO World Heritage Site, underscores the importance of continuous environmental monitoring. Over and above that, there is a need to implement measures to prevent, ensure, and support the well-being of the aquatic ecosystem aligned with the Water Framework Directive. Ecosystems are seriously threatened by pollution from a variety of sources, including industrialization, agriculture, urbanization, and untreated sewage. Over time, these pollutants may have detrimental effects on the environment and human health. Moreover, this research reflects the importance of future studies regarding the concentration levels of pollutants, also in biota. Monitoring priority substances, reducing pollutants discharge and strengthening the control measures would support and improve the quality of aquatic environment.

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REFERENCES

Bănăduc, D., Rey, S., Trichkova, T., Lenhardt, M., & Curtean-Bănăduc, A. (2016). The Lower Danube River–Danube Delta–North West Black Sea: A pivotal area of major interest for the past, present and future of its fish fauna - A short review. *Science of The Total Environment*, *545–546*, 137–151. https://doi.org/10.1016/j.scitotenv.2015.12.058

Belháčová-Minaříková, M., Smedes, F., Rusina, T. P., & Vrana, B. (2020). Application of equilibrium passive sampling to profile pore water and accessible concentrations of hydrophobic organic contaminants in Danube sediments. *Environmental Pollution*, 267, Article 115470. https://doi.org/10.1016/j.envpol.2020.115470

Chițescu, C. L., Ene, A., Geana, E.-I., Vasile, A. M., & Ciucure, C. T. (2021). Emerging and Persistent Pollutants in the Aquatic Ecosystems of the Lower Danube Basin and North West Black Sea Region - A Review. *Applied Sciences*, *11*, 9271. https://doi.org/10.3390/app11209721

Chitescu, C. L., Kaklamanos, G., Nicolau, A. I., & Stolker, A. A. M. (Linda) (2015). High sensitive multiresidue analysis of pharmaceuticals and antifungals in surface water using U-HPLC-Q-Exactive Orbitrap HRMS. Application to the Danube river basin on the Romanian territory. *Science of The Total Environment*, *532*, 501–511. https://doi.org/10.1016/j.scitotenv.2015.06.010

Covaci, A., Gheorghe, A., Hulea, O., & Schepens, P. (2006). Levels and distribution of organochlorine pesticides, polychlorinated biphenyls and polybrominated diphenyl ethers in sediments and biota from the Danube Delta, Romania. *Environmental Pollution*, *140*(1), 136–149. https://doi.org/10.1016/j.envpol.2005.06.008

Ene, A., Teodorof, L., Chițescu, C. L., Burada, A., Despina, C., Bahrim, G. E., Vasile, A. M., Seceleanu-Odor, D., & Enachi, E. (2025). Surface Water Contaminants (Metals, Nutrients, Pharmaceutics, Endocrine Disruptors, Bacteria) in the Danube River and Black Sea Basins, SE Romania. *Applied Sciences*, *15*, 5009. https://doi.org/10.3390/app15095009

Gati, G., Pop, C., Brudasca, F., Gurzau, A. E., & Spinu, M. (2019). Hydrological modeling of arsenic in the Danube Delta. *Environmental Engineering and Management Journal*, *18*(1), 99–108. https://doi.org/10.30638/eemj.2019.011

ICPDR. (2005). *TNMN_Yearbook_2005_short_version.pdf*. https://www.icpdr.org/sites/default/files/TNMN_Yearbook_2005_short_version.pdf

ICPDR. (n.d.). *Danube Delta | ICPDR - International Commission for the Protection of the Danube River*. Retrieved from https://www.icpdr.org/danube-basin/sub-basins/danube-delta (accessed April 25, 2026).

Iticescu, C., Georgescu, L., Topa, M.C., & Murariu, G. (2014). Monitoring the danube water quality near the galati city. *Journal of Environmental Protection and Ecology*, *15*, 30–38.

Katsoyiannis, A., & Samara, C. (2005). Persistent organic pollutants (POPS) in the conventional activated sludge treatment process: Fate and mass balance. *Environmental Research*, *97*, 245–257. https://doi.org/10.1016/j.envres.2004.09.001

Loos, R., Tavazzi, S., Mariani, G., Suurkuusk, G., Paracchini, B., & Umlauf, G. (2017). Analysis of emerging organic contaminants in water, fish and suspended particulate matter (SPM) in the Joint Danube Survey using solid-phase extraction followed by UHPLC-MS-MS and GC–MS analysis. *Science of The Total Environment*, *607–608*, 1201–1212. https://doi.org/10.1016/j.scitotenv.2017.07.039

Mănoiu, V.-M., & Crăciun, A.-I. (2021). Danube river water quality trends: A qualitative review based on the open access web of science database. *Ecohydrology & Hydrobiology*, *21*(4), 613–628. https://doi.org/10.1016/j.ecohyd.2021.08.002

Matei, N., Seceleanu-Odor, D., Burada, A., Gheorghe, P.B., Tiganus, M., Suliman, I., Ibram, O., & Despina, C. (2025). Review: Long-term trends of pesticide residues in the Danube River Basin. *Scientific Annals of the Danube Delta Institute*, *30*, 1–16. https://doi.org/10.3897/saddi.30.160456

Moldovan, Z., Marincas, O., Povar, I., Lupascu, T., Longree, P., Rota, J. S., Singer, H., & Alder, A. C. (2018). Environmental exposure of anthropogenic

micropollutants in the Prut River at the Romanian-Moldavian border: A snapshot in the lower Danube river basin. *Environmental Science and Pollution Research International*, *25*(31), 31040–31050. https://doi.org/10.1007/s11356-018-3025-8

Saad, H., Elfeky, S. A., El-Gamel, N. E. A., & Abo Dena, A. S. (2025). Organophosphate pesticides: A review on classification, synthesis, toxicity, remediation and analysis. *RSC Advances*, *15*(48), 40802–40822. https://doi.org/10.1039/d5ra05552k

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., Parihar, R. D., Dar, O. I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, *1*(11), 1446. https://doi.org/10.1007/s42452-019-1485-1

Stancheva, M., Georgieva, S., & Makedonski, L. (2013). Persistent organic pollutants - PCBs and DDTs in fish from Danube River and from Black Sea, Bulgaria. *CBU International Conference Proceedings*, *1*, 354-361. https://doi.org/10.12955/cbup.v1.57

Tasselli, S., Marziali, L., Roscioli, C., & Guzzella, L. (2023). Legacy Dichlorodiphenyltrichloroethane (DDT) Pollution in a River Ecosystem: Sediment Contamination and Bioaccumulation in Benthic Invertebrates. *Sustainability*, *15*(8). https://doi.org/10.3390/su15086493

UNESCO World Heritage. (n.d.). UNESCO World Heritage Centre. Retrieved from https://whc.unesco.org/en/list/588/ (accessed April 25, 2026).

van den Berg, H., Amwele, H. R., Brooke, B. D., Fortelius, L. E., Jain, T., Karunaratne, S. H. P. P., Munyinda, N. S., Rubio-Palis, Y., Yadav, R. S., & Kleinschmidt, I. (2025). DDT: Last mile in the global phase-out of its use for disease vector control? *The Lancet Planetary Health*, *9*(8), 101283. https://doi.org/10.1016/j.lanplh.2025.06.007

Zlati, M. L., Georgescu, L. P., Iticescu, C., Ionescu, R. V., & Antohi, V. M. (2023). New Approach to Modelling the Impact of Heavy Metals on the European Union's Water Resources. *International Journal of Environmental Research and Public Health*, *20*(1). https://doi.org/10.3390/ijerph20010045