MICROPLASTIC DISTRIBUTION IN RIVER SEDIMENT: A CASE STUDY AT U-TAPHAO, SOUTHERN THAILAND

NOPPRADIT, P.[1,2] – PRADIT, S.[1,2*] – SENGLOYLUAN, K.[3] – NITIRATSUWAN, T.[4] – SUWANNO, P.[5] – SORNPLANG, K.[1,2] – JITKAEW, P.[1,2] – TANRATTANAKUL, V.[6]

[1]*Coastal Oceanography and Climate Change Research Center, Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand*

[2]*Marine and Coastal Resources Institute, Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand*

[3]*International College, Prince of Songkla University, Songkhla 90110, Thailand*

[4]*Faculty of Science and Fisheries Technology, Rajamangala University of Technology Srivijaya, Trang 92150, Thailand*

[5]*Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand*

[6]*Faculty of Science, Prince of Songkla University, Songkhla 90110, Thailand*

[*]*Corresponding author*
e-mail: siriporn.pra@psu.ac.th

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Abstract. Microplastic is everywhere in the aquatic ecosystem including river sediment. In this study, seven sediment sampling stations were selected along the basin, from upstream to downstream (7 stations) of the U-Taphao river for 4 months (February, April, June, and August) in 2022. The total number of microplastic particles found was 1,470 pieces, consisting of 814 fibers (55.37%) and 656 fragment particles (44.63%) from the four sampling months. Station 5 showed the highest concentration of microplastics, followed by station 1. Seven polymers were found throughout the study: PE, PP, PET, rayon, copolymer, PA, and PVA. Polymer analysis from microplastic samples by FTIR polymer analysis showed significant differences in the frequency of polymer types found in each month ($p < 0.001$).
Keywords: *lagoon, fiber, polymer, debris, estuary*

Introduction

Plastic has been widely utilized since its development in 1907 and has significantly enhanced people's quality of life (Wang et al., 2019). In the second half of the 20th century, nine billion metric tons of plastic were produced; approximately 59% of this was discarded as waste and is now found in landfills or in natural surroundings (Buckingham et al., 2022). In 2010, it was predicted that 12.7 million metric tons of waste plastic had entered the ocean from coastal sources, and by 2025, it is expected that this number will more than double (Buckingham et al., 2022). Since Thailand is the sixth-largest producer of marine trash globally, the existence of marine and plastic waste in marine and coastal environments is a serious issue that requires immediate action (Pradit et al., 2021). When large-sized plastics enter the ocean, physicochemical (such as UV rays in sunlight, wave action, pH, salinity, etc.) cause them to break down into smaller particles which are known as microplastics. Microplastics, which are commonly defined as plastic particles less than 5 mm in size, have recently drawn substantial attention from both the scientific

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community and broader public (Li et al., 2021). Microplastics are divided into two categories: primary and secondary microplastics. Primary microplastics are produced in microscopic sizes and are widely used in health care and personal products (Firdaus et al., 2020). Large plastics are broken down into smaller pieces via photodegradation, thermal degradation, biodegradation, hydrolysis, and thermo-oxidative degradation, which is known as secondary microplastics (Ta and Babel, 2020). In addition, the morphology of microplastics can also be classified by shape, color, polymer type, and size (Choong et al., 2021).

Microplastic pollution is a rampant problem that has garnered a great deal of attention, and it is considered to be a prevalent issue among researchers (Yan et al., 2022). According to experts, there are 24.4 trillion pieces of microplastic in the ocean, each roughly the size of a sesame seed, weighing between 82,000 and 578,000 tons (Cho, 2022). Since modern technology cannot filter them out at wastewater treatment facilities, the majority of it drains out to sea and is deposited in the ocean or in sediment (Cho, 2022). To characterize the global distribution of microplastics and advance our understanding of their origins, fate, and effects, as well as to facilitate and evaluate effective policy decision-making, researchers are developing new methods to isolate, count, and measure microplastics in various environmental settings (Jenkins et al., 2022). Microplastics has been identified in all marine ecosystems, including in the ocean surface, coastal zone, water column as well as in sediments (Firdaus et al., 2020). Microplastics appear to have a long-term sink in sediments (Yang et al., 2021). Low-density particles typically float in the water column or on the sea surface, but plastics with densities greater than seawater (>1.02 g cm^3) will sink and accumulate in the sediment (Van Cauwenberghe et al., 2015). According to research, the key factor contributing to the emergence of microplastics in sediments is the buildup of biofilms, pollutants' adsorption, and accumulation, which increase the density of polymer debris (Yang et al., 2021).

Microplastics reach the marine environment through land and marine-based sources. They build up and distribute across the ocean's surface, sea floor, shorelines (beaches), water column, marine sediments, and biota (Pirsaheb et al., 2020). According to laboratory research, it is proven that microplastics can be consumed by a variety of marine animals when particles are mistaken for food (Mohamed Nor and Obbard, 2014). Microplastic easily enter the food chain via ocean due to their microscopic size. These microplastic particles have the potential to severely harm these species, resulting in oxidative stress, reproductive issues, growth rate suppression, and pathological stress (Firdaus et al., 2020). Moreover, marine animals may also experience blockages and physical abrasions from microplastics. Research has revealed that zooplankton—the most prevalent creature in the world—is capable of ingesting microplastics of various shapes and sizes (Choong et al., 2021). Additionally, because zooplankton connects two trophic levels, microplastics are transferred to the next level of the food chain and endanger other aquatic life (Choong et al., 2021). Microplastics absorb into human body through bioaccumulation and biomagnification by the food chain (Nanthini et al., 2022). One pathway that microplastics can enter the human body is through ingestion of contaminated foods. Based on research, humans may consume 80 g of microplastics every day through fruits and vegetables that uptake microplastics from contaminated soil (Campanale et al., 2020). Additionally, inhalation is another route through which microplastics can enter the human body. However, little attention has been paid to the presence of microplastics in the atmosphere (Akanyange et al., 2021). The last route for microplastics to enter the human body is through the skin while washing or when using

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cosmetics and scrubs that contain microplastics (Campanale et al., 2020). However, microplastics absorbed by the human body via skin contact is thought to be a less significant way to be exposed, although it has been hypothesized that nanoplastics (less than 100 nm) might be able to pass through the skin barrier (Prata et al., 2020). Humans may experience both short and long-term effects from exposure to microplastic contamination. Short-term effects include coughing, respiratory irritation, increased phlegm production, and dyspnea, while long-term effects include asthma, obesity, cancer, and cardiovascular diseases (Akanyange et al., 2021).

U-Taphao Canal, situated in Hat Yai, is utilized as a source of water to provide water for the region of Songkhla, Thailand (Srimuang, 2011). This canal regularly receives 41,000 m^3 of industrial wastewater per day, which originates from the wood, rubber, seafood, and plastic industries (Kingsley and Witthayawirasak, 2020a). This is because the U- Taphao Canal is regularly exposed to both types of pollution sources, including point and non-point sources, due to changes in land-use patterns, urbanization, and rapid economic growth, similar to other water bodies (Kingsley and Witthayawirasak, 2020b).Microplastic pollution in sediment is a serious issue that is currently gaining worldwide attention (Jualaong et al., 2021). Therefore, this study identifies the types, colors, sizes, and polymers of microplastic particles in order to focus on the contamination of microplastics in sediment in the U- Taphao Canal.

Methods and Materials

Study area

This study was conducted in the Khlong U- Taphao canal, which is located in Southern Thailand's Songkhla Province. It is a part of the Songkhla Lake Basin and is located west of Hat Yai at a latitude of 7 9' 24' North and a longitude of 100 27' 7' East. The Khlong U- Taphao is the largest freshwater supply for southern Thailand, extending for 68 km and reaching depths of 3 to 8 m (Kingsley and Witthayawirasak, 2020a). The lagoon has endured environmental decline caused by current large-scale economic growth and population expansion in the surrounding area which will lead to deterioration of the quality of sediment and canal ecology (Gyawali et al., 2012; Chuvanich et al., 2017). This is due to industrial effluent produced by companies that manufacture seafood, village and urban development, the agriculture sector, pollution from boats in Songkhla harbor, and municipal trash from Hat Yai. *Figure 1* presents a map of the sampling site in Khlong U-Taphao.

Sediment collection

In this study, seven sampling stations for sediment were selected along the basin, from upstream to downstream. The sites are classified into three categories: upstream (station 1 to station 3), midstream (station 4), and downstream (stations 5 to station 7). Sediment samples were collected from seven sampling stations using Ekman grab and transferred onto a pre-treated tray. During the sampling period, sediment was collected three times and kept in a plastic bag. After the bags were sealed completely, they were brought to the laboratory for further analysis. Sediment collection was carried out in four periods in 2022 in the months of February, April, June, and August.

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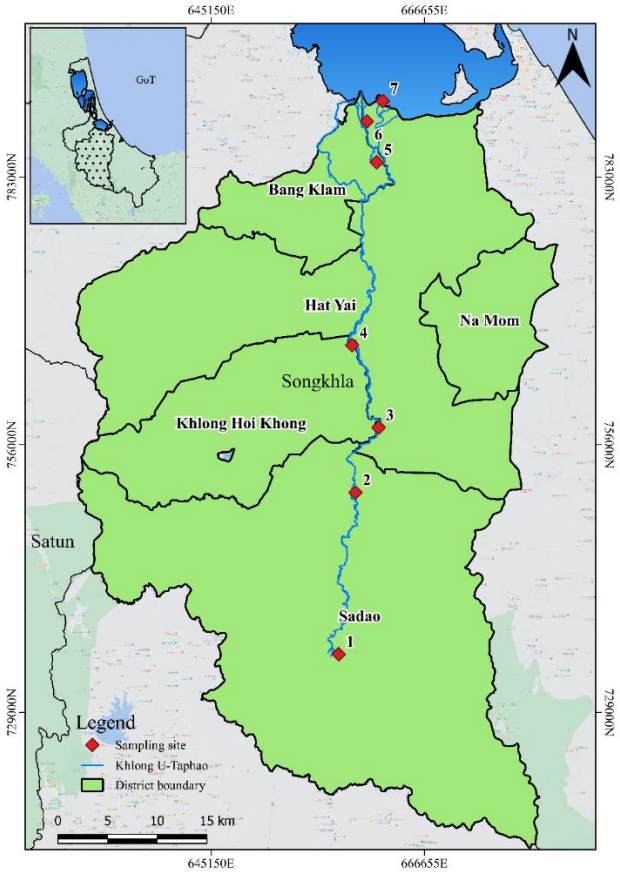

Figure 1. *Map of the sampling site in Khlong U- Taphao, Southern Thailand*

Sample preparation and extraction

Experimental control and QA/QC

To prevent contamination of microplastics, solutions such as distilled water, saturated sodium chloride (NaCl), ferrous sulphate ($FeSO_4$), and 30% hydrogen peroxide (H_2O_2) were stored carefully after being filtered through a 47 mm Whatman® glass microfiber membrane (GF/C; 1-µm pore size) (Pradit et al., 2022). Before beginning the experiments, all containers, glassware, apparatus, and equipment used in this research were rinsed with filtered distilled water. Furthermore, cotton lab coats and polymer-free gloves were worn during the experiments to prevent minimum microplastic contamination as per recommendations from Jahan et al. (2019).

Microplastic extraction from sediment

Before the experiment, samples collected from the sampling sites were left to dry in the oven at 50°C for approximately 48 hours. After the sediments were completely dry, the samples were weighed (~50 g) and placed in a beaker. Then, 200 mL of saturated sodium chloride (NaCl) was added to the sediment and stirred vigorously by using a glass stirrer before being covered with aluminum foil. Sediments in the beaker were left for 30 minutes. After 30 minutes, 100 mL of samples from the beaker were filtered using 300 µm filter paper and 100 ml of NaCl was added into the original beaker again before being left for another 30 minutes. This step was repeated for 3 times. After the filtering

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process, the filter paper was rinsed with distilled water and transferred into another beaker. The remaining filtered water in the big beaker from the 300 μm filter paper was filtered through 20 μm filter paper. Then, 10 ml of ferrous sulphate ($FeSO_4$) and hydrogen peroxide (H_2O_2) were added to the filtered samples and closed with aluminum foil before being placed on the hot plate for the digestion process. After the samples were completely digested, 6 g of NaCl per 20 mL of the sample solution was added into the beaker to separate plastic material from the denser sediment (Masura et al., 2015) and left for 1 hour. After 1 hour, the filtering process continued by filtering through 300 μm and GF/C filter paper and the filter paper was kept in a petri dish. After that, all petri dishes that contained the filter paper were oven dried at 50°C. Particle size analysis was undertaken using the hydrometer method (Gee et al., 1986).

Microplastic identification

During visual identification of MPs in filter paper under a stereomicroscope, the morphological and physical features were the main criteria that were taken into consideration. The classification was performed using a stereo microscope with a camera attachment (Olympus SZ61, lenses 110AL2X-2 with Canon EOS 600D). The main criteria that applied to the items during the identification of microplastic was the "hot needle test" (De Witte et al., 2014). This test is normally applied in past research when faced with a struggle to distinguish between plastic and non-plastic particles or organic matter where the plastic will melt or curl in the presence of a hot needle (De Witte et al., 2014). Moreover, guidelines extracted from the article of Hidalgo-Ruz et al. (2012) were used to identify the preponderance of MPs found in this investigation. In the guidelines, three rules are often applied in microplastic research: Rule 1 - no cellular or biological features evident; Rule 2 - fibers should be uniformly thick over their whole length; Rule 3 - particles should demonstrate homogeneous color throughout the object. Therefore, the items that passed all these criteria will be classified as potential microplastics. Microplastics were identified and recorded based on three categories, the type of microplastic (fiber or fragments), color (dark blue, translucent, bright blue, black, red, white, green, and other colors), and size (<500μm, <1mm, >1mm).

Identification of plastic types using Fourier-transform infrared spectroscopy (FTIR)

Among the total 1468 potential microplastic items that were found, three items per station were randomly selected from sediment samples and analyzed using a Fourier Transform Infrared (FTIR) spectrometer Frontier model coupled with a Spotlight 200i FTIR microscope to determine polymer type. The FTIR wavelength was set at 4000-600 cm^{-1}. The FTIR mode was attenuated total reflection (ATR) with a scanning rate of 16 and a resolution of 4 cm^{-1}. During the identification process through FTIR analysis, the peak of CO_2 and H_2O was removed to help prevent errors from the background during the identification process in the FTIR analysis (Pradit et al., 2022).

Statistical analyses

Data of MPs including color, size, and shape were analyzed through MS Excel. All abundance figures are presented as averages along with their associated standard errors (SE). The microplastics in the study showed a normal distribution. One-way ANOVA and Post hoc were used to determine differences in microplastics in each month and at each study station. Statistical significance was calibrated at $p < 0.05$.

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Results and Discussion

Characteristics of microplastics in sediment

The total number of microplastics particles found from the four sampling stations was 1,470 items, consisting of 814 fibers (55.37%) and 656 fragment particles (44.63%). Station 5 showed the highest concentration of microplastics followed by station 1. In this study, fibers, fragments, and other characteristics of microplastic were found. The characteristic results of the microplastics recorded from sediment samples collected from Khlong U-Taphao, Thailand are shown in *Figure 2*. In February, Station 5 recorded the highest number of microplastic fragments with 102 pieces, followed by Station 1 (45 pieces), Station 4 (44 pieces), and Station 2 (43 pieces). Meanwhile, in February, Stations 3 and 7 recorded the lowest number of microplastic fragments found with 2 pieces respectively, followed by Station 2 (7 pieces), and fiber from Station 4 (8 pieces), while the other stations recorded 0 pieces. In April, Stations 1 and 2 recorded the highest number of fragments with 88 and 89 pieces, respectively, while Stations 5, 6, and 7 recorded the lowest number of fibers with 9, 5, and 8 pieces, respectively, and the other stations recorded 0 pieces. The highest number of fragments found overall were recorded in February (199 pieces) and April (223 pieces) compared to fiber which recorded 192 pieces in February, 88 pieces (in April), and others recorded 0 for both months. In June, the highest number of microplastics was recorded at Station 6 which was fiber (66 pieces), followed secondly by fragment in Station 4 (54 pieces), and thirdly was fragment in Station 5 (46 pieces). The lowest number of microplastics recorded in June was Station 1 (2 pieces) while Stations 2 to 7 recorded at 0 prices, followed by fragments in Station 2, Station 3, and Station 7 with 3, 4, and 7 pieces, respectively. The highest number of fibers recorded overall was in June (239 pieces) and August (295 pieces) compared to fragments which recorded 176 pieces in June, and 56 pieces in August. The nubmer of fiber (with size <1 mm) and fregment (with size > 1 mm) found was significant differenct between stations ($p<0.05$). From Post hoc analysis found that fiber microplactic in April, June and August was signiciantly different ($p < 0.05$).

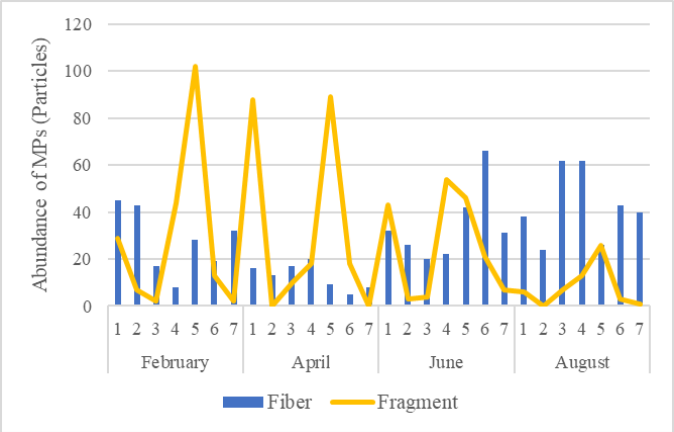

Figure 2. *Characteristics of microplastics found in the sediment samples from February to August. Blue represents fiber and yellow represents fragments*

River morphology and riparian vegetation are among the top natural factors controlling the amount and distribution of plastic waste in rivers (van Emmerik et al., 2019; Kundu

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et al., 2022). There was a greater influence on the number of microplastics found in sediments than in surface water. Due to the low water velocity, the accumulation rate of microplastics in the sediment increases. Areas with small slopes (low river elevation) and rocky areas play an important role in plastic sequestration (Kundu et al., 2022).

Sediment texture data show that sediments vary by station (upstream to downstream) and by month. Upstream stations have sand>silt>clay; middle stations have clay>silt>sand; and downstream stations have sand>clay>silt. The distribution patterns of the sand, silt, and clay fractions are shown in *Figures 3-4*. Vermeiren et al. (2021) discovered high microplastic in the tiny grainsize of sandy beach sediment, which appears to be comparable to our investigation, with the amount of microplastic found high in the middle area being of a mainly fine grain texture.

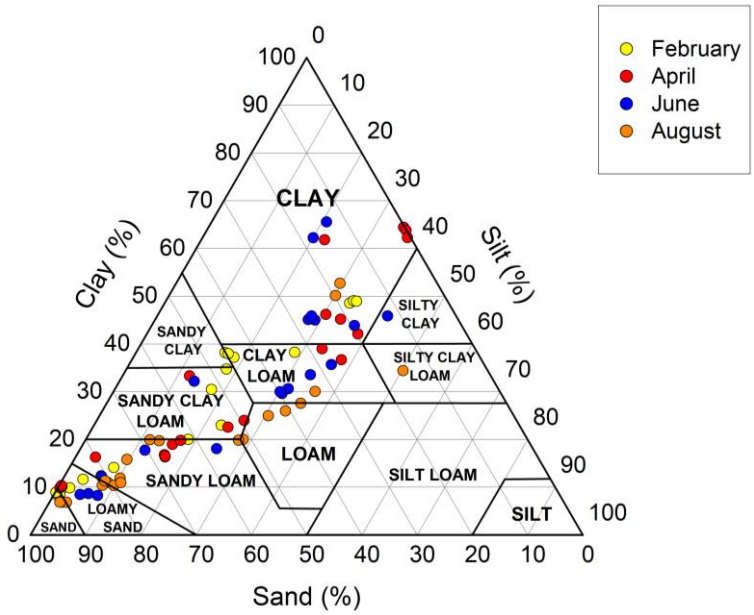

Figure 3. *Sediment textures of U-Taphao sediments*

Sizes of microplastics in sediment

In this study, the microplastics found were recorded in three different sizes, <500 µm, <1 mm, and >1 mm. *Figure 5* presents the microplastic size results from the sediment samples. From the figure, it can be observed that in all four months, the size range of <500 µm recorded the highest amount of microplastics. In February, the size of <500 µm was recorded as the highest abundance of microplastic found in Station 5 (at 108 pieces), followed by Stations 4 and 1 with 43 and 42 pieces, respectively. The lowest was recorded in Stations 3, 4, and 6 of the size range <1 mm at 5, 4, and 4 pieces, respectively and >1 mm at 5, 5, and 9 pieces, respectively. In April, the highest amount of microplastics were recorded for the size range of <500 µm in Station 5 with 86 pieces followed by Station 1 (72 pieces) of the same size range. The lowest was recorded for the size range of <1 mm at Stations 2 and 6 with 0 pieces respectively, and the size range of <500 µm at Station 7 with 0 pieces. In June, the size range of <500 µm was recorded as the highest microplastic abundance in Station 4 with 62 pieces, followed by Station 5 with 55 pieces for the same size range. The lowest was recorded for the size range of >1mm in Station 2 which recorded at 4 pieces of microplastics. In August, the highest number of

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microplastics were recorded to be in the size range of <500 μm for Station 5 at 38 pieces, followed by Stations 3 and 4 where both stations recorded 37 pieces of microplastics each. Whereas the lowest was recorded in Station 2 for the size range of <1 mm at about 3 pieces and the size range of >1 mm for Station 5 with about 4 pieces.

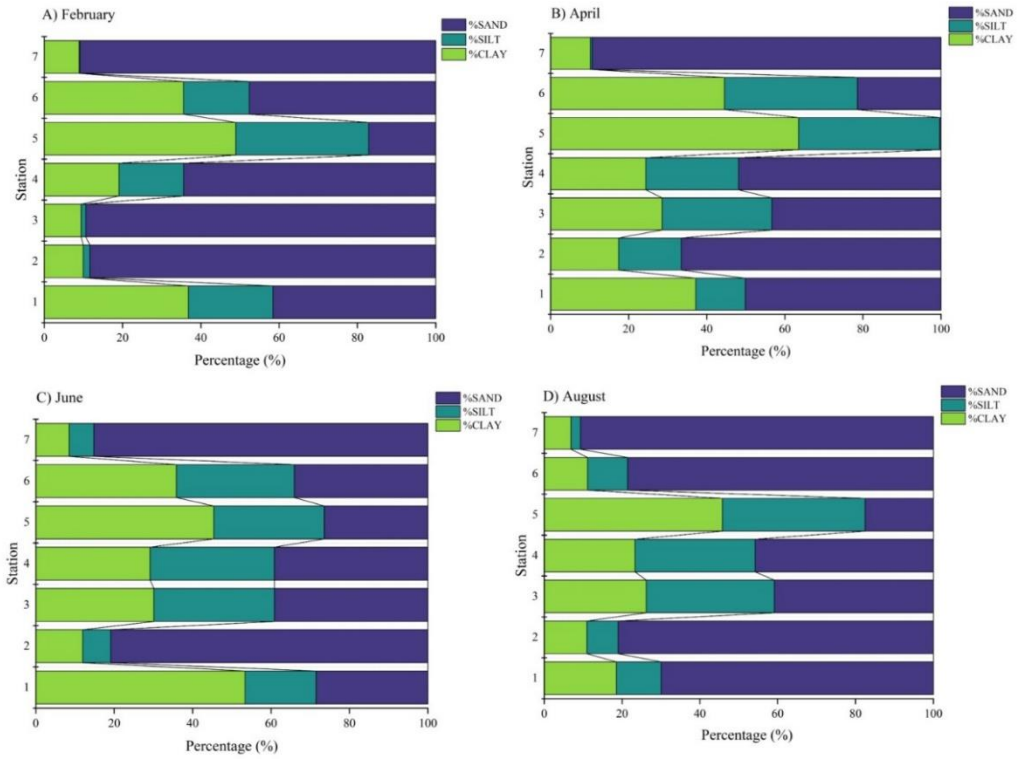

Figure 4. *Sediment textures of U-Taphao sediment at each stations in A) February, B) April, C) June and D) August*

Colors of microplastics in sediment

The main colors distributed in this study are dark blue, translucent, bright blue, black, red, white, green, and other colors. *Figure 6* presents the results of the colors of microplastic found in the sediment samples. From the figure, it can be seen that both February and June recorded the highest microplastic in dark blue whereas April recorded the highest in green and August had the blackest color. In February, the color that recorded the highest microplastic is dark blue with 24.3% or 95 pieces, followed by black color with 20.2% or 79 pieces, and green with 18.4% or 72 pieces. The color that recorded the lowest microplastic is white with 1.8% and other with 0.5% only (7 and 2 pieces, respectively). In April, the highest abundance of microplastic was recorded in green color with 28.9% (at 90 pieces), followed by dark blue color with 20.6% (64 pieces), and red with 15.8% which had about 49 pieces. The least common color of microplastic was other colors with 0.3% which is about 1 piece only. In June, dark blue was recorded to be the highest color of microplastic found with 43.4% which is about 181 pieces, followed by black color which was recorded at 92 pieces (22.1%). The lowest abundance of microplastic was recorded in white color with 1.9% (at 8 pieces) and other colors with 0.2% (at 1 piece only). In August, the color that recorded the highest abundance of microplastic is black color which recorded about 147 pieces which is equivalent to 41.9%,

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followed by dark blue color with 31.1% (109 pieces). The lowest was recorded to be the white color which was about 2% (7 pieces). In this study, the highest color of microplastic that is mostly recorded in all 4 months of the sediment samples is dark blue (with a total of 449 pieces), black (with a total of 362 pieces), and green color (with a total of 229 pieces).

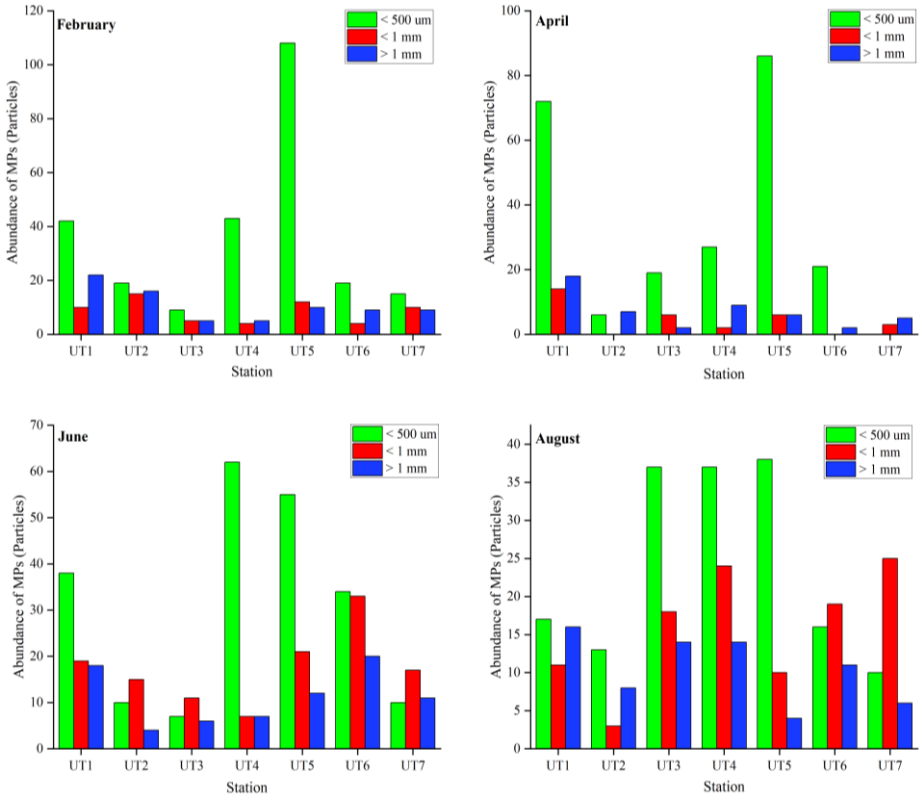

Figure 5. *Sizes of microplastics found in sediment samples from February to August*

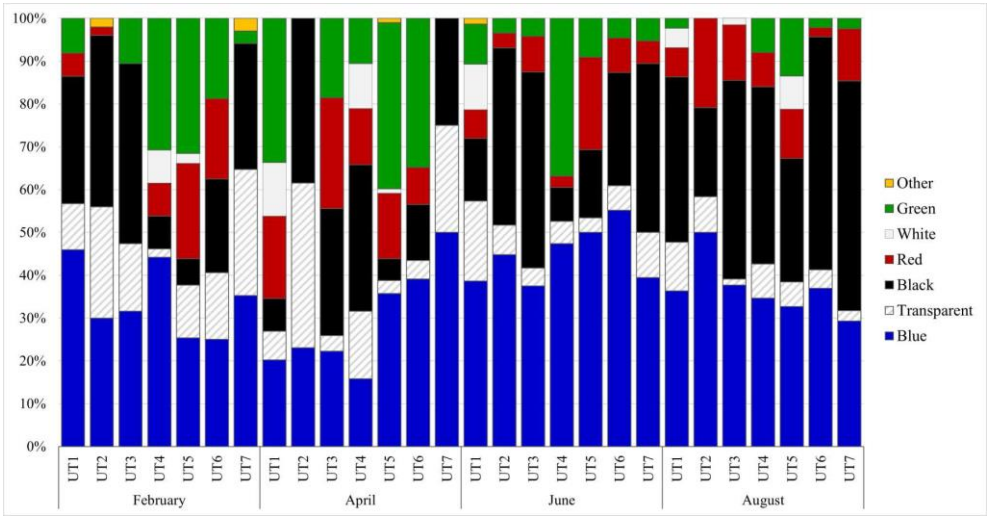

Figure 6. *Colors of microplastics found in sediment samples from February to August*

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Polymer of microplastics in sediment

The distribution of polymers in this study is shown in *Figure 7.* Seven polymers were found throughout the study, PE, PP, PET, rayon, copolymer, PA, and PVA. Overall, PET, PP, and PE polymers were the most common, accounting for 28%, 25%, and 22%, respectively, which were found in all study station Other polymers include rayon, copolymer, PA, and PVA. The frequencies of six polymer species were found. From Chi-Square Test found polymer types in each month was significant different ($p<0.001$).

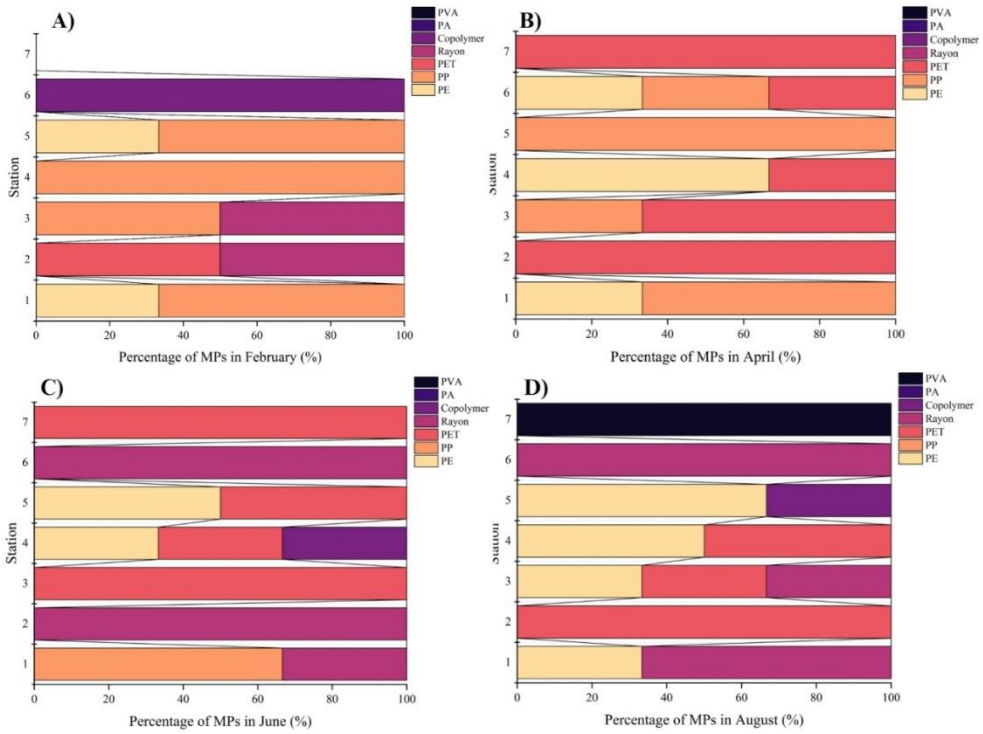

Figure 7. *Distribution of polymers found in four months in the U-Taphao canal, A) February, B) April, C) June and D) August. Note: PE = Polyethylene, PP = Polypropylene, PET = Poly (Ethylene terephthalate), PA = Polyamide, PVA = Polyvinyl Alcohol, Copolymer = Poly (Ethylene terephthalate): Polypropylene:Dien*

The polymers found in sediment have higher densities than water. For example, PET has a density of 1.37 – 1.45 g/cm^3 and PA has a density of 1.02 – 1.05 g/. cm^3, indicating a high probability of sinking into ground sediments. Meanwhile, microplastics with a lower density than water, such as PE, have a density of 0.91 – 0.97 g/cm^3 (Choong et al., 2021) which are shown in *Table 1.* Over time, these microplastics can build up with bacteria in the water and sink to the bottom and attach to sediment. As a result, waste and microplastics were found in the bottom of the water (Erni-Cassola et al., 2019). At the same time, it may depend on the characteristics and utilization in the area, such as the release of wastewater by the community during the rainy season. This causes small pieces of plastic debris to float in the water due to erosion during the rainy season. Additionally, wastewater from the community is contaminated by washing machine washing water (Bronzo et al., 2021; Jiwarungrueangkul et al., 2021). The types of microplastics found including PE, PP, and PET were found to be the most abundant in sediments (Matsuguma et al., 2017; Bošković et al., 2022; Li et al., 2022), where these polymers are substrates.

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Table 1. *Density of plastic polymer and the most common application*

Polymer	Abbreviation	Density (g/cm^3)	Main application
Polyethylene	PE	0.91 - 0.97	Packaging
Polypropylene	PP	0.90 - 0.92	Packaging
Poly (Ethylene terephthalate)	PET	1.37 - 1.45	Packaging
Rayon	-	1.15	Clothes
Polyamide	PA	1.14	Textiles, fishing nets
Poly vinyl Alcohol	PVA	1.19 - 1.31	Textiles

Noted information from Choong et al., 2021; Montarolo et al., 2018; Li et al., 2022; Jiwarungrueangkul et al., 2021

Conclusion

Microplastics were found to accumulate in the river sediment, both upstream and downstream, during the four-month study period. Polymer types found include PE, PP, PET Rayan, PA, and PVC, the main sources of which come from packaging, clothing, textiles, and fishing nets. Further studies should be conducted to investigate the additive chemicals of plastic in river sediment.

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REFERENCES

[1] Akanyange, S. N., Lyu, X., Zhao, X., Li, X., Zhang, Y., Crittenden, J. C., Anning, C., Chen, T., Jiang, T., Zhao, H. (2021): Does microplastic really represent a threat? A review of the atmospheric contamination sources and potential impacts. – Science of The Total Environment 77: 146020. https://doi.org/10.1016/j.scitotenv.2021.146020.

[2] Bošković, N., Joksimović, D., Perošević-Bajčeta, A., Peković, M., Bajt, O. (2022): Distribution and characterization of microplastics in marine sediments from the Montenegrin coast. – Journal of Soils and Sediments 22(11): 2958-2967. https://doi.org/10.1007/s11368-022-03166-3.

[3] Bronzo, L., Lusher, A. L., Schøyen, M., Morigi, C. (2021): Accumulation and distribution of microplastics in coastal sediments from the inner Oslofjord, Norway. – Marine Pollution Bulletin 173: 113076. https://doi.org/10.1016/j.marpolbul.2021.113076.

[4] Buckingham, J. W., Manno, C., Waluda, C. M., Waller, C. L. (2022): A record of microplastic in the marine nearshore waters of South Georgia. – Environmental Pollution 306: 119379. https://doi.org/10.1016/j.envpol.2022.119379.

[5] Campanale, C., Massarelli, C., Savino, I., Locaputo, V., Uricchio, V. F. (2020): A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. – International Journal of Environmental Research and Public Health 17(4): 4. https://doi.org/10.3390/ijerph17041212.

[6] Cho, R. (2022): How Do We Clean Up All That Ocean Plastic? – State of the Planet. https://news.climate.columbia.edu/2022/10/13/how-do-we-clean-up-all-that-ocean-plastic/.

[7] Choong, W. S., Hadibarata, T., Yuniarto, A., Tang, K. H. D., Abdullah, F., Syafrudin, M., Al Farraj, D. A., Al-Mohaimeed, A. M. (2021): Characterization of microplastics in the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_45634576

water and sediment of Baram River estuary, Borneo Island. – Marine Pollution Bulletin 172: 112880. https://doi.org/10.1016/j.marpolbul.2021.112880.

[8] Chuvanich, S., Thongnoo, K., Chevakidagarn, P., Phongdara, A. (2017): Evaluation of Artificial Neural Networks for Electrical Conductivity-based and Flow Rate-based Prediction of the Nitrate Nitrogen Concentration in the U-Tapao Canal, Hat Yai, Thailand. – Environment Asia 10(2): 15-24.

[9] De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., Robbens, J. (2014): Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. – Marine Pollution Bulletin 85(1): 146-155. https://doi.org/10.1016/j.marpolbul.2014.06.006.

[10] Erni-Cassola, G., Zadjelovic, V., Gibson, M. I., Christie-Oleza, J. A. (2019): Distribution of plastic polymer types in the marine environment; A meta-analysis. – Journal of Hazardous Materials 369: 691-698. https://doi.org/10.1016/j.jhazmat.2019.02.067.

[11] Firdaus, M., Trihadiningrum, Y., Lestari, P. (2020): Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia. – Marine Pollution Bulletin 150: 110790. https://doi.org/10.1016/j.marpolbul.2019.110790.

[12] Gee, G. W., Bauder, J. W., Klute, A. (1986): Methods of soil analysis, part 1, physical and mineralogical methods. – Soil Science Society of America, American Society of Agronomy.

[13] Gyawali, S., Techato, K., Yuangyai, C., Monprapussorn, S. (2012): Assessment of Surface Water Quality Parameters and Their Variations for Effective River Monitoring System: A Case Study of U-Tapao River Basin. – Applied Environmental Research 34(2): 89-106.

[14] Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., Thiel, M. (2012): Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. – Environmental Science & Technology 46(6): 3060-3075. https://doi.org/10.1021/es2031505.

[15] Jahan, S., Strezov, V., Weldekidan, H., Kumar, R., Kan, T., Sarkodie, S. A., He, J., Dastjerdi, B., Wilson, S. P. (2019): Interrelationship of microplastic pollution in sediments and oysters in a seaport environment of the eastern coast of Australia. – Science of The Total Environment 695: 133924. https://doi.org/10.1016/j.scitotenv.2019.133924.

[16] Jenkins, T., Persaud, B. D., Cowger, W., Szigeti, K., Roche, D. G., Clary, E., Slowinski, S., Lei, B., Abeynayaka, A., Nyadjro, E. S., Maes, T., Thornton Hampton, L., Bergmann, M., Aherne, J., Mason, S. A., Honek, J. F., Rezanezhad, F., Lusher, A. L., Booth, A. M., Van Cappellen, P. (2022): Current State of Microplastic Pollution Research Data: Trends in Availability and Sources of Open Data. – Frontiers in Environmental Science 10. https://www.frontiersin.org/articles/10.3389/fenvs.2022.912107.

[17] Jiwarungrueangkul, T., Phaksopa, J., Sompongchaiyakul, P., Tipmanee, D. (2021): Seasonal microplastic variations in estuarine sediments from urban canal on the west coast of Thailand: A case study in Phuket province. – Marine Pollution Bulletin 168: 112452. https://doi.org/10.1016/j.marpolbul.2021.112452.

[18] Jualaong, S., Pransilpa, M., Pradit, S., Towatana, P. (2021): Type and Distrubution of Microplastics in Beach Sediment along the Coast of the Eastern Gulf of Thailand. – Journal of Marine Science and Engineering 9(1405): 1-12.

[19] Kingsley, O., Witthayawirasak, B. (2020a): Deterministic Assessment of the Risk of Phthalate Esters in Sediments of U-Tapao Canal, Southern Thailand. –Toxics 8(4):93. https://doi.org/10.3390/toxics8040093.

[20] Kingsley, O., Witthayawirasak, B. (2020b): Occurrence, Ecological and Health Risk Assessment of Phthalate Esters in Surface Water of U-Tapao Canal, Southern, Thailand. – Toxics 8(3):58. https://doi.org/10.3390/toxics8030058.

[21] Kundu, M. N., Komakech, H. C., Lugomela, G. (2022): Analysis of Macro- and Microplastics in Riverine, Riverbanks, and Irrigated Farms in Arusha, Tanzania. – Archives of Environmental Contamination and Toxicology 82(1): 142-157. https://doi.org/10.1007/s00244-021-00897-1.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_45634576

[22] Li, B., Liang, W., Liu, Q.-X., Fu, S., Ma, C., Chen, Q., Su, L., Craig, N. J., Shi, H. (2021): Fish Ingest Microplastics Unintentionally. – Environmental Science & Technology 55(15): 10471-10479. https://doi.org/10.1021/acs.est.1c01753.
[23] Li, Z., Chao, M., He, X., Lan, X., Tian, C., Feng, C., Shen, Z. (2022): Microplastic bioaccumulation in estuary-caught fishery resource. – Environmental Pollution 306: 119392. https://doi.org/10.1016/j.envpol.2022.119392.
[24] Masura, J., Baker, J., Foster, G., Arthur, C. (2015): Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments. – Siver Spring, MD, NOAA Marine Debris Division, 31p. http://dx.doi.org/10.25607/OBP-604.
[25] Matsuguma, Y., Takada, H., Kumata, H., Kanke, H., Sakurai, S., Suzuki, T., Itoh, M., Okazaki, Y., Boonyatumanond, R., Zakaria, M. P., Weerts, S., Newman, B. (2017): Microplastics in Sediment Cores from Asia and Africa as Indicators of Temporal Trends in Plastic Pollution. – Archives of Environmental Contamination and Toxicology 73(2): 230-239. https://doi.org/10.1007/s00244-017-0414-9.
[26] Mohamed Nor, N. H., Obbard, J. P. (2014): Microplastics in Singapore's coastal mangrove ecosystems. – Marine Pollution Bulletin 79(1): 278-283. https://doi.org/10.1016/j.marpolbul.2013.11.025.
[27] Nanthini devi, K., Raju, P., Santhanam, P., Perumal, P. (2022): Impacts of microplastics on marine organisms: Present perspectives and the way forward. – The Egyptian Journal of Aquatic Research 48(3): 205-209. https://doi.org/10.1016/j.ejar.2022.03.001.
[28] Pirsaheb, M., Hossini, H., Makhdoumi, P. (2020): Review of microplastic occurrence and toxicological effects in marine environment: Experimental evidence of inflammation. – Process Safety and Environmental Protection 142: 1-14.
[29] Pradit, S., Towatana, P., Nitiratsuwan, T., Jualaong, S., Jirajarus, M., Sornplang, K., Noppradit, P., Darakai, Y., Weerawong, C. (2020): Occurrence of microplastics on beach sediment at Libong, a pristine island in Andaman Sea, Thailand. – Scienceasia 46: 336-343.
[30] Pradit, S., Noppradit, P., Goh, B. P., Sornplang, K., Ong, M. C., Towatana, P. (2021): Occurrence of microplastics and trace metals in fish and shrimp from Songkhla lake, Thailand during the COVID-19 pandemic. – Appl. Ecol. Environ. Res. 19(2): 1085-1106.
[31] Pradit, S., Noppradit, P., Loh, P.-S., Nitiratsuwan, T., Le, T. P. Q., Oeurng, C., Mohamed, C. A. R., Lee, C. W., Lu, X., Anshari, G. Z., Kandasamy, S., Wang, J. (2022): The Occurrence of Microplastics in Sediment Cores from Two Mangrove Areas in Southern Thailand. – Journal of Marine Science and Engineering 10(3): 3. https://doi.org/10.3390/jmse10030418.
[32] Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., Rocha-Santos, T. (2020): Environmental exposure to microplastics: An overview on possible human health effects. – Science of The Total Environment 702: 134455. https://doi.org/10.1016/j.scitotenv.2019.134455.
[33] Srimuang, K. (2011): Characterization and reduction of fractionated dissolved organic matter in raw water supply from U-Tapao canal by enhanced coagulation. – Prince of Songkla University.
[34] Ta, A. T., Babel, S. (2020): Microplastics pollution with heavy metals in the aquaculture zone of the Chao Phraya River Estuary, Thailand. – Marine Pollution Bulletin 161: 111747. https://doi.org/10.1016/j.marpolbul.2020.111747.
[35] Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., Janssen, C. R. (2015): Microplastics in sediments: A review of techniques, occurrence, and effects. – Marine Environmental Research 111: 5-17. https://doi.org/10.1016/j.marenvres.2015.06.007.
[36] van Emmerik, T., Strady, E., Kieu-Le, T.-C., Nguyen, L., Gratiot, N. (2019): Seasonality of riverine macroplastic transport. – Scientific Reports 9(1): 1-9.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_45634576

[37] Vermeiren, P., Lercari, D., Muñoz, C. C., Ikejima, K., Celentano, E., Jorge-Romero, G., Defeo, O. (2021): Sediment grain size determines microplastic exposure landscapes for sandy beach macroinfauna. – Environmental Pollution 286: 117308. https://doi.org/10.1016/j.envpol.2021.117308.
[38] Wang, J., Wang, M., Ru, S., Liu, X. (2019): High levels of microplastic pollution in the sediments and benthic organisms of the South Yellow Sea, China. – Science of The Total Environment 651: 1661-1669. https://doi.org/10.1016/j.scitotenv.2018.10.007.
[39] Yan, J., Yao, S., Zhang, T., Ye, Z., Weng, J., Hu, X., Zhang, K. (2022): Microplastics and Their Impacts on Organisms and Trophic Chains. – Water 14(24): 24. https://doi.org/10.3390/w14244069.
[40] Yang, L., Zhang, Y., Kang, S., Wang, Z., Wu, C. (2021): Microplastics in freshwater sediment: A review on methods, occurrence, and sources. – Science of The Total Environment 754: 141948. https://doi.org/10.1016/j.scitotenv.2020.141948.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_45634576