



The potential development of a micro plastic pond skimmer device for the reduction of the presence of micro plastics in fish ponds

Liam S. Tongol^a, Cyrelle M. Gragasin^b, Jayson B. Eugelio^c, Corazon U. Apoderado^{d*}

San Miguel National Highschool, San Miguel, Bulacan, Philippines

ABSTRACT:

Microplastic pollution is becoming a problem in freshwater environments and may affect fish, water quality, and aquaculture. This study aimed to develop and test a microplastic pond skimmer device that uses a reverse osmosis (RO) membrane and an Arduino-based monitoring system to reduce simulated microplastics in water. The researchers used an experimental design to build and test the device using an Arduino Nano, booster pump, RO membrane, pressure sensor, flow sensor, and other materials. Simulated microplastics made from ground polypropylene bottle caps were mixed with distilled water and passed through the device in three trials. The results showed that the device recovered an average of 78.047% of the simulated microplastics, with recovery percentages of 78.289%, 77.896%, and 77.956% in the three trials. The device also filtered 1.0 liter of water in an average of 3.48 minutes, with an average flow rate of 0.287 L/min and operating pressure of 82.7 PSI. The results showed that the device worked consistently during the three trials. However, it was not able to recover all of the simulated microplastics, with about 21.953% remaining unrecovered. Since the experiment was conducted only under laboratory conditions using simulated microplastics, further testing using actual fish pond water is needed. This study shows that the developed device has potential to reduce microplastics in water and may be improved for future use in aquaculture.

Keywords: Microplastics, Pond skimmer, Arduino, Reverse Osmosis(RO), Simulated Microplastics

Main text

The Philippines is widely recognized for its rich marine biodiversity and thriving aquaculture industry, both of which contribute significantly to the country's food security and economy. However, the increasing presence of microplastics (MPs) in freshwater and marine ecosystems has become a growing environmental concern. Microplastics are plastic particles measuring less than 5 millimeters in diameter that originate from the breakdown of larger plastic materials or are intentionally manufactured for industrial and commercial use. These particles include plastic beads, fragments, pellets, films, and foams. Due to their persistence and small size, microplastics are capable of spreading throughout aquatic environments, posing risks to both aquatic organisms and human health.

Agriculture remains one of the Philippines' most important economic sectors, supplying essential resources such as crops, livestock, poultry, and fisheries. Among these sectors, fisheries play a crucial role in providing food and livelihood to millions of Filipinos. However, the quality and safety of fish harvested from freshwater systems are increasingly threatened by microplastic contamination. Rivers, lakes, and fish ponds serve as pathways through which microplastics accumulate, eventually settling in sediments or remaining suspended in the water where they can be ingested by aquatic organisms.

Global plastic production has reached approximately 390.7 million metric tons annually, contributing significantly to plastic pollution in terrestrial and aquatic environments. In the Philippines alone, the National Research Council of the Philippines (NRCPP) estimates that approximately 2.3 million tons of plastic waste are generated each year. As plastic waste degrades over time, it breaks down into microplastics that can enter rivers, lakes, and fish ponds. Once introduced into these environments, microplastics may be consumed by aquatic organisms and transferred through the food chain.

Several studies have demonstrated the widespread occurrence of microplastics in Philippine freshwater ecosystems. Seyad et al. (2022) detected plastic polymers, including acrylonitrile butadiene styrene (ABS), ethylene vinyl acetate (EVA), polyamide (PA), and polyethylene terephthalate (PET), in surface water samples collected from Visayas State University, with an average concentration of 132.5 particles per liter. Likewise, researchers from Mindanao State University reported the presence of 100 microplastic particles across ten sampling stations in Laguna de Bay, the largest freshwater lake in the Philippines, with an average concentration of 14.29 particles per cubic meter. These findings indicate that microplastic pollution has become a significant concern in Philippine freshwater environments.

Microplastics enter aquatic ecosystems through various sources, including fishing activities, coastal tourism, industrial discharge, urban runoff, and river transport. Because these particles are highly resistant to natural degradation, they persist in aquatic environments and become available for ingestion by fish and other aquatic organisms. Studies have reported that up to 97% of fish samples collected from contaminated waters in the Philippines contain microplastics. The accumulation of these particles has been associated with tissue damage, oxidative stress, immune system disruption, cytotoxicity, and neurotoxicity in aquatic organisms.

In addition to their physical effects, microplastics can adsorb toxic chemicals known as Persistent Organic Pollutants (POPs). According to Andrady (2022), these pollutants attach to microplastics and are transported through aquatic food webs after being ingested by marine organisms. Martin et al.

(2022) also reported increasing microplastic abundance in North Atlantic plankton populations, demonstrating the long-term accumulation of plastics within aquatic ecosystems. Human exposure to microplastics through contaminated food and water has become an emerging public health concern, with studies suggesting possible associations with respiratory diseases, inflammation, and certain cancers (Diaz, 2025).

Although several techniques have been developed to reduce microplastic contamination, each method has limitations. Manual removal is labor-intensive and impractical for large bodies of water, while conventional filtration systems often experience rapid clogging and reduced efficiency (Hamann et al., 2025). Boiling has also been explored as a treatment method; however, it is unsuitable for fish ponds because elevated water temperatures may harm aquatic organisms (Cherian, 2023). As a result, membrane filtration has emerged as one of the most promising technologies for microplastic removal due to its high filtration efficiency and minimal impact on aquatic life.

Recent studies have shown that membrane filtration technologies, including microfiltration, ultrafiltration, nanofiltration, and reverse osmosis (RO), are highly effective in removing suspended particles from water (Lin et al., 2025). Among these technologies, reverse osmosis membranes possess the smallest pore sizes, ranging from approximately 0.0001 to 0.0005 micrometers, enabling them to remove extremely fine contaminants, including many microplastics (Bodzek, 2025). Pressure-driven RO systems force water through semi-permeable membranes while retaining contaminants, producing cleaner permeate and concentrated waste known as retentate. Studies have reported removal efficiencies approaching 99% for particles within the effective filtration range of RO membranes.

Another promising technique is skimming, which removes floating debris from the water surface through continuous circulation. Tursi et al. (2022) identified skimming as a low-cost and efficient method for mitigating floating contaminants in aquatic environments. Integrating skimming technology with reverse osmosis membrane filtration may therefore provide a more comprehensive approach to reducing microplastic contamination in fish ponds by combining debris collection with high-efficiency filtration.

Despite recent advances in membrane filtration and skimming technologies, there remains a lack of affordable, automated systems specifically designed to reduce microplastic contamination in fish ponds. Most existing technologies are intended for wastewater treatment or drinking water purification and are often too expensive or impractical for small-scale aquaculture applications. This research seeks to address this gap by proposing the development of an automated microplastic pond skimmer that incorporates reverse osmosis membrane technology to improve water quality in fish ponds.

This study supports Sustainable Development Goal (SDG) 6: Clean Water and Sanitation by promoting improved water quality through the reduction of harmful contaminants. It also supports Sustainable Development Goal (SDG) 14: Life Below Water by contributing to the protection of aquatic ecosystems and the health of freshwater organisms. Ultimately, this research aims to develop a practical and affordable prototype that may help improve fish pond water quality, support safer aquaculture practices, and provide valuable information for future studies on microplastic removal technology.

Microplastics are plastic particles measuring less than 5 millimeters in diameter that originate from the breakdown of larger plastic materials or from products manufactured in microscopic sizes. Their persistence and resistance to natural degradation have made them one of the most common pollutants in aquatic environments. According to Ahmed et al. (2023), the continuous increase in plastic production and improper waste disposal has resulted in the widespread accumulation of microplastics in freshwater and marine ecosystems. Similarly, Katare et al. (2022) stated that rivers and lakes serve as major pathways that transport these particles across different aquatic environments. The increasing presence of microplastics has also become a concern in aquaculture systems, including fish ponds. Since many fish ponds receive water from rivers, canals, and other freshwater sources, they are vulnerable to contamination from surrounding environments. Hossain et al. (2023) reported that microplastics are commonly detected in fish culture ponds, while Hapal et al. (2024) confirmed the presence of microplastics in freshwater fish ponds in the Philippines. These findings indicate that fish ponds are continuously exposed to plastic pollution through water exchange and surface runoff. The accumulation of microplastics in fish ponds threatens both aquatic organisms and food safety. Fish may ingest these particles during feeding, which can lead to tissue damage, oxidative stress, immune system disruption, and reduced growth (Bhuyan, 2022). Similatan et al. (2023) also documented the ingestion of microplastics by milkfish raised in Philippine aquaculture systems, demonstrating that cultured fish are vulnerable to contamination. These studies highlight the need for effective technologies that can reduce microplastic pollution in fish ponds and support the development of safer and more sustainable aquaculture practices.

RO membranes are widely used in desalination plants, municipal drinking water treatment facilities, and industrial wastewater treatment because of their high contaminant rejection efficiency. Studies have reported that RO membranes can effectively remove dissolved ions, heavy metals, pathogens, pharmaceuticals, and other emerging pollutants that cannot be completely removed by conventional treatment technologies. Their ability to reject both particulate and dissolved contaminants makes them one of the most reliable membrane processes available (Albergamo et al., 2021). Several studies have shown that reverse osmosis is highly effective in removing microplastics and nanoplastics from water. Compared with conventional treatment methods and other membrane technologies, RO consistently achieves the highest removal efficiencies, often exceeding 99%, because its dense membrane structure prevents even extremely small plastic particles from passing through. However, researchers also note that membrane fouling remains a challenge and proper pretreatment is necessary to maintain long-term performance (Pinto et al., 2025). The principle of reverse osmosis is based on applying pressure greater than the natural osmotic pressure of water. During this process, water is forced through a semipermeable membrane from a concentrated solution toward a less concentrated one, leaving dissolved salts, contaminants, and other impurities behind. This process is the opposite of natural osmosis and is widely applied in seawater desalination and freshwater purification because of its high separation efficiency (Biesheuvel et al., 2021).

The reviewed literature demonstrates that microplastic pollution has become an increasing environmental concern in freshwater ecosystems and aquaculture systems. Recent studies have shown that microplastics enter freshwater through domestic wastewater, agricultural runoff, industrial discharge, and the degradation of plastic materials used in fish farming. Once introduced into fish ponds, these particles accumulate in water and sediments, where they may be ingested by aquatic organisms and eventually enter the food chain. The reviewed studies consistently emphasize that the increasing occurrence of microplastics poses significant threats to aquatic biodiversity, fish health, and water quality, highlighting the need for more effective water treatment technologies (AhXue et al., 2022). The literature further indicates that reverse osmosis (RO) membrane technology is among the most effective filtration methods for removing microplastics from water. Due to its dense semi-permeable membrane and pressure-driven filtration process, RO systems are capable of rejecting extremely small contaminants, including microplastics and nanoplastics, with higher efficiency than many conventional treatment methods. However, previous researchers have also identified challenges such as membrane fouling, high energy consumption, maintenance requirements, and operational costs, which may affect the long-term application of RO systems in water treatment (Xue et al., 2022; Zhou et al., 2024). Studies on water skimming and automated filtration systems have also shown promising results in improving water quality in aquaculture. Water skimmers effectively remove floating debris, organic waste, and surface contaminants, while automated filtration systems reduce the need for continuous manual cleaning and maintain stable water conditions. Despite these advantages, existing studies primarily evaluate these technologies independently rather than integrating them with advanced membrane filtration systems such as reverse osmosis. Consequently, limited information is available regarding the combined performance of water skimming and reverse osmosis for reducing microplastic contamination in freshwater fish

ponds (Wang et al., 2024). Although numerous studies have investigated microplastic pollution and membrane filtration technologies, several research gaps remain. Most existing research has focused on municipal drinking water treatment plants, wastewater treatment facilities, and laboratory-scale membrane experiments, whereas relatively few studies have examined the application of reverse osmosis technology in freshwater fish ponds used for aquaculture. Furthermore, there is limited research on developing an integrated filtration device that combines reverse osmosis with automated water-skimming or pre-filtration mechanisms to improve microplastic removal while maintaining practical operation in aquaculture environments (Zhou et al., 2024; Wang et al., 2024). Therefore, this study seeks to address these research gaps by developing and evaluating a reverse osmosis membrane-based filtration device intended for freshwater fish ponds. Unlike previous studies that focused primarily on conventional water treatment facilities or individual filtration methods, this research aims to investigate the potential application of an integrated filtration approach for reducing microplastic contamination in aquaculture systems. The findings of this study are expected to contribute to the advancement of sustainable water treatment technologies and provide useful information for future researchers and aquaculture practitioners seeking effective methods for improving freshwater quality and reducing microplastic pollution (Xue et al., 2022; Zhou et al., 2024).

This study aims to develop an automatic device that uses a reverse osmosis (RO) membrane to filter microplastics present in water. The device combines the RO membrane with several components to automate the filtration process. Specifically, the study seeks to determine the possible limitations of the device's capability to remove microplastics from fish ponds, as well as the statistics of the Arduino monitoring data during the trials in terms of pressure (PSI), TDS value of water, and power consumption. The study also aims to determine the average filtration time within three trials, the recovery percentage of the simulated microplastic particles, and the operational statistics of the device in terms of filtration time, flow rate, and operating pressure.

1.1. Statement of the problem

The study focused on developing an automatic device that aims to filter majority of microplastics present in bodies of water with the use of a Reverse Osmosis(RO) membrane that allows the filtering of microparticles combined with several parts that help form automated execution. As the study sought to answer the following questions.

- 1. What are the possible limitations of the microplastic pond skimmer's capabilities in filtering water?
- 2. What are the statistics of Arduino monitoring data when a trial is performed in terms of:

2.1:Pressure(PSI)

2.2:TDS value of water

2.3:Energy consumption(V)

- 3. What is the recovery percentage of simulated microplastic particles?
- 4. What are the operational statistics of the device during execution in terms of:

4.1:Filtration time

4.2:Flow rate

4.3:Operating Pressure

Methodology

1.2. Preparation of water samples

The first stage of the study is conducted by grinding a clean polypropylene bottle cap from a water bottle to create simulated microplastics particles which are sizes ranging from 1mm – 5mm, it is then weighed using a digital kitchen scale to get the initial weight of the simulated microplastic particles. After weighing the sample it is then transferred to the prepared distilled water.

1.3. Gathering of the necessary parts

The second stage of the study was conducted by acquiring all the required parts of the envisioned prototype by purchasing the needed materials and parts for the device via online shops.

1.4. Coding of the modules

The third stage of the study, the parts of the device are coded to their specific use in order to ensure the proper and right functions of each individual device and allowing the device to function how it is desired to be. The code regulates the operation of the pump and other electronic components to automate the water circulation and filtration process. This stage also included debugging and calibration to verify that the device performs its intended functions consistently before experimental testing begins by hiring a programmer.

1.5. Testing of hardware

Before the construction of the prototype the main electrical or mechanical parts were tested to detect any defects and qualities that are not up to the standard for proper execution. This process ensured that the device doesn't contain any hardware error.

1.6. Assembly of the device

Once the code and materials were provided the construction of the hardware prototype was started carefully assembling the device for an increased chance of success and to ensure that the functions of the individual materials are correct which lead to secure and safe outcomes.

1.7. Device Troubleshooting

The fifth stage of the study, after completing the programming process, the prototype was tested using the prepared fish pond water samples. During this stage, contaminated water circulated through the skimmer and reverse osmosis membrane, allowing floating debris and microplastics to be blocked through the filtration process. The operation of the device was carefully observed in order to identify any mechanical or programming issues, and make the necessary adjustments to improve its overall performance and reliability.

1.8. Filtering of the permeate

The permeate was passed through filter paper to retain all remaining simulated microplastic particles in the water. After all the remaining simulated microplastic particles were recovered it was then dried to remove excess moisture that gave extra weight to the simulated microplastic particles.

1.9. Recording and analysis of the permeate

After the water was turned into permeate it was filtered into filter paper and retained microplastics was then weighed in a digital kitchen scale. Using a formula of dividing the weight of the retained microplastics over the weight of the initial amount of microplastics applied to get the percentage of total microplastics retained and subtracted to 100, the total percentage of microplastics removed is known.

1.10. Recording of the collected data

After performing 3 trials of the filtration process and recovering all simulated microplastic particles the data gathered were recorded in a table for further testing and analysis about the effectiveness of the device.

Results

At this stage of the study, results are now presented. The prototype was used to determine its overall effectivity for the process of removing microplastics in simulated fish pond water. The gathered data were analyzed and discussed to present the overall effectivity.

1.11. Limitations of the device.

The device was able to remove/recover an average of 78.047% of the simulated microplastic particles across the three trials. This means that approximately 21.953% of the simulated microplastic particles were not recovered/removed during the filtration process. Therefore, the main observed limitation of the device is that it was not able to remove all of the simulated microplastic particles, achieving about 78.05% effectiveness under the conditions of the experiment. The device was also tested only under laboratory conditions using simulated microplastics, so its performance may be limited to the conditions used in this study.

1.12. Arduino monitoring data

Table 3. The statistics of arduino monitoring data when each trials are performed is shown on table 1 and is divided via, pressure, showntds value of water, and Power consumption.

Number of trials	Pressure	TDS value of water	Power consumption
1st trial	82.4 PSI	B:247ppm A:54ppm	24.1V, 1.42A and 34.20W
2nd trial	84.1 PSI	B:263ppm A:58ppm	24.0V, 1.45A and 34.80W
3rd trial	81.7 PSI	B:251ppm A:55ppm	24.2V, 1.43A and 34.54W
Mean	82.7 PSI	B:253.7ppm A:55.7ppm	24.1V, 1.43A and 34.51W

The monitoring data showed relatively consistent operating conditions across the three trials. The device recorded an average pressure of 82.7 PSI, with individual readings ranging from 81.7 to 84.1 PSI. The TDS readings decreased from an average of 253.7 ppm before filtration to 55.7 ppm after filtration, showing a substantial reduction in the measured dissolved-solids value after treatment. Power consumption also remained consistent, with an average of 24.1 V, 1.43 A, and 34.51 W. The small differences among the three trials suggest that the device operated under relatively stable conditions during testing. These results show that the Arduino monitoring system provided useful measurements for observing the operating condition of the prototype. The average filtration time of filtration within three trials of filtration.

1.13. Recovery percentage of microplastics

Table 2. The estimated percentage of each trials are shown on table 3. Each trials are run at the same filtration time, flow rate, and operating pressure to ensure the most accurate result.

Number of trials	Percentage of microplastics filtered per trial.
1st trial	78.289%
2nd trial	77.896%
3rd trial	77.956%
Mean	78.047%

The three trials produced recovery percentages of 78.289%, 77.896%, and 77.956%, with an overall mean of 78.047%. The small difference among the trial results indicates that the prototype produced relatively consistent microplastic recovery. The first trial produced the highest recovery, while the second trial produced the lowest, but the difference was less than one percentage point. This consistency suggests that the prototype performed similarly when operated under the same filtration conditions. Still, the average recovery of 78.047% shows that a portion of the simulated microplastics remained unrecovered, indicating an area for further improvement.

1.14. Operational statistics of the device

Table 3. shows the operational statistics of the device according to the following: filtration time, flow rate, operating pressure.

Trials	Filtration time	Flow rate	Operating pressure
1 st trial	3.47min	0.289 L/min	82.4 PSI
2 nd trial	3.52min	0.284 L/min	84.1 PSI
3 rd trial	3.44min	0.290 L/min	81.7 PSI
Mean	3.48min	0.287 L/min	82.7 PSI

The operational results showed that the prototype maintained relatively stable filtration conditions throughout the three trials. The mean filtration time was 3.48 minutes, the mean flow rate was 0.287 L/min, and the mean operating pressure was 82.7 PSI. The flow rate ranged only from 0.284 to 0.290 L/min, while the operating pressure ranged from 81.7 to 84.1 PSI. These small variations indicate that the device operated consistently during the experiment. The results also show a relationship between the filtration time and flow rate, since the device processed approximately one liter of water in about three and a half minutes. Overall, the operational data demonstrate that the prototype was able to maintain stable filtration performance during the three experimental trials.

Recommendations

Based on the findings of the study, the following recommendations are proposed in order to give the proposed prototype its full capabilities.

1. *Use laboratory-based microplastic identification.* Future researchers should use a microscope or appropriate laboratory analysis to identify and measure the size, shape, and quantity of simulated microplastic particles before and after filtration.
2. *Test different types and sizes of plastic particles.* Future studies should examine whether the prototype can retain different plastic materials and particle sizes to evaluate its filtration performance under varied conditions.
3. *Increase the number of trials.* Researchers should conduct more repeated trials to obtain more reliable average removal efficiency and determine the consistency of the prototype's performance.
4. *Evaluate the prototype using different water samples.* Future researchers should test the system using water with different levels of suspended particles and other contaminants to determine how water conditions affect filtration performance.
5. *Monitor operating pressure, flow rate, and energy consumption.* The Arduino-controlled prototype should be evaluated under different operating conditions to determine its efficiency, power requirements, and consistency during filtration.

6. *Examine membrane durability and maintenance.* Future studies should investigate membrane fouling, cleaning requirements, and filtration performance after repeated use to determine the prototype's long-term practicality.
7. *Improve the collection and measurement of rejected particles.* Researchers should establish a consistent method for collecting particles from the retentate and other parts of the system to reduce measurement errors and distinguish actual particle retention from losses during handling.
8. *Conduct further testing before practical application.* The prototype should undergo additional controlled testing before being considered for actual fish ponds. Researchers should also evaluate its effects on water quality and determine whether the treated water remains suitable for its intended use.

5. Conclusion

Overall, the findings support the potential of combining skimming, reverse osmosis filtration, and automated monitoring as an approach for reducing simulated microplastic contamination. The prototype provides baseline results for future improvements, particularly in increasing microplastic recovery and improving the filtration system. Further testing using actual fish pond water, longer operating periods, and improved particle recovery methods would provide additional information about the device's effectiveness and reliability.

REFERENCES :

- Ahmed, A. S. S., Billah, M. M., Ali, M. M., Bhuiyan, M. K. A., Guo, L., Mohinuzzaman, M., Hossain, M. B., Rahman, M. S., Islam, M. S., Yan, M., & Cai, W. (2023). Microplastics in aquatic environments: A comprehensive review of toxicity, removal, and remediation strategies. *Science of the Total Environment*, 162414.
- Andrady, A. L. (2022). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8), 1596–1605.
- Bhuyan, S. (2022). Effects of microplastics on fish and in human health. *Frontiers in Environmental Science*, 10.
- Chatterjee, S., & Sharma, S. (2024). Microplastics in our oceans and marine health. *Field Actions Science Reports. The Journal of Field Actions*, 2(Special Issue 19), 54–61.
- Cherian, A. G., Liu, Z., McKie, M. J., Husein Almuhtaram, & Andrews, R. C. (2023). Microplastic removal from drinking water using point-of-use devices. *Polymers*, 15(6), 1331–1331.
- Diaz, G. (2025). Effect of water filters on the removal of microplastics.
- Espiritu, E. Q., Rodolfo, R. S., Evangelista, S. M. J., Feliciano, J. J. G., Sumaway, A. M. N., Pauco, J. L. R., Alvarez, K. V. N., & Enriquez, E. P. (2023). Microplastics contamination in the fishes of selected sites in Pasig River and Marikina River in the Philippines. *Marine Pollution Bulletin*, 187, 114573.
- Hamann, L., Schreiber, K., & Blanke, A. (2025). A self-cleaning, bio-inspired high retention filter for a major entry path of microplastics. *NPJ Emerging Contaminants*, 1(1).
- Hapal, E., Reyes, A. T., Vera, E. M., & Gutierrez, R. L. (2024). Identification and characterization of microplastics in freshwater fishponds and marine cages in Baler, Aurora, Philippines. 17(5), 1963–1982.
- Hossain, M. B., Banik, P., Nur, A.-A., Choudhury, T. R., Liba, S. I., Albeshr, M. F., Yu, J., & Arai, T. (2023). Microplastics in fish culture ponds: Abundance, characterization, and contamination risk assessment. *Frontiers in Environmental Science*, 11.
- Katare, Y., Singh, P., Singh Sankhla, M., Singhal, M., Jadhav, E., Parihar, K., Nikalje, B., Trpathi, A., & Bhardwaj, L. (2022). Microplastics in aquatic environments: Sources, ecotoxicity, detection & remediation. *Biointerface Research in Applied Chemistry*, 12, 3407–3428.
- Kleopatra Miserli, Christos Lykos, Kalampounias, A. G., & Konstantinou, I. (2023). Screening of microplastics in aquaculture systems (fish, mussel, and water samples) by FTIR, scanning electron microscopy–energy dispersive spectroscopy and micro-Raman spectroscopies. *Applied Sciences*, 13(17), 9705–9705.
- Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications*, 8(15611), 15611.
- Lin, Z., Hu, X., Lin, H., Yu, G., Shen, L., Yu, W., Li, B., Zhao, L., & Ying, M. (2025). Membrane technology for microplastic removal: Microplastic occurrence, challenges, and innovations of process and materials. *Chemical Engineering Journal*, 520, 166183.
- Martin, J., Lusher, A., Thompson, R. C., & Morley, A. (2022). The deposition and accumulation of microplastics in marine sediments and bottom water from the Irish Continental Shelf. *Scientific Reports*, 7(1).
- Maryna Stokal, Vriend, P., Bak, M. P., Kroeze, C., van Wijnen, J., & van Emmerik, T. (2023). River export of macro- and microplastics to seas by sources worldwide. *Nature Communications*, 14(1).
- Multisanti, C. R., Merola, C., Perugini, M., Aliko, V., & Faggio, C. (2022). Sentinel species selection for monitoring microplastic pollution. *Ecological Indicators*, 145, 109587.
- Pal, D., Prabhakar, R., Barua, V. B., Zekker, I., Burlakovs, J., Krauklis, A., Hogland, W., & Vincevica-Gaile, Z. (2024). Microplastics in

aquatic systems: Its distribution, environmental interactions, and health risks. *Environmental Science and Pollution Research*, 32.

- Similatan, K. M., Arcadio, C. G. L. A., Navarro, C. K. P., Capangpangan, R. Y., & Bacosa, H. P. (2023). Microplastic ingestion by adult milkfish *Chanos chanos* (Forsskål, 1775) in aquaculture system: The case of Butuan Bay, Philippines. *Marine Pollution Bulletin*, 194, 115409.
- Subaramaniyam, U., Allimuthu, R. S., Vappu, S., Ramalingam, D., Balan, R., Paital, B., Panda, N., Rath, P. K., Ramalingam, N., & Sahoo, D. K. (2023). Effects of microplastics, pesticides and nano-materials on fish health, oxidative stress and antioxidant defense mechanism. *Frontiers in Physiology*, 14.
- Wijaya, B. M. A., Saiful, S., Fathanah, U., & Arahman, N. (2025). Identification of microplastic pollution in surface water and removal strategies using a combination of gravel-zeolite filter. *IOP Conference Series: Earth and Environmental Science*, 1477(1), 012034.
- Yang, J., Monnot, M., Sun, Y., Asia, L., Wong-Wah-Chung, P., Doumenq, P., & Moulin, P. (2023). Microplastics in different water samples (seawater, freshwater, and wastewater): Methodology approach for characterization using micro-FTIR spectroscopy. *Water Research*, 232, 119711.