An Intelligent Embedded System for detecting and analyzing pollution in water samples.

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Introduction

Oceans are essential to human survival and prosperity [1]. They are the source of many vital medicines such as for tumor growth and human cancer because the ocean are home of many unique biodiversity that provide medicines and treatments to many diseases, specifically, the text highlights that compounds derived from marine organisms are being explored and used for treating various diseases, including cancer [2], they are the food source for millions of organisms, and the waters are constantly changing, leading to a changing world [3].

Many small island developing states, especially those located in the Caribbean, Pacific, Indian Ocean, and African regions, face various health challenges, including diseases like diabetes and obesity. Additionally, the isolation of these islands can lead to issues such as boredom, which may affect mental health. To address these challenges, these communities heavily rely on their surrounding waters, using them as a source of food, medicine, and recreation to maintain their health and well-being[4].

However, the health and sustainability of these waters are threatened by pollution, which is one of the major challenges of our time. Pollution, caused by household waste, agricultural runoff, and industrial activities, introduces hazardous materials into the environment[5]. This pollution not only degrades the marine ecosystems that these island states depend on but also poses a direct risk to their health and economic stability[6].

Water pollution not only threatens marine biodiversity but also poses significant risks to human health and the economy[7, 8]. The contamination of water bodies disrupts ecosystems, leading to the loss of marine life and the degradation of water quality, which is essential for drinking, agriculture, and recreation. Innovative solutions are necessary to tackle this issue[9].

In recent years, environmental pollution caused by microplastics has become a growing concern due to its negative effects on aquatic ecosystems, marine life, and ultimately human health[10]. Microplastics are small plastic particles less than 5 millimeters in size[11] that accumulate in aquatic environments, such as oceans, rivers, and lakes, polluting the water and directly affecting organisms that depend on these waters.

Microplastics enter the marine food chain when ingested by marine organisms, putting the entire ecosystem at risk and increasing the likelihood of humans being exposed to pollution through the consumption of contaminated seafood. This challenge has prompted many scientists and inventors to seek innovative solutions to address this growing problem. Research indicates that water pollution is responsible for 50% of child deaths and 80% of common diseases in humans[12].

In addition, this pollution contributes to the elimination of organisms that depend on aquatic environments, which are an essential part of the human food chain, thus disrupting the ecological balance. It is known that half of the oxygen we need is produced by algae and aquatic plants[13].

Microplastics are formed from the breakdown of larger plastics due to chemical decomposition, exposure to sunlight, and ocean waves [14]. Scientists estimate that there are at least 170 trillion plastic particles in the oceans, with a total weight of nearly two million tons [15].

In 2022, researchers from Hull York Medical School in the United Kingdom discovered 39 microplastic particles in 11 out of 13 samples of living human lungs, demonstrating that these particles can reach places previously considered inaccessible due to narrow airways [16]. This discovery follows the first similar discovery of plastic particles in human blood, indicating that these materials are widespread in the human body and may contain carcinogens that affect human health [17].

As the health and environmental threats resulting from the spread and accumulation of microplastics in aquatic ecosystems increase, finding innovative solutions becomes imperative. This invention contributes to the detection and treatment of microplastic particles, improving water quality, protecting the environment, and promoting public health by reducing pollution and its harmful effects.

Advanced technologies for monitoring and treating water pollution can play a critical role in mitigating these impacts. The development and implementation of such technologies like the invention are crucial steps towards ensuring clean and sustainable water resources for future generations.

The invention can detect : Total Dissolved Solids (organic and inorganic matter), Turbidity (clarity of water), Microplastics, pH (acidity of water), etc.

There are various solutions available to address pollution issues, such as using plastic-free cosmetics, biodegradable straws, and implementing green farming practices to lessen pollution. These measures are part of the broader effort to reduce contamination in seawater and other water bodies.

The Intelligent Embedded System is an eco-friendly invention designed to address global water pollution. It utilizes multiple sensors to detect contamination and treats the water if necessary. Constructed from recyclable materials like metal, glass, and filament, and powered by solar panels, the invention aligns with several Sustainable Development Goals (SDGs), including SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 14 (Life Below Water).

Figure1: The four different SDGs the invention covers.

To advance SDG No. 6 and No. 13 and improve water treatment, the invention will use a layer of Metal-Organic Frameworks (MOFs), detailed in the following paragraphs.

Metal-Organic Frameworks (MOFs)

Metal-Organic Frameworks (MOFs) is a highly porous compound formed by metal ions and organic ligands. To treat water pollution this invention will use either the two types of the MOFs which are: MIL-101-Cr and MIL-101-Cr-SO3.

MIL-101-Cr

Overview: MIL-101(Cr), a chromium-based metal-organic framework, features an ultra-high surface area, large pore size, and excellent stability. Its unique structure allows for diverse applications in aqueous phase adsorption, gas storage, separation, and catalysis, with ongoing advancements in synthesis and functionality.

Positive: MIL-101-CR is a highly effective Metal-Organic Framework (MOF) for water pollution treatment. It features a high surface area, selective adsorption of pollutants, reusability, and chemical stability, making it ideal for removing contaminants like heavy metals and toxic dyes. Additionally, it's eco-friendly, ensuring sustainable and efficient water purification[18].

MIL-101-Cr-SO3

Overview: MIL-101-Cr-SO3 is a material that's effective in tackling water pollution. It has special properties that help remove harmful substances from water, such as heavy metals and dyes. It's designed to work well in water, making it a useful tool for cleaning up polluted environments.

Positive: MIL-101-Cr-SO_3 outperforms MIL-101-Cr in water purification with its sulfonic acid groups, which enhance its ability to capture microplastics. It offers better stability in water, improved selectivity for contaminants, and increased efficiency in adsorption and removal, making it a superior choice for addressing microplastic pollution[19].

MIL-101-CR OR MIL-101-Cr-SO3

Based on much research, MIL-101-Cr-SO3 is generally more reliable than MIL-101-Cr in water environments. It offers enhanced stability due to sulfonic acid functionalization, which also improves its ability to treat microplastics and dissolved solids. Although it is more expensive, MIL-101-Cr-SO3 provides better performance in maintaining water clarity and handling various contaminants. In contrast, MIL-101-Cr is less costly but may have limited stability and effectiveness in aqueous conditions. For overall reliability and performance in water treatment, (MIL-101-Cr-SO3 is the better choice).

Electrostatic Interaction

The electrostatic interaction between MIL-101-Cr-SO3 and microplastics in water is an interaction that depends on the charges of the two MIL-101-Cr-SO3 components being bound to the charges present in the microplastics. MIL-101-Cr-SO3 is a negatively charged sulfonic acid group (-SO3H), which attracts positively charged pollutants, such as microplastics in water, making it effective in environmental treatment.

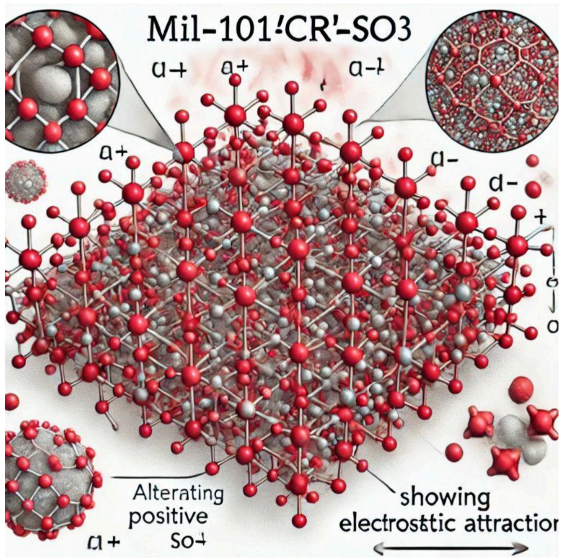

Figure2: The electrostatic interaction between microplastics and MIL-101-Cr-SO3

Scientific Background

Water pollution, especially from microplastics, is a huge threat to aquatic ecosystems and human health. Microplastics are small plastic particles less than 5 mm in size and often come from the degradation of larger plastic debris, synthetic textiles, and some personal care products. These can be ingested by marine organisms, thus creating blockages, reduced feeding, and exposure to harmful toxins. Further, microplastic penetrates the human food chain via seafood consumption and hence causes potential health hazard due to endocrine disruption and bioaccumulation of chemicals in the body. Driven by the pressing environmental issue, we propose the design of an Intelligent Embedded System specifically for monitoring and treating water pollution aimed at microplastics. The system is innovative and eco-friendly; it has advanced sensors that are capable of monitoring critical water quality parameters such as TDS, pH, and turbidity to effectively measure the pollution extent that might affect the quality of water for both marine life and human beings. The system embodies this paper with MOFs, more specifically MIL-101-Cr-SO3, to capture and remove contaminants in water efficiently. Besides, it is powered by renewable energy from the sun; hence, this echoes through the call for sustainable living in developing countries by reducing overdependence on non-renewable energy sources. Basically, this intelligent system is a milestone toward the management of water pollution, aiming at protection of the marine ecosystem and contributing to a cleaner, more sustainable future.

Objectives

The project will contribute to a reduction of microplastic material in marine ecosystems and an improvement of environmental health. The detection, monitoring, and water pollution treatment will be effected with the use of eco-friendly MOFs that capture the contaminants. The system will measure the most relevant metrics of water quality, leveraging AI techniques to realize real-time detection of microplastics. This also includes a mobile application for accessing data on pollution, enabling communities, governments, and individuals to make informed choices based on water quality. This all-in-one solution is aimed at facilitating sustainability in concert with marine life globally, yielding cleaner and healthier marine systems.

Hypothesis

The proposed introduction of an Intelligent Embedded System based on MOFs, which will capture microplastic, effectively reduces the concentration of microplastic in water. This shall guarantee quantifiable improvements in the quality of water; further, real-time monitoring shall improve public awareness and translate into actionable insights within communities and by policy actors. Which will culminate in

Novelty

As shown in Figure The invention is an intelligent embedded system, including a real-time enabled microfluidic chip for monitoring, together with AI-based analysis, will provide an opportunity for continuous and accurate detection of microplastics. In this system, the treatment involves Metal-Organic Frameworks, more specifically MIL-101-Cr-SO3, which selectively captures microplastics with high efficiency and stability in water. It is also integrated with a mobile app, ensuring transparency through the availing of real-time data on water quality and, therefore, allowing the public and governments to access very vital information about pollution. Eco-friendly design powered by solar energy with recyclable material meets the goals of sustainability, making this invention not only effective but also an environmentally responsible advance in marine conservation.

Methods

In relation to the Intelligent Embedded System, laboratories play a crucial role in monitoring water pollution. The typical procedures involve:

- pH test strips (range 1-14)
- Chlorine test strips (range 0-5 ppm)
- Nitrate test strips
- Water hardness test strips
- Samples from different water sources
- Beakers or cups
- Distilled water
- A laboratory notebook

Laboratories procedure

1. Start by measuring the pH, chlorine, nitrate, and hardness of tap and distilled water.

2. Dip the pH strip, compare the colors, and note the findings right away.

3.Dip the chlorine strip; after five seconds, compare the colors, and note.

4.Dip the nitrate strips, brush off any extra liquid, and then compare a minute later.

5. Take a dip hardness strip, compare right away, and note.

6.Repeat steps 2 through 5 using various water sources and distilled water.

7.If desired, test other factors such as pH within a restricted range or phosphate.[20]

The invention procedure

1.**General explanation**

The current invention is an integrated system designed to monitor, control, and treat water pollution, specifically focusing on microplastics in the marine environment. Utilizing advanced technologies, such as Metal-Organic Frameworks (MOFs), the system effectively targets and treats these pollutants, contributing to the restoration of water cleanliness and the protection of marine ecosystems. The system operates on electrical energy, which can be generated through the addition of solar panels installed on the device, ensuring a sustainable approach to environmental management.

2. Detailed explanation

The Intelligent Embedded System automatically draws seawater using a submersible pump and measures its pH, TDS, and turbidity. The water is then pushed through a microfluidic chip for real-time observation under a microscope. An AI system detects microplastics, and then, the water is treated using a MIL-101-Cr-SO3 MOF. The treated or clean water is then either released back into the sea. The entire system is powered by solar panels for sustainable

3. Detection System Overview

The device is designed to automatically collect seawater, measure its pH, Total Dissolved Solids (TDS), and turbidity, and then detect microplastics using a microfluidic chip and optical microscope using an AI method. The system will treat or release the water based on the pollution levels detected. **(To be discussed for treatment method)**

4. Components and Materials

- **Submersible Pump**: Mini DC submersible pump (3-6V, 120-240 L/H)
- **Reservoir**: It will be inside the system and the size will be 500ml
- **pH Sensor**: Analog pH sensor
- **TDS Sensor**: Analog TDS sensor
- **Turbidity Sensor**: Analog turbidity sensor
- **Syringe Pump**: Stepper motor-driven syringe pump (compatible with 5 ml syringes)

- Syringe: 5 ml syringe

- **Solenoid Valve**: 12V DC normally closed solenoid valve

- **Check Valve**: one-way check valve - Microfluidic Chip: Custom microfluidic chip made from plexiglass and a parafilm

- **Optical Microscope**: USB digital microscope with 1000x magnification and video capture capability.

- **Secondary Reservoir**: the reservoir will be inside the system it will store polluted water for treatment

- **Tubing**: Silicone tubing (2 mm inner diameter, 4 mm outer diameter).

- **Microcontroller**: Arduino Uno

- **solar panel**: to provide power for the system

5. **Operation Procedure**

Step 1: **Seawater Sampling**

- The submersible pump is placed in the seawater and activated by the microcontroller to draw seawater into the reservoir.

- The reservoir is equipped with pH, TDS, and turbidity sensors to measure the water's properties.

Step 2: **Microplastics Detection**

- A tube connected to the reservoir leads to the syringe pump. This tube includes a solenoid valve and a check valve to prevent backflow.

- The solenoid valve is opened, allowing seawater to flow into the syringe. The syringe pump then draws seawater from the reservoir into the syringe.

- After filling, the solenoid valve closes, and the syringe pump pushes the seawater through the microfluidic chip. The microfluidic chip, positioned on the stage of an optical microscope, allows for real-time observation and video capture of the seawater flow.

- The camera on the microscope sends a live video feed to an AI system to detect microplastics.

Step 3: **Water Management**

- After passing through the microfluidic chip, the seawater is directed straight to the treatment tank through tubing. A check valve is installed between the microfluidic chip and the treatment tank to ensure the water only flows in one direction and prevents any backflow.

-The AI detection system for microplastics analyzes the water in real-time as it flows through the microfluidic chip.

-Regardless of whether microplastics are detected or not, all water is sent to the treatment tank for further processing, ensuring that no contaminated water is released back into the ocean.

Step 4: **Treatment**

- When water is moved to the seawater treatment reservoir, a layer of MIL-101-Cr-SO3 will remove irregular pollutants and tiny microplastics. This is achieved through the unique capabilities of metal-organic frameworks to target and capture specific contaminants.

Step 5: **Data Collection and Analysis**

- The real-time video of the seawater flowing through the microfluidic chip is analyzed by AI for microplastic detection.

- Sensor data (pH, TDS, turbidity) is recorded and correlated with the presence of microplastics.

Step 6 :**The Application**

- To share the informations, a gps and a IOT (Internet of things) will be installed on the device so when a user is using the device on a local sea he will get every bit of information by the application that is design to suit any category of people

- The application will have the database of every single polluted area that was detected. It will also have some information and statistics about pollution on water to spread awareness.

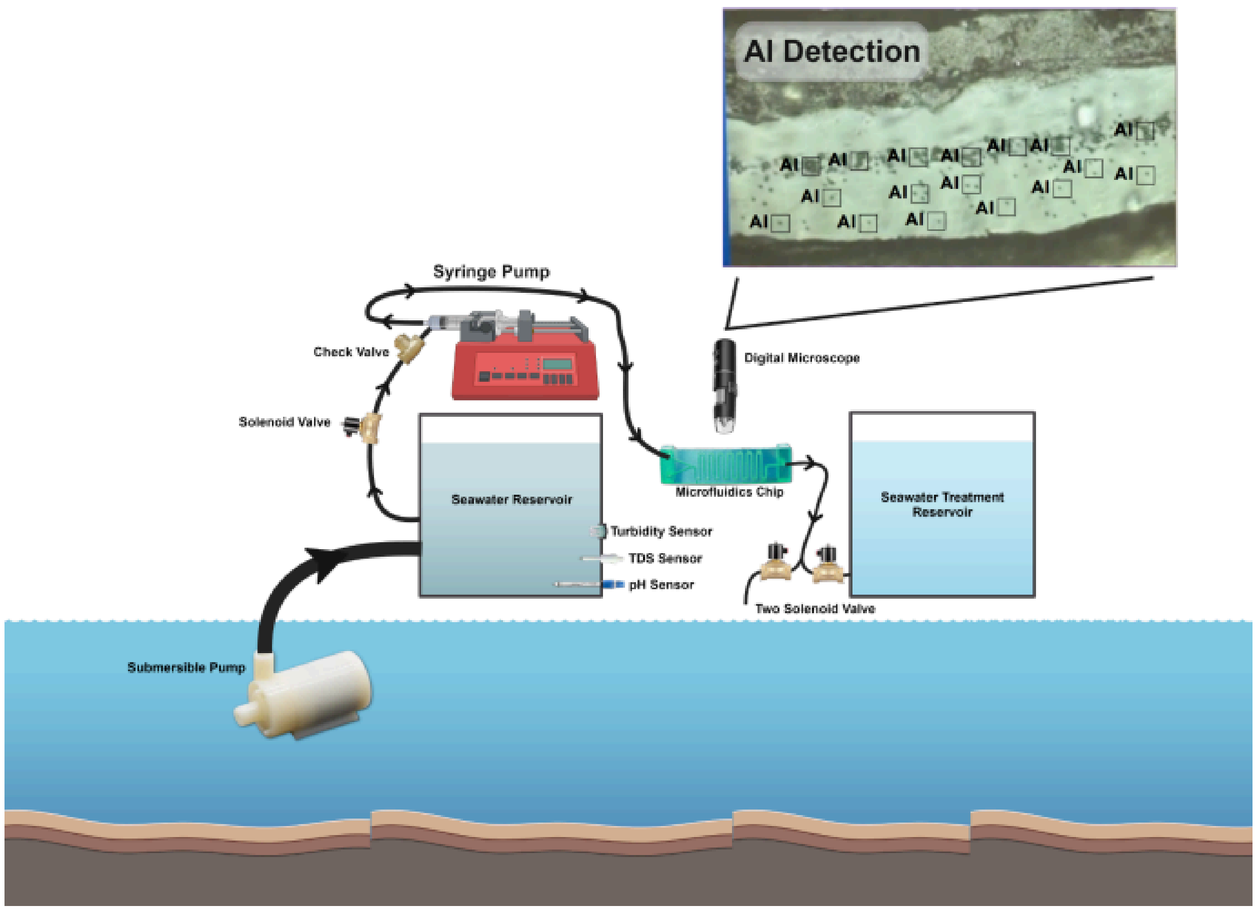

Figure3: How does the invention detect and treat water pollution and microplastics is explained in this figure.

Results

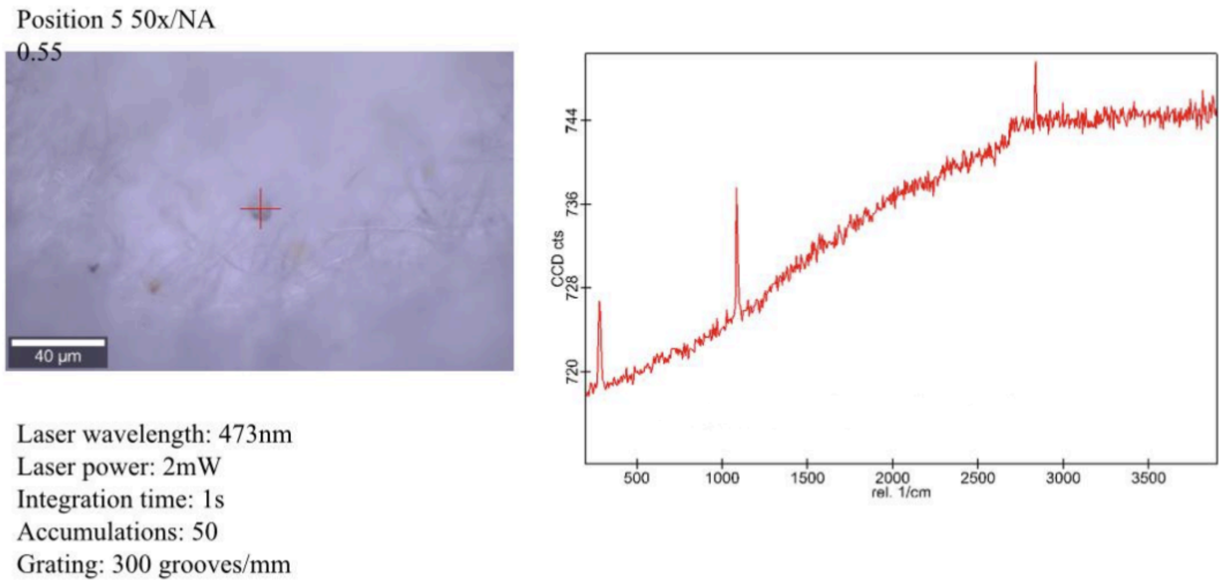

Figure4: The experiment to detect microplastics in bottled water aimed to determine the concentration and types of plastic particles present. This analysis utilized a Raman microscope, with a laser wavelength of 473 nm and a power of 2 mW, providing precise conditions for detecting specific polymers. The microscope was set at a magnification of 50x and an integration time of 1 second, with 50 accumulations to enhance signal accuracy. Additionally, a high-resolution grating of 300 grooves/mm helped produce detailed data, making this setup suitable for identifying microplastic particles.

In the resulting Raman spectrum, the presence of three distinct peaks at approximately 200, 1200, and 2700 cm^{-1} confirmed the presence of plastic polymers, as these peaks correspond to molecular vibrations characteristic of synthetic materials. The Raman shift and intensity both increased with these peaks, strongly suggesting the presence of specific microplastic polymers in the sample. The observed peaks suggest the presence of common polymers like polyethylene (PE), polypropylene (PP), and polystyrene (PS), which are frequently found in environmental samples.

Microplastics typically appear in recognizable shapes such as fibers, microbeads, fragments, nurdles, and foam. Each shape and polymer type is linked to distinct applications and sources, with fibers often originating from textiles, while fragments and beads are more commonly associated with consumer products. This experiment aligns with other studies that have employed Raman spectroscopy to identify microplastics, demonstrating similar findings in both spectral characteristics and polymer types detected in bottled water samples, as reported in comparable literature sources [21].

References

1.Depledge, M. H., White, M. P., Maycock, B., & Fleming, L. E. (2019). Time and tide. BMJ, 366.https://doi.org/10.1136/bmj.l4671

2.Ercolano, G., De Cicco, P., & Ianaro, A. (2019). New drugs from the sea: Pro-apoptotic activity of sponges and algae derived compounds. Marine drugs, 17(1), 31 https://doi.org/10.3390/md17010031

3.Jackson, R. B., Carpenter, S. R., Dahm, C. N., McKnight, D. M., Naiman, R. J., Postel, S.L., & Running, S. W. (2001). Water in a changing world. Ecological applications, 11(4), 1027-1045 . https://doi.org/10.1890/1051-0761(2001)011[1027:WIACW]2.0.CO;2

4.Gratzer, J. (2019). Saving the Pacific islands from extinction. Lancet, 394(10196), 359. https://doi.org/10.1016/S0140-6736(19)31722-2

5.Khatun, R. (2017). Water pollution: Causes, consequences, prevention method and role of WBPHED with special reference from Murshidabad District. International Journal of Scientific and Research Publications, 7(8), 269-270. Retrieved from http://www.ijsrp.org/research-paper-0817.php?rp=P686703

6.Landrigan, P. J., Fuller, R., Acosta, N. J., Adeyi, O., Arnold, R., Baldé, A. B., ... &

Zhong, M. (2018). The Lancet Commission on pollution and health. The Lancet, 391(10119), 462-512. https://doi.org/10.1016/S0140-6736(17)32345-0

7.Tozer, L. (2023). Water pollution'timebomb'threatens global health. Nature. https://doi.org/10.1038/d41586-023-02337-7

8.Avakian, M. (2021). New study finds ocean pollution a threat to human health. Global Environmental Health Newsletter. Retrieved from https://www.niehs.nih.gov/research/programs/geh/geh_newsletter/2021/2

9.Ogidi, O. I., & Akpan, U. M. (2022). Aquatic biodiversity loss: impacts of pollution and anthropogenic activities and strategies for conservation. In Biodiversity in Africa: potentials, threats and conservation (pp. 421-448). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-3326-4_16

10. Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B.

(2010). Global water pollution and human health. Annual review of environment and resources, 35(1), 109-136. https://doi.org/10.1146/annurev-environ-100809-125342

11.Calore, D., & Fraticelli, N. (2022). State of the art offshore in situ monitoring of microplastic. Microplastics, 1(4),640-650 https://doi.org/10.3390/microplastics1040044

12. Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: a review. Frontiers in environmental science, 10, 880246. https://doi.org/10.3389/fenvs.2022.880246

13.Chapman, R. L. (2013). Algae: the world's most important "plants"—an introduction. Mitigation and Adaptation Strategies for Global Change, 18, 5-12.

14. Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. Environment international, 102, 165-176. https://doi.org/10.1016/j.envint.2017.02.013

15.Eriksen, M., Cowger, W., Erdle, L. M., Coffin, S., Villarrubia-Gómez, P., Moore, C. J.,

... & Wilcox, C. (2023). A growing plastic smog, now estimated to be over 170 trillion plastic particles afloat in the world's oceans—Urgent solutions required. Plos one, 18(3), e0281596. https://doi.org/10.1371/journal.pone.0281596

16.Jenner, L. C., Rotchell, J. M., Bennett, R. T., Cowen, M., Tentzeris, V., & Sadofsky, L. R. (2022). Detection of microplastics in human lung tissue using μFTIR spectroscopy. Science of the Total Environment, 831, 154907. https://doi.org/10.1016/j.scitotenv.2022.154907

17.Goswami, S., Adhikary, S., Bhattacharya, S., Agarwal, R., Ganguly, A., Nanda, S., & Rajak, P. (2024). The alarming link between environmental microplastics and health hazards with special emphasis on cancer. Life Sciences, 122937. https://doi.org/10.1016/j.lfs.2024.122937

18.Retrieved from https://www.pasco.com/resources/lab-experiments

19.Zou, M., Dong, M., & Zhao, T. (2022). Advances in metal-organic frameworks

MIL-101 (Cr). International Journal of Molecular Sciences, 23(16), 9396. https://doi.org/10.3390/ijms23169396

20.Bedia, J., Muelas-Ramos, V., Peñas-Garzón, M., Gómez-Avilés, A., Rodriguez, J. J., & Belver, C. (2020). Metal–organic frameworks for water purification. In Nanomaterials for the Detection and Removal of Wastewater Pollutants (pp. 241-283). Elsevier. https://doi.org/10.1016/B978-0-12-818489-9.00009-8

21.Chakraborty, I., Banik, S., Biswas, R. et al. Raman spectroscopy for microplastic detection in water sources: a systematic review. Int. J. Environ. Sci. Technol. ***20****, 10435–10448 (2023). https://doi.org/10.1007/s13762-022-04505-0*