 https://doi.org/10.1051/bioconf/202410901013

Initial Discovery of Microplastic Presence in the Gastrointestinal Tract of Certain Fish Species in Al-Hoceima Bay

Iliass Achoukhi[1*], *Yahya* El Hammoudani[1], *Khadija* Haboubi[1], *Lahcen* Benaabidate[2], *Abdelhak* Bourjila[1], *Abdelaziz* Touzani[1], *Chaimae Benaissa* [3], *Mohamed* Moudou[1], *Mustapha* El Boudammoussi[1], *Hatim* Faiz[1] *and Fouad Dimane*[1]

[1] Engineering Sciences and Applications Laboratory, National School of Applied Sciences of Al-Hoceima, Abdelmalek Essaâdi University, Tetouan, Morocco

[2] Laboratory of Functional Ecology and Environment Engineering, University of Sidi Mohammed Ben Abdellah, Fez 30500, Morocco

[3] Faculty of Science and Technology of Tangier, Department of Earth Sciences / Geosciences research team on natural risks / Abdelmalek Essaâdi University, Tetouan, Morocco

Abstract. The accumulation of plastic waste in ocean environments is a critical ecological issue impacting marine wildlife and human health. This study assesses the presence of microplastics in the gastrointestinal tracts of fish from Al-Hoceima Bay, a key part of the Mediterranean marine ecosystem. Using Fourier Transform Infrared (FT-IR) spectroscopy, we analyzed 90 individuals from two different species, finding that 33% of the examined fish contained microplastics. Specific occurrences were 26% in mackerel and 40% in gilthead sea bream. These findings highlight significant contamination even in commercial fishing areas, raising urgent questions about the long-term ecological effects and health risks. Therefore, the need for effective plastic waste management policies is critical to protect our marine ecosystems and food safety.

* Iliass.achoukhi@fso.ump.ac.ma

1 Introduction

As the production of plastic keeps increasing, so do the worries about its buildup in coastal and oceanic ecosystems. In the year 2022, the production exceeded 360 million tons [1-3]. The Al-Hoceima Bay, located in the north of Morocco, is a unique marine ecosystem that, like many other coastal environments around the world, is under increasing pressure due to the accumulation of microplastic debris [4-19].

These small-sized plastic particles, often less than 5 millimeters, originate from various sources, including the degradation of larger plastic waste, cosmetic products, textiles, and urban runoff [4, 20-22]. The continuous fragmentation of plastics due to UV radiation, waves, and mechanical friction produces an abundance of microplastics which, due to their small size, become accessible to a wide range of marine organisms [23-33].

The presence of these particles in the Al Hoceima Bay is particularly concerning because it is known to be a spawning and feeding area for many marine species [34, 35]. Additionally, the bay serves as a migratory corridor for various species of fish and seabirds, which amplifies the risks associated with the bioaccumulation of microplastics through the trophic networks [36-42].

Microplastics are not only a mechanical problem for the marine organisms that ingest them, but they also pose a chemical threat due to their ability to absorb and concentrate persistent organic pollutants present in seawater [43, 44]. Fish and other marine organisms may be exposed to these toxins, which can be transferred and magnified in the food chain, thereby posing potential risks to human health, especially for coastal communities that rely on fishing [45].

The study conducted in Al-Hoceima Bay aims not only to document the presence of microplastics in planktivorous organisms but also to understand the ecological consequences of this pollution on the dynamics of fish populations and on the health of the marine ecosystem as a whole[4]. The preliminary results indicate an urgent need to develop waste management strategies and policies to reduce the entry of microplastics into the marine environment [46].

2 Materials and methods

2.1 Study area

Between February 23 and 29, 2024, our research team secured 20 samples from both the surface and the water column utilizing a manta trawl. This sampling initiative commenced at Al Hoceima Bay, near the port entrance and close to the wastewater treatment station, symbolizing a coastal zone influenced by various human activities (see Figure 1 for map details). Al Hoceima Bay, critical to the Mediterranean ecosystem, is noted for commercial fishing and aquaculture. Moreover, Al Hoceima's port serves as a hub for leisure activities, adding to the region's environmental complexity. Presently, it faces pressures from nearby fishing ventures, tourist activities, and proximity to wastewater discharge, potentially affecting marine life and water quality.

This location, with its diverse human activities, provides a significant context for studying the prevalence of microplastics in marine organisms, reflecting unique environmental and anthropogenic pressures. Adding information, the accumulation of leisure boats contributes to marine pollution, emphasizing the need for sustainable practices to mitigate environmental impacts. The used manta trawl featured a rectangular opening measuring 0.9 by 0.15 meters, leading to a net 3.5 meters in length with a 333-micrometer mesh, ending in a collection bag of 30 by 10 centimeters.

2.2 Fish sampling and Identification

The collected neuston and nekton samples undergo a standardized lab process for precise, orderly analysis. Following the methodologies from the study of [47, 48], fish samples are prepared for microplastics extraction. This involves delicately detaching the fish's inner organs from the head to the anal region with scissors and a knife.

The dissected gastrointestinal tract — esophagus, stomach, intestines — is then isolated, weighed, and stored in a 250 mL Pyrex beaker covered with aluminum foil. Microplastics extracted are subsequently sorted by size, shape, and color for identification, and spectroscopic methods like FT-IR spectroscopy are applied to ascertain their chemical makeup and origins.

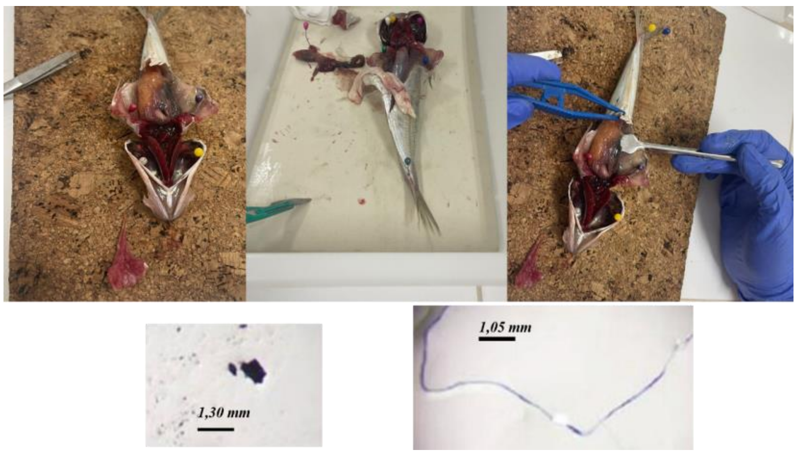

Fig.1. Photographic evidence from the stereo microscope of various fish species and microplastics that were discovered in the examined fish samples.

2.3 Analytical methods

In the lab, the collected fish samples were meticulously cleaned with filtered distilled water to eliminate any external sediment and debris. Following this cleaning process, each fish was measured for total length (TL), fork length (FL), and mouth size (as shown in Figure 2), and their total weight (W) was recorded.

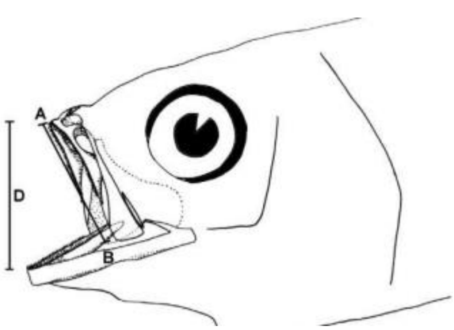

Fig. 2. Assessing the Mouth Opening Dimensions in Fish [49].

To determine the size of the fish's mouth, we utilized the method proposed in study [50], which calculates the mouth gap size as follows:

$$\boldsymbol{D = \sqrt{AB}}$$

(where D represents the mouth gap size, and A and B are specific measurements related to the mouth's dimensions). The assessment was conducted according to Shirota's [50]. It was assumed that the maximum width of potential ingested items, such as plastic particles, should not exceed half the fish's mouth gap size, denoted as D. Each fish was then meticulously dissected starting from the upper oesophagus to extract the stomach, employing techniques outlined in prior studies [51-53]. The stomach contents were placed in a petri dish for further examination under a Microscope to identify and categorize plastic debris by size and color. The sizes of ingested plastics were classified into microplastics, mesoplastics, and macroplastics based on dimensions established by [54].

3 Results and Discussion

3.1 Occurrence of Microplastics in Various Fish Species

Microplastics are encountered by a diverse range of aquatic species across different environments and food chain levels. This exposure is attributed to the significant tendency of microplastics to either remain buoyant or accumulate in the sediment of marine ecosystems [55-57]. In our study, we focused on the mackerel and the gilthead sea bream, noting results that were almost similar to those previously mentioned. The total length and weight of the examined mackerels and gilthead sea breams were within ranges comparable to those of species studied earlier. We identified a significant amount of microplastics in both species, highlighting once again the extensive contamination by microplastics in marine habitats[58, 59]. Specifically, our research revealed that both the mackerel and the gilthead sea bream exhibited similar levels of microplastic accumulation, indicating that these species, despite their ecological and behavioral differences, are equally vulnerable to microplastic pollution[60]. This finding is particularly concerning considering the popularity of these fish in human diets, raising potential public health concerns. Parallel to the work of the study [61-67] our results suggest that dietary habits and foraging behavior are key factors influencing exposure to microplastics. Although our target species do not strictly adopt a planktivorous diet like the clupeid S. maderensis studied by the study [68] they are nonetheless exposed to significant contamination, likely due to their interactions with highly polluted environments or their position in the food chain [69-72].

Table 1. Biodata Information of Analyzed Fish Samples.

Species	*Common Name*	*Habitat*	*Length Range (cm)*	*Weight Range (g)*
Trachurus trachurus	Mackerel	Pelagic	15-35	50-250
Sparus aurata	Gilthead Sea Bream	Demersal	30-45	200-300

The analysis for microplastics revealed the following results:

- ✓ Mackerel (Trachurus trachurus): Out of 50 individuals examined, 13 showed the presence of microplastics, with an average of 1.75 ± 0.5 microplastics per fish.
- ✓ Gilthead Sea Bream (Sparus aurata): Out of 40 individuals examined, 16 showed the presence of microplastics, with an average of 2 ± 0.6 microplastics per fish.

This analysis would indicate that the Gilthead Sea Bream has a slightly higher prevalence of microplastics compared to the Mackerel in this sample. This could suggest a difference in exposure or susceptibility to microplastics based on the habitat or dietary habits of the species.

In our examination of the gastrointestinal tracts from selected fish species, the overall incidence of microplastic presence was calculated at 33%. Notably, the Gilthead Sea Bream (Sparus aurata) demonstrated the highest occurrence at 26%, followed by the Mackerel (Trachurus trachurus) with a frequency of 40%. These findings align with the global trend reported in various studies on coastal and marine fisheries, underscoring the widespread issue of microplastic contamination not just in species commonly consumed in specific regions, but across the globe's oceans [66, 73-76]. Research akin to [77]found the occurrence of microplastics to vary between 60 to 87% in species from the North Western coast of the Alberian continental shelf. Similar studies, such as the study [78], reported a 77% incidence of microplastics in the Japanese anchovy (Engraulis japonicus) from Tokyo Bay, and [79] identified microplastics in 68% of Salmo trutta along the Swedish coast. In a comprehensive survey by [80], about 70% of commercial fish samples from the northern Persian Gulf contained microplastics in their gastrointestinal tracts. This prevalence highlights a consistent pattern across various studies [56, 81] reporting up to 100% incidence rates in specific species. The diversity in microplastic pollution can be attributed to several factors, including geographical location, habitat, and trophic level. Many studies have suggested that the habitat of a species can offer insights into its feeding strategies, trophic levels, and susceptibility to environmental pollutants. According to [82], demersal fishes tend to have higher rates of microplastic ingestion. There's a noted tendency for pelagic fish to consume more microplastic particles on average compared to those from other habitats [83]. Despite these observations, the relationship between microplastic abundance and habitat type remains unclear, as shown in studies by [76, 77, 84] ,emphasizing the need for further research to solidify these findings. The unchecked influx of plastics into marine environments poses a significant threat to sustainable fish stocks, with microplastics having profound implications on fish health and ecotoxicology [85-88]. The ingestion of microplastics has been linked to adverse effects, such as the translocation of harmful chemicals and reduced efficiency in predatory performance and feeding [89]. Moreover, microplastics have been associated with trophic transfer, potentially increasing their toxicity to consumers [58, 59]. The presence of microplastics in commonly consumed fish thus presents a significant concern, potentially compromising the safety of seafood [88, 90, 91], and underscores the urgent need for comprehensive studies and mitigation strategies to address this pervasive issue.

3.2 Properties of Microplastics in Various Fish Species

In our investigation, fibers constituted the predominant form of microplastics ingested, comprising 82.5% of the total microplastics found across the examined marine species. This predominance of fibers aligns with global research, which often identifies them as a significant form of microplastic pollution in aquatic environments due to their widespread use and disposal [92-94]. The remaining 7.5% consisted of pellets, primarily found in two of the species under study, indicating a more selective distribution or ingestion pattern. Our results echo global findings, such as those by [95, 96] and [97], highlighting fibers as the most encountered microplastic type in marine organisms from various regions including the North Atlantic, Mediterranean, and Pacific Oceans. The significant presence of fibers is of particular concern due to their synthetic origin, often consisting of materials like polyester and nylon, which are not only resistant to degradation but may also harbor harmful chemicals and additives. These substances can leach into marine life, posing risks to both aquatic ecosystems and human health [94, 98]. Moreover, the specific prevalence of fibers in our study suggests their ubiquitous presence in the marine environment, likely resulting from sources such as household laundry, industrial discharges, and particularly from the degradation of fishing equipment, which aligns with findings by [99, 100]. The implications of such widespread fiber contamination are significant, impacting not just marine species but also the broader ecological balance and food safety concerns. In terms of size distribution, our study estimates that the majority of ingested microplastics fall within the 0.1 mm to 1.0 mm size range, with a noticeable prevalence in the 0.5–1.0 mm category. This observation is crucial as it suggests that smaller microplastics, which are more likely to be ingested by a variety of marine species, dominate the contamination. This size range is particularly concerning as it allows for easier integration into the food chain and potential bioaccumulation [101, 102]. Given the widespread distribution and varying sizes of microplastics detected, our findings contribute to the growing body of evidence demonstrating the extensive reach of microplastic pollution and its potential impacts on marine biodiversity and health. The results underscore the urgent need for strategies aimed at mitigating microplastic pollution and understanding its long-term implications on marine ecosystems and human consumption.

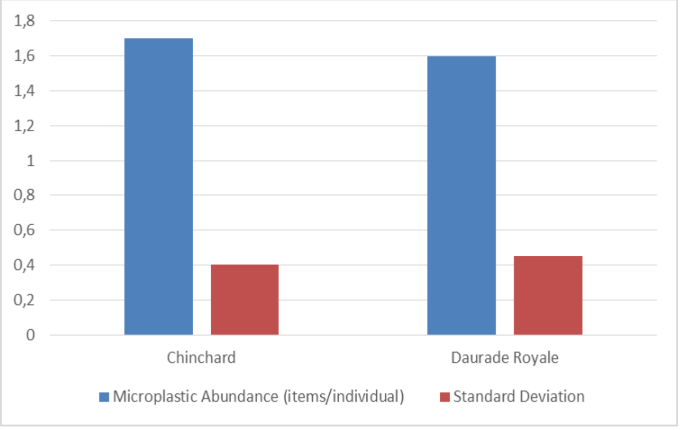

Fig.3. Prevalence of microplastics in the examined fish species.

3.3 Identification of Polymers

In the assessment of polymer content, twenty samples, consisting of five from each species, were subjected to micro-Fourier Transform Infrared (μ-FT-IR) spectroscopy for the verification of identified plastics. Spectral data were matched against reference libraries in Omnic and Openspecy software to classify specific plastic polymers. Only spectra with a matching accuracy greater than 80% with the polymer reference database were selected for further analysis using FT-IR. This process confirmed that all the 20 suspected microplastics were indeed plastic polymers. The procedure used for polymer identification confirmed the existence of Polyethylene (PE), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET), and Polystyrene (PS) in the fish samples, making up 62.70%, 30.95%, and 6.35% of the polymers, respectively. PET emerged as the most prevalent polymer, accounting for over 50% in the chinchard, and was the sole polymer detected in the daurade royal. The identification of these polymers in the fish indicates potential sources of these particles within the biota. The significant occurrence of PE mirrors its ubiquity in the environment due to its common use in various packaging materials like plastic bags, food containers, bottles, and films. This is consistent with its documentation in numerous ecological studies

[56, 103]. PE's low density contributes to its ability to float, which is a primary reason it's frequently encountered by marine organisms at the ocean's surface.

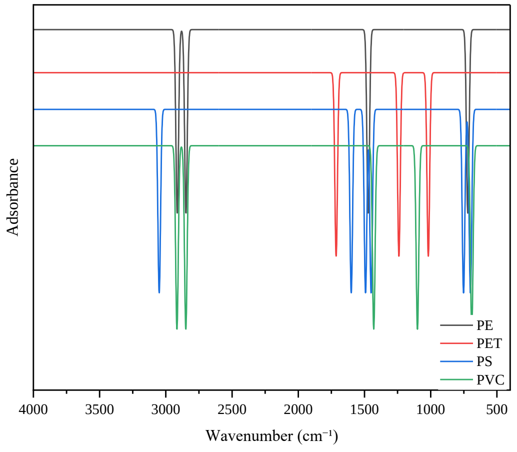

Fig.4. Comparative FT-IR Spectral Analysis of Various Polymers.

This figure displays the Fourier-Transform Infrared (FT-IR) spectra of four different polymers: Polyethylene (PE), Polyethylene Terephthalate (PET), Polystyrene (PS), and Polyvinyl Chloride (PVC), each represented by different colors. The spectra are plotted against a wavenumber range from 4000 to 500 cm^{-1}, which is typical for IR spectroscopy. Each spectrum shows characteristic absorbance peaks corresponding to the unique chemical structure of the polymer:

- PE (shown in black): Characteristic peaks are observed around 2914 cm^{-1} and 2848 cm^{-1}, which are likely due to C-H stretching vibrations, and a peak near 1472 cm^{-1}, probably attributable to C-H bending. There's also a peak at 720 cm^{-1}, indicating rocking vibrations of CH2 groups.
- PET (shown in blue): The sharp peak at around 1714 cm^{-1} is indicative of C=O stretching vibrations from the ester group, while peaks near 1240 cm^{-1} and 1018 cm^{-1} suggest C-O-C stretching vibrations, characteristic of PET's ester linkages.
- PS (shown in green): The peaks at around 3050 cm^{-1} can be attributed to the aromatic C-H stretching. Other significant peaks include those near 1450 cm^{-1}, 1492 cm^{-1}, and 1600 cm^{-1}, which are associated with the aromatic ring vibrations typical of styrenic polymers.
- PVC (shown in red): Prominent peaks are visible around 2916 cm^{-1} and 2849 cm^{-1}, which could be associated with C-H stretching in the alkyl chain, and a peak at 1430 cm^{-1} possibly corresponds to C-H deformation in CH2. Additionally, there's a strong signal near 690 cm^{-1} that is likely related to C-Cl stretching.

3.4 Exposure of microplastics to humans

The accumulation of microplastics in fish might not only suggest contamination of the marine ecosystem but also reflect potential health hazards for humans who consume seafood containing these plastics. Previous research regarding annual dietary exposure has indicated that the human ingestion of microplastics from seafood, especially through consuming shellfish, could be substantial and should not be ignored [104-106]. In developing countries, where most fish consumers eat the entire fish, particularly small pelagic species like sardinellas, this study has calculated the potential microplastic intake from such fish. The ingestion of microplastics may disrupt human physiological functions, affecting the digestive, cardiovascular, endocrine, and nervous systems, as reported in various studies [96, 107-109]. These findings highlight the urgent need to reduce microplastic exposures.

4 Conclusion

This study found microplastic particles in the gastrointestinal tracts of commercially available fish in Ghana, emphasizing significant pollution from microplastics in the Gulf of Al-Hoceima. This issue highlights the severe consequences of inadequate plastic waste management. The fish examined showed a propensity for ingesting plastics, which could endanger the safety and integrity of seafood in Morocco, especially considering the broad consumption among different groups of people. Moreover, this research addresses the previously unexplored area of microplastics within marine species of this particular region. It paves the way for future studies on the impact and ecotoxicological relevance of microplastics in a variety of marine organisms. The results underscore the critical level of plastic pollution and the urgent need to create effective waste management policies in Morocco, fostering a circular economy framework.

References

[1] économiques O d c e d d, *Global plastics outlook: economic drivers, environmental impacts and policy options*. 2022: OECD publishing.

[2] Achoukhi I, El Hammoudani Y, Dimane F, Haboubi K, Bourjila A, Haboubi C, Benaissa C, Elabdouni A, and Faiz H. Investigating Microplastics in the Mediterranean Coastal Areas–Case Study of Al-Hoceima Bay, Morocco. Journal of Ecological Engineering 2023;24:12-31.

[3] Abouabdallah A, El Hammoudani Y, Dimane F, Haboubi K, Rhayour K, and Benaissa C. Impact of Waste on the Quality of Water Resources – Case Study of Taza City, Morocco. Ecological Engineering and Environmental Technology 2023;24:170-182. 10.12912/27197050/173375.

[4] Achoukhi I, El Hammoudani Y, Dimane F, Haboubi K, Bourjila A, Haboubi C, Benaissa C, Elabdouni A, and Faiz H. Investigating Microplastics in the Mediterranean Coastal Areas–Case Study of Al-Hoceima Bay, Morocco. Journal of Ecological Engineering 2023;24:

[5] Benaissa C, Bouhmadi B, Rossi A, and El Hammoudani Y. *Hydro-chemical and bacteriological Study of Some Sources of Groundwater in the GHIS-NEKOR and the BOKOYA Aquifers (AL HOCEIMA, MOROCCO)*. in *Proc of The 4th Edition of International Conference on Geo-IT and Water Resources*. 2020.

[6] Benaissa C, Bouhmadi B, Rossi A, El Hammoudani Y, and Dimane F. Assessment of Water Quality Using Water Quality Index – Case Study of Bakoya Aquifer, Al Hoceima, Northern Morocco. Ecological Engineering & Environmental Technology 2022;23:31-44. 10.12912/27197050/149495.

[7] Benaissa C, Rossi A, Bouhmadi B, El Hammoudani Y, and Dimane F. *Assessment of the physicochemical and bacteriological quality of water source and a well in Bakoya aquifer, northern Morocco*. in *E3S Web of Conferences*. 2024. EDP Sciences.

[8] Bouhout S, Haboubi K, El Abdouni A, El Hammoudani Y, Haboubi C, Dimane F, Hanafi I, and Elyoubi M S. Appraisal of Groundwater Quality Status in the Ghiss-Nekor Coastal Plain. Journal of Ecological Engineering 2023;24:

[9] Bouhout S, Haboubi K, Hammoudani Y E, Abdouni A E, Haboubi C, Dimane F, Hanafi I, and Elyoubi M S. Groundwater Quality Assessment in the Coastal Mediterranean Aquifer of Northeastern Morocco – A GIS-Based Approach. Ecological Engineering and Environmental Technology 2024;25:22-45. 10.12912/27197050/173567.

[10] Bourjila A, Dimane F, Ghalit M, Taher M, Kamari S, El Hammoudani Y, Achoukhi I, and Haboubi K. Mapping the spatiotemporal evolution of seawater intrusion in the Moroccan coastal aquifer of Ghiss-Nekor using GIS-based modeling. Water Cycle 2023;4:104-119.

[11] El Hammoudani Y and Dimane F. Assessing behavior and fate of micropollutants during wastewater treatment: Statistical analysis. Environ. Eng. Res. 2020;0:0. https://doi.org/10.4491/eer.2020.359.

[12] El Hammoudani Y and Dimane F. Occurrence and fate of micropollutants during sludge treatment: Case of Al-Hoceima WWTP, Morocco. Environ. Chall. 2021;5:1-8. https://doi.org/10.1016/j.envc.2021.100321.

[13] El Hammoudani Y, Dimane F, and El Ouarghi H. Removal efficiency of heavy metals by a biological wastewater treatment plant and their potential risks to human health. Environmental Engineering and Management Journal 2021;20:995-1002.

[14] El Hammoudani Y, Dimane F, and El Ouarghi H. *Fate of Selected Heavy Metals in a Biological Wastewater Treatment System*. in *Euro-Mediterranean Conference for Environmental Integration*. 2019. Springer.

[15] El Hammoudani Y, Dimane F, Haboubi K, Benaissa C, Benaabidate L, Bourjila A, Achoukhi I, El Boudammoussi M, Faiz H, and Touzani A. Micropollutants in Wastewater Treatment Plants: A Bibliometric-Bibliographic Study. Desalination and Water Treatment 2024;100190.

[16] Haboubi C, Barhdadi E H, Haboubi K, Hammoudani Y E, Sadoune Z, Abdouni A E, and Dimane F. Characterization of the Mechanical Behavior of Hemp-Clay Composites. Advances in Science and Technology Research Journal 2024;18:71-77. 10.12913/22998624/183949.

[17] Haboubi C, El Hammoudani Y, Jaradat N, Jodeh S, Haboubi K, and Dimane F. A Bibliometric Analysis of Cannabis-Related Research from 2010 To 2022. Palestinian Medical and Pharmaceutical Journal (Pal. Med. Pharm. J.) 2023;9:None-None.

[18] Haboubi K, El Abdouni A, El Hammoudani Y, Dimane F, and Haboubi C. Estimating biogas production in the controlled landfill of fez (morocco) using the land-gem model. Environmental Engineering and Management Journal 2023;22:1813-1820.

[19] Touzani A, El Hammoudani Y, Dimane F, Tahiri M, and Haboubi K. Characterization of Leachate and Assessment of the Leachate Pollution Index–A Study of the Controlled Landfill in Fez. Ecological Engineering & Environmental Technology 25:57-69.

[20] Andrady A L. Microplastics in the marine environment. Marine pollution bulletin 2011;62:1596-1605.

[21] Browne M A, Crump P, Niven S J, Teuten E, Tonkin A, Galloway T, and Thompson R. Accumulation of microplastic on shorelines woldwide: sources and sinks. Environmental science & technology 2011;45:9175-9179.

[22] Alprol A E, Gaballah M S, and Hassaan M A. Micro and Nanoplastics analysis: Focus on their classification, sources, and impacts in marine environment. Regional studies in marine science 2021;42:101625.

[23] Gasperi J, Dris R, Mirande-Bret C, Mandin C, Langlois V, and Tassin B. *First overview of microplastics in indoor and outdoor air*. in *15th EuCheMS International Conference on Chemistry and the Environment*. 2015.

[24] Mason S A, Garneau D, Sutton R, Chu Y, Ehmann K, Barnes J, Fink P, Papazissimos D, and Rogers D L. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environmental pollution 2016;218:1045-1054.

[25] Elazzouzi M, Haboubi K, Elyoubi M, and El Kasmi A. A developed low-cost electrocoagulation process for efficient phosphate and COD removals from real urban wastewater. ES Energy & Environment 2019;5:66-74.

[26] Elazzouzi M, Haboubi K, Elyoubi M S, and El Kasmi A. Development of a novel electrocoagulation anode for real urban wastewater treatment: Experimental and modeling study to optimize operative conditions. Arabian Journal of Chemistry 2021;14:10.1016/j.arabjc.2020.11.018.

[27] Abdouni A E, Bouhout S, Merimi I, Hammouti B, and Haboubi K. Physicochemical characterization of wastewater from the Al-Hoceima slaughterhouse in Morocco. Caspian Journal of Environmental Sciences 2021;19:423-429.

[28] El Abdouni A, Bouhout S, Merimi I, Hammouti B, and Haboubi K. Physicochemical characterization of wastewater from the Al-Hoceima slaughterhouse in Morocco. Casp. J. Environ. Sci. 2021;19:423-429.

[29] Elabdouni A, Haboubi K, Bensitel N, Bouhout S, Aberkani K, and El Youbi M S. Removal of organic matter and polyphenols in the olive oil mill wastewater by coagulation-flocculation using aluminum sulfate and lime. Moroccan Journal of Chemistry 2022;10:191-202. https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i1.28852.

[30] Elabdouni A, Haboubi K, Merimi I, and El Youbi M. Olive mill wastewater (OMW) production in the province of Al-Hoceima (Morocco) and their physico-chemical characterization by mill types. Materials Today: Proceedings 2020;27:3145-3150.

[31] Elyoussfi A, Outada H, Isaad J, Lrhoul H, Salhi A, and Dafali A. Corrosion inhibitors of alloys and metals in acidic solution: A bibliometric analysis from 2010 to 2022. Int. J. Corros. Scale Inhib 2023;12:722-740.

[32] Salhi A, Elyoussfi A, Azghay I, El Aatiaoui A, Amhamdi H, El Massaoudi M, Ahari M, Bouyanzer A, Radi S, and El barkany S. A correlated theoretical and electrochemical investigation of the corrosion inhibition performance of phenolic Schiff bases on mild steel in HCl solution (Part B). Inorganic Chemistry Communications 2023;152:10.1016/j.inoche.2023.110684.

[33] Hassouni H E, Elyousfi A, Benhiba F, Setti N, Romane A, Benhadda T, Zarrouk A, and Dafali A. Corrosion inhibition, surface adsorption and computational studies of new sustainable and green inhibitor for mild steel in acidic medium. Inorganic Chemistry Communications 2022;143:109801.

[34] Thompson R C. Microplastics in the marine environment: sources, consequences and solutions. Marine anthropogenic litter 2015;185-200.

[35] Zarfl C, Fleet D, Fries E, Galgani F, Gerdts G, Hanke G, and Matthies M. Microplastics in oceans. Marine pollution bulletin 2011;62:1589-1591.

[36] Fossi M C, Panti C, Guerranti C, Coppola D, Giannetti M, Marsili L, and Minutoli R. Are baleen whales exposed to the threat of microplastics? A case study of the

Mediterranean fin whale (Balaenoptera physalus). Marine pollution bulletin 2012;64:2374-2379.

[37] El bastrioui M, Haboubi K, Chetouani A, Hammouti B, and Nandiyanto A. Phytochemical study of four leaves extracts of Chamærops humilis L. from the region of Al-Hoceima, Morocco. Moroccan Journal of Chemistry 2022;10:10-4 (2022) 851-860.

[38] Andaloussi K, Achtak H, Nakhcha C, Haboubi K, and Stitou M. Assessment of soil trace metal contamination of an uncontrolled landfill and its vicinity: the case of the city of 'Targuist'(Northern Morocco). Moroccan Journal of Chemistry 2021;9:9-3 (2021) 513-529.

[39] Ait Mansour A, El-Haitout B, Adnin R J, Lgaz H, Salghi R, Lee H-s, Alhadeethi M R, Messali M, Haboubi K, and Ali I H. Insights into the Corrosion Inhibition Performance of Isonicotinohydrazide Derivatives for N80 Steel in 15% HCl Medium: An Experimental and Molecular Level Characterization. Metals 2023;13:797.

[40] Bouknana D, Jodeh S, Sbaa M, Hammouti B, Arabi M, Darmous A, Slamini M, and Haboubi K. A phytotoxic impact of phenolic compounds in olive oil mill wastewater on fenugreek "Trigonella foenum-graecum". Environmental Monitoring and Assessment 2019;191:10.1007/s10661-019-7541-x.

[41] Fernine Y, Arrousse N, Haldhar R, Raorane C J, Kim S-C, El Hajjaji F, Touhami M E, Beniken M, Haboubi K, and Taleb M. Synthesis and characterization of phenolphthalein derivatives, detailed theoretical DFT computation/molecular simulation, and prevention of AA2024-T3 corrosion in medium 3.5% NaCl. Journal of the Taiwan Institute of Chemical Engineers 2022;140:104556.

[42] Tighadouini S, Radi S, Elidrissi A, Haboubi K, Bacquet M, Degoutin S, Zaghrioui M, and Garcia Y. Removal of toxic heavy metals from river water samples using a porous silica surface modified with a new β-ketoenolic host. Beilstein Journal of Nanotechnology 2019;10:262-273.

[43] Teuten E L, Saquing J M, Knappe D R, Barlaz M A, Jonsson S, Björn A, Rowland S J, Thompson R C, Galloway T S, and Yamashita R. Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical transactions of the royal society B: biological sciences 2009;364:2027-2045.

[44] Bakir A, Rowland S J, and Thompson R C. Transport of persistent organic pollutants by microplastics in estuarine conditions. Estuarine, Coastal and Shelf Science 2014;140:14-21.

[45] Rochman C M, *Plastics and priority pollutants: a multiple stressor in aquatic habitats*. 2013, ACS Publications.

[46] Isensee K and Valdes L. Marine litter: microplastics. GSDR 2015 Brief 2015;1-3.

[47] Yuan M, Zhang Y, Guo W, Chen S, Qiu Y, and Zhang P. A rapid staged protocol for efficient recovery of microplastics from soil and sediment matrices based on hydrophobic separation. Marine Pollution Bulletin 2022;182:113978.

[48] Adika S A, Mahu E, Crane R, Marchant R, Montford J, Folorunsho R, and Gordon C. Microplastic ingestion by pelagic and demersal fish species from the Eastern Central Atlantic Ocean, off the Coast of Ghana. Marine pollution bulletin 2020;153:110998.

[49] Jualong S. First evidence of existence of microplastics in stomach of some commercial fishes in the lower Gulf of Thailand. Applied Ecology and Environmental Research 2018;16:7345-7360.

[50] Shirota T and Asano K. On mixed problems for regularly hyperbolic systems. Journal of the Faculty of Science Hokkaido University. Ser. 1 Mathematics 1970;21:1-45.

[51] Claessens M, Van Cauwenberghe L, Vandegehuchte M B, and Janssen C R. New techniques for the detection of microplastics in sediments and field collected organisms. Marine pollution bulletin 2013;70:227-233.
[52] Lusher A L, Tirelli V, O'Connor I, and Officer R. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. Scientific reports 2015;5:14947.
[53] Rocha-Santos T and Duarte A C. A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. TrAC Trends in analytical chemistry 2015;65:47-53.
[54] Galgani F, Hanke G, Werner S, and De Vrees L. Marine litter within the European marine strategy framework directive. ICES Journal of Marine Science 2013;70:1055-1064.
[55] Dong X, Zhu L, Jiang P, Wang X, Liu K, Li C, and Li D. Seasonal biofilm formation on floating microplastics in coastal waters of intensified marinculture area. Marine Pollution Bulletin 2021;171:112914.
[56] Pozo K, Gomez V, Torres M, Vera L, Nuñez D, Oyarzún P, Mendoza G, Clarke B, Fossi M C, and Baini M. Presence and characterization of microplastics in fish of commercial importance from the Biobío region in central Chile. Marine Pollution Bulletin 2019;140:315-319.
[57] Fernández B, Campillo J A, Chaves-Pozo E, Bellas J, León V M, and Albentosa M. Comparative role of microplastics and microalgae as vectors for chlorpyrifos bioacumulation and related physiological and immune effects in mussels. Science of The Total Environment 2022;807:150983.
[58] Welden N A, Abylkhani B, and Howarth L M. The effects of trophic transfer and environmental factors on microplastic uptake by plaice, Pleuronectes plastessa, and spider crab, Maja squinado. Environmental Pollution 2018;239:351-358.
[59] Lusher A L and Welden N A, *Microplastic impacts in fisheries and aquaculture*, in *Handbook of Microplastics in the Environment*. 2022, Springer. p. 977-1004.
[60] Wootton N, Reis-Santos P, and Gillanders B M. Microplastic in fish–a global synthesis. Reviews in Fish Biology and Fisheries 2021;1-19.
[61] Zhang F, Xu J, Zhu L, Peng G, Jabeen K, Wang X, and Li D. Seasonal distributions of microplastics and estimation of the microplastic load ingested by wild caught fish in the East China Sea. Journal of Hazardous Materials 2021;419:126456.
[62] Macieira R M, Oliveira L A S, Cardozo-Ferreira G C, Pimentel C R, Andrades R, Gasparini J L, Sarti F, Chelazzi D, Cincinelli A, and Gomes L C. Microplastic and artificial cellulose microfibers ingestion by reef fishes in the Guarapari Islands, southwestern Atlantic. Marine Pollution Bulletin 2021;167:112371.
[63] Kılıç E and Yücel N. Microplastic occurrence in the gastrointestinal tract and gill of bioindicator fish species in the northeastern Mediterranean. Marine Pollution Bulletin 2022;177:113556.
[64] Justino A K, Ferreira G V, Fauvelle V, Schmidt N, Lenoble V, Pelage L, and Lucena-Frédou F. Exploring microplastic contamination in reef-associated fishes of the Tropical Atlantic. Marine Pollution Bulletin 2023;192:115087.
[65] James K, Vasant K, Padua S, Gopinath V, Abilash K, Jeyabaskaran R, Babu A, and John S. An assessment of microplastics in the ecosystem and selected commercially important fishes off Kochi, south eastern Arabian Sea, India. Marine Pollution Bulletin 2020;154:111027.
[66] Daniel D B, Ashraf P M, and Thomas S N. Microplastics in the edible and inedible tissues of pelagic fishes sold for human consumption in Kerala, India. Environmental Pollution 2020;266:115365.

[67] Welden N. *Microplastics: Emerging contaminants requiring multilevel management*. in *Waste*. 2019. Elsevier.

[68] Covernton G A, Davies H L, Cox K D, El-Sabaawi R, Juanes F, Dudas S E, and Dower J F. A Bayesian analysis of the factors determining microplastics ingestion in fishes. Journal of Hazardous Materials 2021;413:125405.

[69] Cverenkárová K, Valachovičová M, Mackuľak T, Žemlička L, and Bírošová L. Microplastics in the food chain. Life 2021;11:1349.

[70] Okeke E S, Okoye C O, Atakpa E O, Ita R E, Nyaruaba R, Mgbechidinma C L, and Akan O D. Microplastics in agroecosystems-impacts on ecosystem functions and food chain. Resources, Conservation and Recycling 2022;177:105961.

[71] Mercogliano R, Avio C G, Regoli F, Anastasio A, Colavita G, and Santonicola S. Occurrence of microplastics in commercial seafood under the perspective of the human food chain. A review. Journal of agricultural and food chemistry 2020;68:5296-5301.

[72] Al Mamun A, Prasetya T A E, Dewi I R, and Ahmad M. Microplastics in human food chains: Food becoming a threat to health safety. Science of The Total Environment 2023;858:159834.

[73] Zhao Y, Bao Z, Wan Z, Fu Z, and Jin Y. Polystyrene microplastic exposure disturbs hepatic glycolipid metabolism at the physiological, biochemical, and transcriptomic levels in adult zebrafish. Science of the Total Environment 2020;710:136279.

[74] Karthik R, Robin R, Purvaja R, Karthikeyan V, Subbareddy B, Balachandar K, Hariharan G, Ganguly D, Samuel V, and Jinoj T. Microplastic pollution in fragile coastal ecosystems with special reference to the X-Press Pearl maritime disaster, southeast coast of India. Environmental Pollution 2022;305:119297.

[75] Romeo T, Pietro B, Pedà C, Consoli P, Andaloro F, and Fossi M C. First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. Marine pollution bulletin 2015;95:358-361.

[76] Bellas J, Martínez-Armental J, Martínez-Cámara A, Besada V, and Martínez-Gómez C. Ingestion of microplastics by demersal fish from the Spanish Atlantic and Mediterranean coasts. Marine pollution bulletin 2016;109:55-60.

[77] Filgueiras A V, Preciado I, Cartón A, and Gago J. Microplastic ingestion by pelagic and benthic fish and diet composition: A case study in the NW Iberian shelf. Marine pollution bulletin 2020;160:111623.

[78] Tanaka K and Takada H. Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Scientific reports 2016;6:34351.

[79] Karlsson T M, Vethaak A D, Almroth B C, Ariese F, van Velzen M, Hassellöv M, and Leslie H A. Screening for microplastics in sediment, water, marine invertebrates and fish: method development and microplastic accumulation. Marine pollution bulletin 2017;122:403-408.

[80] Hosseinpour A, Chamani A, Mirzaei R, and Mohebbi-Nozar S L. Occurrence, abundance and characteristics of microplastics in some commercial fish of northern coasts of the Persian Gulf. Marine Pollution Bulletin 2021;171:112693.

[81] Gurjar U R, Xavier M, Nayak B B, Ramteke K, Deshmukhe G, Jaiswar A K, and Shukla S P. Microplastics in shrimps: a study from the trawling grounds of north eastern part of Arabian Sea. Environmental Science and Pollution Research 2021;28:48494-48504.

[82] Kühn S and Van Franeker J A. Quantitative overview of marine debris ingested by marine megafauna. Marine Pollution Bulletin 2020;151:110858.

[83] Güven O, Gökdağ K, Jovanović B, and Kıdeyş A E. Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environmental pollution 2017;223:286-294.
[84] Neves D, Sobral P, Ferreira J L, and Pereira T. Ingestion of microplastics by commercial fish off the Portuguese coast. Marine pollution bulletin 2015;101:119-126.
[85] Gamarro E G and Costanzo V. Dietary exposure to additives and sorbed contaminants from ingested microplastic particles through the consumption of fisheries and aquaculture products. Microplastic in the Environment: Pattern and Process 2022;261.
[86] Campanale C, Stock F, Massarelli C, Kochleus C, Bagnuolo G, Reifferscheid G, and Uricchio V F. Microplastics and their possible sources: The example of Ofanto river in southeast Italy. Environmental Pollution 2020;258:113284.
[87] Campanale C, Massarelli C, Savino I, Locaputo V, and Uricchio V F. A detailed review study on potential effects of microplastics and additives of concern on human health. International journal of environmental research and public health 2020;17:1212.
[88] Mallik A, Xavier K M, Naidu B C, and Nayak B B. Ecotoxicological and physiological risks of microplastics on fish and their possible mitigation measures. Science of the Total Environment 2021;779:146433.
[89] de Sá L C, Luís L G, and Guilhermino L. Effects of microplastics on juveniles of the common goby (Pomatoschistus microps): confusion with prey, reduction of the predatory performance and efficiency, and possible influence of developmental conditions. Environmental pollution 2015;196:359-362.
[90] Ma J, Aqeel M, Khalid N, Nazir A, Alzuaibr F M, Al-Mushhin A A, Hakami O, Iqbal M F, Chen F, and Alamri S. Effects of microplastics on growth and metabolism of rice (Oryza sativa L.). Chemosphere 2022;307:135749.
[91] Zhu J, Zhang X, Liao K, Wu P, and Jin H. Microplastics in dust from different indoor environments. Science of The Total Environment 2022;833:155256.
[92] Rowley K H, Cucknell A-C, Smith B D, Clark P F, and Morritt D. London's river of plastic: High levels of microplastics in the Thames water column. Science of the Total Environment 2020;740:140018.
[93] Stanton T, Johnson M, Nathanail P, MacNaughtan W, and Gomes R L. Freshwater and airborne textile fibre populations are dominated by 'natural', not microplastic, fibres. Science of the total environment 2019;666:377-389.
[94] Green D S, Kregting L, Boots B, Blockley D J, Brickle P, da Costa M, and Crowley Q. A comparison of sampling methods for seawater microplastics and a first report of the microplastic litter in coastal waters of Ascension and Falkland Islands. Marine pollution bulletin 2018;137:695-701.
[95] Coleman E. A Plan to Keep Microbeads Out of Lake Michigan. Route 50 2019;NA-NA.
[96] Prata J C, da Costa J P, Lopes I, Andrady A L, Duarte A C, and Rocha-Santos T. A One Health perspective of the impacts of microplastics on animal, human and environmental health. Science of the Total Environment 2021;777:146094.
[97] Martin J, Lusher A, Thompson R C, and Morley A. The deposition and accumulation of microplastics in marine sediments and bottom water from the Irish continental shelf. Scientific Reports 2017;7:10772.
[98] Stanton T, Johnson M, Nathanail P, MacNaughtan W, and Gomes R L. Freshwater microplastic concentrations vary through both space and time. Environmental Pollution 2020;263:114481.

[99] Baxter L, Lucas Z, and Walker T R. Evaluating Canada's single-use plastic mitigation policies via brand audit and beach cleanup data to reduce plastic pollution. Marine Pollution Bulletin 2022;176:113460.
[100] Sullivan E, Cole M, Atwood E C, Lindeque P K, Chin P T, and Martinez-Vicente V. In situ correlation between microplastic and suspended particulate matter concentrations in river-estuary systems support proxies for satellite-derived estimates of microplastic flux. Marine Pollution Bulletin 2023;196:115529.
[101] Jimenez-Guri E, Roberts K E, García F C, Tourmente M, Longdon B, and Godley B J. Transgenerational effects on development following microplastic exposure in Drosophila melanogaster. PeerJ 2021;9:e11369.
[102] Turner A, Holmes L, Thompson R C, and Fisher A S. Metals and marine microplastics: Adsorption from the environment versus addition during manufacture, exemplified with lead. Water research 2020;173:115577.
[103] Tanaka K and Takada H. Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Scientific reports 2016;6:1-8.
[104] Yozukmaz A. Investigation of microplastics in edible wild mussels from İzmir Bay (Aegean Sea, Western Turkey): A risk assessment for the consumers. Marine Pollution Bulletin 2021;171:112733.
[105] Nalbone L, Cincotta F, Giarratana F, Ziino G, and Panebianco A. Microplastics in fresh and processed mussels sampled from fish shops and large retail chains in Italy. Food Control 2021;125:108003.
[106] Wakkaf T, El Zrelli R, Kedzierski M, Balti R, Shaiek M, Mansour L, Tlig-Zouari S, Bruzaud S, and Rabaoui L. Microplastics in edible mussels from a southern Mediterranean lagoon: Preliminary results on seawater-mussel transfer and implications for environmental protection and seafood safety. Marine Pollution Bulletin 2020;158:111355.
[107] Zhang C, Wang J, Zhou A, Ye Q, Feng Y, Wang Z, Wang S, Xu G, and Zou J. Species-specific effect of microplastics on fish embryos and observation of toxicity kinetics in larvae. Journal of Hazardous Materials 2021;403:123948.
[108] Çobanoğlu H, Belivermiş M, Sıkdokur E, Kılıç Ö, and Çayır A. Genotoxic and cytotoxic effects of polyethylene microplastics on human peripheral blood lymphocytes. Chemosphere 2021;272:129805.
[109] Ebrahimi P, Abbasi S, Pashaei R, Bogusz A, and Oleszczuk P. Investigating impact of physicochemical properties of microplastics on human health: A short bibliometric analysis and review. Chemosphere 2022;289:133146.