Microplastic Removal Techniques in Domestic and Municipal Wastewater: A Systematic Review

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Abstract:- Microplastics can be lethal to human health and the environment. Due to the increasing amount of microplastics in the environment, it is significant to access and determine the different methods and techniques to reduce and remove the microplastics in the environment, particularly in wastewater. This study has conducted a systematic review to analyze and identify what kinds of methods and techniques are suitable for the microplastic removal of domestic and municipal wastewater. The researchers utilized search engines and research databases, namely Google Scholar, Science Direct/ Elsevier, NCBI, and IWA Publishing, to look for and select the eligible literature related to this study. The eligibility criteria of the literature are as follows: clearly stated methods or techniques used in removing microplastics; mentioned the type of microplastics removed; specified wastewater source, either domestic or municipal wastewater; a quantitative scientific paper published between 2016 and 2024; original studies as full-text research or review articles that were published in English; and the studies can be studied in multiple countries. Only the stated eligibility criteria were considered; others not mentioned were excluded. Only 20 of the 134 studies that were downloaded and analyzed by the researchers were eligible for this systematic review. The result of the study showed that the best methods for removing microplastics in primary and secondary treatment are electrocoagulation, electro-flotation (EC/EF), and membrane filtration process (MFP) with 100% removal efficiency. Meanwhile, the most efficient method for tertiary treatment is the laboratory-scale sand filter, with up to 100% removal efficiency.

Keywords:- *Efficiency, Methods, Particles, Process, Treatment.*

I. INTRODUCTION

Microplastic pollution has become a significant environmental concern due to its widespread impact on ecosystems and human health. Microplastics, tiny plastic particles produced from commercial products and the degradation of larger plastics, have become a major pollutant with harmful impacts on the environment and animal health (Microplastics, n.d.). Microplastics, defined as plastic particles smaller than 5 mm in length, are found in the environment as a result of plastic pollution (Rogers, 2024). Different sources of wastewater, including domestic, industrial, and agricultural wastewater, have been recognized as significant contributors to microplastic pollution. These sources often carry high concentrations of microplastics due to human activities and the widespread use of plastic materials (Prata et al., 2020). The presence of microplastics in different sources of wastewater poses a significant risk to aquatic life and may potentially infiltrate the human food chain.

Given the seriousness of the issue, there is an urgent need to develop methods for eliminating microplastics from different sources of wastewater. Various techniques have been studied, including physical, chemical, and biological techniques (Talvitie et al., 2017). Physical techniques like filtration and sedimentation work to separate microplastics from wastewater based on their size and weight. Chemical techniques such as coagulation and flocculation involve using chemicals to clump microplastics into larger particles for easier removal. Biological techniques, such as employing microorganisms or enzymes, aim to break down or convert microplastics into less harmful substances.The review aims to assess different methods for removing microplastics from domestic and municipal wastewater sources, identify the types and sizes of microplastics removed in each study, evaluate and to determine the best techniques with the highest removal efficiency. Additionally, the findings of this review will provide insights into potential combinations of these techniques, leading to the development of advanced and efficient microplastic removal techniques.

The framework of this systematic review will follow the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review process will involve a comprehensive literature search using relevant databases and keywords, followed by a systematic screening and selection of studies based on predefined inclusion and exclusion criteria.

By conducting a thorough and systematic analysis of the 20 literatures, this review will contribute to the development of advanced strategies for mitigating microplastic pollution from domestic and municipal wastewater and improving policy decisions related to wastewater management and environmental protection. The findings of this review will be of interest to researchers, government agencies, and industries involved in the development and implementation of sustainable wastewater treatment technologies across various sectors, including domestic, industrial, and agricultural wastewater management.

II. MATERIALS AND METHODS

This study utilized a systematic review design. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA System) was used as a guideline in selecting publications reporting on microplastic removal techniques in municipal and domestic wastewater between 2016 and 2024.

A. Data Sources

As the researchers applied the PRISMA guidelines, all published literature and scientific papers related to the aforementioned studies were systematically selected and reviewed from four universally recognized search databases, namely Google Scholar, ScienceDirect/Elsevier, the National Center for Biotechnology Information (NCBI), and The International Water Association (IWA) Publishing.

B. Literature Search

In order to select an appropriate and effective search strategy, phrases, and words were used in the search engine of the aforementioned databases. Numerous sets of keywords were used and searched in the online databases to obtain suitable references. The first set of keywords used terms related to removal processes, such as “removal technique,” “methods of removal,” and “removal process." The second set of keywords used terms related to microplastics removed from municipal and domestic wastewater, including terms such as “types of microplastics,” “microplastic removed,” “microplastics,” “domestic wastewater," “municipal wastewater," "wastewater," “microplastics in domestic wastewater," “microplastics in municipal wastewater." The third set of keywords used terms related to the efficiency of microplastic removal, including terms such as "efficiency."

To maintain the accuracy of the current trends of the study, the results of the searches from online databases were limited to scientific papers and journal articles published from 2016 to 2024. The initial literature searches identified from searching databases were selected based on their titles, publication dates, and content information to filter and arrange the studies in accordance with the data that was needed by the researchers.

C. Inclusion and Exclusion Criteria

All relevant articles included in this review were categorized based on the following criteria: (1) Studies that tackle different processes or methods of microplastic removal; (2) studies that mentions the type of microplastics removed; (3) studies that mentions the size of microplastics removed; (4) studies that conducted either domestic or municipal wastewater used in the tests; (5) studies that mention the specific stage of wastewater treatment; (6) the study must a quantitative scientific paper; (7) studies conducted and published between 2016 and 2024; (8) original studies published as research articles or review articles; (9) original articles with full text and (10) published in English language or have an English translation. (11) The study papers can be from multiple countries.

Studies were excluded if they (1) The study used both drinking water or bodies of water; (2) were case series, case reports, systematic reviews, or narrative reviews; (3) lack corresponding outcome parameters or research data or (4) do not have available full text or (5) no English translation. In terms of article content, the following articles containing the following are excluded from this review: water used in the study was using drinking water and bodies of water.

D. Search Results

Initially, 134 studies related to the aforementioned study were drawn out by using combinations of search terms from four research directories (53 from GoogleScholar, 28 from Elsevier, 30 from NCBI, and 23 from IWA Publishing). The results from these online directories were limited to review and research articles with English language and the published date restrictions are between 2016 and 2024 which filtered 38 studies from the initial search results. Then, 26 duplicated studies were removed, and 70 review and research articles remained and were subjected for final screening based on the inclusion criteria. A total of 20 research and review articles were finally included in the quantitative analysis after further screening and evaluating the eligibility of the research and review articles based on the contents of titles, abstracts, and availability of the full research material. The stages of selection and results are presented in the PRISMA flow diagram (see Fig. 1).

E. Data Extraction

In this review, it includes a systematic overview of different municipal and domestic wastewater treatment techniques that potentially remove microplastic in the water. The gathered literature was subjected to evaluation, and relevant data specific to the review objectives were recorded in Google Docs. In the quantitative analysis, the data gathered from each article are as follows: author and publication year, different water treatment techniques, types of microplastic removed, type of wastewater treated, range particles of the microplastic, and the efficiency of the process in removing microplastic.

F. Data Analysis

The selected literature is evaluated in terms of its qualitative characteristics for eligibility for quantitative analysis. Different related literature and articles that indicate the efficiency rate of removal of the microplastics were included to distinguish the better methods and techniques for removing the microplastics from wastewater.

III. RESULTS AND DISCUSSION

A. Published Scientific Articles and Definitive Records Related to Microplastic Removal in Wastewater

The findings of accumulated science articles and study reviewing imply that analyses come in a very limited paper—due to limited sources of existing parameters and methods applicable for removal of microplastics in the environment and wastewater treatment plants—related to the evaluation of

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microplastic removal in the environment in the country between the years 2016 and 2024. Upon going through the related articles, it was ascertained from these papers generated by web navigators, such as Google Scholar, that most of the microplastic assessment of prevalence and removal in the wastewater treatment plants studies mostly came from municipal and domestic wastewater including those from municipal and domestic influents, local hospital influents, and household influents.

The extraction of related information is not only limited to a specific region but rather taken from a wider scale. A total of 20 scientific studies were obtained and reviewed thoroughly by the researchers in order to determine the desired data—methods of microplastic removal, type of wastewater, microplastics removed and their sizes, and removal efficiency—for the systematic review. This collected information were tabulated to fully evaluate and understand their significance to the review study.

B. What are Microplastics and How are they Being Discharged into the Environment

Microplastics are small plastic particles that come from the degradation of plastics, ubiquitous in nature, and therefore affect both wildlife and humans (Ziani, *et al.*, 2023). Plastics are one of the most abundant products that are being utilized worldwide for their efficiency and cost-effective value which drives the increasing demand for plastics in various industries. In line with that, the over-production of plastics starts to impose negative impacts on the environment and public health. Plastic waste enters both land and water sources through littering, poor waste management, stormwater runoff, fishing vessels, cargo and cruise ships, and more. Many plastics float, so countless plastic items of all shapes and sizes make their journey downstream, eventually making their way to the oceans (Sulpizio, 2022).

C. Composition of Microplastics and How it can be Degraded

Microplastics are tiny plastic particles primarily composed of carbon and hydrogen atoms linked together in polymer chains. These particles originate from the breakdown of larger plastic products including a wide range of everyday items, such as plastic bottles, bags, food packaging, etc. Microplastics (MPs) chemical composition includes Polystyrene, Polyethylene terephthalate, Polyurethane, Polyamide, Polypropylene, and Polyethylene (Piccardo, *et al.*, 2021). According to the National Oceanic and Atmospheric Administration (NOAA), any small plastic pieces that are less than five millimeters are called microplastics, which can be harmful to ocean and marine biodiversity. Due to its size, it is difficult to eradicate these kinds of plastics, which is why traditional ways of degrading plastics, such as microplastic, cannot be eradicated.

Through the advancement of technology, there are now numerous studies about the recent trends in the degradation of microplastics in the environment, and some of those studies are about the two alternatives currently being studied for the degradation of microplastics: advanced oxidation processes (AOPs) and biological decomposition (Sutkar, P., et al., 2023). In accordance with Silva et al. (2018), microplastics can be decomposed through the breakdown of molecular linkages of microplastics into tiny molecules, which can be transformed into non-hazardous byproducts or oxidized totally into carbon dioxide (CO2) and water (H2O).

D. Parameters and Methods for Quantification and Removal of Microplastics from Wastewater

This study focuses on different methods and processes in removing microplastics specifically from municipal and domestic wastewater sources. The efficiency rate will become the basis of the effectiveness and quality of the process. Researchers assessed and analyzed several studies which critically, scrutinized and summarized the efficiency of the processes utilized to remove the microplastic in the indicated types of wastewaters from each study.

Based on the aforementioned research studies, domestic waste and municipal waste are one of the major sources of microplastics. Primary microplastics are directly discharged in the earth's atmosphere (e.g. plastics that are used to make products and glitters). Microplastics also settle onto surfaces and are transported by rain to water runoffs (streams). The well-known plastic composition are the polymer types such as – Polypropylene (PP), Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Low-density polyethylene (LDPE), Ethylene-vinyl acetate (EVA), Polyamide (PA).

As the study aims to pinpoint the specific sources of wastewater, which are domestic and municipal, (see Fig. 2) shows the number of studies where focused on the specific source of wastewater along with its different methods and techniques in removing the microplastic. Along with this, in each study and type of wastewater, there are different methods and techniques for removing microplastics. Among the gathered studies that is under the primary and secondary wastewater treatment plant (WWTP) treatment, the most effective methods for removing microplastics are the Electrocoagulation – Electro-flotation (EC/EF) and Membrane Filtration Process (MFP) with 100% removal efficiency followed by Advanced Membrane Bioreactor (MBR) with 99.4% removal efficiency. Meanwhile, the least efficient method is the Aeration Grit Chambers with 59% removal efficiency (see Fig. 3.). The most effective methods under tertiary WWTP treatment type are Laboratory-Scale Sand Filter with up to 100% of removal efficiency, Dual Media Sand Filter with 99.2% and Electrocoagulation having 98.5% removal efficiency. On the other hand, the least efficient method is the UVC/H2O2 Oxidation Process with 52.7% removal efficiency of microplastics (see Fig. 4.).

E. Microplastic Removed Using the Most Efficient Method for Microplastic Degradation

As there are numerous types of microplastic, this study indicates the microplastics that are removed with the highest efficiency of the technique to remove the microplastics from wastewater. It shows different references that contributed studies regarding different techniques for treating domestic wastewater [1]. These studies show the efficacy of the study in removing specific microplastics. The following abundant microplastics in domestic wastewater were removed: polyethylene (PE), polyesters, polypropylene (PP), polyethylene terephthalate (PET), polyethersulfone (PES), acrylic fiber, and polyamide (PA). The highest percentage removal is using conventional activated sludge (CAS) with 98.3%, and membrane bioreactor (MBR) with 99.4% (Lares, M., et.al., 2018), and a biofilm reactor with 99.18% (Nur, A., et al., 2022). CAS and MBR used Primary and Secondary type of wastewater treatment plant treatment (WWTP) with <1 mm and 0.5 - 1 mm particle size respectively. The Biofilm reactor used the Primary type of WWTP treatment with gathering 20 - 5000 µm particle size of MPs.

It shows different methods and techniques that are used to treat municipal wastewater to remove microplastics [2] . Each paper demonstrates the efficiency of their chosen methods to effectively remove microplastics. The following are the types of specific microplastics mentioned that are mostly removed from municipal wastewater: polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polyester, polyamide (PA) and Polyethylene terephthalate (PET). The Laboratory Scale Sand Filter (Umar, M., et al., 2023), Electrocoagulation - Electro-flotation (EC/EF) and Membrane Bioreactor (MBR) with Ceramic Microfiltration (Takeuchi, H., et al 2023) have 100% removal efficiency of microplastics. Mostly, Tertiary types of WWTP treatment are used for the three methods. However, secondary treatment was also used on EC/EF gathering 150 µm (PE), and 250 µm (PP) particle size. Laboratory-Scale Sand Filter gathered MPs with 124 - 250 µm particle size range, while MBR gathered MPs ranging > 10 µm in particle size.

IV. CONCLUSION

The findings revealed several highly effective methods for removing microplastics from domestic and municipal wastewater. For domestic wastewater, membrane bioreactors (MBR) with 99.4% removal efficiency, conventional activated sludge (CAS) with 98.3% efficiency, and biofilm reactors with total removal efficiency of 99.18% demonstrated the highest removal rates for microplastics. Moreover, the microplastics primarily removed are polyethylene (PE), polyesters, polypropylene (PP), polyethylene terephthalate (PET), polyethersulfone (PES), acrylic fiber, and polyamide (PA). These methods were effective for particle sizes ranging from <1 mm to 5000 µm (5 mm), utilizing primary and secondary wastewater treatment plant (WWTP) processes. In the case of municipal wastewater, types of microplastics mostly removed are polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polyester, polyamide (PA) and polyethylene terephthalate (PET). Furthermore, laboratory-scale sand filters and electrocoagulation – electro-flotation (EC/EF) combined with membrane filtration process (MFP), emerged as the best removal techniques for microplastics in municipal wastewater water, both achieving up to 100% removal efficiency. These methods primarily employed tertiary WWTP treatment, effectively removing microplastics ranging from 10 µm to 250 µm in size.

This systematic review provides insights into the most effective methods for microplastic removal across domestic and municipal wastewater sources. The findings can guide future research efforts and to develop advanced strategies to mitigate microplastic pollution effectively. However, continued investigations are needed to explore the potential for combining multiple techniques or developing novel approaches to achieve even higher removal efficiencies and address the growing challenge of microplastic pollution in wastewater and aquatic environments completely.

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APPENDICES

Table 1: A Table of Data for 20 Literature Articles that were Collected is Horizontally Arranged by its Type of Wastewater, Type of Wastewater Treatment, Methods or Techniques, Microplastic Removed, Range of particle size, efficiency of removal, and the Corresponding References.

Article No.	Type of Waste water	Type of the WWTP	Methods/Techniques	Microplastic Removed	Range Size Particles	Efficiency of Removal	Author/ References
1	Domestic Wastewater	Tertiary Treatment	Bioretention Systems (HSF System) using Umbrella Plant *(Cyperus alternifolius L.)* and Common Reed *(Phragmites australis)*	*NS	<500 µm 500–1000 µm >1000 µm	Average removal efficiency of 62.89 % and 95.45 % for sizes >1000 µm, 89.21 % for sizes 500–1000 µm, and 44.16 % for sizes <500 µm.	Vijuksungsith, P., *et al.*, (2024)
2	Domestic Wastewater	Primary Treatment and Secondary Treatment	Conventional Activated Sludge (CAS), and Advanced Membrane Bioreactor (MBR)	Microplastics (MPs), Polyester	< 1 mm 0.5 - 1 mm	MBR: 99.4 % CAS: 98.3 %	Lares, M., *et.al.*, (2018)
3	Domestic Wastewater	Tertiary Treatment	Electrocoagulation (Al Electrode and Fe Electrode)	Polyethylene (PE), Polymethylmethacrylate (PMMA), Cellulose Acetate (CE)	286.7 µm 6.3 µm	PE: 93.2% (Al) and 71.6% (Fe) PMMA: 91.7% (Al) and 58.6% (Fe) CA: 98.2% (Al) and 82.7% (Fe)	Shen, M., *et al.*, (2022)
4	Domestic Wastewater	Tertiary Treatment	Pilot-scale Ultrafiltration	Fiber, Polyethylene Terephthalate (PET), Polyethylene (PE), and Polypropylene (PP)	0.05 - 0.5 mm	Up to 96.97%	Tadsuwan, K. and Babel, S. (2022)
5	Domestic Wastewater	Secondary Treatment	Activated sludge	Polyethylene (PE), Polypropylene (PP), Polyethersulfone (PES), Acrylic	300 - 4989 µm	TA: 97% DA: 95% BH: 69% DL: 99%	Le, T., *et al.*, (2023)
6	Domestic Wastewater	Tertiary Treatment	Powdered Activated Carbon (PAC) Adsorption	Acrylic, Polyester, and Polyamide (PA)	0.1 µm	More Than 60%	Atesci, Z. & Inan, H. (2023)
7	Domestic Wastewater	Tertiary Treatment	Electro-Hybrid Ozonation-Coagulation (E-HOC)	Polyethylene (PE), Nylon, and Polyester	< 50 µm 50 - 200 µm 200 - 500 µm > 500 µm	Can Reach Over 90%.	Luo, J., Jin, X., Wang, Y., & Jin, P. (2022)
8	Domestic Wastewater	Primary Treatment	Biofilm Reactor: Anorexic 1, Anorexic 2, Anaerobic.	Polyethersulfone (PES), Cotton, Polypropylene (PP), Polyethylene (PE), Polyamide (PA),	20 - 5000 µm	Anorexic Reactor: 72.43 - 91.77%	Nur, A., *et al.*, (2022)

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				Polyethylene Terephthalate (PET).		Anaerobic Reactor: 98.35% Total efficiency removal: 99.18%	
9	Municipal Wastewater	Secondary Treatment	Application of Inorganic and Organic Coagulants (Ferric chloride, Polyaluminum chloride, and Polyamine)	Synthetic Microplastics (Polymers)	1 µm 6.3 µm	High MP removal above 95% was observed for 1 µm MPs and above 76% for 6.3 µm MPs	K. Rajala., *et al.* (2020)
10	Municipal Wastewater	Secondary Treatment	Pilot-scale Biofilter	Polyamide (PA), Polyester, Polyvinyl Chloride (PVC), Polystyrene (PS), Acrylic, Polymer, Polypropylene (PP)	> 100 µm	Particle Number: Polyester 34% Particle Mass: PE 38% Total Mps: Particle No.: 78.5%, Particle Mass: 88.9%	Liu, F., *et al.*, (2020)
11	Municipal Wastewater	Tertiary Treatment	Membrane Bioreactor (MBR) with Ceramic Microfiltration	Mixed polymers	> 10 µm	WWTPs removed (45%-98%), Ceramic Membranes further removed 72% MPs, Total: >96%	Takeuchi, H., *et al.*, (2023)
12	Municipal Wastewater	Secondary Treatment and Tertiary Treatment	WWT Mechanical, Chemical and Biological (activated sludge) and Biologically Active Filter (BAF)	Polyester, Polystyrene (PS), Polypropylene (PP), Polyethylene (PE)	20 - 100 µm 100 - 300 µm >300 µm	Total of MPs removed: 97% (PE are most abundant, other MPs were not specified)	Talvitie, J., *et al.* (2017)
13	Municipal Wastewater	Tertiary Treatment	Dual Media Sand Filter	Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET), and Polystyrene (PS)	10 - 50 µm >500 µm	99.2% removal efficiency	S. Wolff, *et al.* (2020)
14	Municipal Wastewater	Tertiary Treatment	Electrocoagulation (0 to 30V Eventek KPS3010D)	Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC)	25 - 1500 µm	98.5% removal efficiency (PE are most abundant among other MPs)	Elkhatib, D., Oyanedel-Craver, V., & Carissimi, E. (2021)
15	Municipal Wastewater	Tertiary Treatment	Laboratory-scale Sand Filter	Polymer, Polyethylene (PE)	125 - 250 µm	Up to 100% removal	Umar, M.,

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				and Polypropylene (PP)		efficiency (PE are most abundant among other MPs)	Singdahl-Larsen, C., & Rannekl ev, S. B. (2023)
16	Municipal Wastewater	Primary Treatment	Coagulation: Ferric Chloride and Poly Aluminum Chloride (PAC)	Polyethylene (PE)	10 - 45 µm 40 - 70 µm 70 - 100 µm	76.8% removal efficiency	Tabatabaei, F., *et al.,* (2022)
17	Municipal Wastewater	Tertiary Treatment	UVC/H2O2 Oxidation Process	Polyethylene Terephthalate (PET)	*NS	52.7% removal efficiency	Easton, T., Koutsos, V., & Chatzisymeon, E. (2023)
18	Municipal Wastewater	Tertiary Treatment	Aluminosilicate Filter Media	Polyethylene (PE), Polyamide (PA)	10 µm 100 µm	Removal efficiency of 95%	Shen, M., Hu, T., *et al.*, (2021)
19	Municipal Wastewater	Secondary/Tertiary treatment	Electrocoagulation - Electroflotation (EC/EF), and Membrane Filtration Process	Polyethylene (PE) Polyvinyl Chloride (PVC)	150 µm 250 µm	EC/EF:100% MFP: 100% (both PE and PVC)	Ceyhum, A., *et al.* (2021)
20	Municipal Wastewater	Primary Treatment and Secondary Treatment	Aeration Grit Chambers and Conventional Activated Sludge (CAS)	Microfibers	1 - 5 mm	AGC: 59% influent with 1-5mm size CAS: 90%	Bilgin, M., *et al.,* (2020)

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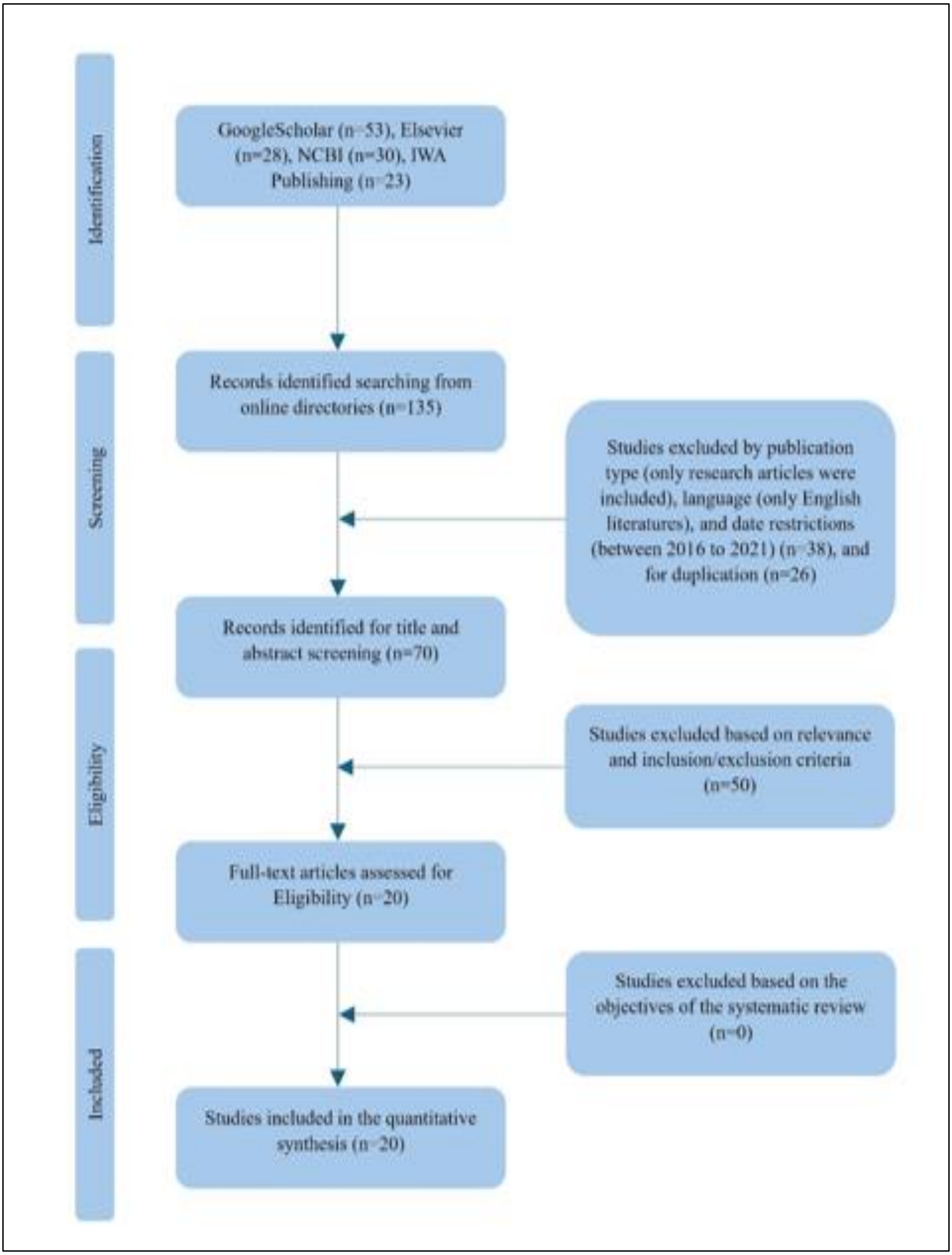

Fig 1: PRISMA Stages of Study Selection of Related Studies Flow Diagram

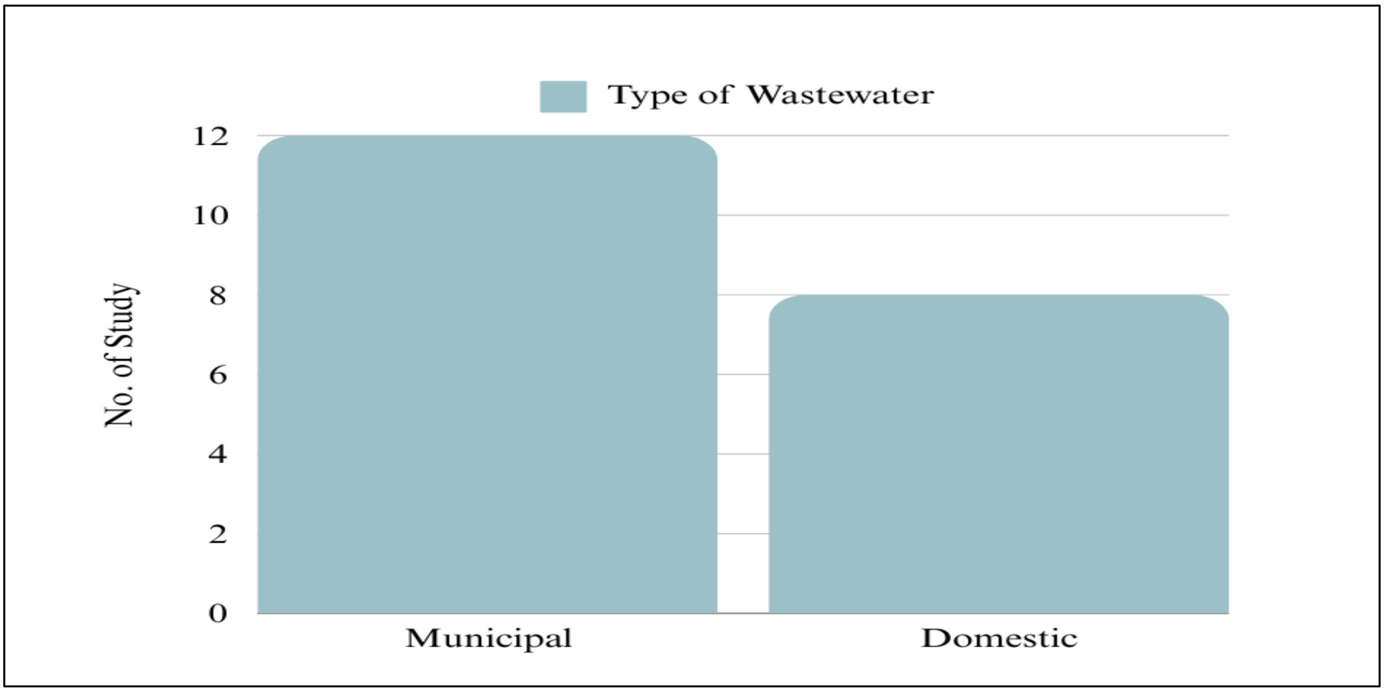

Fig 2: A Graph Comparing the Number of Reference Studies According to the Type of Wastewater they Used in the Study. Municipal=12 studies, Domestic=8 Studies

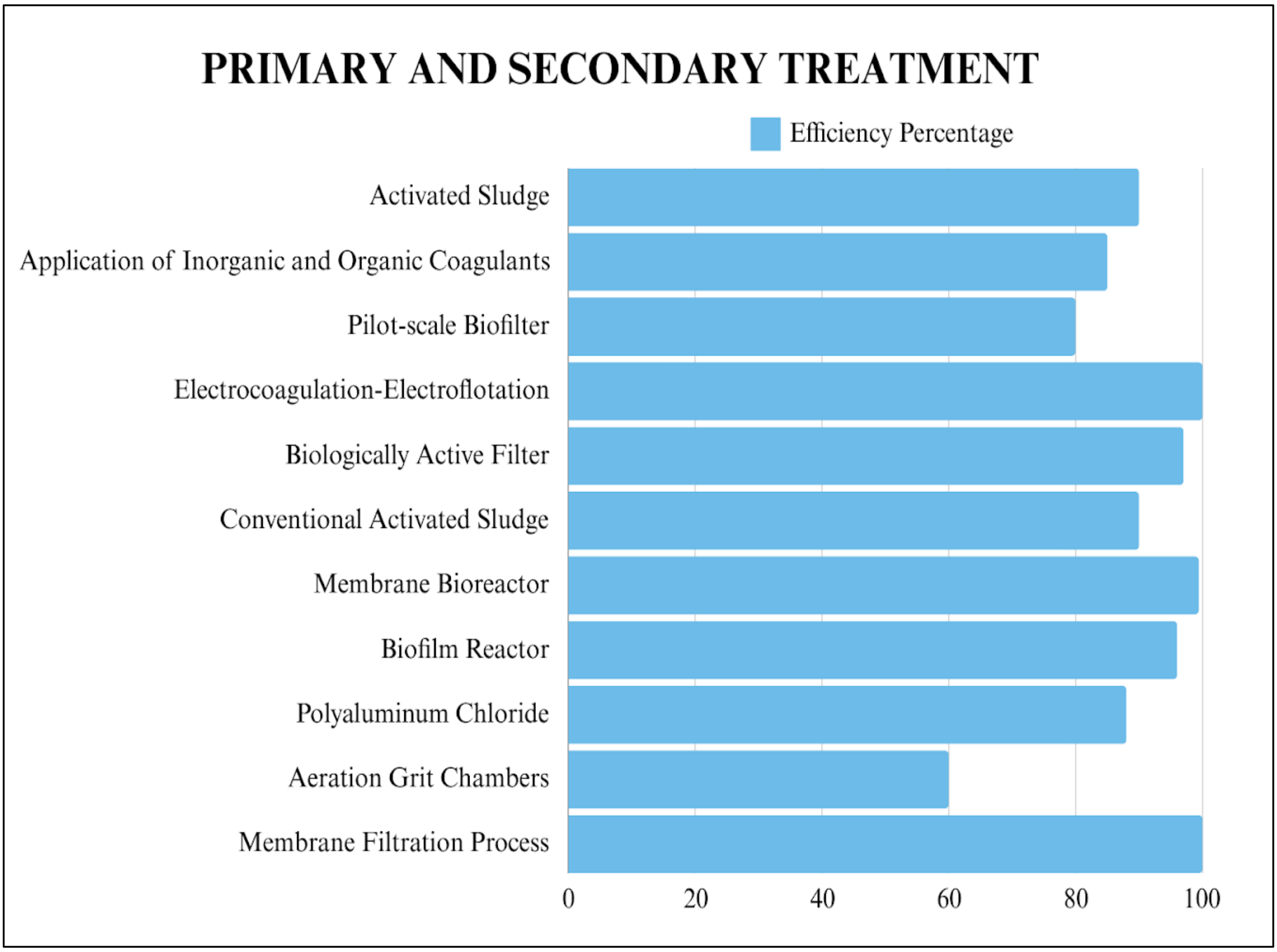

Fig 3: A Graph Illustrating the Removal Efficiency Percentage of Microplastics during the Process of Primary and Secondary Wastewater Treatment using Different Methods and Techniques

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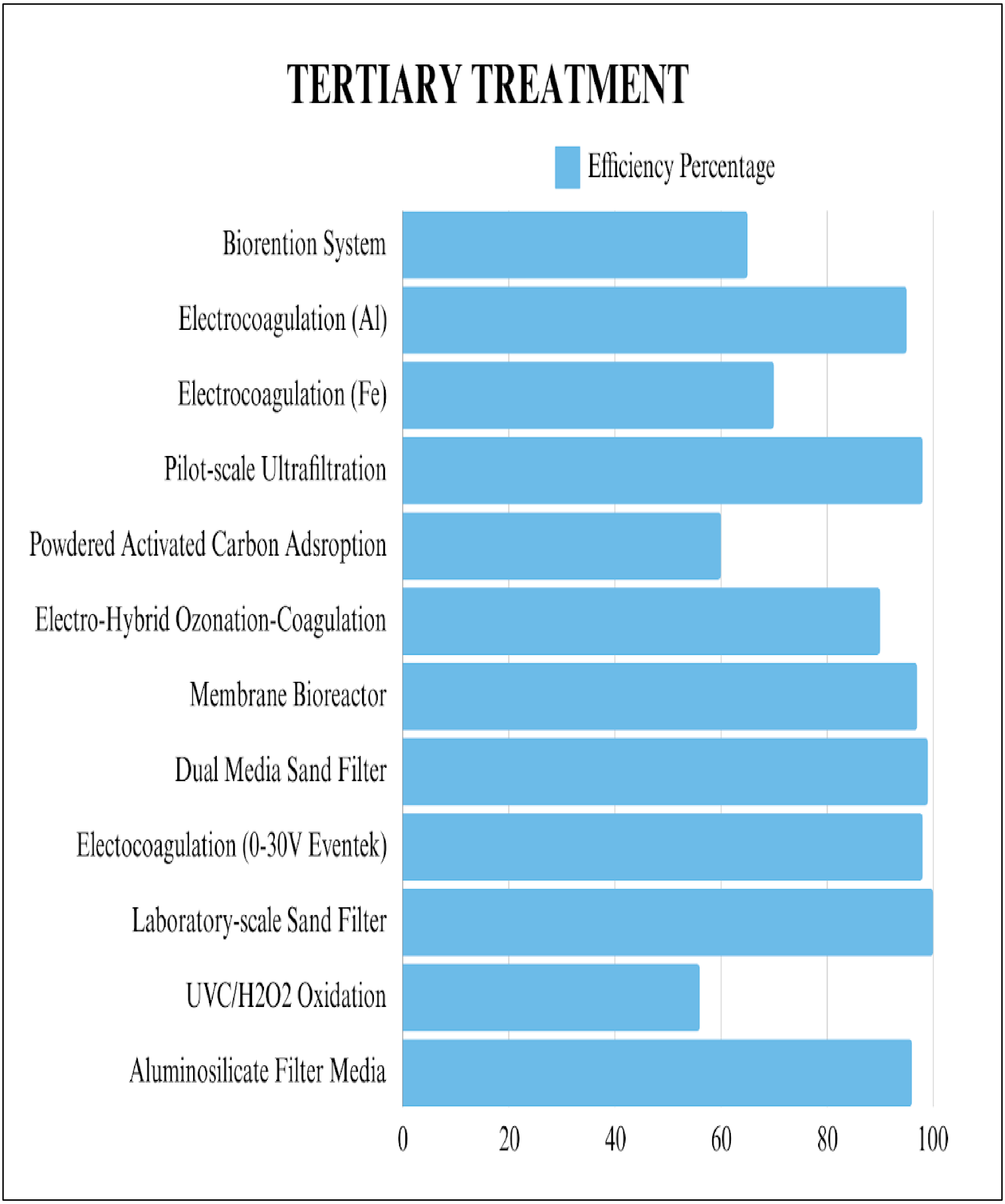

Fig 4: A Graph Illustrating the Removal Efficiency Percentage of Microplastics during the Process of Tertiary Wastewater Treatment using Different Methods and Techniques