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A Systematic Review of Polluting Processes Produced by the Textile Industry and Proposals for Abatement Methods

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Review

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ABSTRACT

The textile industry is one of the most polluting industries worldwide because of its processes that entail the excessive use of water and chemicals, resulting in textile effluents that, in turn, are not treated and controlled correctly. This review aims to identify the most polluting processes in the textile industry and the most efficient methods to reduce the water footprint. The PICO method was used to define the search equation and obtain studies based on the topic, resulting in a total of 4783 articles; then, the PRISMA statement was used to carefully select studies, of which 32 articles met the inclusion criteria. The textile industry's supply chain presents high pollution levels, especially in the dyeing process, with a percentage of 33% effluents, since they use toxic chemicals such as ammonia, sulphide, and lead. Therefore, the study analyzes physical methods (hydrodynamic cavitation and flocculation), chemicals (electrocoagulation, EC-EO, and EC-EF), and biological (degradation assisted by bacteria) to treat wastewater. After analysis of the above methods for treating wastewater, electrocoagulation combined with electro-oxidation (EC-EO) obtained the highest efficiency rate with 88% COD removal and 100% colour removal.

KEYWORDS

textile industry, wastewater, water footprint, electrocoagulation, PRISMA-statement

INTRODUCTION

Initially, the term "textile industry," which comes from the Latin word "Texere," which means weaving, was associated with fabric based on fibres, while it currently refers to several processes, including tissue dyeing [1]. Over the years, the evolution within the textile industry caused it to become one of the industries most contaminated worldwide. The industry uses large amounts of resources, mainly water, that generate large amounts of waste that affect environmental sustainability [2–4]. It also hurts the aquatic ecosystem, endangering the lives of these organisms [5,6]. On the other hand, the increase in clothing consumption is a consequence of the fast fashion that some companies have brought to the market, as they introduce new styles every week [7,8], the continuous renewal of garments, and the water footprint. This industry significantly impacts the global economy [9], as in the case of Bangladesh, which became a fundamental pillar of its economy, becoming the second-largest exporter of garments after China [10,11]. However, this industry negatively affects the environment, as the United Nations states that the fashion industry accounts for 20% of all global wastewater [12].

On the one hand, the textile industries use toxic chemicals at various stages, such as sizing, softening, desizing, polishing, and finishing agents [13–16]. These processes are followed by wastewater containing caustic, ammonia, sulfur, lead, heavy metals, and other toxic substances [10,17,18]. Based on these problems, industrial companies need to implement appropriate methods to reduce or eliminate the pollution produced by this industry, one of them being the beginning of the supply chain, which refers to procuring raw materials from suppliers that market environmentally friendly products [19,20]. Therefore, within the advances of the textile industry is the Sol-Gel, which is a wet treatment process that is carried out at low temperatures, which uses the least amount of chemicals and has low health toxicity in humans, to make tissues more durable and presenting different properties in textile finances [21]. Similarly, concerning the care of the environment, the use of the natural dye derived from the fruits of Syzygium cumini is studied through the use of biomordiers; this is enhanced with the use of ultrasonic energy that will increase the concentration of the extracted colouring, of this way, increasing colour intensity and presenting greater fixation in the fabric, making it more sustainable and ecological [22].

On the other hand, one of the new methods studied today is the hybrid nanoparticle method, which is used for the remediation of textile effluents due to its high adsorption capacity. Likewise, sedimentation is considered an integrated method within the wastewater treatment process and is used to remove gravity-suspended particles, generating a layer of mud; this process can be carried out after coagulation to increase filtration effectiveness [23]. Finally, assisted ultrafiltration with Keggin-type polyaxomethals (PW12) is presented as an efficient complex agent for eliminating heavy metals in contaminated industrial discharges [24]. Also, to use treatments that will be mentioned throughout this research to reduce the impact of pollution. The justification presented is based on the fact that many companies in the textile industry cannot implement adequate methodologies to treat wastewater due to a lack of funds and high operational costs [25]. For this reason, this literature review aims to provide information on the different adverse effects of the textile industry, based on further research, where the water footprint produced by this industry was analyzed. In addition, proposals for reducing the impact, starting from the supply chain to dealing with the waste produced.

This systematic review aims to identify the most polluting processes in the textile industry and mention the most efficient methods to reduce the water footprint, which are based on electrochemical, physical, and biological.

In this respect, the document is organized as follows. The Methodology section describes in detail the method used for elaborating the SLR (Systematic Literature Review), specifying the procedure for its elaboration, which in this case is the PICO method. The PRISMA method was used to extract information from the selected articles. The Results section shows and organizes the results from the studies analyzed, from the most polluting processes to the methods proposed for solving the problem.

METHODOLOGY

The following research used the PICO strategy for the research question construction and existing evidence searches, which included the problem/population, intervention, comparison, and results of a specific topic through keywords. In addition, this methodology is fundamental for conducting a systematic review, as it will pose a search question and thus obtain studies precisely related to the research [26].

In the search for more specific information on the research topic, the following question was posed: "How do production methods affect environmental pollution caused by toxic waste in the textile industry? As the first component of the PICO method problem/population, toxic waste was considered the research problem for the intervention, production methods, the results, reduction of environmental pollution, and finally, in the context of the textile industry. In Table 1, the keywords corresponding to each component will be mentioned.

Table 1. PICO method

P	Problem/Population	Toxic wastes	Wastewater, water footprint, toxic waste, effluents
I	Intervention	Production methods	Processes, methods, production, treatments, sustainable, pretreatment.
C	Comparison	-	-
O	Outcomes	Reducing environmental pollution	Reduction, emission, pollution.
C	Context	Textile Industry	Textiles, textile products, textile plants, clothing, textile industry.

After defining the PICO method, the keywords for each component were used to obtain the following search equation: ("wastewater" OR "water footprint" OR "toxic waste" OR "effluents") AND ("processes" OR "methods" OR "production" OR "treatments" OR "sustainable" OR "pretreatment") AND ("reduction" OR "emission" OR "pollution") AND ("textiles" OR "textile product" OR "textile plant" OR "clothing" OR "textile industry")

Finally, the PRISMA statement using a flow diagram was elaborated, which is a relevant method for analyzing a systematic review and that guarantees the transparency of an investigation since it helps to select the appropriate studies based on specific criteria, both inclusion and exclusion, for developing a research topic, of interest and then analyze and review the results obtained. While this method is used in systematic reviews focused on the health sector, it currently applies to any research [27,28].

Inclusion criteria:

- Studies should address statistical issues on the impact of wastewater (IC1).
- Studies should describe the success rate after the application of the solution methods. (IC2).
- Studies provide information on supply chain improvement within the textile industry (IC3).
- Studies using technologies to reduce Water footprint (IC4).

Exclusion criteria:

- Studies based on environmental methods that have yet to be tested will not be considered (EC1).
- Studies covering methods to utilize textile waste to create a new product within the industry (EC2).
- Studies focused on the quality of the workforce within the industry processes (EC3).
- Studies are primarily based on the chemical and biological research areas (EC4).

RESULTS

After carrying out the PICO method, where the search equation was used in the SCOPUS database, a result of 4783 articles was obtained, which was carried out in mid-June 2023. Based on this, the PRISMA method was applied, where no duplicate articles weren't found because only one database (SCOPUS) was used. Likewise, 4254 articles were excluded, being the excluded periods (referring to the year of publication) different from 2018 to 2023 (2052 documents), the type of document (including 1673 documents), and when considering the keyword "textile industry," a result of 529 articles was obtained. Following this result, 122 articles were discarded, based on the review of titles and abstracts, and 228 articles that needed open access. Finally, the exclusion above criteria were applied, resulting in 32 articles selected for the research. Figure 1 shows the number of studies for each exclusion point.

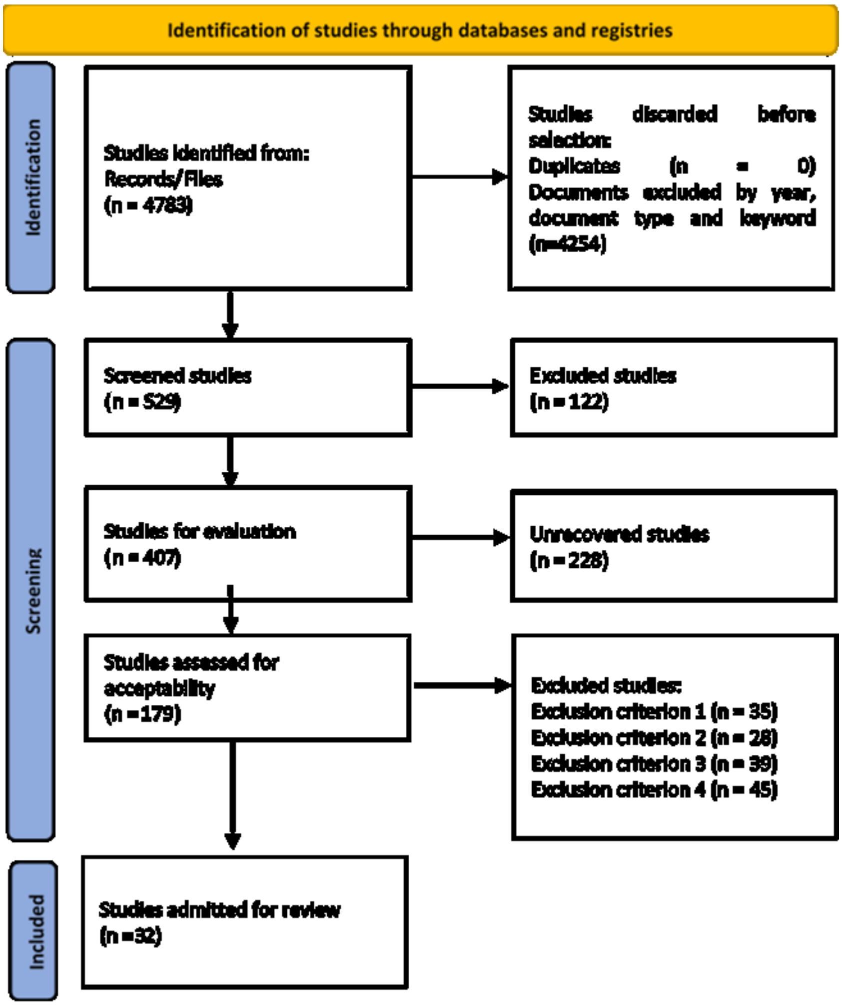

Figure 1. PRISMA flow diagram

Once the filters had been carried out, 32 articles were obtained, which were analyzed for implementation in this systematic review. Based on this, an analysis was carried out on the keywords described in each article (see Figure 2), where it could be deduced that the most used keyword is "textile industry", being used in 10 articles, followed by "water footprint", "wastewater treatment" and "sustainability", used in 6, 5 and 4 articles respectively.

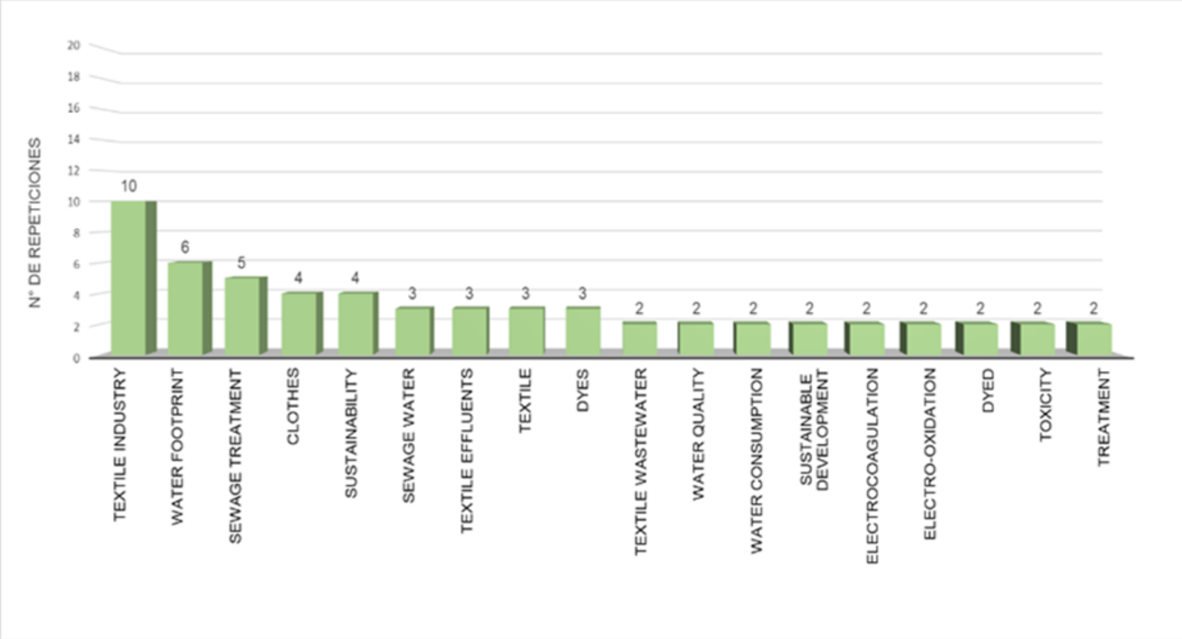

Figure 2. Keywords of most mentioned authors

We also analyzed the origin of these studies, which showed that most of the items studied are from China, with six items (see Figure 3). This is because China is one of the countries where large quantities of textile products are produced, generating high water consumption during its process chain [29]. Furthermore 2019, in Zhejiang province, the textile industry was responsible for 47.64% of wastewater discharges [30].

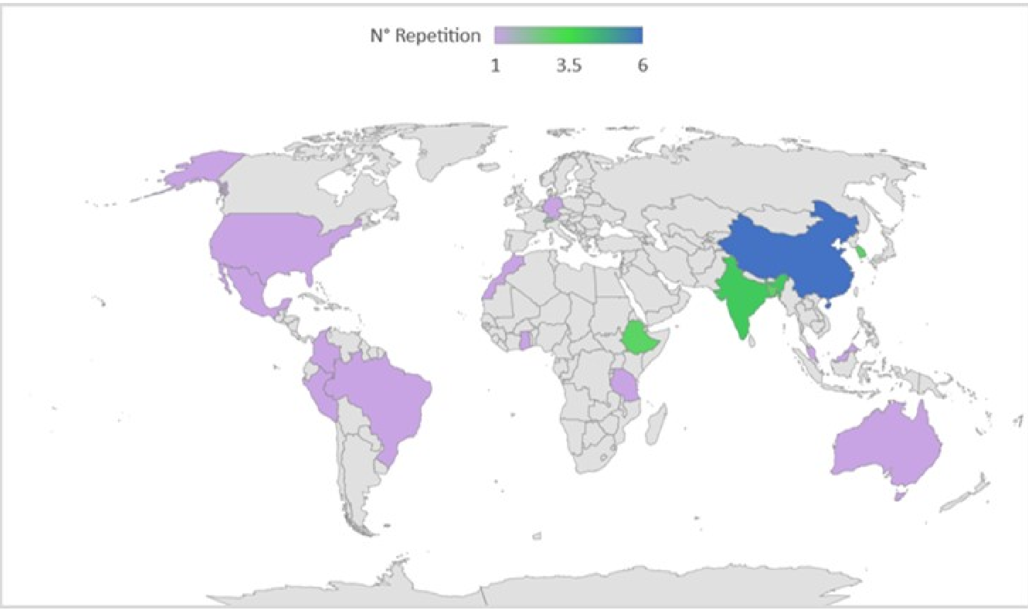

Figure 3. Country of origin of research

Upon analysis, China has the highest number of researches conducted, with most published in 2022 (8 researches). Other Asian countries where research is concentrated are India, South Korea and Bangladesh. Table 2 explains in detail the number of each research concerning the country of origin and year of publication.

Table 2. Country of origin and year of research publication

Country	N° Repetition	Year
China	6	2021 2022 (5)
India	4	2018 2020 (2) 2023
South Korea	3	2022 2023 (2)
Ethiopia	3	2022 (2) 2023
Bangladesh	3	2022 (2) 2023
Switzerland	2	2022 2023
Mexico	1	2023
Germany	1	2021
Peru	1	2021
Colombia	1	2020
Malaysia	1	2021
Morocco	1	2020
Australia	1	2021
Spain	1	2023
Tunisia	1	2020
USA	1	2022
Ghana	1	2022

One industry generates large amounts of wastewater due to the increased demand for textile products caused by fast fashion, thus increasing pollution worldwide [12,31]. The processes involved in the manufacture of textile products, in addition to consuming large amounts of water, also produce waste that is difficult to treat.

Following the research, some studies [10,32] detailed the contamination percentages of each process within the textile industry (see Table 3), depending on the place of study, which in this case mentions Bangladesh and Ethiopia.

Table 3. Percentage of contamination of textile industry processes

References	Processes	Hydric footprint, %
Hossain y Khan [10]	Yarn dyeing	27.96
	Fabric manufacturing and dyeing	53.04
	Spinning	0.90
	Cutting, sewing and threading stage	18.10
Azanaw; Birlie; Birlie, Teshome y Jemberie [32]	Preparatory process	45
	Dyeing process	33
	Finishing process	22

Based on the problems above, the information provided by the authors was collected, where they mention different methods to reduce and eliminate the water footprint; the latter is a quantitative tool referring to the impact caused by the use of water throughout the product life cycle [33]. Therefore, the number of methods that different authors mention was analyzed. After this analysis, Figure 4 shows that one of the major methods to reduce water pollution is the electrocoagulation method used in 5 research articles.

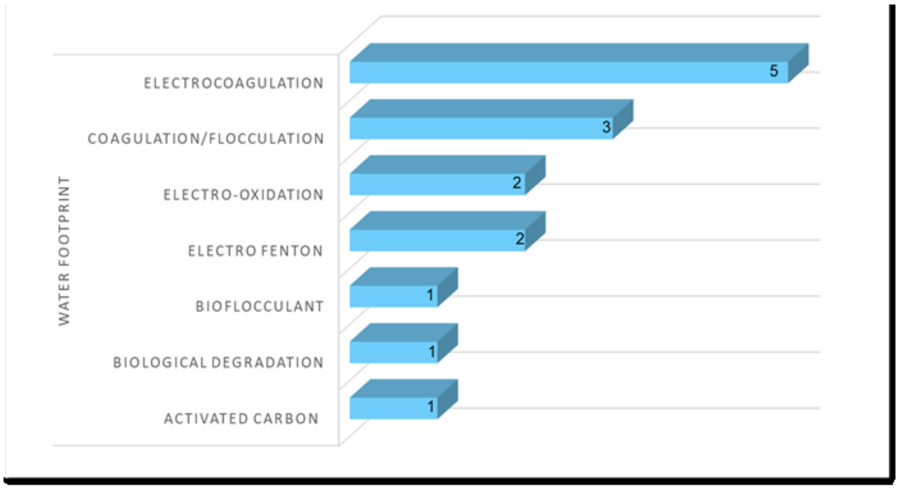

Figure 4. Methods investigated

On the one hand, there are three types of conventional methods for wastewater: chemical, physical, and biological treatment [9]. As an example of chemical treatment, the electrocoagulation (EC) method consists of the electrochemical dissolution of sacrificial metal electrodes (iron/aluminium) in soluble or insoluble species depending on the pH of the solution [34]. This method, together with the coagulation method, has a colour removal efficiency that is in the range of 80% and 93.9% [35]. In addition, another study proves that the fusion of electrocoagulation (EC) and electro-oxidation (EO) reduces chemical oxygen demand (COD) by up to 88% after 180 min of electrolysis [36]. Likewise, the proposed electrocoagulation (EC) method combined with Electro Fenton (EF) achieves more than 97% efficiency [34].

As a physical treatment, the hydrodynamic cavitation method consists of the process of generation and implosion of bubbles, which originates in a liquid flowing due to the decrease and subsequent increase in pressure by a cavitation element, i.e., orifice plate, in terms of results, the pH was reduced by 23.95%, total suspended solids by 82.82%, biological oxygen demand (BOD) by 64.77%, COD by 63.05%, and the presence of oils and fats reduction was 93% [37]. On the other hand, the coagulation/flocculation method is a physicochemical treatment where it could be deduced that the most effective organic flocculant was the cactus because its success in removing colour in the wastewater studied was 89.33%; COD, 65.75%; TSS (Total Suspended Solids), 76.67%; DS (Total Dissolved Solids), 93.43% and TS (Turbidity), 85.05% [32].

Finally, as a biological treatment, the adsorption and degradation process decolorizes the dye in the wastewater. Bacteria-assisted degradation reduces up to 100% by eliminating colour from wastewater, and this method is environmentally friendly. Likewise, the research mentions that enzymes, fungi, yeasts, and algae can be used, the latter's efficiency depending on the species, its metabolic activity, and the molecular structure of the dye [13]. The biological method is more environmentally friendly than the physical and chemical methods; however, it is less efficient and has a long shelf life [35]. Table 4 details the results of success for each method mentioned.

Table 4. Wastewater treatment methods

Method type	Methods	Success outcome
Chemical treatment	Electrocoagulation	Efficiency of 80% and 93.9% [35].
	Electrocoagulation (EC) - Electrooxidation (EO)	COD reduction up to 88% and 100% color removal [36].
	Electrocoagulation - Electro Fenton	97% efficiency [34].
Physical treatment	Hydrodynamic cavitation	Reduction of pH by 23.95%; BOD, 64.77%; COD, by 63.05%; oils and fats reduction was 93% [37].
	Flocculation	Colour removal, 89.33%; COD, 65.75%; SS, 76.67%; DS, 93.43% and TS, 85.05% [32].
Biological Treatment	Bacteria-assisted degradation	Colour reduction up to 100% [13].

Although textile industries have to apply treatments to reduce and eliminate wastewater, it is necessary to improve the supply chain processes of this industry to reduce the rate of pollutants in this water from the beginning and obtain a more sustainable industry [19].

Based on this, one of the most used dyes in the textile industry is indigo; due to the popularity of blue jeans, it is estimated that the annual production of fabric dyed with indigo is 7 to 10 billion m^2, for this reason, the methodology regenerative Redox system also called Reversible Redox was used in the dye bath, The method during the experimentation resulted in a 79% efficiency, in addition to reducing water consumption by 80%; also, the consumption and generation of chemicals such as sulfate, sulfite and thiosulfate was decreased by 50% [38]. On the other hand, a study conducted in Ethiopia proposes the use of natural indigo because the use of synthetic indigo is toxic in the manufacturing processes of the textile industry products, which generates environmental pollution and health risks in the places where it is located; on the other hand, natural indigo, in addition to being non-toxic, is durable and renewable. Therefore, it would be the most viable option in the supply chain; natural indigo only represents 1% of the world's indigo production [20].

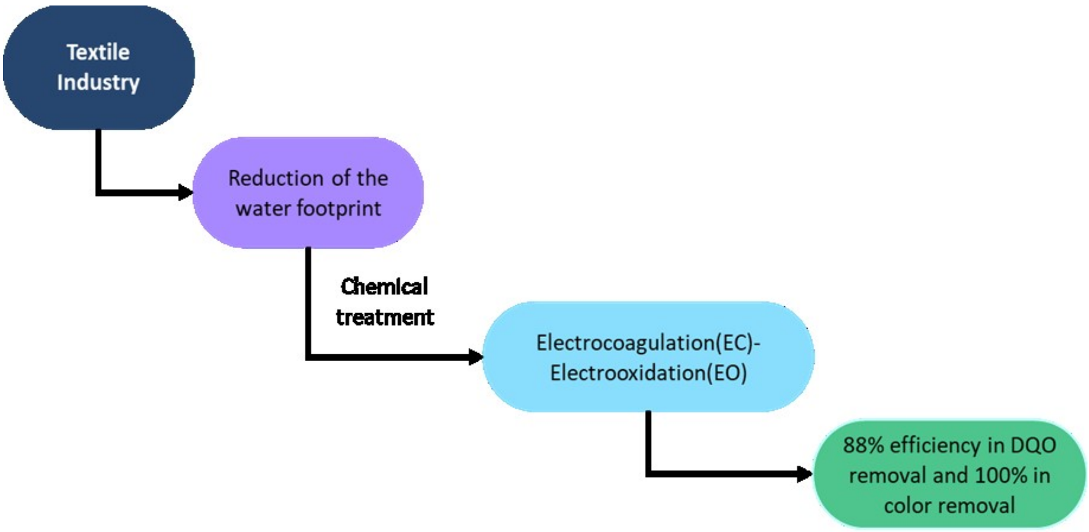

Figure 5. More efficient abatement methods

DISCUSSION

In this review, the most mentioned method for wastewater treatment in the studied research is electrocoagulation (EC), which turns out to be very efficient since the authors agree on its high results (93.9% and 94%) of colour removal from wastewater [35,36]. However, this method generates sludge, causing the implementation of a subsequent method, which would generate a higher cost to treat these waters [35]. However, one study mentions that the electrocoagulation method does not produce sludge, which contradicts the abovementioned study. Likewise, it adds that this approach includes high electricity costs [13], coinciding with Afanga et al., who mention that the energy consumption for electrocoagulation is 3kWh kg-1 of TOC (total organic carbon) [34].

On the one hand, electrocoagulation, when combined with other methods as in the case of electrooxidation, with the operating conditions of pH: 4 and j: 4.1 mA/cm2, 73% COD removal was obtained [35], while GilPavas et al. with the conditions pH= 3 and j: 10 mA/cm2, obtained a better result of 88% COD removal, and in turn 100% colour reduction [36]. Applying this fusion of methods, the energy consumption is lower than the consumption of using the electrocoagulation method alone, in addition to increasing the removal of organic matter [39].

On the other hand, by merging electrocoagulation with electro Fenton, the energy use is 0.45 kWh kg-1 TOC compared to electrocoagulation alone [34]. GilPavas et al. obtained 97% removal of TOC from wastewater [36], while Afanga et al. obtained 98%, i.e., this method in both types of research had approximate removal efficiencies [34].

It should be noted that new methods such as nanoparticles and sedimentation are expensive for their application since, in the case of sedimentation, it is needed (horizontal, multilayer, or radial flow); while in ultrafiltration, it is necessary to implement an inverse process to reduce its high cost and recover metals [23,24].

CONCLUSION

It was identified which was the most polluting process in the textile industry, which turned out to be the dyeing process with a representation of 33% of effluents. It is where different chemicals such as caustic soda, ammonia, heavy metals, and other toxic substances are used, to impregnate the colour in the fabric. Consequently, these processes cause an increase in the water footprint.

Therefore, the study mentions different methods to reduce the pollution produced by the textile industry. The most efficient methods to treat wastewater were chemical treatments such as EC-EO, which obtained 88% COD removal and 100% colour removal, while the EC-EF method received 97% TOC removal; likewise, physical treatments such as hydrodynamic cavitation achieved 63.05% COD reduction and the flocculation method, 65.75%. Based on this, the most efficient method for treating wastewater is electrocoagulation combined with electro-oxidation (EC-EO), achieving 100% colour removal and 88% COD removal (see Figure 5).

In addition, within the supply chain, using the redox method in the dyeing process would help reduce water consumption by 80% and reduce the generation of chemicals involved in this process by 50%, as well as promoting these methods with the use of natural indigo, which is renewable and non-toxic.

After conducting this research, one of the limitations to obtaining more information was the need for more accessible access to documents, as seen in the prism of the large number of discarded reports. On the other hand, for future works, it is recommended to go deeper into the supply chain because, from the procurement of raw materials to the final product, there is a high index of water footprint. To this end, research should be conducted on the efficiency of sustainable products in the textile industry and, in turn, on their acquisition costs.

Author Contributions

Conceptualization – Conde E, Gabriel P; methodology – Conde E, Gabriel P; formal analysis– Conde E, Gabriel P; investigation – Conde E, Gabriel P, León C; resources – Conde E, Gabriel P, León C; writing-original draft preparation – Conde E, Gabriel P; writing-review and editing – Conde E, Gabriel P; supervision – Conde E, Gabriel P, León C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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