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Systematic Review and Meta-analysis on the Use of Algae for the Removal of Organic Matter from Domestic Effluents

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Abstract*– Water treatment methods have been changing and improving over the years in order to meet the demands of the population and the care of the environment, using a viable and low-cost technology. The objective of this research was to evaluate the use of algae for the removal of organic matter (OM) from domestic effluents by means of a systematic review and meta-analysis. The research had a quantitative approach, applied type, non-experimental design (documentary review) and descriptive-explanatory level. The Scopus and Web of science databases were used for the information search, taking the period from January 2011 to September 2021. The results of the meta-analysis showed low statistical heterogeneity (l2 = 12%) and that the application of algae for MO removal from domestic effluents showed higher efficiency at high initial concentrations. It was also observed that algae achieve 100% removal of OM. Finally, it is concluded that the use of algae is efficient in removing OM and represents a viable alternative to improve water quality.

***Keywords*-- systematic review, meta-analysis, algae, organic matter removal, domestic effluents.**

I. INTRODUCTION

The negative alteration of water quality is mainly caused by domestic and industrial discharges that represent a worldwide problem because it influences human health, economic and social aspects of surrounding populations. According to Ref. [1], sustainable development with respect to the use of freshwater has been limited by the increase in its demand and at the same time the increase in the deterioration of water quality. Water pollution hinders the development of a population due to the scarcity of drinking water, affecting basic activities in households and industries and other services [2].

Currently, various methods have been developed for the treatment of contaminated water to meet the increased water demand caused by large urban growth and development. According to Ref [3], populations migrate to major cities with development and economic growth to improve their quality of life without considering the water demand generated by this population growth. Thus, algae represent a cost-effective alternative for wastewater treatment systems compared to conventional systems such as

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as activated sludge [4]. Algae are a renewable resource widely used in wastewater bioremediation [5], [6]. Some strains are better adapted to wastewater, with the genus Chlorella being one of the most widely used due to its high capacity to remove nutrients and organic load [2], [7].

The domestic effluent treatment system is costly, both in investment and operation, and more economical and reliable alternative methods should be available to meet the needs of developing countries. Ref [8], in domestic effluent treatment used Chlorella vulgaris (a freshwater algae) and Nannochloropsis salina (a marine algae) for nutrient and organic matter removal, the sample was collected from a municipal wastewater reclamation facility in China. Both species obtained high growth rates and cell densities in secondary wastewater effluent [9] and could achieve removal efficiency (> 99%) of N and P from municipal wastewater [10].

Wastewater treatment aims to significantly reduce the amount of carbonaceous (organic; determined predominantly as biological oxygen demand (BOD)) materials and when dealing with sensitive waters nitrogen (N) and phosphorus (P) compounds before discharging them into receiving systems [11]. Ref [12] analyzed the use of microalgae Chlorella vulgaris to carry out the purification process by testing three different types of wastewaters. The removal of organic matter reached 69% and an almost total elimination of phosphates. In addition, they performed different wastewater purification cycles of 25%, 50%, 75%, 90% and 90%, respectively. Algal growth was monitored by microalgae cell and optical density measurements at 680 nm. They reached a maximum growth of 15,805.56 ± 432 cells/ml at pH values within the range of 7.60 ± 0.04 to 9.7 ± 0.01 recorded throughout the growth cycle. The good adaptability of this microalgae and the good survival rate over time were demonstrated.

Consequently, taking into account the statements mentioned above, this research summarized and compiled studies on the application of various types of algae for the removal of organic matter from domestic effluents, providing a general and systematic understanding of this topic. The amount of scientific material on this subject is vast and this systematic review and meta-analysis allowed synthesizing the results of the various authors, which makes it possible to integrate them in order to make this information feasible for future research. The general objective of the present study was to evaluate, by means of a systematic review and meta-analysis, the efficiency of the application of algae according to two different initial concentrations of organic matter to determine the highest percentage of organic matter removal from domestic effluents. To achieve this purpose, the following was considered: (a) to identify the researches that applied algae for the removal of organic matter from domestic effluents, (b) to identify the physicochemical parameters and the concentration of organic matter, (c) to identify the operational conditions of the algae and (d) to perform a meta-analysis to evaluate the efficiency of organic matter removal using algae in two different initial concentrations of organic matter.

II. METHODOLOGY

A. Type of study

The research had a quantitative approach, applied type, non-experimental design (documentary review) and descriptive-explanatory level.

B. Sources of information and search strategy

The systematic review of the present study used the PRISMA method (Preferred Reporting Items for Systematic Reviews). The scientific articles were extracted from reliable sources of information, such as Scopus and Web of Science. Care was taken to ensure that the research obtained was no more than 10 years old as of the current date (February, 2022), although research that exceeded this time limit was taken into account if it met the specifications for the present investigation. The search in the electronic databases was carried out systematically according to the key words that make up the title of the present investigation; these words were generally searched in the English language [13]-[16]. Thus, the following terms were used: systematic review, meta-analysis, algae, organic matter removal, domestic effluents. In addition, references of reviews on the subject were checked to explore more relevant studies.

C. Inclusion and exclusion criteria

The research considered articles and reviews related to information concerning the title, starting by eliminating documents with the same title. Then, articles were selected according to the content of their abstract and irrelevant documents were excluded.

Subsequently, the selected articles were downloaded for detailed review. Finally, all the selected papers were evaluated according to the inclusion and exclusion criteria that correspond to:

1. all investigations showing pollutant removal from domestic effluents were included as long as the organic matter data had been collected individually.
2. All investigations that worked with different concentrations of organic matter were included.
3. All investigations that evaluated the use of algae for the removal of organic matter from domestic effluents were included.
4. All investigations that performed organic matter removal in other media (soil, plants, sludge, etc.) were excluded.
5. All investigations that applied an agent other than algae for organic matter removal were excluded.
6. All investigations with insufficient data and opinion articles were excluded.

D. Article selection and data extraction

After identifying potentially eligible papers, the information from each article studied was individually reviewed, extracted and summarized according to the inclusion and exclusion criteria. The data extracted from each included research (using validated data collection instruments) consisted of the following elements: (a) author(s) name and year, (b) origin of effluent sample, (c) type of microorganism, (d) pH, (e) contact time, (f) temperature and (g) dose, (h) initial Cr(VI) concentration, (i) final C(VI) concentration, and (k) percentage Cr(VI) removal.

E. Meta-analysis of data

For data analysis, Review Manager software version 5.4.1 was used; it is a free program developed by the Cochrane Collaboration to support the preparation of systematic reviews and meta-analyses. This tool facilitates the generation of figures, tables, among others for a good presentation of the required results. The Forest plot statistical graph was obtained from the software, which was worked with 95% confidence intervals and the Mantel-Haenszel statistical method with fixed effect was applied.

III. RESULTS

A. Inclusion and exclusion of studies

Figure 1 shows the process flowchart of the research considered for the meta-analysis.

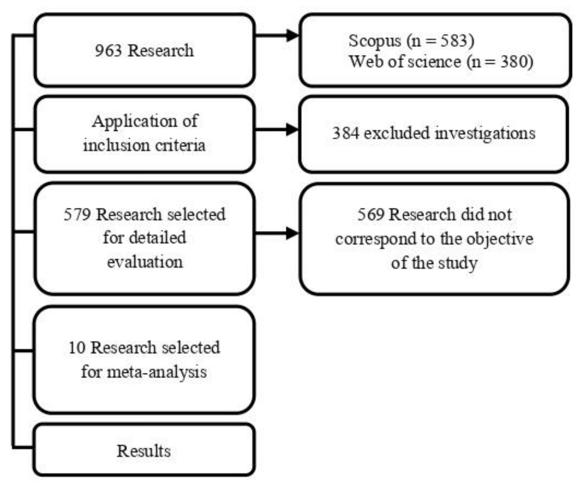

Fig. 1 Flowchart for the selection of included and excluded research

Figure 1 shows that initially 963 studies were obtained from the Scopus and Web of Science databases. Subsequently, applying the search strategy resulted in 579 studies, where 384 were excluded. The 579 studies were re-evaluated taking into account the review of the complete document, excluding 569 studies. The exclusion criteria were: insufficient data (n=554), application of algae in the removal of other parameters (not organic matter) in domestic effluents (n=10), removal of organic matter by the application of another type of agent (n=5). Finally, a total of 10 studies were obtained for meta-analysis.

B. Description of the included studies

Table 1 shows the types of algae in the included studies, being 10 the total of accepted researches with publication date between January 2011 and September 2021. Of the types of algae, the most used was the genus Chlorella. In addition, it was observed that Chlorella vulgaris was the most used algae by researchers, with 7 articles. On the other hand, the algae least used by researchers were Chlorella sp. with 2 articles and Cenedesmus quadricauda with 1 article. It was also observed that the Scopus database provided the most research on the use of algae, with 6 articles. Meanwhile, the Web of science database was the one that contributed the least research on the use of algae, with 4 articles.

TABLE I
TYPES OF ALGAE FOR THE REMOVAL OF ORGANIC MATTER

Nro.	Type of algae	Journal	Database	Results	Author(s)
1	*Chlorella sp.*	Water Science & Technology	Web of science	Domestic wastewater was treated using Chlorella sp. to remove organic matter, having an efficiency of 84%.	[17]
2	*Chlorella Vulgaris*	Bioresource Technology	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 94%.	[18]
3	*Chlorella Vulgaris*	Environmental Science and Pollution Research	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 90%.	[19]
4	*Chlorella Vulgaris*	Bioresource Technology	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 43%.	[20]
5	*Chlorella Vulgaris*	Science of the Total Environment	Web of science	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 88%.	[21]
6	*Chlorella Vulgaris*	International Journal of Environmenta l Research	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 53%.	[12]
7	*Chlorella sp.*	Water Environment Research	Web of science	Domestic wastewater was treated using Chlorella sp. to remove organic matter, having an efficiency of 21%.	[22]
8	*Chlorella Vulgaris*	Bioresource Technology	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 98%.	[5]
9	*Scenedesmus quadricauda*	Desalination	Web of science	Domestic wastewater was treated using Scenedesmus quadricauda to remove organic matter, having an efficiency of 100%.	[7]
10	*Chlorella Vulgaris*	Bioresource Technology	Scopus	Domestic wastewater was treated using Chlorella vulgaris to remove organic matter, having an efficiency of 77%.	[23]

C. Influence of operational conditions on organic matter removal

Operational conditions such as pH, illumination, temperature, contact time, algae concentration, and initial organic matter concentration (see Table 2 and Table 3) can affect the effectiveness of algae in the organic matter removal process.

Therefore, the effects of these parameters on the treatment should be considered to optimize the process and maximize organic matter removal rates from industrial effluents.

TABLE II
OPERATIONAL CONDITIONS FOR APPLYING ALGAE

Nro.	Type of algae	pH	Illumination (µmol/m²s)	Temperature (°C)	Dose (mg/l)	Contact time (min)	Author(s)
1	*Chlorella sp.*	7.8	-	25	300	192	[17]
2	*Chlorella Vulgaris*	8	1417	21	680	624	[18]
3	*Chlorella Vulgaris*	7.2	100	23	200	168	[19]
4	*Chlorella Vulgaris*	6.5	-	27	5	48	[20]
5	*Chlorella Vulgaris*	6.8	-	21	268	480	[21]
6	*Chlorella Vulgaris*	7.6	50	20	90	360	[12]
7	*Chlorella sp.*	6.9	-	22	250	240	[22]
8	*Chlorella Vulgaris*	6	440	25	1200	68	[5]
9	*Scenedesmus quadricauda*	7.5	150	25	200	64	[7]
10	*Chlorella Vulgaris*	7.5	200	25	196	264	[23]

TABLE III
REMOVAL OF ORGANIC MATTER

Nro.	Type of algae	Organic matter				Author(s)
		Concentration (mg/L)		Removal (%)		
		C1	C2	1	2	
1	*Chlorella sp.*	412	834	74	84	[17]
2	*Chlorella Vulgaris*	497	963	94	87	[18]
3	*Chlorella Vulgaris*	99	197	90	83	[19]
4	*Chlorella Vulgaris*	99	225	43	36	[20]
5	*Chlorella Vulgaris*	2278	4340	81	88	[21]
6	*Chlorella Vulgaris*	720	1360	29	53	[12]
7	*Chlorella sp.*	318	635	17	21	[22]
8	*Chlorella Vulgaris*	645	1328	98	81	[5]
9	*Scenedesmus quadricauda*	120	250	92	100	[7]
10	*Chlorella Vulgaris*	1864	3665	71	77	[23]

D. Meta-analysis

Figure 2 shows the ten (10) investigations included for the meta-analysis that were processed in RevMan 5.4.1. software, which were worked with a 95% confidence interval. The organic matter removal efficiency is represented by the polygon at the bottom of the graph, and its edges represent the limit of the confidence interval.

The odds ratio (Odds Ratio "OR") was used to evaluate the effect of the treatment on a population, using a scale with the following intervals:

Odds < 1: Treatment favors concentration C2.

Odds > 1: Treatment favors the C1 concentration.

Odds = 1: Treatment favors both concentrations.

According to the Odds Ratio, the treatment favors concentration C2, because it shows a value less than 1 (0.26), and according to this value it is affirmed that the percentages of organic matter removal obtained in the C2 concentrations are higher than those obtained in the C1 concentration, that is, with high initial concentrations of organic matter, a higher percentage of pollutant removal (organic matter) was obtained. The use of algae in the treatment of domestic effluents is efficient for removing organic matter, thanks to its capacity for growth in domestic effluents, which allows removal.

From Figure 2, it was observed that in the 10 investigations included there is low statistical heterogeneity (I2 = 12%, p<0.33) according to fixed effects. The heterogeneity of the meta-analysis indicates that the work methodologies and samples used in the studies are not very different. On the other hand, the average polygon of the meta-analysis is far from the reference line, and when comparing (p<0.00001, Z= 64.83) it was observed that there is a great difference between the removal percentages obtained. Likewise, according to the weight values, it was observed that the study by [21] presented a value of 31.2%, which indicates that it worked with higher organic matter concentrations than the rest of the other studies. The intervals obtained in this study were from 0.26 to 0.30 and a mean of 0.28.

	Concentration C1		Concentration C2			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Fixed, 95% CI
Arango et al., 2016	412	1246	834	1246	6.1%	0.24 [0.21, 0.29]
Ergin Taskan, 2016	99	296	197	296	1.4%	0.25 [0.18, 0.36]
García et al., 2019	497	1460	963	1460	7.0%	0.27 [0.23, 0.31]
He et al., 2013	99	324	225	324	1.7%	0.19 [0.14, 0.27]
López et al., 2019	2278	6618	4340	6618	31.2%	0.28 [0.26, 0.30]
Maeng et al., 2018	120	370	250	370	1.8%	0.23 [0.17, 0.31]
Salgueiro et al., 2018	720	2080	1360	2080	9.7%	0.28 [0.25, 0.32]
Terán et al., 2021	645	1973	1328	1973	9.8%	0.24 [0.21, 0.27]
Wang et al., 2015	1864	5529	3665	5529	26.6%	0.26 [0.24, 0.28]
Zielinski et al., 2018	318	953	635	953	4.6%	0.25 [0.21, 0.30]
Total (95% CI)		**20849**		**20849**	**100.0%**	**0.26 [0.25, 0.27]**
Total events	7052		13797			

Heterogeneity: Chi² = 10.24, df = 9 (P = 0.33); I² = 12%

Test for overall effect: Z = 64.83 (P < 0.00001)

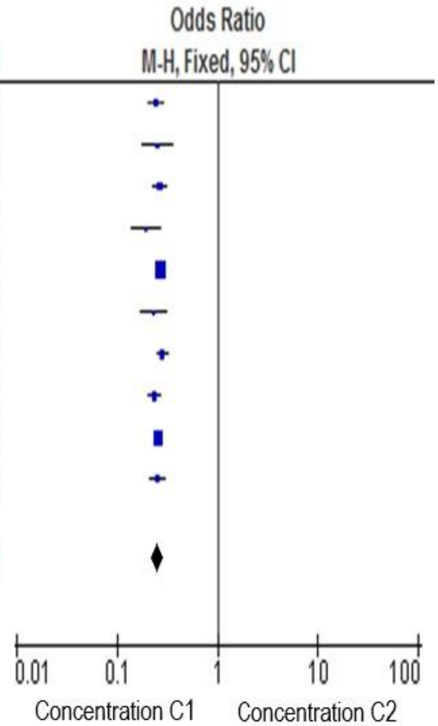

Fig. 2 Meta-analysis of the percentage of organic matter removal by applying seaweeds

IV. Discussion

1) From the development of this research, ten (10) investigations that met the inclusion criteria were analyzed. The highest percentage of organic matter removal (100%) was obtained by [7], with an algae dosage of 200 mg/l and contact time of 64 hours for an initial organic load of 250 mg/l. On the other hand, the lowest percentage of organic matter removal (17%) was obtained by Ref. [22], with an algae dosage of 250 mg/l and contact time of 240 hours for an initial organic load of 318 mg/l. Scenedesmus quadricauda was used for the study with the highest percentage of organic matter removal and Chlorella sp. was used for the study with the lowest percentage of organic matter removal. From the above, it can be indicated that a longer contact time or higher dose does not necessarily result in a higher percentage of organic matter removal; other factors should be considered, such as the operational conditions of the algae and/or the physicochemical characteristics of the sample.

2) Of the 10 investigations included for the meta-analysis, high percentages of organic matter removal were evidenced after the application of the algae. For the C1 concentration, the researchers that achieved the highest removal values were Ref. [5] and [18]. Ref. [5] obtained an organic matter removal of 98% after the application of Chlorella vulgaris with a dose of 1200 mg/l and contact time of 68 hours for an initial organic load of 645 mg/l, with pH value 6 and temperature of 25 °C. While, Ref. [18] obtained an organic matter removal of 94% after the application of Chlorella vulgaris with a dose of 680 mg/l and contact time of 624 hours for an initial organic load of 497 mg/l, with pH value 8 and temperature of 21°C. On the other hand, for the C2 concentration, the researchers who achieved the highest removal values were Ref. [7] and [21]. Ref. [7] obtained an organic matter removal of 100% after the application of Scenedesmus quadricauda with a dose of 200

mg/l and contact time of 64 hours for an initial organic load of 250 mg/l, with pH value 7.5 and temperature of 25°C. While, Ref. [21], obtained an organic matter removal of 88% after the application of Chlorella vulgaris with a dose of 268 mg/l and contact time of 480 hours for an initial organic load of 4340 mg/l, with pH value 6.9 and temperature of 21°C.

3) From the operational conditions of the algae, the pH parameter in the removal of organic matter in the treatment of domestic effluents shows that it can influence the removal of organic matter. For Ref. [18], [19], [5] and [7] worked with a pH value of 8, 7.2, 6 and 7.5 and obtained values of 94%, 90%, 81% and 100% organic matter removal, respectively. However, for Ref. [20] and [22] worked with a pH value of 6.5 and 6.9 and obtained values of 43% and 17% organic matter removal, respectively.

4) From the use of algae, the dose applied for the removal of organic matter in the treatment of domestic effluents shows that it is not necessarily a limiting factor in obtaining the highest percentage of organic matter removal. Ref. [18], [19], [5] and [7] applied doses of 680, 200, 1200 and 200 mg/l and obtained values of 94%, 90%, 81% and 100% organic matter removal, respectively. However, Ref. [20] and [22] applied doses of 5 and 250 mg/l and obtained values of 43% and 17% organic matter removal, respectively.

5) The contact time of algae for organic matter removal in domestic effluent treatment also shows that it is not necessarily a limiting factor in obtaining the highest percentage of organic matter. Ref. [18], [19], [5] and [7] used contact times of 624, 168, 68 and 64 hours and showed values of 94%, 90%, 81% and 100% organic matter removal, respectively. However, Ref. [20] and [22] used contact times of 48 and 240 hours and showed values of 43% and 17% organic matter removal, respectively.

6) From the results obtained, it can be established that the concentrations of organic matter should be less than 500 mg/l to obtain results below the 200 mg/l of organic matter allowed according to Supreme Decree No. 003-2010-MINAM - Maximum Permissible Limits (MPL) in the Peruvian standard. In this way, the renewable resource that is algae can be used efficiently. However, for organic matter concentrations higher than 500 mg/l, a cycle treatment should be implemented to obtain results below the 200 mg/l of organic matter allowed according to the MPL.

V. Conclusions

The systematic review showed that algae are efficient for the removal of organic matter (OM) in the treatment of domestic effluents. The best removal efficiency (100%) of OM was achieved with the application of the alga Scenedesmus quadricauda. Among the most relevant results are:

1. The algae used by the researchers in the selected studies for the removal of organic matter (OM) were Chlorella sp., Chlorella vulgaris and Scenedesmus quadricauda, with Chlorella vulgaris being the most used due to its adaptability to wastewater and its high organic load removal capacity, showing OM removal results greater than 72%.

It was determined that pH, illumination, temperature and contact time are the necessary parameters for algae growth. Also, the 10 selected investigations worked with average values of 7.21, 392.83 μmol/m2s, 23.4 °C and 250 hours for pH, illumination, temperature and contact time, respectively.

3. From the 10 selected investigations, it was identified that the average value of the initial organic matter (OM) concentration employed by the researchers was 705.20 and 1379.70 mg/l for low and high concentrations, respectively.

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