Comparative study for Treatment of Domestic Wastewater Using Chlorella Vulgaris

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Research

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Abstract

Tertiary treatment using chemicals frequently prompts secondary contamination of sludge, making other issues of safe disposal. Thus, vitality and cost required for tertiary treatment of wastewater stay an issue for industries and municipalities. In this study, different microalgal concentrations (20%, 25%, 30%, 35%, 40% and 45%) were studied to treat domestic wastewater at 11 hours HRT for both filtered and non-filtered effluent. During the study, removal was observed in Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electrical Conductivity (EC), phosphate, ammonia and COD for all the microalgal concentrations mentioned. However, the maximum removal efficiency was observed at 30% microalgal concentration. Maximum removal efficiency found in ammonia, phosphate and COD for non-filtered effluent was 96.60%, 91.73% and 84.71% respectively, whereas, in the case of the filtered sample, removal efficiency reached up to 97.62%, 92.47% and 88.75% for ammonia, phosphate and COD respectively. In the case of solids (specifically TSS) and EC, removal efficiency reached up to 30.87% and 24.31% respectively for non-filtered effluent and was 48.00% and 25.88% in the filtered sample. The study showed that an algae-based system could accomplish more affordable and environment-friendly way to treat domestic wastewater without tertiary treatment to a desirable limit.

1. Introduction

The world will confront 40% water deficiency by 2030, which is a challenge for sustainable development [1, 2]. This shortfall may emerge from the expanding interest for water, degradation of water assets and the absence of innovations to recover the used water. Water contamination is a joined after effect of various anthropogenic exercises [3]. The untreated wastewater contains fluctuating degrees of organic and inorganic mixes. The deterioration of water quality when the sewage is discharged into receiving bodies would likewise prompt water shortage, which is a significant issue far and wide. Sewage is the conversion of 70–80% of the total water supplied for domestic purpose, of different chemical compositions with varying quality and quantity, depending on the source.

In India, 61,754 MLD is the sewage generated against the sewage treatment capacity of 22,963 MLD, owing to the distinct gap between sewage generation and treatment capacity, about 38,791 MLD of untreated sewage (62% of total sewage) is directly discharged into nearby water channels [4]. The wastewaters originating from these point or nonpoint sources, if disposed of in a nearby water body without any treatment, adversely affect the water quality and aquatic ecosystem [5]. Thus, the current need is to minimize the consumption of water as well as to return it to the earth with minimum possible pollution because of the limited potential of self-purification in water bodies [6].

However, most existing sewage treatment processes in developing countries are confronting difficulties with nitrogen and phosphorus removal to meet the necessities for disposal and water reuse. Conventional nutrients removal methods, such as activated sludge-based treatment process, nitrification-denitrification, chemical phosphorus removal, and coagulating sedimentation are facing difficulties in meeting the stringent nutrient release guidelines effectively at low expenses [4, 7]. Besides, their downsides, for

example, high vitality utilization, flimsiness treatment impact, long procedure, carbon emanation, excess sludge discharge are additionally obvious obstructions to coordinate the idea of the practical advancement in wastewater treatment with low-carbon, low vitality utilization and asset reusing [8, 9].

The most eco-friendly and economical technique for wastewater treatment is with biological methods, where chemical break down and treatment of residues is done by microorganisms also with the production of added-value compounds [10, 11]. Many studies have proposed microalgae as an alternative biological treatment that efficiently removes nutrients from wastewater [12] even when nutrient concentrations are high [13–16]. Wastewater treatment using microalgae was first described in early 1950s. The term “phycoremediation” was coined by John in 2000 to address bioremediation carried out by algae. Municipal wastewater is enriched with a substantial amount of ammonia, phosphate and other essential nutrients which support algal biomass production [17, 18].

Literatures have been reported with nitrogen (> 90%) and phosphorus (> 50%) removal using microalgae [11]. *Chlorella vulgaris* can effectively remove nitrogen (up to 81–85%) and phosphorus (32–36%), respectively [19], *Galdieria sulphuraria* when used removed ammonia nitrogen (63–89%) and phosphorus (71–95%), respectively [20]. The green algae *Micractinium sp*. when used for nutrient removal, it gave efficiency to the system about > 90% in the case of both phosphorus and nitrogen respectively [13].In the present study, an attempt was made to analyze the effectiveness of the microalgal system if incorporated in wastewater treatment regarding the removal of the different physico-chemical parameters along with nutrients at much lesser Hydraulic Retention Time (HRT) in the Indian context.

2. Materials And Methods

Nutrient and organic removal batch study was performed using *Chlorella vulgaris* in 2L glass beakers with a working volume of 1800 mL at 11 hours HRT as shown in Fig. 1. Different glass beaker with varying microalgal concentrations 360 mL (20%), 450 mL (25%), 540 mL (30%), 630 mL (35%), 720 mL (40%) and 810 mL (45%) while the remaining volume was made up by the raw domestic wastewater collected from the nearby sewage pumping station at Surat. The study was conducted in an open atmosphere under natural light conditions. External aeration was provided for 10 hours to keep microalgae in suspension, followed by an hour of settling. After the settling period, the supernatant was drawn for physico chemical analysis. The time slot for an 11-hour study was 10:00 hours – 21.00 hours, which has both the effect of light and dark phase. The light intensity during this phase was about 6 hours. The study was conducted in a pair of different microalgal concentration, i.e., 20% and 25%, 30% and 35%, 40% and 45%. Various parameters analyzed during the study (for both the phase) were pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Solids (TS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), phosphate, ammonia, nitrate and Dissolved Oxygen (DO) as prescribed in APHA, 2012 manual. During the initial phase of the study, a faint green tint was observed in the effluent due to the presence of filamentous algae. But with the time, the microalgal settleability improved and the intensity of color decreased to nil. Hence the study was also conducted with the effluent, filtered with a coarse filter (4-5.5 µm) to get an idea about the color impartment. The study was

conducted to analyze the sustainability of the microalgae system to have the effect of both light and dark phases when used in an actual scenario.

3. Results And Discussion

During the experimental process, various physico chemical parameters were measured at 11 hours HRT for all the concentrations of *C. vulgaris* (20%, 25%, 30%,35%, 40% and 45%). The average concentration of raw domestic wastewater collected from a nearby sewage pumping station for various parameters studied is tabulated in Table 1.

After the treatment of the raw domestic wastewater with microalgae, it was found that even though with low HRT of 11 hours in the present study, efficient removal was observed in all the parameters analysed at different microalgal concentration when compared with various literatures where the HRTs varied in days to weeks [21–23]. Chlorella vulgaris was used because of its characteristics features like (1) high growth rate, (2) fast nutrient removal rate; (3) strong adaptability to different types of wastewater and local climate; and (4) high biomass productivity [1].After the treatment of the raw domestic wastewater with microalgae, it was found that coupling WWT with algae can be a reasonable, cost-effective viable opportunity for water treatment, with an opportunity for clean water production in areas of water scarcity [24]. Removal in different parameters was observed in each concentration studies. However, maximum removal was found in the effluent of the 30% microalgae.

Nitrogen is transformed into N_2 gas in conventional nitrogen removal methods, whereas in the algal treatment system, nitrogen compounds are taken up for their growth [25]. The uptake of nitrate is light energy-dependent, and also microalgae prefer to utilize already reduced nitrogen, such as ammonium in comparison to nitrate, which is less energy intensive conversion [26]. Ammonia was efficiently removed in the system as it is incorporated into protein via protein anabolism for microalgal growth [27, 28]. Variation in percentage removal efficiency for ammonia at different concentration considered in the study was 59.84 ± 24.29 for 20% concentration, 67.37 ± 22.44 for 25% concentration, 73.65 ± 24.79 for 30% concentration, 69.56 ± 27.92 for 35% concentration, 49.84 ± 19.50 for 40% concentration and 54.37 ± 20.08 for 45% concentration in case of non- filtered effluent respectively. However, when effluent was filtered with coarse filter to remove filamentous microalgae if any, percentage removal efficiency further increased to 65.63 ± 23.45 for 20% concentration, 71.13 ± 21.94 for 25% concentration, 77.66 ± 22.64 for 30% concentration, 75.27 ± 24.56 for 35% concentration,55.93 ± 18.42 for 40% concentration and 58.47 ± 19.09 for 45% concentration respectively shown in Fig. 2(a). Increase in nitrate concentration was observed during the study as ammonia was converted to nitrate in aerobic condition via nitrification [29]. Nitrate concentration raised to 3.47 mg/L, 3.82 mg/L, 5.87 mg/L, 5.82 mg/L, 3.85 mg/L and 3.82 mg/L, when wastewater treated with 20%, 25%, 30%, 35%, 40% and 45% microalgae respectively.

Microalgae have also shown the great potential to utilize phosphorus from wastewater, but mainly in the form of orthophosphate [30], and it is incorporated into organic compounds such as nucleic acids, phospholipids and proteins [31]. Variation in percentage removal efficiency for phosphate at different

concentration considered in the study was 60.46 ± 18.62 for 20% concentration, 63.95 ± 16.17 for 25% concentration, 71.47 ± 17.92 for 30% concentration, 69.29 ± 18.22 for 35% concentration, 54.61 ± 13.16 for 40% concentration and 56.14 ± 13.22 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae if any, percentage removal efficiency further increased to 66.27 ± 15.99 for 20% concentration, 69.94 ± 13.48 for 25% concentration, 74.56 ± 16.98 for 30% concentration, 71.33 ± 18.08 for 35% concentration, 57.84 ± 12.68 for 40% concentration and 60.05 ± 12.87 for 45% concentration. Removal efficiency phosphate at different microalgal concentrations is shown in Fig. 2(b).

COD removal is performed in the microalgae system in symbiotic relation with the heterotrophic bacteria [32], as the oxygen produced by algae as an end product is utilised by bacteria for their growth and survival [33]. Variation in removal efficiency for COD at different concentration considered in the study was 52.40 ± 17.32 for 20% concentration, 55.13 ± 18.88 for 25% concentration, 65.13 ± 20.21 for 30% concentration, 62.54 ± 22.15 for 35% concentration, 57.51 ± 14.94 for 40% concentration and 59.35 ± 13.77 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae if present, percentage removal efficiency further increased to 59.91 ± 16.34 for 20% concentration, 63.59 ± 15.14 for 25% concentration, 69.90 ± 20.54 for 30% concentration, 66.01 ± 21.60 for 35% concentration, 62.01 ± 12.87 for 40% concentration and 64.53 ± 12.94 for 45% concentration as shown in Fig. 3.

During the study, removal in TS and TSS was also observed to a certain extent due to the formation of algal bacterial biomass that settles down and leaves a clear supernatant. Variation in percentage removal efficiency for TS at different microalgal concentration considered in the study was 11.74 ± 7.2 for 20% concentration, 12.36 ± 6.6 for 25% concentration, 13.72 ± 4.13 for 30% concentration, 11.14 ± 4.85 for 35% concentration, 11.23 ± 4.77 for 40% concentration and 11.53 ± 5.00 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae, removal efficiency further increased to 18.17 ± 6.71 for 20% concentration, 17.64 ± 6.71 for 25% concentration, 22.27 ± 5.68 for 30% concentration, 19.98 ± 6.62 for 35% concentration, 18.44 ± 5.52 for 40% concentration and 18.69 ± 5.51 for 45% concentration as shown in Fig. 4(a). Variation in removal efficiency for TSS at different concentration considered in the study was 15.28 ± 11.65 for 20% concentration, 16.64 ± 10.18 for 25% concentration, 19.49 ± 6.85 for 30% concentration, 15.97 ± 7.83 for 35% concentration, 16.13 ± 7.74 for 40% concentration and 15.49 ± 8.28 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae, removal efficiency further increased to 25.69 ± 10.95 for 20% concentration, 24.60 ± 11.20 for 25% concentration, 32.73 ± 10.19 for 30% concentration, 29.75 ± 10.98 for 35% concentration, 26.47 ± 8.00 for 40% concentration and 25.51 ± 7.89 for 45% concentration as shown in Fig. 4(b). The problem of separating algae from water may be solved by using attached algae because these attached algae are often observed in the form of algal biofilm in sufficient sunlight [34].

When compared to TS and TSS removal in TDS was low. Variation in removal efficiency for TDS at different concentration during the study was 7.29 ± 3.99 for 20% concentration, 7.11 ± 4.53 for 25%

concentration, 5.83 ± 2.64 for 30% concentration,4.48 ± 2.11 for 35% concentration, 3.62 ± 1.59 for 40% concentration and 5.45 ± 2.39 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae increase in removal efficiency was observed up to 8.68 ± 4.08 for 20% concentration, 8.98 ± 4.16 for 25% concentration, 8.05 ± 2.56 for 30% concentration, 6.59 ± 2.96 for 35% concentration, 6.13 ± 2.14 for 40% concentration and 8.65 ± 2.62 for 45% concentration as shown in Fig. 5(a). Variation in removal efficiency for EC at different microalgal concentration was 6.95 ± 4.27 for 20% concentration, 6.4 ± 3.69 for 25% concentration, 7.27 ± 6.97 for 30% concentration, 5.68 ± 6.28 for 35% concentration, 3.88 ± 2.51 for 40% concentration and 5.49 ± 3.35 for 45% concentration in case of non- filtered effluent. However, when effluent was filtered with a coarse filter to remove filamentous microalgae, removal efficiency further increased 8.84 ± 4.05 for 20% concentration, 8.79 ± 3.51 for 25% concentration, 9.27 ± 6.92 for 30% concentration, 6.97 ± 6.41 for 35% concentration, 6.11 ± 2.53 for 40% concentration and 7.08 ± 3.09 for 45% concentration as shown in Fig. 5(b).

Microalgal system lead to increase in DO concentration, which raised up to 6.6 mg/L, 6.8 mg/L, 7.2 mg/L, 7.6 mg/L, 7.6 mg/L and 7.8 mg/L respectively when influent was treated with microalgal concentration of 20%, 25%, 30%, 35%, 40% and 45% respectively. The increase in DO was mainly because of the photosynthetic effect of algae in addition to external aeration provided for the mixing of algae in the influent. Algal growth increases alkalinity to a remarkable level regardless of the initial pH [35]. The rise of pH by photosynthesis was impeded due to the production of $H+$ ions by nitrification and by the use of ammonium as a nitrogen source for the photosynthesis process itself [36]. The elevated pH also enhances Ammonical-N removal. pH increased to 8.40 when treated with 20% microalgal concentration and 8.56 when treated with both 25% and 30% microalgae, whereas pH reached to 8.81, 8.53 and 8.57 when treated with 35%, 40% and 45% microalgal concentration respectively.

4. Conclusions

Algal treatment of wastewater, mediated through a combination of nutrient uptake, raised pH and high dissolved oxygen concentration, can offer an ecologically safe, cost-effective and efficient means to expel nutrients than conventional tertiary treatment. The study found that 30% concentration of *Chlorella vulgaris* is the optimum concentration among all the concentration studied to remove the nutrients, organic content and solids effectively with maximum removal efficiency greater than 90% without causing secondary sludge unlike other conventional and chemical treatments used for domestic wastewater treatment. Algae in wastewater can significantly contribute to the management of freshwater ecosystems by providing a more environmentally sound approach to deal with lessen eutrophication capacity of the point source.

Declarations

Availability of data and materials

Not applicable as all data generated or analyzed during this study are incorporated in the manuscript itself.

Competing interests

The authors declare they have no competing interests.

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Authors' contributions

NM has done in detailed literature survey to find research gaps which lead to way for this study. She also collected samples, conducted all the experiments, along with data interpretation and statistical analysis single handedly during the study.

NDJ provided administrative and technical support in addition to critical comments and revisions in manuscript as being the co-supervisor for the study.

RAC administrative and technical support was given by him along with the critical comments for the experimental setup initially as well as during the study. Study was conducted under his supervision. All authors read and approved the final manuscript.

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Tables

Table 1 Raw wastewater characteristics for the study with different microalgal concentration

Parameter	Set 1 (20% and 25%)	Set 2 (30% and 35%)	Set 3 (40% and 45%)
pH	7.24±0.23	7.16±0.21	7.32±0.29
EC (mS/cm)	2.18±0.13	2.23±0.22	2.18±0.23
TDS (mg/L)	1133.33±127.52	1120.83±97.37	1090.83±118.36
TSS (mg/L)	1429.50±265.43	1587.50±254.49	1682.42±242.95
TS (mg/L)	2587.83±306.08	2699.33±295.42	2719.25±282.74
COD (mg/L)	251.80±46.81	281.6±26.00	285.60±22.96
Phosphate (mg/L)	2.44±0.71	2.81±0.42	2.42±0.48
Ammonia (mg/L)	11.16±1.12	12.54±1.68	13.72±2.43
Nitrate (mg/L)	0.97±0.36	1.05±0.34	0.96±0.34
DO (mg/L)	0.13±0.16	0.14±0.16	0.11±0.14

Figures

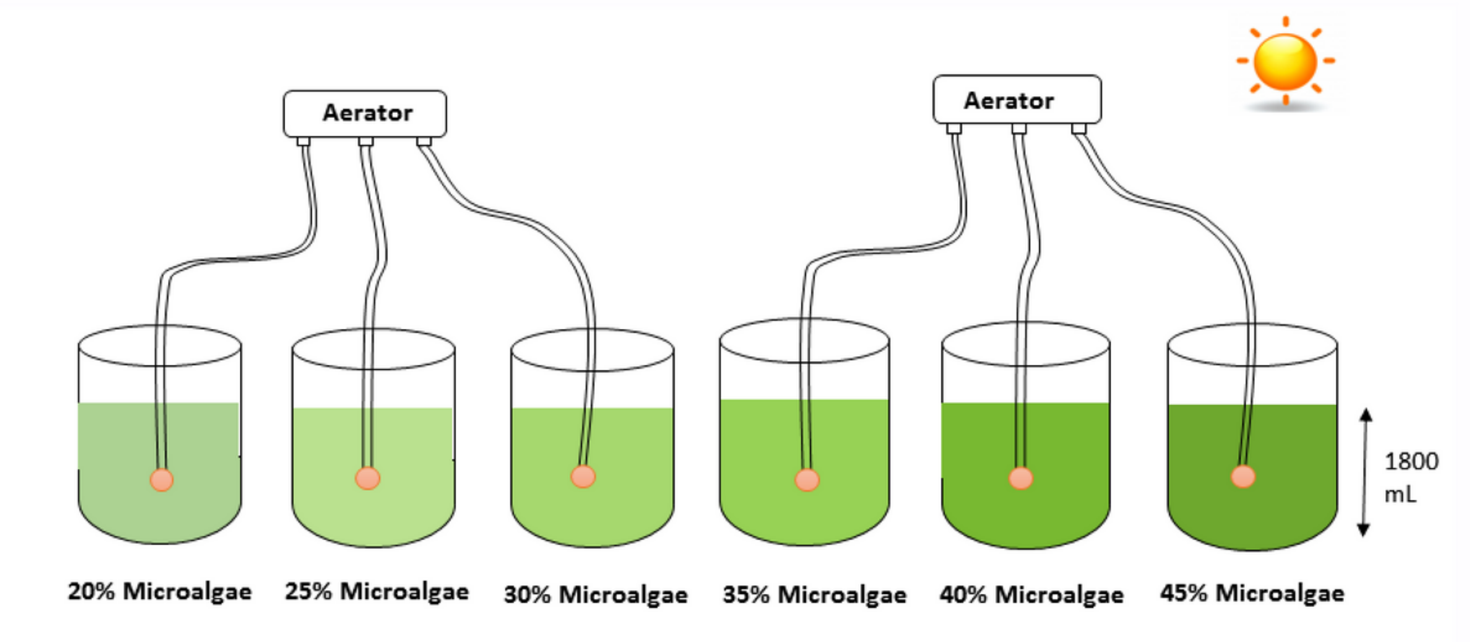

Figure 1

Pictorial view of experimental setup

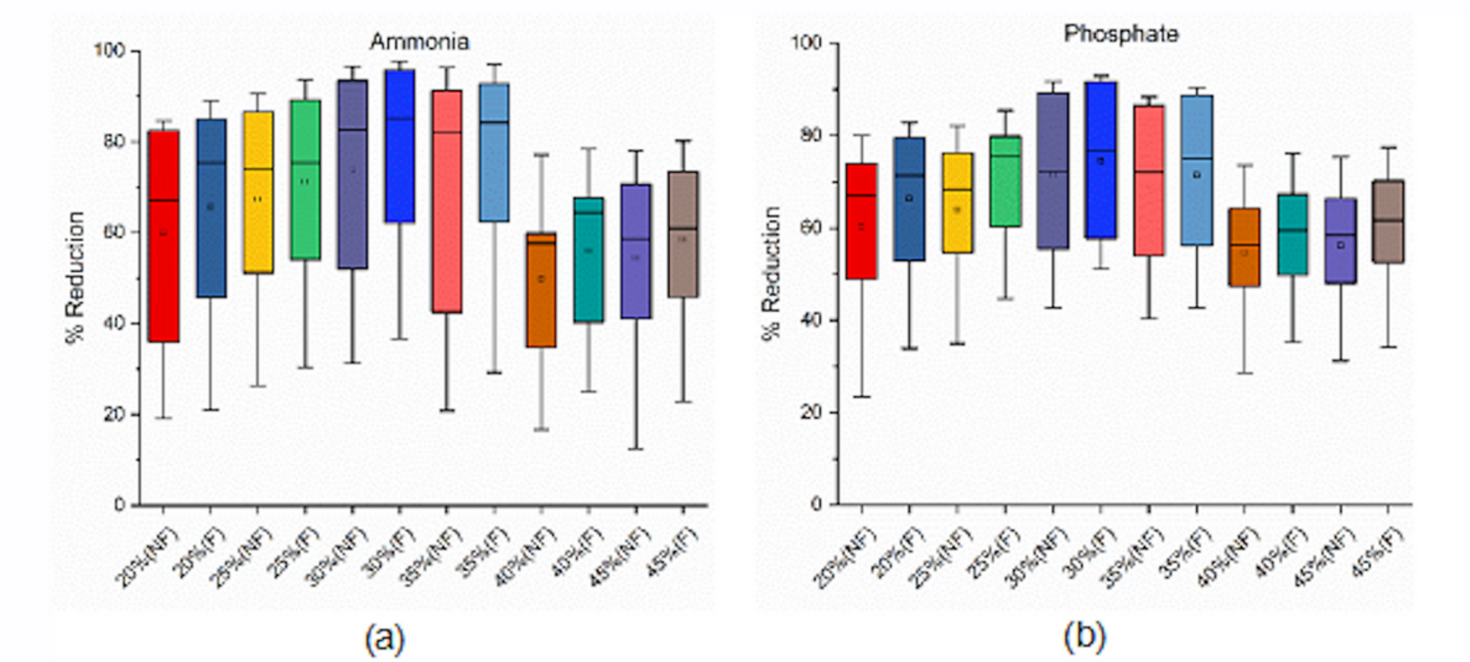

Figure 2

Variation in removal efficiency in (a) Ammonia and (b) Phosphate at different microalgal concentration

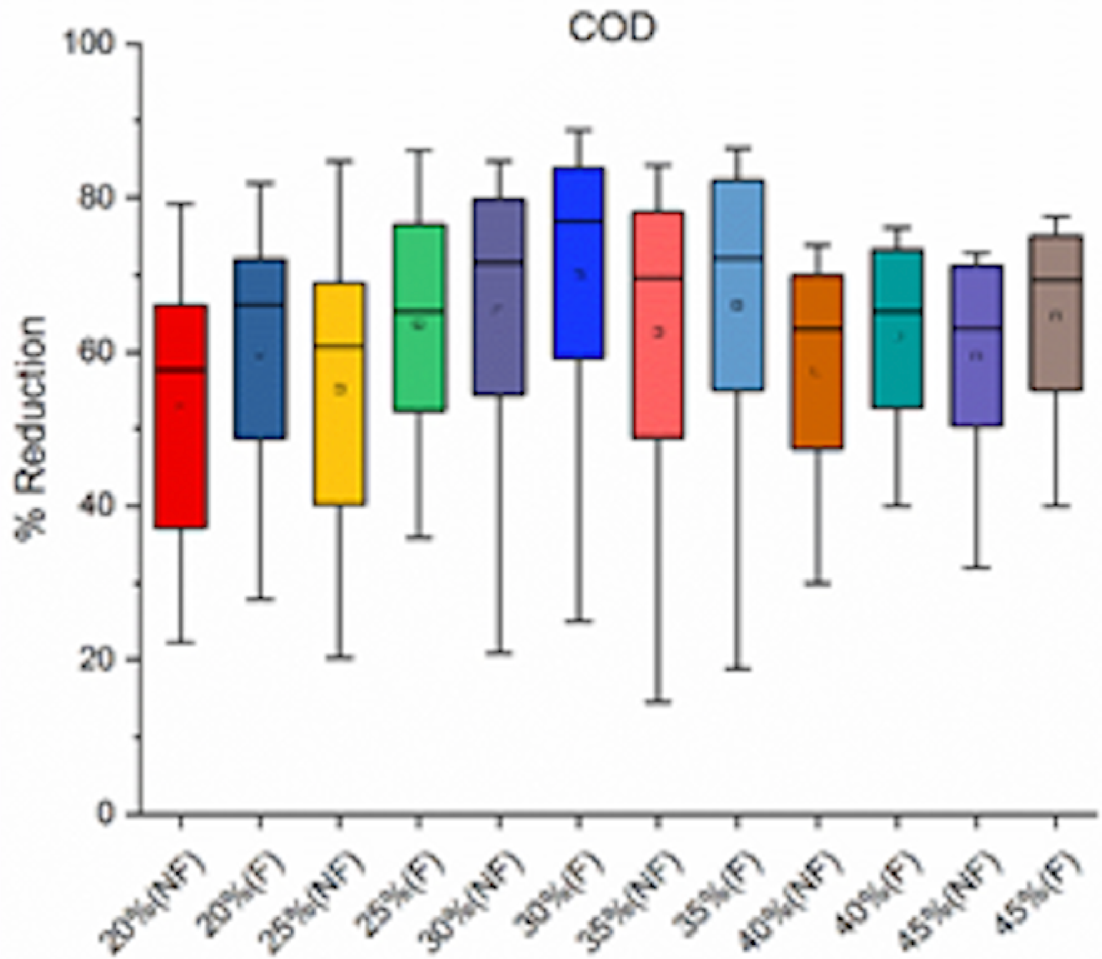

Figure 3

Variation in removal efficiency in COD at different microalgal concentration

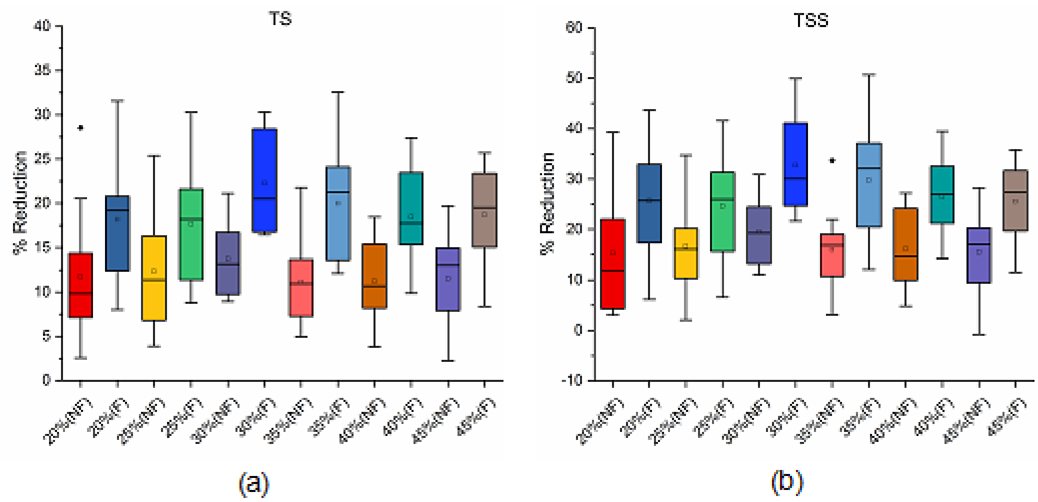

Figure 4

Variation in removal efficiency in (a) TS and (b) TSS at different microalgal concentration

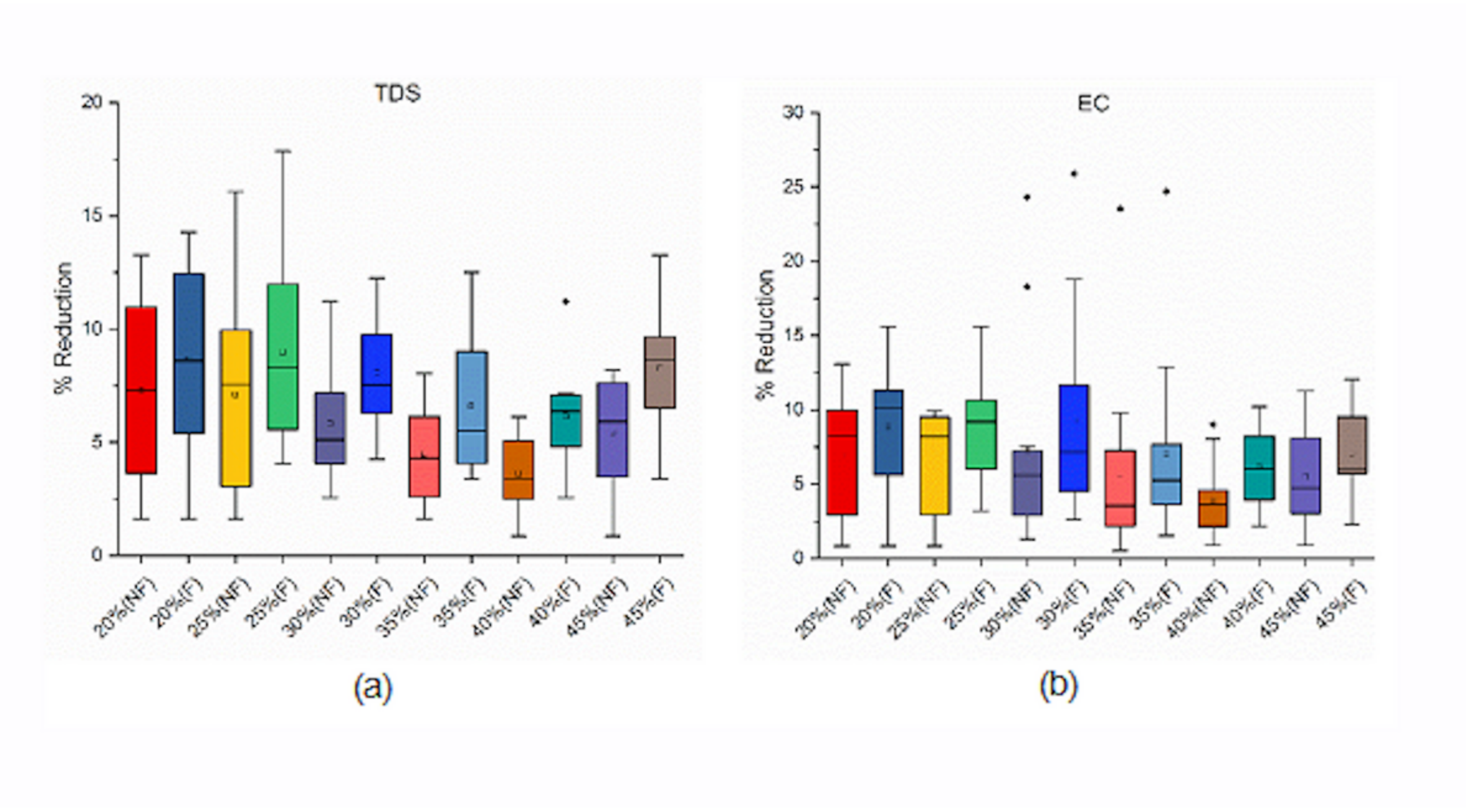

Figure 5

Variation in removal efficiency in(a) TDS and (b) EC at different microalgal concentration