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Effect of salinity on the performance of a sequencing batch reactor during the remediation of agricultural wastewater with duckweed as vegetation: Effect on the dominant microbial species

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Abstract

Effect of increased salinity levels (0 to 30 g/L of NaCl dose) on a symbiotic reactor was evaluated during the assimilation of pollutants in a synthetic agricultural wastewater. Removals of urea (99% to 11%), COD (88% to 9%), potassium (98% to 5%), and ammonia-N (81% to 29%) decreased with increase in salinity. Removal of phosphorous was only hampered after 25 g/L of salt. Decrease in the overall reactor performance was due to the reduction in the ability of the reactor biomass at hypersaline condition. Overall reactor biomass decreased (9.21 g/L to 7.49 g/L) with increase in influent NaCl. Biomass yield rate and biomass productivity decreased with increase in salinity. Formation of nitrate-N and nitrite-N were reduced as ammonia-N oxidation was hampered. Overall elemental C, H, N, and S increased with increase in the dead biomass settlement on the soil. SVI and MDD increased, suggesting the increase in the puffy nature of the reactor soil. Dominant reactor microbes were hampered by high salinity.

1. Introduction

Increase in the salt content of the soil occurs either naturally or anthropogenically by poor agricultural management, inadequate drainages, and use of saline irrigation water [1]. Excessive salt leaching to the agricultural wastewater is an obvious result of soil salinization. Increase in the salinity levels can have detrimental effects on the remediation processes employed for such wastewater. High salinity may clog pipes and reduce flow capacity, making it difficult for treatment plants to handle very salty water. Biological treatment systems are always prudent while treating complex wastewaters even at high saline conditions [2]. Biological treatment of nutrient rich agricultural wastewaters by various bioreactors starting from conventional [3] to hybrid [4, 5] have been reported in the absence of much of salinity. Few reported literatures of effect of salinity while treating agricultural wastewater include the evaluation of continuing effect of salt on the efficiency of an anoxic membrane bioreactor at varied NaCl doses (2.5 to 15 g/L) during the assimilation of nutrients from wastewater have been reported [6]. Similarly, salinity shock was evaluated for a membrane bioreactor during simultaneous nitrification and denitrification [7]. Study on the influence of aquaculture salinity on the adaptability of moving bed reactors [8], effect of saline condition on the microbes and stability of membrane bioreactors [9], and on petroleum refinery wastewater treatments by moving bed [2] and aerobic granular reactors [10] have been reported.

Recently nature-based wastewater treatment systems have gained popularity due to their ease of operation, and efficiency close to the modern hybrid systems for the treatment of agricultural wastewater [11]. Such systems work on the principle of symbiosis where the microorganisms get the oxygen through photosynthesis of the vegetation and assimilate the organic compounds subsequently releasing carbon dioxide. The carbon dioxide is ultimately taken by the vegetation for their growth. Current nature-based technologies used for the remediation of toxic wastewater from agriculture operations involves the use of algae-based system for pesticide rich wastewater [12], constructed wetlands for the mitigation of nutrients and pesticide [13], and floating vegetation for the removal of pesticide in mixture of nitrates [14]. Lab based bioreactors were operated in all the mentioned literatures. But reports on the stability analysis of such reactors specifically treating nutrient rich agricultural wastewater have been limited. For the long-term use and continued successful operation of bioreactors, lab scale stability analysis gives idea about the applicability of the reactor. Considering the presence of salt in agricultural wastewater, performance of a nature-based bioreactor in the presence of varied salinity levels is the gap that needs to be bridged.

In the current study an attempt has been made to analyse the gradual increase in salt concentration on the performance of a sequencing batch reactor previously working for the treatment of wastewater laden with nutrients and pesticide. The study included the performance analysis of various wastewater parameters along with the continuous monitoring of the removal of pollutants at gradual increase on salinity. In addition, behaviour of the biomass and soil were checked to have a complete picture of the reactor performance. Finally, the pure culture analysis was carried out to determine the effect of varied salt concentrations on the performance of the dominant microbial species isolated from the reactor biomass.

2. Study design

2.1 Raw materials for the study

Chemicals and reagents procured for the study were of the analytical grade (AR). Urea, N-P-K (20:20:20), and pesticide (Thiamethoxam, 25% WG) were purchased locally (Patnaik and Mallick, 2024). Preparation of stock solution, properties of the soil and vegetation used can be obtained elsewhere [15]. At the start of the current study, the reactor was already acclimatized [15] and was operational for 413 days initially treating synthetic and real wastewaters [15].

2.2 Reactor fabrication and operation

The reactor described elsewhere [15] was used for this study. The operational conditions of the reactors are summarized in Table 1. Steady state effluent data confirmed the end of each phase. For the calculation of the reactor parameters, average of last five cycles of steady state data was considered.

Table 1
Operational conditions of the reactor during NaCl variation

Day	NaCl (g/L)	Reactor volume (L)	Decant volume (L)	Fill Time (min)	Settle time (min)	Decant time (min)	React time (min)	Cycle time (min)	HRT (day)	SRT (day)
415–449	0	15	12	60	30	15	3351	3456	3	6.8–7.2
451–485	5									
487–521	10									
524–558	15									
560–594	20									
596–630	25									
632–666	30									
668–702	0 (Rec.)									

The performance of the reactor was evaluated by hydraulic retention time (HRT, day) (Eq. 1), Solids retention time (SRT, day) (Eq. 2), removal (%) (Eq. 3), and removal rate [g/(m^3.d)] (Eq. 4).

$$\mathrm{HRT}\ (\mathrm{day}) = \frac{\mathrm{Reactor\ volume}\ (\mathrm{L})}{(\mathrm{Volume\ decanted\ per\ cycle},\ \mathrm{L}) \times\ (\mathrm{No.\ of\ cycles\ per\ day})}$$

1

...

$$\mathrm{SRT}\ (\mathrm{d}) = \frac{\mathrm{Total\ biomass}\ (\mathrm{g})}{\mathrm{biomass\ wasted/day}\ \left(\frac{\mathrm{g}}{\mathrm{d}}\right)}$$

2

...

$$\mathrm{Removal}\ (\%) = \frac{(S_0 - S_e) \times 100}{S_0}$$

...

$$\mathrm{Removal\ rate} = \frac{S_0 - S_e}{\mathrm{HRT}}$$

4

...

where,

S_0 = Influent concentration (mg/L); S_e = Effluent concentration (mg/L).

2.3 Examining the influent, effluent, and soil

At the end of each phase, different soil properties (physical and chemical) and wastewater parameters (for both influent and effluent) listed elsewhere [11] were analysed.

2.4 Biomass properties and pure culture analysis

Biomass was measured per Patnaik and Mallick, 2025. For the pure culture analysis, isolation of the colonies was carried out by pour plate technique described elsewhere [11]. Activity of the biomass was measured as mentioned elsewhere [2].

3. Observations

Initially the reactor was operated without any external addition of salt. At the start of the further phases, salt concentrations were gradually increased by 5 g/L keeping all the other concentrations of pollutants constant (Table 2).

Table 2
Feed characteristics during NaCl variation

Day	NaCl (g/L)	Urea (mg/L)	N-P-K (mg/L)	Pesticide (mg/L)	Turbidity (NTU)	Conductivity (mS/cm)	Salinity (g/L)	TDS (g/L)	TSS (mg/L)
415–449	0	600	100	30	27 ± 3	4.76 ± 0.12	1.89 ± 0.11	1.09 ± 0.02	49.85 ± 0.19
451–485	5					11.78 ± 0.11	7.22 ± 0.14	6.08 ± 0.03	
487–521	10					19.45 ± 0.24	14.45 ± 0.19	11.09 ± 0.03	
524–558	15					28.87 ± 1.12	18.87 ± 1.12	16.10 ± 0.02	
560–594	20					39.45 ± 1.09	23.11 ± 1.67	21.09 ± 0.03	
596–630	25					50.77 ± 0.98	29.67 ± 2.12	26.09 ± 0.03	
632–666	30					64.44 ± 1.15	35.66 ± 2.34	31.08 ± 0.02	
668–702	0 (Rec.)					4.54 ± 0.09	2.02 ± 0.08	1.09 ± 0.02	

3.1 Pollutants degradation dynamics from the reactor

3.1.1 Functionality of the bioreactor

The effluent urea (Fig. 1a), COD (Fig. 1b), TDS (Fig. 1c), and PO_4^{3-}-P (Fig. 1d) were minimum in the absence of the external NaCl addition. With increased addition of salt in each phase, effluent urea, COD, and TDS increased at constant cycle time of 24 h. From Fig. 1, it can also be deduced that, there was an initial jump in the effluents after the start of each phase due to increase in the salinity. The microbial population gradually adapted to the change in environment [16] and steady state was achieved after 7 to 8 cycles of reactor operation (Fig. 1). There was no change in the effluent PO_4^{3-}-P even after the NaCl dose of 25 g/L. However, effluent PO_4^{3-}-P increased beyond that dose (30 g/L), suggesting arrest in the microbial growth [17] and limited vegetative activity beyond an initial NaCl dose of 25 g/L [18]. During the study, there was decrease in the removals (%) of urea (99% to 12%), COD (89% to 9%), TDS (97% to 7%), and PO_4^{3-}-P (100% to 78%) with gradual increase in salinity. Hydrolysis of urea is negatively affected at higher salt stress [19]. Which was observed in this study as rate of urea degradation decreased from 209 g/(m^3.day) to 24 g/(m^3.day) with increase in salinity, subsequently increased to 193 g/(m^3.day) during the recovery phase. Rate of COD assimilation [from 120 g/(m^3.day) to 22 g/(m^3.day)] decreased with increased salinity levels. The results corroborate the literature findings [20] during remediation of synthetic wastewater by constructed wetland at varied salinity. In the same study, COD removal rate of 47 g/(m^3.day) was obtained compared to 48 g/(m^3.day) at similar salinity (20 g/L) level. Sudden increase in the initial TDS was observed due to the addition of NaCl. Rate of TDS elimination increased from 356 g/(m^3.day) to 826 g/(m^3.day) up to 25 g/L of NaCl, then decreased to 740 g/(m^3.day) at 30 g/L NaCl. During the recovery phase, TDS removal rate was 349 g/(m^3.day) due to the lesser influent TDS. Removal rate of PO_4^{3-}-P was always more than 10 g/(m^3.day) and degreased slightly to 9 g/(m^3.day) beyond 30 g/L of NaCl. Higher phosphorous removal of 46 g/(m^3.day) was achieved using microalgae [21]. In the current study, lesser rate was due to the presence of multipollutants.

Effluent NH_4^+-N increased with increase in salinity (Fig. 2a). Subsequently decrease in the removal (%) (81% to 29%), and removal rate [6 g/(m^3.day) to 2 g/(m^3.day)] was observed. Decrease in the NH_4^+-N removal was observed in a sequencing batch reactor with increase in salinity levels (30 g/L to 70 g/L) [22]. The removal rate of NH_4^+-N was 154 g/(m^3.day) at 30 g/L NaCl dose in the reported literature, which was much higher than the current study at the same dose of NaCl and in the presence of pesticide. In the same study [22], higher removal rate of PO_4^{3-}-P [34 g/(m^3.day)] was reported at 30 g/L NaCl compared to the present work [9 g/(m^3.day)]. Decrease in both NO_2^--N, and NO_3^--N was observed with increasing NaCl during the present study due to lessened oxidation of NH_4^+-N. This suggests that NH_4^+-N was mainly converted through assimilation with decreased nitrification. In another study, the increase in salt concentration (5 to 37.7 g/L of NaCl) did not have any effect on the ammonia (initial 70 mg/L) oxidation [23]. Beyond 37.7 g/L of NaCl, decrease in the degradation of ammonia was observed along with nitrite accumulation. However, decrease in the NH_4^+-N oxidation was observed at the onset of NaCl and nitrite accumulation was never observed (Fig. 2b) in the current work.

Effluent pH increased in the absence of NaCl and due to conversion of urea to NH_4^+-N [11]. With increase in NaCl doe, oxidation of urea decreased and subsequent decrease in the formation of NH_4^+-N led to lesser change in pH (Fig. 2c). Similarly, effluent K^+ increased with increase in NaCl (Fig. 2d). High

salt concentration leads to the removal of potassium from plant roots, necessary for protein synthesis [18], can be the reason for lower K^+ uptake and accumulation.

3.2 Effect of salinity on the reactor biomass

Decrease in the biomass (both suspended and soil) was observed as salinity increased (Table 3), that resulted in the decrease in total biomass, biomass yield, and productivity. Specific removal rates of urea, COD, PO_4^{3-}-P, K^+, and NH_4^+-N decreased due to their lesser respective degradation at constant influent concentrations at higher salinity levels. Specific removal rate of COD (Table 3) was higher compared to another duckweed system [24] involved in the wastewater treatment at higher salinity levels. Negative effects of increased salinity on the growth of activated sludge [25], aerobic granules [11, 26] and attached biomass [2] during industrial wastewater treatment by sequencing batch reactors have been discussed is recent literatures. Current study reports the effect of salinity on the different types of symbiotic reactor biomass for the first time. To understand the exact reason for the decreased performance of the reactor at gradual increase of salinity, biomass activity tests were conducted, and the activity cycles have been illustrated in Fig. 3. The results of the biomass activity indicate fall in the enzymatic activity of the overall reactor biomass due to high salt content (Fig. 4). Activity of the biomass regained its original stature after normalcy was resumed i.e. no external supply of NaCl, suggesting the recovery potential of the symbiotic reactor treating multipollutants.

Table 3
Biomass properties and specific removal rates during NaCl variation

Biomass properties							
NaCl (g/L)	Suspended biomass (gVS/L)	Soil biomass (gVS/L)	Total biomass (gVS/L)	Biomass Yield rate [gVS/(L.day)]	Biomass productivity [gVS/(m^2.day)]		
0	8.97 ± 0.02	0.24 ± 0.03	9.21 ± 0.03	3.84 ± 0.03	152.37 ± 0.22		
5	8.61 ± 0.05	0.23 ± 0.02	8.84 ± 0.02	3.68 ± 0.02	146.02 ± 0.18		
10	8.19 ± 0.01	0.22 ± 0.02	8.41 ± 0.01	3.50 ± 0.02	138.88 ± 0.33		
15	7.99 ± 0.03	0.20 ± 0.02	8.19 ± 0.02	3.33 ± 0.02	132.13 ± 0.42		
20	7.76 ± 0.02	0.19 ± 0.03	7.95 ± 0.01	3.23 ± 0.01	128.17 ± 0.34		
25	7.45 ± 0.01	0.17 ± 0.01	7.62 ± 0.02	3.10 ± 0.02	123.01 ± 0.26		
30	7.23 ± 0.03	0.16 ± 0.01	7.49 ± 0.01	3.01 ± 0.02	119.43 ± 0.20		
Rec.	8.65 ± 0.09	0.28 ± 0.07	8.93 ± 0.02	3.60 ± 0.01	142.85 ± 0.27		
Specific removal/formation rate [mg/(gVS.d)]							
NaCl (g/L)	Urea	COD	PO_4^{3-}-P	K^+	NH_4^+-N	NO_2^--N	NO_3^--N
0	67.95 ± 0.76	39.04 ± 0.17	3.26 ± 0.04	6.34 ± 0.07	1.99 ± 0.02	24.81 ± 0.08	43.22 ± 0.08
5	64.29 ± 0.88	38.37 ± 0.07	3.91 ± 0.03	5.99 ± 0.04	1.92 ± 0.03	15.44 ± 0.11	31.67 ± 0.09
10	58.26 ± 0.47	30.77 ± 0.12	3.92 ± 0.05	5.49 ± 0.03	1.83 ± 0.01	11.32 ± 0.06	21.24 ± 0.04
15	50.62 ± 0.19	22.81 ± 0.09	4.18 ± 0.03	4.22 ± 0.05	1.76 ± 0.02	7.23 ± 0.08	15.46 ± 0.07
20	37.99 ± 0.17	18.42 ± 0.11	4.30 ± 0.04	2.42 ± 0.05	1.26 ± 0.02	2.11 ± 0.02	6.43 ± 0.06
25	19.06 ± 0.09	13.39 ± 0.08	4.51 ± 0.03	0.71 ± 0.01	1.05 ± 0.03	0.24 ± 0.04	1.23 ± 0.06
30	9.48 ± 0.04	8.81 ± 0.06	3.60 ± 0.04	0.45 ± 0.01	0.91 ± 0.02	0.02 ± 0.01	0.26 ± 0.02
Rec.	64.79 ± 0.15	37.72 ± 0.09	3.72 ± 0.05	6.47 ± 0.02	2.33 ± 0.02	25.21 ± 0.07	45.27 ± 0.03
*Indicates formation of the pollutant							

3.3 Effect of salinity on reactor soil

A gradual decrease in the specific gravity of the soil was observed (Table 4) during the study (Table 4) due to possible compaction [27] and settling of dead biomass [11]. Soil volume index (SVI) started to increase with increase in salt due to the swelling of the excess dead biomass inside the soil, suggesting the adsorption of cations on soil particles, which can lead to dispersion and swelling of the soil structure [28]. Although increase in the

maximum dry density (MDD) of the soil was observed, there was decrease in the fineness modulus (Table 4). The behaviour of MDD corroborates the literature findings [29]. However, the decrease in the fineness modulus may have been due to the excess accumulation of dead biomass on the soil. Minor decrease in the plastic and liquid limits was observed with increase in salinity (Table 4), suggesting more solid nature of the soil [30]. Elemental analysis showed increase in C, H, N, S contents of the soil. The biomass growth was hampered with increase in salinity. The increase in the elemental composition must have been due to the dead biomass. Optimum moisture content (OMC) increased with increase in NaCl dose due to increased water retention [31]. Significant increase in the soil conductivity and Na^+ content was observed due to increase in NaCl dose. Apart from minor increase in the K^+ ions, other heavy metals remained same, and no significant change was observed. During the entire period, heavy metals in the soil were within the prescribed limit if disposals was attempted [15].

Table 4
Soil properties during NaCl variation

Physical properties											
NaCl (g/L)	Specific gravity	Soil Volume Index (mL/g of sample)	Fineness modulus	Maximum dry density (g/cm^3)	Plastic Limit (%)	Liquid Limit (%)	OMC (%)	C, H, N, S analysis (%)			
								C	H	N	S
0	2.45 ± 0.01	31 ± 1	1.70	1.14 ± 0.01	25 ± 1	20 ± 1	18 ± 1	15 ± 1	7 ± 1	10 ± 1	3 ± 1
5	2.42 ± 0.02	32 ± 1	1.68	1.17 ± 0.01	26 ± 1	19 ± 1	20 ± 1	15 ± 1	8 ± 1	10 ± 1	3 ± 1
10	2.37 ± 0.02	34 ± 1	1.64	1.20 ± 0.01	26 ± 1	17 ± 1	22 ± 1	16 ± 1	8 ± 1	11 ± 1	3 ± 1
15	2.26 ± 0.02	35 ± 1	1.63	1.27 ± 0.01	27 ± 1	17 ± 1	24 ± 1	17 ± 1	9 ± 1	11 ± 1	3 ± 1
20	2.19 ± 0.02	37 ± 1	1.61	1.35 ± 0.01	28 ± 1	16 ± 1	27 ± 1	17 ± 1	9 ± 1	12 ± 1	3 ± 1
25	2.04 ± 0.02	38 ± 1	1.57	1.42 ± 0.01	29 ± 1	16 ± 1	28 ± 1	18 ± 1	9 ± 1	12 ± 1	3 ± 1
30	1.86 ± 0.02	39 ± 1	1.55	1.57 ± 0.01	29 ± 1	15 ± 1	29 ± 1	18 ± 1	9 ± 1	13 ± 1	3 ± 1
Rec.	2.43 ± 0.02	30 ± 1	1.74	1.12 ± 0.01	26 ± 1	19 ± 1	19 ± 1	15 ± 1	7 ± 1	10 ± 1	3 ± 1

Chemical properties																
NaCl (g/L)	pH	Conductivity (µS/cm)	Metallics (mg/kg of the sample)													
			Na^+	K^+	Ca^+	Cr^{3+}	Fe^{2+}	Mg^{2+}	Cu^{2+}	Zn^{2+}	Co^{2+}	Ni^{2+}	Mn^{2+}	As^{3+}	Pb^{2+}	Cd^{2+}
0	7.94 ± 0.02	3.4 ± 0.1	31 ± 3	27 ± 3	43 ± 2	2 ± 1	33 ± 3	7 ± 1	11 ± 1	11 ± 2	4 ± 1	2 ± 1	8 ± 1	ND	2 ± 1	3 ± 1
5	7.92 ± 0.02	3.8 ± 0.1	38 ± 3	28 ± 2	44 ± 2	3 ± 1	31 ± 3	7 ± 1	12 ± 2	10 ± 1	5 ± 1	3 ± 1	8 ± 1	ND	2 ± 1	3 ± 1
10	7.92 ± 0.02	4.3 ± 0.1	44 ± 2	28 ± 2	44 ± 2	3 ± 1	32 ± 2	7 ± 1	12 ± 1	11 ± 1	4 ± 1	3 ± 1	9 ± 1	ND	2 ± 1	3 ± 1
15	7.91 ± 0.02	4.9 ± 0.1	47 ± 2	29 ± 3	44 ± 3	3 ± 1	34 ± 3	8 ± 1	11 ± 2	12 ± 2	4 ± 1	3 ± 1	9 ± 1	ND	2 ± 1	3 ± 1
20	7.92 ± 0.02	5.4 ± 0.1	51 ± 3	29 ± 3	42 ± 3	3 ± 1	33 ± 3	8 ± 1	10 ± 1	12 ± 1	4 ± 1	3 ± 1	8 ± 1	ND	2 ± 1	3 ± 1
25	7.92 ± 0.02	5.9 ± 0.1	54 ± 3	29 ± 2	42 ± 2	2 ± 1	32 ± 2	7 ± 1	10 ± 1	12 ± 2	4 ± 1	3 ± 1	9 ± 1	ND	2 ± 1	3 ± 1
30	7.94 ± 0.02	6.4 ± 0.1	58 ± 3	30 ± 3	44 ± 2	2 ± 1	34 ± 3	8 ± 1	10 ± 2	12 ± 1	4 ± 1	2 ± 1	8 ± 1	ND	2 ± 1	3 ± 1
Rec.	7.93 ± 0.02	3.6 ± 0.1	34 ± 3	27 ± 2	44 ± 3	2 ± 1	32 ± 2	8 ± 1	10 ± 2	11 ± 2	4 ± 1	2 ± 1	8 ± 1	ND	2 ± 1	3 ± 1

3.4 Effect of salinity on the dominant cultures

Effect of gradual increase in salinity was examined for the dominant cultures *Exiguobacterium aurantiacum* strain 1910ICU112 and *Staphylococcus haemolyticus* strain JCM 2416 isolated from the reactor [11] by pure culture analysis. Increase in the salinity levels decreased the performance of both the cultures (Fig. 5) analysed through the removals of urea, COD, TDS, PO_4^{3-}-P, and NH_4^+-N. However, at the same influent concentrations, the removal capacity of *Exiguobacterium aurantiacum* strain 1910ICU112 (Fig. 5a) was better compared to *Staphylococcus haemolyticus* strain JCM 2416 (Fig. 5b). *Exiguobacterium aurantiacum* has been reported to tolerate up to 50 g/L of NaCl and heavy metals (Su et al., 2021). Similarly, the effective salt resistance of *Staphylococcus haemolyticus* has been studied as a salt tolerant plant growth promoting bacteria [32]. However, in the present study the effectiveness of the cultures decreased in the presence of multi pollutants and pesticide. A comparative analysis of recent published literatures with the present study is summarized in Table 5 considering simultaneous organics and nutrient removals in the presence of different salinity levels. Decrease in the performance of the reactors have been reported in most of the studies in the absence of pesticide. The current study bridges that gap.

Table 5
Summary of studies related to effect of salinity on the performance of bioreactors

Sl. No	Type of reactor and wastewater	Pollutants	Salt/Salinity dose	Inference	Reference
1	Anoxic-Aerobic moving bed reactor system treating petroleum refinery wastewater	Phenol: 750 mg/L TH: 1250 mg/L NH_4^+-N: 350 mg/L NO_3^--N: 1000 mg/L S^{2-}: 750 mg/L	0 to 45 g/L of NaCl, then switch back to recovery mode	Decrease in the hydrocarbon removal and increased sloughing beyond 30 g/L of NaCl	Mallick and Chakraborty, 2020
2	Granular aerobic reactor treating petroleum refinery wastewater	TH: 350 mg/L Phenol: 50 mg/L NH_4^+-N: 51 mg/L PO_4^{3-}-P: 100 mg/L SO_4^{2-}: 250 mg/L	0 to 35 g/L of NaCl	Granule disruption beyond 20 g/L of NaCl dose	Ghosh and Chakraborty, 2021
3	Sequencing batch reactor treating synthetic nutrient rich wastewater	Nitrate: 80 mg/L COD: 200 mg/L	0 to 10 g/L of NaCl	Accumulation of Nitrite and generation of polyhydroxyalkanoates (PHAs) with increase in salinity	Zhang et al., 2025
4	Packed bed photobioreactor treating municipal wastewater	Nitrate: 41 mg/L Phosphorous: 4 mg/L Sulfate: 10 mg/L Calcium: 30 mg/L Magnesium: 125 mg/L	0 to 40 g/L of salinity	No significant effect was observed for the nutrient removal in the presence of microalgae (*D salina*)	Liu and Yildiz, 2018
5	Modified University of Cape Town system of 70L working volume	COD: 275 mg/L NH_4^+-N: 32 mg/L PO_4^{3-}-P: 7 mg/L	0 to 16 g/L of salt	Decrease in the removals of nutrients and COD was observed with increase in salinity levels	Zhang et al., 2021
6	Symbiotic reactor with duckweed as vegetation treating agricultural wastewater	Urea: 600 mg/L N-P-K: 100 mg/L Thiamethoxam: 30 mg/L	0 to 30 g/L of NaCl	Decrease in pollutants removal with increase in salinity	Present study

4. Conclusion

Decrease in the performance of the symbiotic reactor with increase in salinity levels was observed in relation to pollutants removal capacity. However, phosphorous removal was not hampered. Suspended and soil biomass decreased due to excess salinity. Pure culture analysis revealed the detrimental effect of increased salinity in the presence of pesticide on the salt tolerant microorganisms. The bottom soil of the reactor was stable during the study

and can be recommended for safe disposal after the usage of the reactor is completed. The reactor was able to recover to its original state after the withdrawal of the imposed salinity.

Declarations

Statement for conflict of interest

The authors are related academically, are fully aware of the submission of this article, and have no conflict of interest about the work.

Credit author statement

Author 1:

Name: Lipsa Patnaik

Contribution: Reactor operation, Laboratory work, Data analysis

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Contribution: Conceptualization, Writing, Supervision, Submission

Declaration of generative AI in scientific writing

No AI tool was used for the analysis of data or generation of any figure.

Ethical declaration

No animal or human subjects were used during any analysis at any period of time for the development of the current manuscript.

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Figures

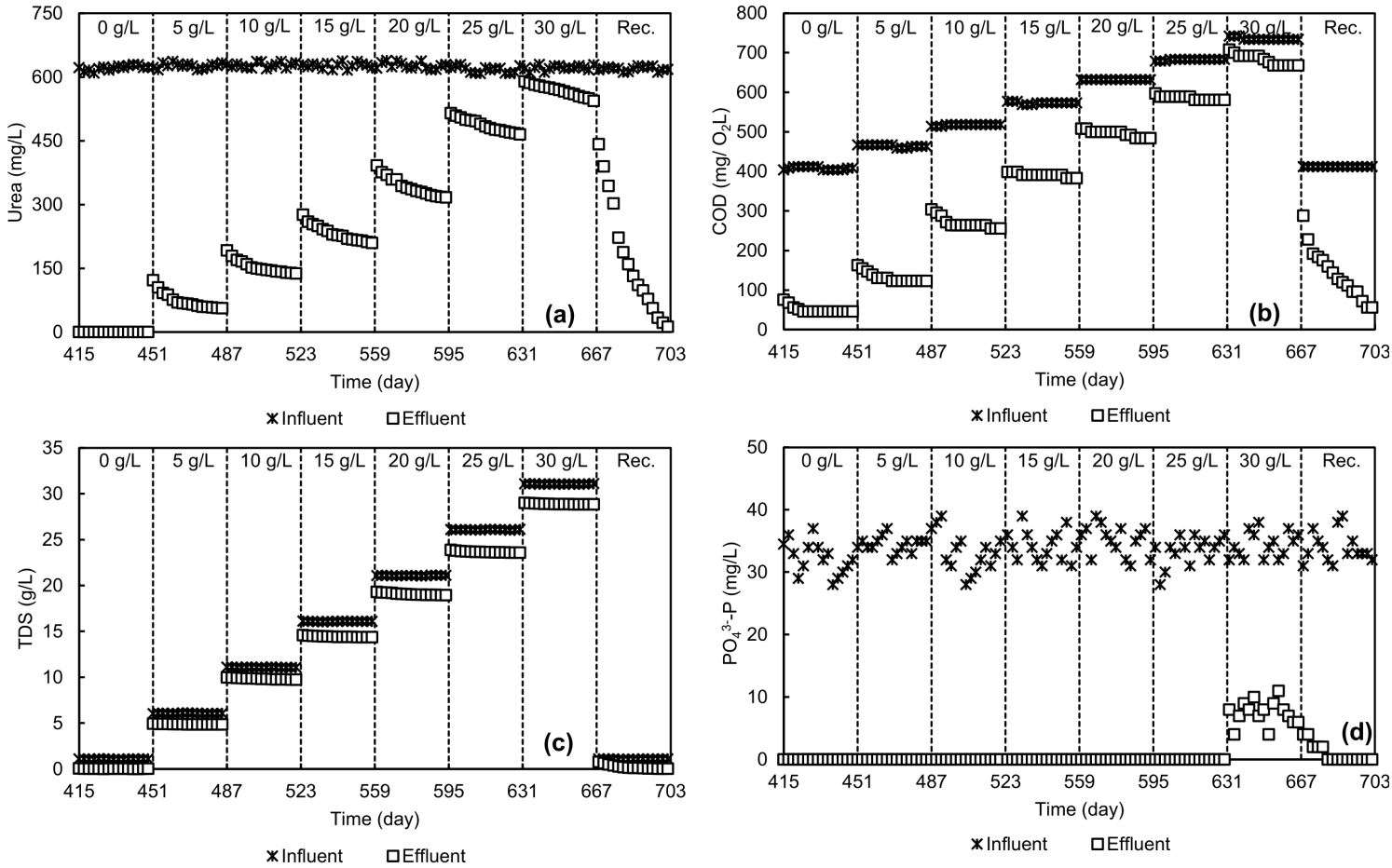


Fig. 1: Influent and effluent (a) Urea, (b) COD, (c) TDS, and (d) Phosphorous during the effect of salinity

Figure 1

See image above for figure legend

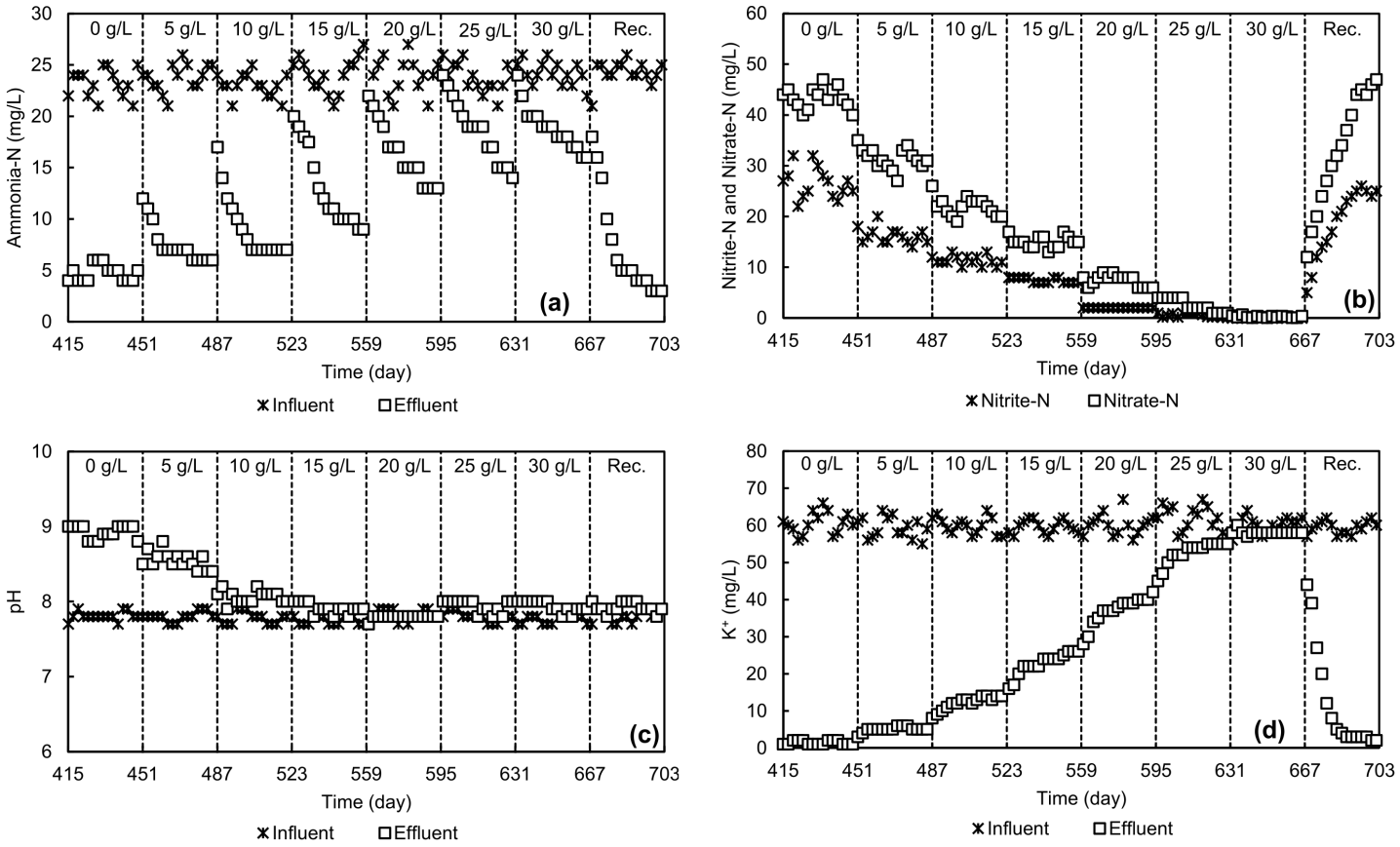


Fig. 2: (a) Influent and effluent ammonia-N, (b) Effluent nitrate-N and nitrite-N, and (c) Influent and effluent pH during salinity variation study

Figure 2

See image above for figure legend

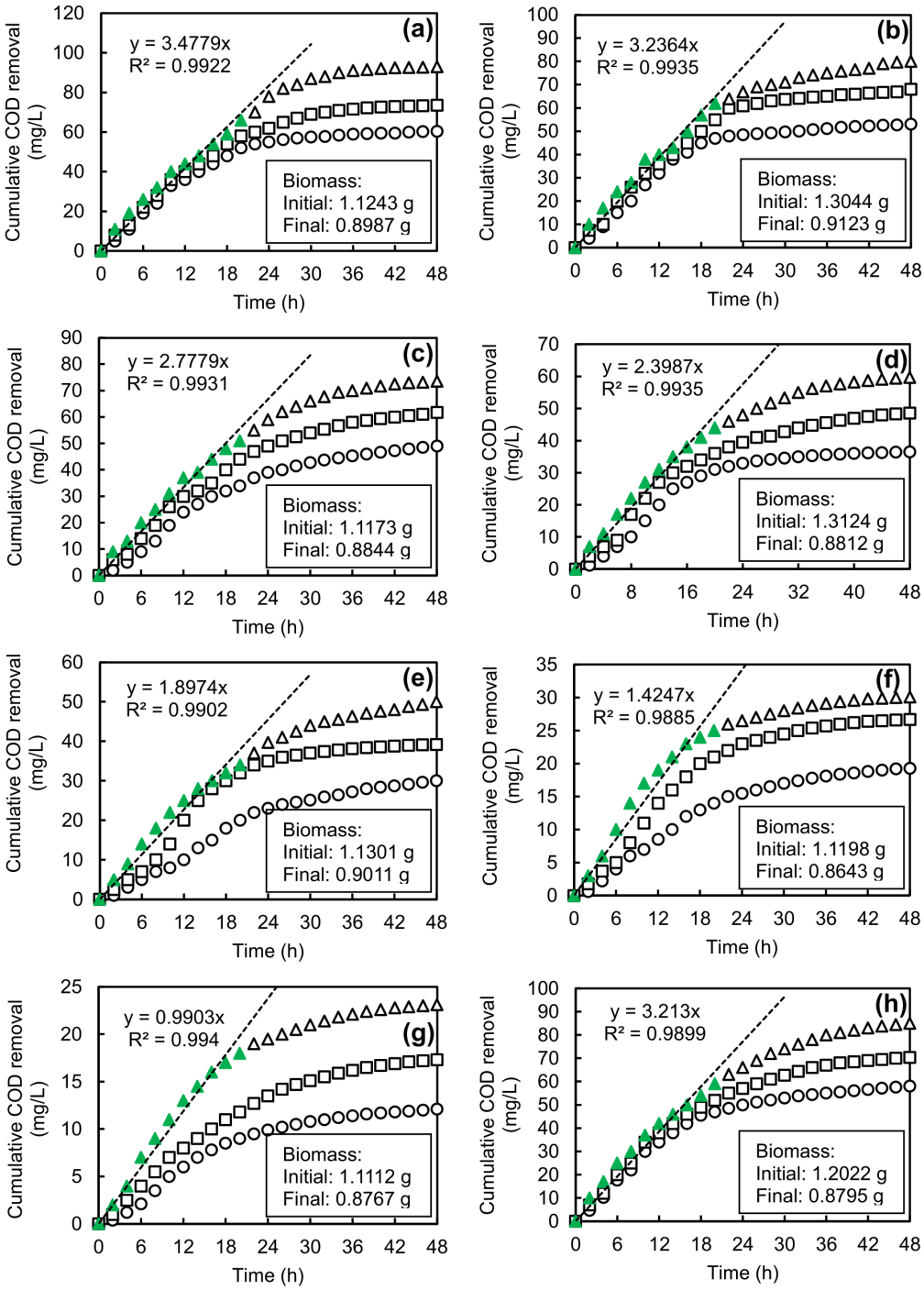


Fig. 3: Cumulative COD removal at different cycles at NaCl dose variation of (a) 0 g/L, (b) 5 g/L, (c) 10 g/L, (d) 15 g/L, (e) 20 g/L, (f) 25 g/L, (g) 30 g/L, and (f) recovery during the biomass activity study

Figure 3

See image above for figure legend

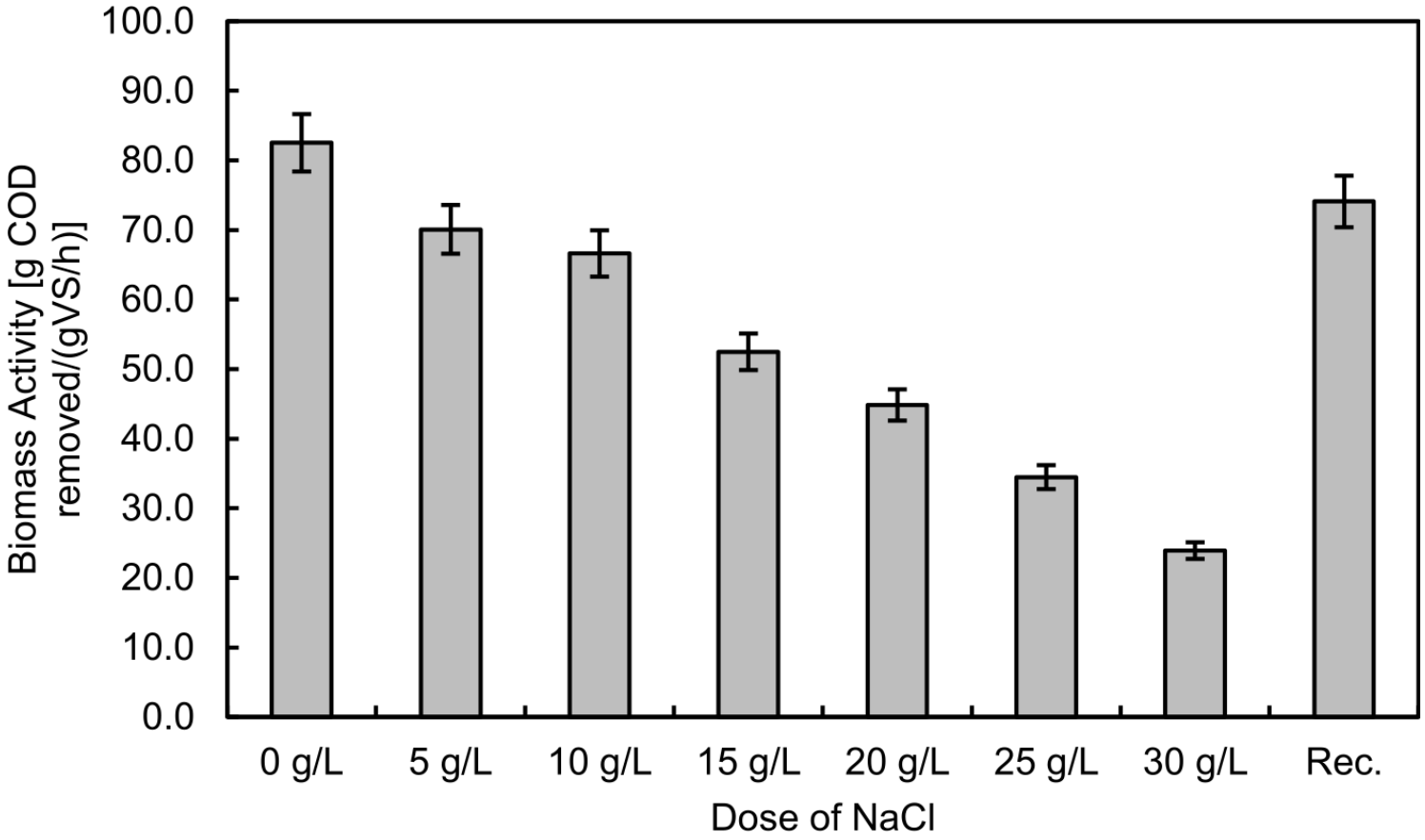


Fig. 4: Biomass activity during varied NaCl dose

Figure 4

See image above for figure legend

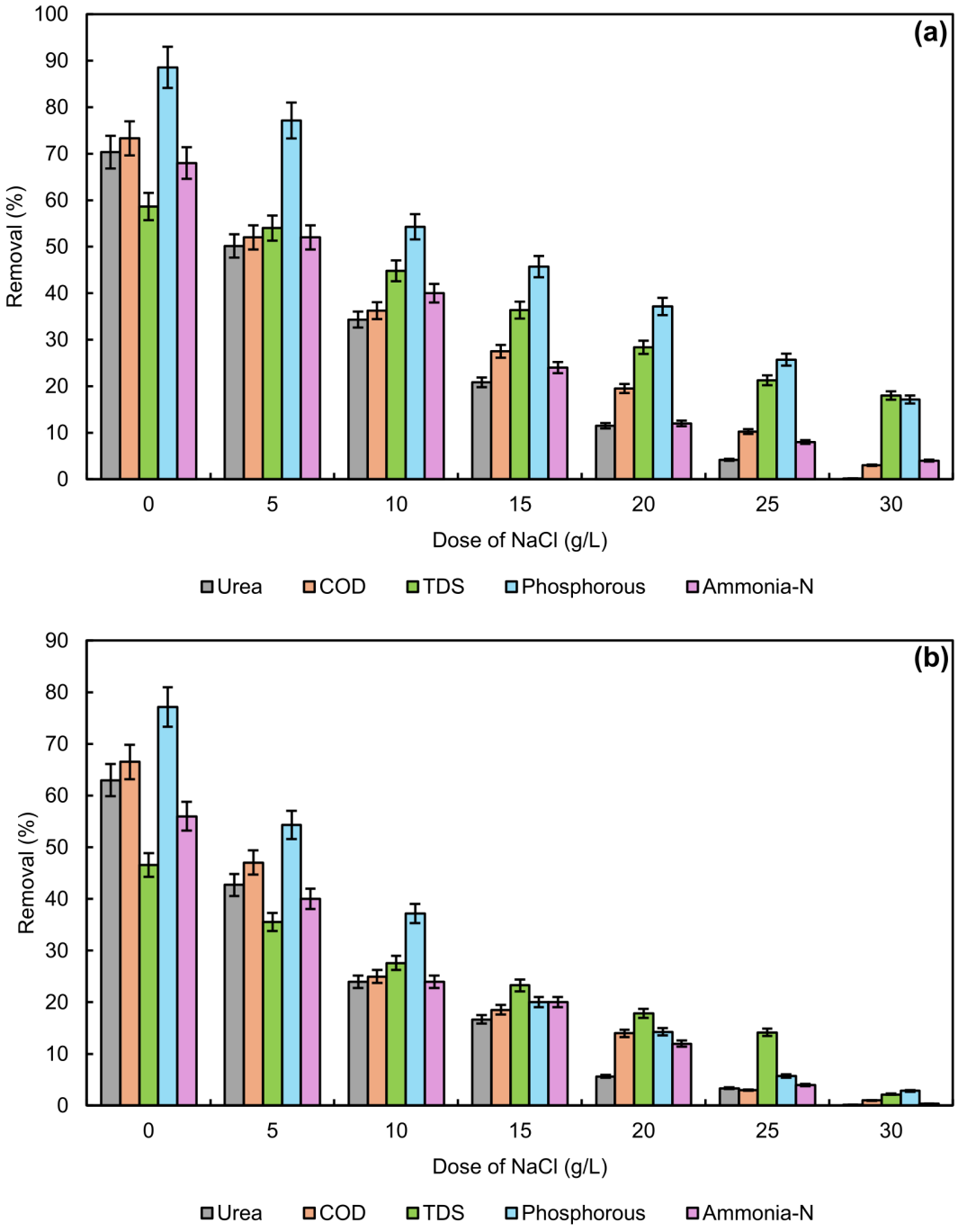


Fig. 5: Removal (%) of urea, COD, TDS, phosphorous, and ammonia-N by (a) *Exiguobacterium aurantiacum* strain 1910ICU112 and (b) *Staphylococcus haemolyticus* strain JCM 2416

Figure 5

See image above for figure legend