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Environmental Impact of Shrimp Pond Effluents on Water Quality and Phytoplankton Biomass in a Tropical Mangrove Estuary

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Water quality and phytoplankton biomass were examined over one year period concerning aquaculture farming periods in a river-dominated, mangrove estuary receiving periodic inputs of effluents at outfall of shrimp farms (OFSF) stations from adjacent brackishwater shrimp ponds and in away from shrimp farms (AFSF) stations. Salinity, dissolved oxygen (DO) and total suspended solids (TSS) at the OFSF stations were significantly different ($p \leq 0.01$) from AFSF stations. There were no significant differences between the OFSF and AFSF stations in dissolved nutrient concentrations. Water quality and phytoplankton biomass in OFSF stations were within the ambient levels, based on comparison with AFSF stations. Regular river discharge and tides of semi-diurnal type cause water quality and phytoplankton biomass in the OFSF stations of lower and middle reaches of estuary returned to levels equivalent to those in the AFSF stations. The limited spatial and temporal impact suggests that the effluents were dissipated by tides and assimilated and/or mineralized by the estuarine food web. Our results imply that river-dominated, mangrove estuary has some capacity, atleast over short spatial and temporal scales, to process intermittent inputs of pond-derived effluents.

KEYWORDS

Brackishwater, Aquaculture, Effluents, Farming periods, Nutrients, Phytoplankton, Water quality

1. INTRODUCTION

Estuarine and coastal areas have complex and dynamic aquatic environments [1]. Estuarine ecosystems are most productive natural habitat for brackishwater aquaculture and are considered to be excellent natural nursery grounds for a variety of fish and shrimp [2-5]. Estuaries and coastal areas are essential for domestic, industrial, aquaculture and agricultural purposes and are also used as a means for waste disposal [6]. The contribution of aquaculture to the global production of capture fisheries and aquaculture combined has risen continuously, reaching 46.8% in 2016, up from 25.7% in 2000 [7]. Worldwide brackishwater aquaculture production was 28.7 million tonnes in 2016. In sharp contrast to the dominance of finfish in inland aquaculture, shelled molluscs (16.9 million tonnes) constitute 58.8%, finfish (6.6 million tonnes) and crustaceans (4.8 million tonnes) together were responsible for 39.9% [7]. Instances of possible deleterious effects of effluents from shrimp ponds on the water quality of the coastal zone concerning water pollution as the most common complaint have been reported [8-15]. Most commonly shrimp aquaculture is being practised in ponds that are near or on the coast as per guidelines of the Coastal Aquaculture Authority (CAA). Semi-intensive or intensive shrimp culture production systems, lead to a significant increase in the levels of nutrients, phytoplankton biomass, organic matter and suspended solids in the environment receiving the farm's effluents [16-19]. Water is discharged from these shrimp ponds to the coastal ecosystem as part of the water exchange during the culture period and complete draining of pond water is typically done at the end of each culture, to discard the water rich in nutrients and suspended solids and to aerate the bottom soils in the preparation of next culture [20,21]. Such practice can rapidly alter the nutrient levels and quality of nearby waters. Impacts of aquaculture effluents on the water quality of coastal creeks and mangrove swamps have already received great attention [19,22-26]. The impact of pond effluents on adjacent ecosystems is variable and depends on various factors, including the magnitude of the discharge, the chemical composition of the pond effluents and the specific characteristics of the environment that receive the discharge, such as

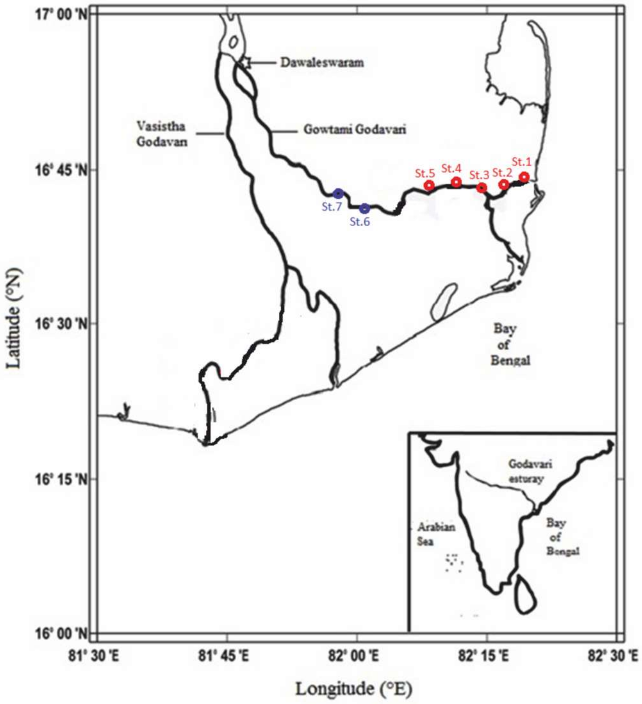

Figure 1. *Stations' locations map*

circulation and dilution rates [27].

River Godavari is the second largest river after the Ganges in India with rich biodiversity of flora and fauna. Shrimp aquaculture along the banks of the river in the estuarine waters have been practised for a few decades with the tiger shrimp *Penaeus monodon* and now with imported pacific white shrimp *P. vannamei* through semi-intensive methods. Andhra Pradesh ranks first in coastal and second in freshwater aquaculture, situated around Godavari river. There are no studies so far on the impact of aquaculture on the estuarine ecosystem of river Godavari. Therefore, the objective of the study is to assess the impact of shrimp culture pond effluents/discharge water on the quality of receiving waters at the outfall of shrimp farms and away from shrimp farms to detect environmental changes if any and to distinguish potential impacts from natural variability.This study is to our knowledge the first one that combines data on effluent fluxes from brackishwater pond culture with related effects on water quality in adjacent coastal waters of Godavari estuary.

2. MATERIAL AND METHOD

2.1 Study area

The study area is Godavari estuary, comprising two estuarine systems called Gautami Godavari estuary (GGE) and Vasishta Godavari estuary (VGE). Gautami Godavari is an eastern distributary of the Godavari estuarine system and Vasishta Godavari is a western distributary of the Godavari estuarine system emptying into the Bay of Bengal. The present study focus on GGE. Shrimp aquaculture is going on along the banks of Godavari for the past three decades. Semi-intensive type of shrimp aquaculture is being practised and discharge water is released into the river without treating. The species *P. vannamei* is cultured in about 90-110 days. Like other monsoon-fed Indian estuaries, it has an annual flood phase between July and September (SW monsoon). The rest of the year can be divided into recovery or post-monsoon phase of highly fluctuating low salinities (October to December), a stable phase of moderate salinities with typical estuarine conditions (January to March) and drought or pre-monsoon phase of total marine domination (April to June). Based on the seasonality of brackishwater and tidal conditions, tide and pump-fed dependent cultures are being practised in this region. There are three farming periods (FPs) in this region. FP-1 starts in August; FP-2 starts in January and FP-3 starts in April. After harvest in each farming period, effluents were discharged into the estuary.

2.2 Sample collection and analysis

The present study was undertaken during the period 2016-2017 to compare the physico-chemical parameters of water in the receiving water bodies at the outfall of shrimp farms (OFSF) and away from shrimp farms (AFSF) during the discharge time of all farming periods (FP) as the complete draining of pond water is typically done at the end of each farming period. Strategic sampling stations were selected to carry out the sampling in the estuary (Figure 1). The sampling places, where aquaculture effluents were discharged, located at lower and middle reaches of the estuary were labelled as stations at the outfall of shrimp farms (OFSF) (station 1, 2, 3, 4 and 5) and the sampling places away from the shrimp farms located far away from shrimp ponds and at extreme ends of upper reaches of the estuary, that is beyond 40 km from the mouth towards upstream were labelled as stations away from shrimp farms (AFSF) (stations 6 and 7). The water samples were collected from the surface and bottom (5 m depth) with a Niskin sampler at each sampling station. Water samples were also collected from the shrimp culture ponds of representative farms ($n = 5$) located on the estuary during all the farming periods. Dissolved oxygen was fixed with Winkler's reagents onboard and determined by the titrimetric method in the laboratory. The temperature was measured with a calibrated clean thermometer (± 0.1 °C) put in the Niskin sampler by opening its lid. Salinity was determined by argento-

Table 1. *Physico-chemical parameters of shrimp pond waters*

Water parameter	Farms using GGE water		
	FP-1	FP-2	FP-3
pH	7.2 ± 1.14	7.9 ± 0.48	7.4 ± 1.12
Salinity (ppt)	11.12 ± 5.4	26.45 ± 1.45	28.15 ± 1.45
DO (mg/L)	5.45 ± 1.45	5.96 ± 1.15	5.86 ± 1.13
BOD (mg/L)	10.05 ± 2.58	8.15 ± 3.15	12.12 ± 1.25
TAN (ppm)	0.9 ± 0.01	0.85 ± 0.02	0.78 ± 0.01
Total nitrogen (mg/L)	1.5 ± 0.21	1.7 ± 0.44	1.2 ± 0.33
Phosphate (mg/L)	0.09 ± 0.01	0.04 ± 0.02	0.03 ± 0.01
Total phosphorus (mg/L)	0.6 ± 0.21	0.7 ± 0.19	0.8 ± 0.17
TSS (mg/L)	14.13 ± 9.5	23.15 ± 6.4	31.5 ± 8.5
Chlorophyll a (mg/m ^{3})	9.52 ± 5.59	3.50 ± 0.50	7.80 ± 1.40

Table 2. *Physico-chemical parameters of water in the receiving water body (GGE) at the outfall and away from shrimp farms during the discharge time of farming periods (values alongwith SD are average of five sampling stations for OFSF and two sampling stations for AFSF)*

Parameter	OFSF			AFSF			Comparison between OFSF and AFSF stations		
	FP-1	FP-2	FP-3	FP-1	FP-2	FP-3	OFSF	AFSF	Calculated t-statistic
Temperature (^{0}C)	29.75 ± 0.34	29.32 ± 0.59	30.0 ± 0.47	30.75 ± 0.95	30.25 ± 0.25	30.25 ± 0.28	29.69	30.42	3.78**
pH	8.01 ± 0.07	7.91 ± 0.10	8.44 ± 0.04	8.39 ± 0.08	8.19 ± 0.19	7.74 ± 0.61	8.12	8.11	0.08^{NS}
Salinity (ppt)	11.33 ± 4.87	27.09 ± 1.63	29.16 ± 0.56	0.16 ± 0.008	5.84 ± 6.33	14.36 ± 14.3	22.53	6.79	5.08**
DO (mg/L)	6.84 ± 0.74	6.98 ± 0.48	7.64 ± 0.71	8.97 ± 0.76	7.48 ± 1.10	8.12 ± 0.35	7.16	8.19	3.78**
BOD_5 (mg/L)	0.77 ± 0.68	2.07 ± 0.21	0.08 ± 0.01	1.71 ± 0.06	0.86 ± 0.52	0.80 ± 1.93	0.98	1.40	1.39^{NS}
NO_2^- (mg/L)	0.021 ± 0.007	0.011 ± 0.001	0.04 ± 0.001	0.02 ± 0.004	0.011 ± 0.014	0.01 ± 0.007	0.03	0.02	2.09^{NS}
NO_3^- (mg/L)	1.64 ± 0.39	0.97 ± 0.27	0.004 ± 0.001	1.95 ± 0.16	0.79 ± 0.28	0.007 ± 0.003	0.88	0.92	0.17^{NS}
PO_4^{3-} (mg/L)	0.11 ± 0.01	0.06 ± 0.09	0.03 ± 0.005	0.09 ± 0.009	0.11 ± 0.007	0.01 ± 0.004	0.07	0.08	0.46^{NS}
SiO_4^{2-} (mg/L)	11.99 ± 2.71	5.29 ± 1.20	0.82 ± 0.39	17.86 ± 2.03	18.14 ± 7.30	14.71 ± 6.45	6.04	16.91	6.25**
NH_4^+ (mg/L)	0.02 ± 0.005	0.009 ± 0.002	0.01 ± 0.006	0.009 ± 0.005	0.002 ± 0.001	0.006 ± 0.004	0.02	0.01	5.28**
TSS (mg/L)	15.13 ± 7.94	24.83 ± 4.54	32.74 ± 3.03	6.19 ± 4.25	8.59 ± 0.35	19.05 ± 11.7	24.24	11.28	4.22**
Chl a (mg/m^3)	10.62 ± 6.90	3.74 ± 0.57	8.16 ± 1.15	20.34 ± 4.51	5.56 ± 0.89	7.29 ± 3.77	7.51	11.14	1.86^{NS}
NS – Not significant; *Significant at 5% level; **Significant at 1% level									

metric titration method and the pH was measured on Thermo Scientific Orion Star benchtop pH metre with an accuracy of ±0.01. For the determination of chlorophyll-a, water samples were filtered through GF/F filters and extracted with 90% acetone overnight at 4°C measured by spectrophotometric method. Those filtered water samples were used for the determination of nutrients (NO_2^--N, NO_3^--N, PO_4^{3-}-P and SiO_4^{2-}-Si) by standard spectrophotometric methods. All the samples were analyzed for the remaining parameters, namely 5-day biological oxygen demand (BOD_5), total suspended matter (TSM), total ammonia nitrogen (TAN), total nitrogen (TN) and total phosphorous (TP) by following the standard methods [28,29].

2.3 Statistical analysis

The physico-chemical parameters of shrimp farm pond waters and receiving water bodies at OFSF and AFSF stations in the GGE for each farming period are represented as mean ± SD in tables 1 and 2, respectively. T-test was done to compare the significant difference for each water parameter between OFSF and AFSF

Table 3. *Correlation matrix for OFSF stations of GGE*

Variable	Temperature	pH	Salinity	DO	BOD	NO_2^-	NO_3^-	PO_4^{3-}	SiO_4^{2-}	NH_4^+	TSM	Chl a
Temperature	1											
pH	0.87*	1										
Salinity	-0.04	0.43	1									
DO	0.66	0.94	0.71*	1								
BOD	-0.99	-0.86	0.06	-0.64*	1							
NO_2^-	0.94	0.98*	0.27	0.87*	-0.93*	1						
NO_3^-	-0.45	-0.82*	-0.86*	-0.96*	0.43	-0.72	1					
PO_4^{3-}	-0.22	-0.66*	-0.96*	-0.87*	0.20	-0.52	0.96*	1				
SiO_4^{2-}	-0.25	-0.68*	-0.95*	-0.88*	0.23	-0.55	0.97*	0.99*	1			
NH_4^+	0.23	-0.52	-0.98*	-0.56*	-0.25	-0.09	0.75*	0.89*	0.88*	1		
TSM	0.30	0.72*	0.93*	0.91*	-0.28	0.59	-0.98*	-0.99*	-0.99*	-0.85*	1	
Chl a	0.74	0.33	-0.70*	-0.00	-0.75*	0.48	0.25	0.48	0.45	0.82*	-0.40	1
*Indicates significant correlations at 5% level												

Table 4. *Correlation matrix for AFSF stations of GGE*

Variable	Temperature	pH	Salinity	DO	BOD	NO_2^-	NO_3^-	PO_4^{3-}	SiO_4^{2-}	NH_4^+	TSM	Chl a
Temperature	1											
pH	0.73	1										
Salinity	-0.80	0.99	1									
DO	0.90	0.37	-0.47	1								
BOD	0.99	0.77	-0.83	0.87	1							
NO_2^-	0.99	0.79*	-0.85*	0.86*	0.99*	1						
NO_3^-	0.91	0.94*	-0.97*	0.65*	0.93*	0.94	1					
PO_4^{3-}	0.32	0.87*	-0.82*	-0.10	0.38	0.41	0.67	1				
SiO_4^{2-}	0.43	0.92*	-0.88*	0.00	0.48	0.51	0.75	0.99*	1			
NH_4^+	0.82	0.22	-0.32*	0.98*	0.78	0.76	0.52	-0.26	-0.15	1		
TSM	-0.64	-0.99*	0.97	-0.25	-0.68	-0.71	-0.89	-0.93*	-0.96*	-0.09	1	
Chl a	0.99	0.66*	-0.73	0.94*	0.98*	0.98	0.86*	0.22	0.33	0.87*	-0.5	1
*Indicates significant correlations at 5% level												

stations at probability levels of 0.05 and 0.01 and denoted as * and **, respectively. Correlation coefficients were estimated among the water parameters in OFSF and AFSF stations. All the statistical analyses were done using SPSS-2016.

3. RESULT AND DISCUSSION

The results of physico-chemical parameters (mean ± SD) of shrimp farm pond waters at OFSF and AFSF stations in the GGE and their interpretation are presented in tables 1 and 2, respectively. Correlation coefficients among the water parameters at OFSF and AFSF stations are shown in tables 3 and 4, respectively.

3.1 Temperature

The mean temperature values at OFSF and AFSF stations ranged from 29.32°C (FP-2) to 30°C (FP-3) and from 30.25°C (FP-2) to 30.75°C (FP-1), respectively. There were no significant differences between surface and bottom temperatures at OFSF and AFSF stations during all the farming periods. The mean temperature values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table

2). The maximum and minimum temperatures were observed in OFSF stations during FP-3 (pre-monsoon-summer) and FP-2 (post-monsoon), respectively. In contrast, the maximum and minimum temperatures were observed in AFSF stations during monsoon and pre-monsoon, respectively which might have due to high river discharge (fluid dynamics) prevailing at AFSF stations in these seasons. Similar results were reported in GGE which are corroborated with the results of our study [30,31].

3.2 pH

The mean pH values in OFSF and AFSF stations ranged from 7.91 (FP-2) to 8.44 (FP-3) and from 7.74 (FP-3) to 8.39 (FP-1), respectively. There were no significant differences between surface and bottom pH values at AFSF and OFSF stations during all the periods of sampling. The mean pH values of all the farming periods were not significant between OFSF and AFSF stations (Table 2). Anilakumary reported that pH values change from acidic to alkaline when colloidal particles mix with seawater and become coagulated [32]. A slightly alkaline range in pH was observed at all the sampling stations (Table 2). The pH values were relatively low in OFSF stations than in AFSF stations as the salinity increases downstream (Figure 1). Similar results reported by Pankaj in Kali estuary are corroborated with the results of our study [33].

3.3 Salinity

The mean salinity values in OFSF and AFSF stations ranged from 11.33 ppt (FP-1) to 29.16 ppt (FP-3) and from 0.16 ppt (FP-1) to 14.36 ppt (FP-3), respectively. The mean salinity values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table 2). The surface and bottom salinity differences were considered during all the periods of sampling in OFSF and AFSF stations, with higher bottom salinity values (Figures 2a,b, 3a,b and 4a,b). The salinity difference between surface and bottom shows an increasing trend from head to mouth (AFSF stations to OFSF stations. Figure 1 concludes that the Godavari estuary is similar to other Indian estuaries [34,35]. High salinity values in OFSF stations over the AFSF stations during all the periods of sampling indicates pristine marine domination in the OFSF stations of middle and lower reaches of the estuary, which is witnessed by the weak negative correlation of salinity with nitrate, phosphate, ammonium except silicate (Figures 2a,b, 3a,b and 4a,b and Table 3). In AFSF stations, salinity was lowest in monsoon, showing an increasing trend from post-monsoon followed by pre-monsoon. The freshwater inflow from the river influenced significantly on lowering of the salinity during the monsoon. Salinity shows a strong negative correlation with nitrate, phosphate, silicate and ammonium indicates that these stations are dominated by freshwater (Tables 3 and 4) [36-38].

3.4 Dissolved oxygen

The mean DO values in OFSF and AFSF stations ranged from 6.84 mg/L (FP-1) to 7.64 mg/L (FP-3) and from 7.48 mg/L (FP-2) to 8.97 mg/L (FP-1), respectively. The difference between surface and bottom DO were marked in AFSF stations than OFSF stations and were high in pre-monsoon, which is attributed to the river discharge (Figures 2c,d, 3c,d and 4c,d). The mean dissolved oxygen values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table 2). Relatively lower DO values were found in OFSF stations than in AFSF stations except in FP-2 during all the periods (Figure 2c,d, 3c,d and 4c,d). The low DO concentration in FP-1 followed by FP-3 in GGE of OFSF in lower and middle reaches of estuary might be either because of organic matter load discharged through the shrimp pond effluents or the influence of salinity and upwelling tides [39-42]. This is also supported by the negative correlation of DO with all nutrient species in OFSF stations of GGE, which indicates that a relatively lower DO water mass was brought into the OFSF stations from the inner part of the estuary (Table 3) [43]. However, relatively higher DO values in the AFSF stations could be attributed to the input of DO rich freshwater through river discharge.

3.5 Biochemical oxygen demand

The mean BOD values in OFSF and AFSF stations ranged from 0.08 mg/L (FP-3) to 2.07 mg/L (FP-2) and from 0.80 mg/L (FP-3) to 1.71 mg/L (FP-1), respectively. The surface and bottom differences of BOD were marked in AFSF stations than OFSF stations (Figures 2c,d, 3c,d and 4c,d). The BOD values of all the farming periods were not significant between OFSF and AFSF stations. BOD is often used as a surrogate of the degree of organic pollution of water, giving an estimate of the anthropogenic amount and natural biodegradable organic matter [44]. Relatively higher BOD values were found in AFSF stations than in OFSF stations during all the periods of study, which might be due to the high amounts of wastewater from urban and agricultural activities, rich in organic matter entering into these regions (Table 2) [45].

3.6 Total suspended solids

The mean total suspended solids (TSS) levels in OFSF and AFSF stations ranged from 15.13 mg/L (FP-1) to

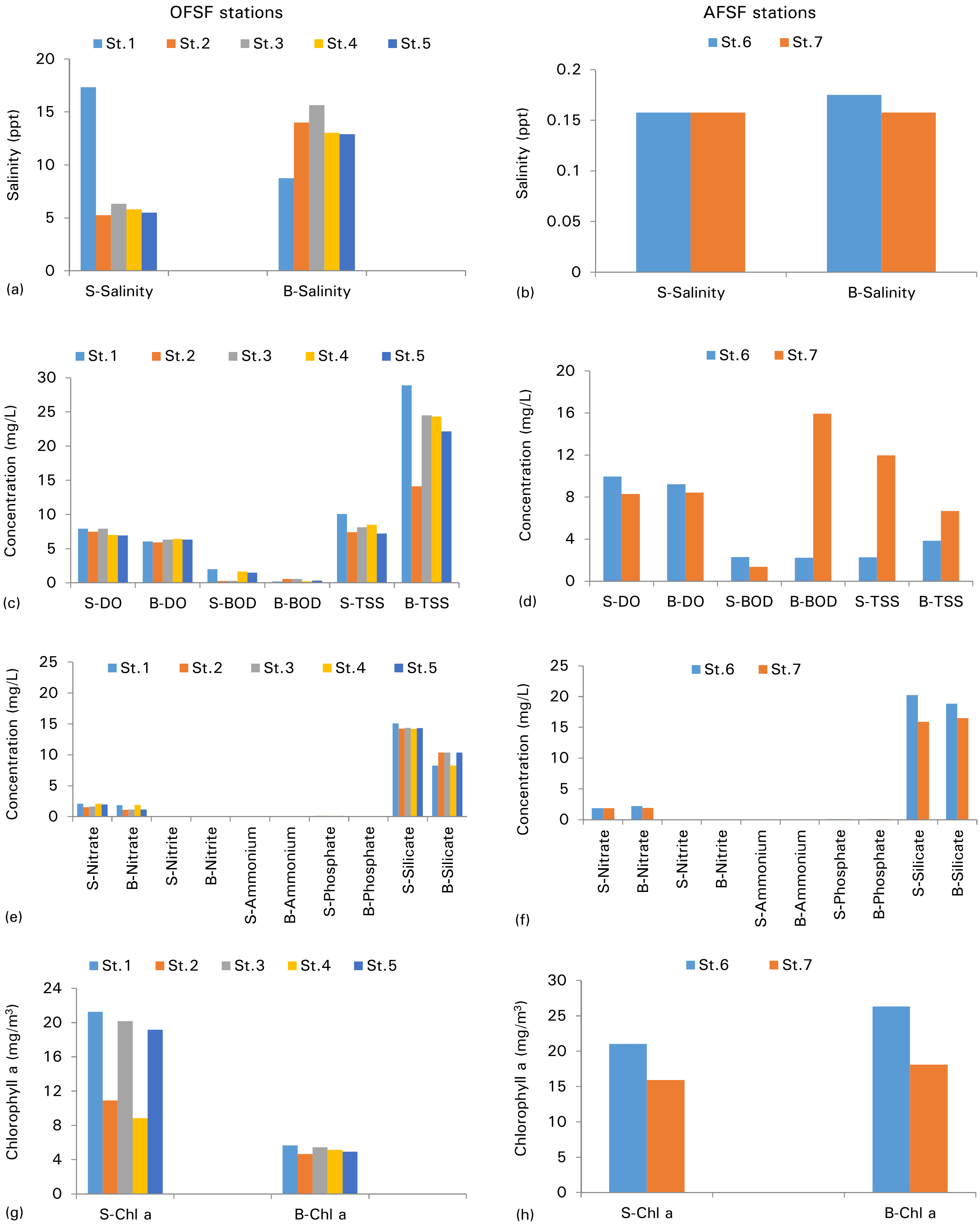

Figure 2. *Physico-chemical parameters of surface and bottom waters of GGE during FP-1: (a and b) salinity ; (c and d) dissolved oxygen, biochemical oxygen demand and total suspended solids; (e and f) nutrients and (g and h) chlorophyll-a*

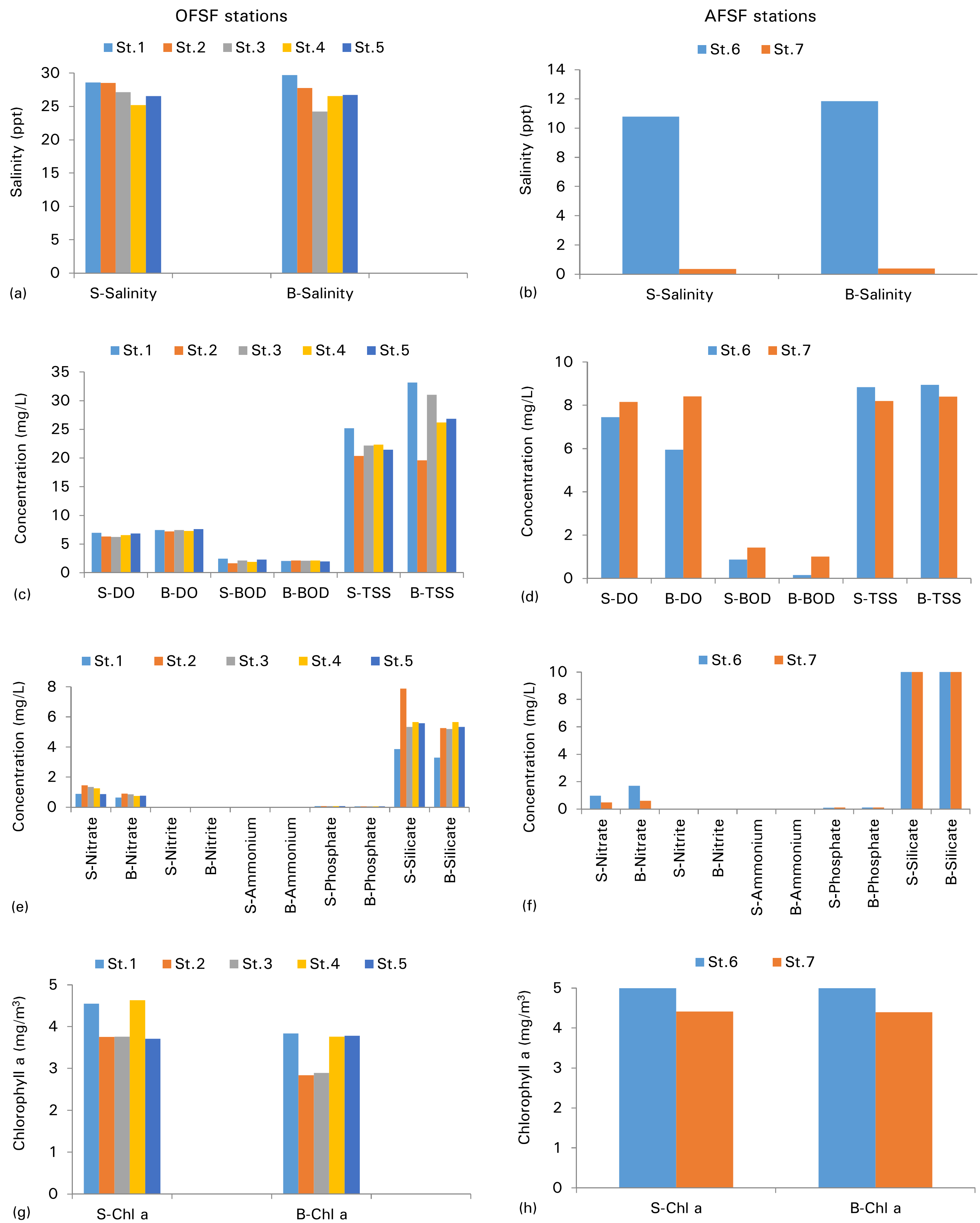

Figure 3. *Physico-chemical parameters of surface and bottom waters of GGE during FP-2: (a and b) salinity ; (c and d) dissolved oxygen, biochemical oxygen demand and total suspended solids; (e and f) nutrients and (g and h) chlorophyll-a*

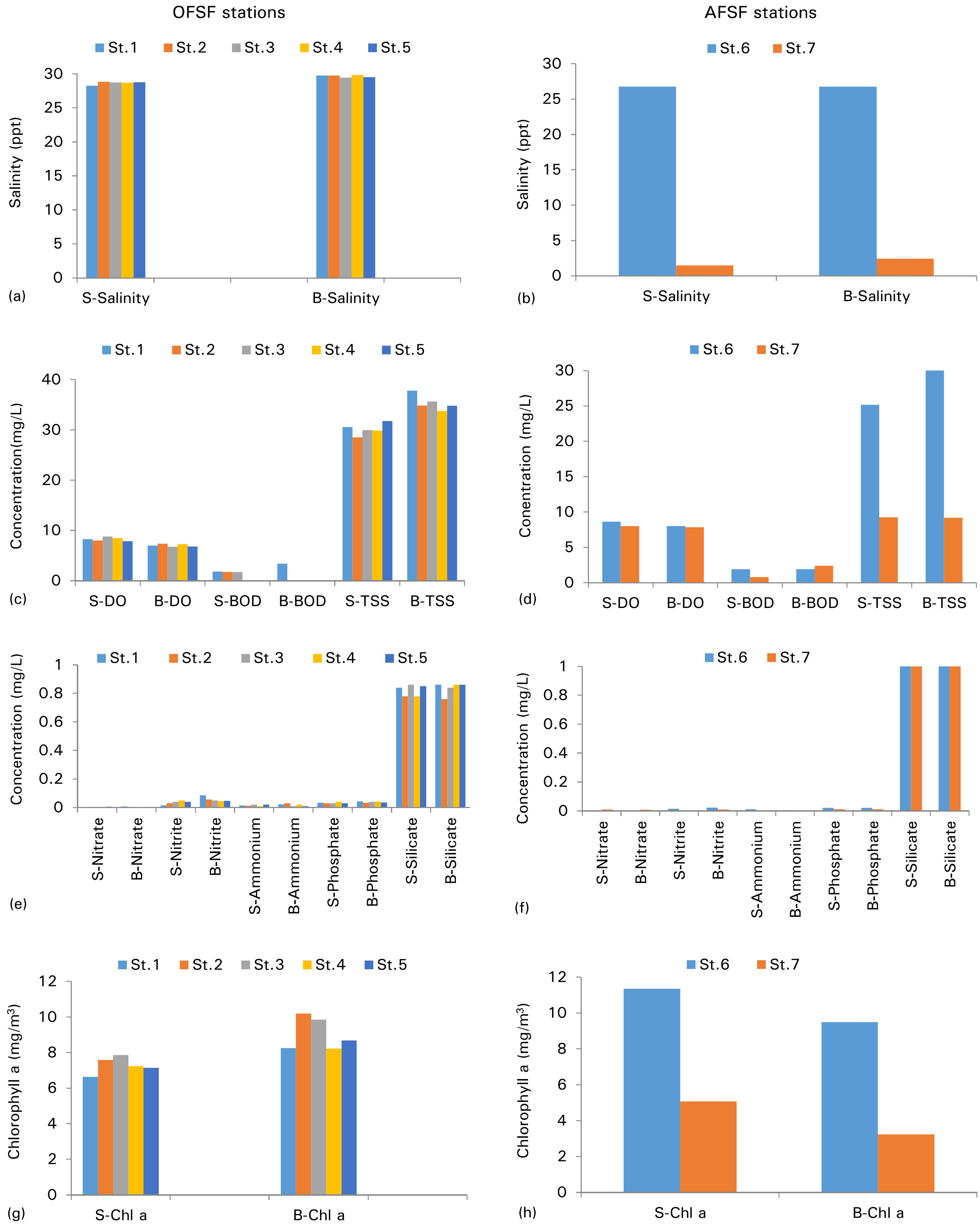

Figure 4. *Physico-chemical parameters of surface and bottom waters of GGE during FP-3: (a and b) salinity ; (c and d) dissolved oxygen, biochemical oxygen demand and total suspended solids; (e and f) nutrients and (g and h) chlorophyll-a*

32.74 mg/L (FP-3) and from 6.19 mg/L (FP-1) to 19.05 mg/L (FP-3), respectively. The concentrations of TSS between surface and bottom water differ significantly at OFSF and AFSF stations (Figures 2c,d, 3c,d and 4c,d). The mean TSS values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table 2). TSS levels in OFSF stations were found higher than AFSF stations in both the estuaries (Table 2 and Figure 2c,d, 3c,d and 4c,d) with high values in bottom water and showed much difference among farming periods. A decreasing trend in TSS values was followed from FP-3 to FP-2 and FP-1. The TSS levels increased during shrimp pond effluents discharge (especially FP-3) due to resuspension of bottom sediments of shrimp ponds and erosion of channels walls and absence of this during FP-1 might be diminished by monsoon discharge [46]. However, in AFSF stations, worth considering levels of TSS were observed even there was no discharge of pond effluents illustrating the close link between short-term weather events and water quality [47].

3.7 Nutrients

The mean nitrite values in OFSF and AFSF stations ranged from 0.01 mg/L (FP-2) to 0.04 mg/L (FP-3) and from 0.01 mg/L (FP-3) to 0.02 mg/L (FP-1), respectively. There were no significant differences between surface and bottom concentrations of nitrite at OFSF and AFSF stations. The mean nitrite values of all the farming periods were not significant between OFSF and AFSF stations (Table 2). Nitrite is the intermediate oxidation state between ammonium and nitrate. It can appear as a transient species by the oxidation of ammonium or by the reduction of nitrate. The nitrite concentrations were observed low at all stations during all the periods of sampling. Nitrite levels above 0.1 mg/L in water bodies can be toxic [48]. Concentrations of nitrite in OFSF stations were relatively high compared to AFSF stations though not much variation exists between OFSF and AFSF stations might be due to discharge of shrimp pond effluents, surface runoff and nutrient-rich backwater intrusion into OFSF stations of middle and lower reaches of estuary (Table 2 and Figures 2c,d, 3c,d and 4c,d) [49,50]. This is corroborated by the positive correlation of salinity with nitrite, which indicates that inhibition of nitrification process due to the absence of Nitrobacter sp. in OFSF stations and high levels of nitrite accumulation at different salinities.

The mean values of nitrate in OFSF and AFSF stations ranged from 0.004 mg/L (FP-3 discharge) to 1.64 mg/L (FP-1) and from 0.007 mg/L (FP-3) to 1.95 mg/L (FP-1) respectively. Nitrate concentration between surface and bottom water did not differ significantly in FP-1, FP-3 farming periods in OFSF and AFSF stations (Figures 2e,f, 3e,f and 4e,f). The mean nitrate values of all the farming periods were not significant between OFSF and AFSF stations (Table 2). Nitrate showed decreasing trend both in OFSF and AFSF stations with the highest values during monsoon (FP-1) followed by pre-monsoon (FP-3) and post-monsoon (FP-2) (Table 2). The highest monsoon values were due to freshwater influx. The negative correlation between salinity and nitrate both in OFSF stations and AFSF stations as reported by others showed that freshwater influx is the main source of this nutrient (Table 3 and 4) [37,51,52]. The mean NH_4^+ - N values in OFSF and AFSF stations ranged from 0.009 mg/L (FP-2 begin) to 0.02 mg/L (FP-1) and from 0.002 mg/L (FP-2) to 0.009 mg/L (FP-1), respectively. NH_4^+-N concentration between surface and bottom did not differ significantly in OFSF and AFSF stations during all the periods of sampling. The mean NH_4^+-N values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table 2). The NH_4^+-N concentrations were observed low at OFSF and AFSF stations during the entire study period (Table 2). The negative correlation of NH_4^+-N with salinity as reported by others both in OFSF stations and AFSF stations indicates that freshwater is the source of this nutrient into the study area and not related to the aquaculture activities (Tables 3 and 4) [50,53].

The mean phosphate values in OFSF and AFSF stations ranged from 0.03 mg/L (FP-3) to 0.11 mg/L (FP-1) and from 0.01 mg/L (FP-3) to 0.09 mg/L (FP-1), respectively. There was no significant difference between surface and bottom water concentration of phosphate in OFSF and AFSF stations during all the periods of sampling (Figures 2e,f, 3e,f and 4e,f). The mean phosphate values of all the farming periods were not significant between OFSF and AFSF stations (Table 2). Phosphate concentration in coastal waters depends upon its concentration in the freshwater that mixed with the seawater within the sea-land interaction zone, phytoplankton-uptake addition through localized upwelling and replenishment as a result of microbial decomposition of organic matter [54]. Phosphate showed a decreasing trend in OFSF and AFSF stations during all the periods of sampling with the highest values during monsoon followed by pre and post-monsoon seasons (Table 2). The highest values in AFSF stations and OFSF (especially in FP-1) stations during monsoon are due to the freshwater influx and mixing of freshwater with seawater accompanied by aquaculture effluents in the middle and lower reaches of estuary respectively [55,56].

To differentiate the OFSF and AFSF stations silicate was measured. The mean silicate concentration in OFSF and AFSF stations ranged from 0.82 mg/L (FP-3) to 11.99 mg/L (FP-1) and from 14.71 mg/L (FP-3) to 18.14 mg/L (FP-2), respectively. Silicate concentration between surface and bottom differ significantly in OFSF and AFSF stations during all the farming periods (Figures 2e,f, 3e,f and 4e,f). According to Patra silicate content of water varies with water salinity and higher silicate content was recorded in low salinity areas, which is corroborated with the results of our study [57]. The mean silicate values of all the farming periods were highly significant ($p \leq 0.01$) between OFSF and AFSF stations (Table 2). Silicate showed an increasing trend in both OFSF and AFSF stations from pre-monsoon followed by post-monsoon and monsoon (Table 2). The observed higher silicate concentration in monsoon after post-monsoon was due to flooding influx from land drainage and silicate leaching from rocks and sediments [58,59]. Higher silicate concentrations were observed in pre-monsoon in contrast to monsoon both in OFSF and AFSF stations, which are supported by the negative correlation of salinity with silicate both in OFSF and AFSF stations (Tables 3 and 4). This might be due to the release of surplus water stored in the dam above the study area in the pre-monsoon for irrigation purposes in low lying areas. From this, it is logical to say that river discharge is high throughout the study area.

3.8 Chlorophyll-a

The mean chlorophyll-a (chl a) concentrations in OFSF and AFSF stations ranged from 3.74 mg/m^3 (FP-2) to 10.62 mg/m^3 (FP-1) and from 5.56 mg/m^3 (FP-2) to 20.34 mg/m^3 (FP-1), respectively. Chl-a concentration between surface and bottom water differ significantly in OFSF and AFSF, which were more marked in monsoon season (Figures 2g,h, 3g,h and 4g,h). The mean chlorophyll values of all the farming periods were not significant between OFSF and AFSF stations (Table 2). The primary productivity potential of the aquatic environments depends upon the phytoplankton, which alone contributes 90% of the total primary production. Thus chlorophyll-a which constitutes the chief photosynthetic pigment of phytoplankton is an index that would provide the primary production potential upon which the biodiversity, biomass and carrying capacity of that system depends upon [60]. Chl-a concentration in AFSF stations was found higher than OFSF stations during the study period without the intervention of whether it is surface or bottom (Table 2). Chl-a concentration showed a decreasing trend from monsoon followed by pre-monsoon and post-monsoon in AFSF and OFSF stations. The high chl-a concentration observed in AFSF stations might be due to higher phytoplankton abundance, which is supported by a strong positive correlation of pH with chl-a indicating the rapid growth of algae caused by high concentrations of nitrogen and phosphorous released from continuously dosed bait with river discharge (Table 4) [61]. In OFSF stations insignificant correlation of pH with chl-a and worthy considering values of chl-a, especially during the FP-1 and FP-3 was due to high Chl-a concentration in shrimp ponds (Table 3) [62].

4. CONCLUSION

The present study summarizes the environmental impact of shrimp pond effluent and phytoplankton biomass in a tropical mangrove estuary concerning aquaculture farming periods as exploratory statistical data output. This provides information on the water quality status at outfall stations of aquaculture effluents compared to the stations away from aquaculture activities. Shrimp farm effluents cause significantly high salinity and suspended solids to the coastal ecosystem as well as reduced dissolved oxygen. Effluents could not elevate the nutrient loadings in OFSF stations and are quite similar to the situation in the AFSF stations. The reported high salinities in OFSF stations of the middle and lower reaches of the estuary were due to pristine marine domination. The reported reduced DO levels are either due to organic matter load discharged through shrimp pond effluents or due to the influence of salinity and upwelling tides. No significant difference in chlorophyll-a between OFSF and AFSF stations. However, high chlorophyll-a concentrations in AFSF stations are due to higher phytoplankton abundance. No significant difference in BOD between OFSF and AFSF. Our results conclude that some water quality characteristics are altered by effluent discharge in outfall sites, but a comparison of water quality between OFSF and AFSF stations imply that the conditions at the outfall sites returned to ambient levels. Moreover, the impacted mangrove estuary has some capacity to assimilate or transform nutrients derived from periodic inputs from the shrimp ponds. The assimilative and/or dissimilative mechanisms were not examined but it is likely that a combination of processes, most likely mineralization and subsequent dissipation (for example respiration, denitrification) by planktonic food webs and dilution by river discharge, physical processing by tides were the major mechanisms.

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