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Assessing the impact of shrimp farming on the water quality of Vasishta Godavari estuary, East coast of India

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ABSTRACT

The growth of the shrimp cultivating industry around the world has been caused mainly by the shrimp culture technology that took shape from various research works. This shrimp cultivating industry has not only met the growing consumer demands but also helped reduce the pressure on the wild shrimp resources that were unable to meet the increase in demand. However the benefits are not without a price. There are acknowledged ecological consequences for estuarine environments because of shrimp cultivating and they require a lot of attention too. In this study, water quality attributes were analyzed for one year time frame with respect to aquaculture farming periods in a tropical wave dominated, estuary getting intermittent contributions of effluents at outfall of shrimp farm (OFSF) stations from nearby brackishwater shrimp ponds and in away from shrimp form (AFSF) stations. Significant distinctions ($p \leq 0.01$) were discerned in the salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), and Chlorophyll-a levels between the OFSF and AFSF stations. In contrast, no notable variations were observed in dissolved nutrient concentrations between these station types. When evaluating water quality and phytoplankton biomass, the OFSF stations consistently conformed to the ambient standards, particularly in relation to the AFSF stations. This pattern was primarily attributed to the interplay of factors such as river discharge and semi-diurnal tides, especially in the lower and middle reaches of the estuary, which effectively harmonized the water quality and phytoplankton biomass levels at the OFSF stations with those documented at the AFSF stations. The restricted spatial and transient effects suggest that the effluents get disseminated by tides, acclimatized, and mineralized by the estuarine food web. Our studies inferred that wave dominated estuary could process intermittent contributions of pond – derived effluents atleast over short spatial and temporal scales

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1. Introduction

Estuarine and coastal areas have complex and dynamic aquatic environments (Morris *et al*., 1995). Estuarine ecosystems are most productive natural habitat for brackishwater aquaculture (Simpson *et al*., 2001) and are considered to be excellent natural nursery grounds for a variety of fish and shrimp (Minello *et al.,* 2003; Dorenbosch *et al*., 2005; Kimiri *et al.,* 2011). Estuaries and coastal areas are essential for domestic, industrial, aquaculture and agricultural purposes and are also used for waste dumping (Boon *et al*., 1992). The contribution of aquaculture to the worldwide production of capture fisheries and aquaculture combined has risen persistently, arriving at 46.8 % in 2016, up from 25.7 % in 2000 (FAO, 2018). 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 % (FAO, 2018). Instances of conceivable harmful effects of effluent from shrimp ponds on the water quality of the coastal zone with reference to water pollution as the most prevalent complaint have been reported (Ziemann *et al*., 1992; Twilley *et al*., 1993; Bardach, 1997; Boyd, 2003; Sara, 2007; Anh *et al*., 2010; Bui *et al*., 2012). Most commonly shrimp aquaculture is being practiced 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 huge increments in the degrees of nutrients, phytoplankton biomass, organic matter, and suspended solids in the environment receiving the farm's effluents (McKinnon *et al*., 2002; Biao *et al*., 2004; De Lacerda *et al*., 2006; Cardozo *et al.,* 2011). Water is discharged from these shrimp ponds to the coastal ecosystem as part of the water exchange during the culture period, and complete depletion of pond water is commonly done at the end of each culture so as to dispose the water rich in nutrients and suspended solids and to circulate air through the base soils in the planning of next culture (Wang and Wang, 2007; Wu *et al.,* 2014). Such practice can quickly alter the nutrient levels and quality of nearby waters. Impacts of aquaculture effluents on the water quality of coastal creeks (Wolanski *et al*., 2000; Bufford *et al*., 2003; Costanzo *et al*., 2004) and mangrove swamps (Molnar *et al*.,2013; Cardoso-Mohedano *et al*., 2016a, 2016b) have already received great attention. The effect of pond effluents on adjacent ecosystems is variable and relies on various factors, including the extent of the discharge, the chemical composition of the pond effluents, and the particular attributes of the environment that receives the discharge, such as flow and dilution rates (Aez-Osuna, 2001).

River Godavari is the second largest river after the Ganges in India, with a rich biodiversity of flora and fauna. Shrimp aquaculture along the banks of the river in the estuarine waters has been practiced 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 positions first in coastal and second in freshwater aquaculture, situated around the 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 the first of its kind in the Godavari estuary that joins information on profluent motions from brackishwater pond culture with related impacts on water quality in adjacent coastal waters.

2. Materials and Methods

2.1 Study area

The study area Godavari estuary, comprising two estuarine systems called Gautami Godavari Estuary (GGE) and Vasishta Godavari Estuary (VGE). Gautami Godavari is the eastern distributary of the Godavari estuarine system and Vasishta Godavari is the western distributary of the Godavari estuarine system opening into the Bay of Bengal. The present study focuses on VGE. Shrimp aquaculture has been going along Godavari's banks for the past three decades. Semi-intensive type of shrimp aquaculture is being practiced and discharge water is released into the river without treatment. The species *P. vannamei* is cultured in about 90 to 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 a recuperation or post monsoon phase of exceptionally fluctuating low salinities (October to December), a steady phase of moderate salinities with common estuarine conditions (January to March) and a dry spell or pre monsoon phase of all out marine mastery (April to June). In our extensive field study and a long chain of enquiry, we found a captivating fact that based on the seasonality of brackishwater and tidal conditions, tide and pump-fed dependent cultures are being practiced in this region and there are three farming period (FPs) in this region. FP-1, starts in August, FP-2, begins in January, and FP-3, starts in April. After harvest in each farming period, effluents were discharged into the estuary.

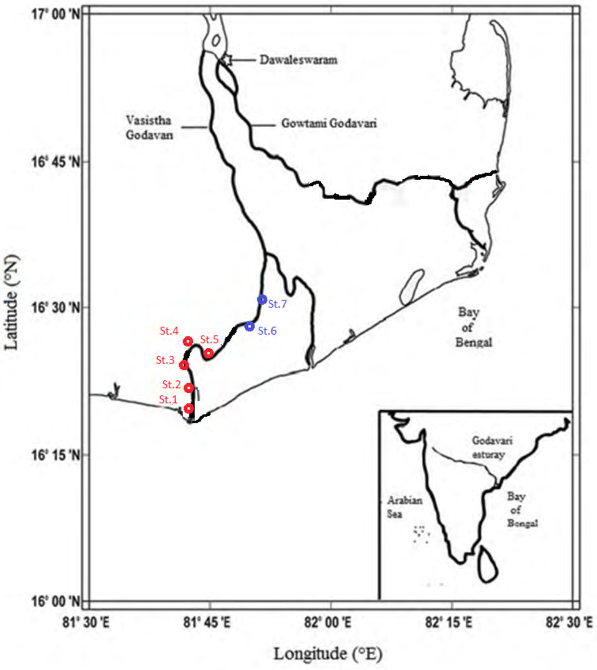

Fig. 1. Map of study area showing the stations locations at Vasishta Godavari Estuary

2.2 Sampling Procedures and Experimental Design.

The present study was undertaken during the period 2016 -2017 to compare the physicochemical parameters of water in the receiving water bodies at 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 (Fig.1) were selected to carry out the sampling in the estuary. The sampling places, where aquaculture effluents discharged, located at lower and middle reaches of estuary were labelled as stations at outfall of shrimp farms (OFSF) (St.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 i.e. beyond 40 km from the mouth towards upstream were labelled as stations away from shrimp farms (AFSF) (St. 6 and 7). The water samples were collected from the surface and bottom (5 m depth) with 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 titrimetric method in the laboratory. Temperature was measured with a calibrated clean thermometer (±0.1°C) put in the Niskin sampler by opening its top. Salinity was determined by argentometric titration method and the pH was measured on Thermo Scientific Orion Star benchtop pH metre with a precision of ±0.01. For the determination of Chlorophyll a, water samples were sifted through GF/F filters and extracted with 90% acetone overnight at 4°C estimated by spectrophotometric method. Those filtered water samples were utilized for the estimation of nutrients (NO_2^- -N, NO_3^- -N, PO_4^{3-}-P and SiO_4^{2-}-Si) by standard spectrophotometric methods (Grasshoff *et al.*, 1999). 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. (Grassaph *et al.*, 1999; APHA, 1989).

2.3 Statistical analysis

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

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

Table 1. Physico-chemical parameters (Mean ± SD) of shrimp farms (n=5 each) located on Vasishta Godavari Estuary

Water parameter	Farms using VGE water		
	FP-1	FP-2	FP-3
pH	7.9±1.13	7.2 ± 0.21	7.5 ± 0.13
Salinity (ppt)	14.65±4.54	20.15±3.45	25.82±3.56
DO (mg/l)	5.65 ± 0.95	5.55 ±0.58	6.34 ± 0.65
BOD (mg/l)	11.14±1.05	7.45±4.23	11.85±3.36
TAN (ppm)	0.8 ± 0.02	0.9 ± 0.01	0.85±0.03
Total N (mg/l)	1.4 ± 0.14	1.45±0.18	1.24±0.19
Phosphate(mg/l)	0.42±0.13	0.04±0.01	0.03 ± 0.01
Total P (mg/l)	0.7 ± 0.22	0.8 ±0.23	0.6 ± 0.18
TSS (mg/l)	13.6 ± 8.7	10.5 ± 2.4	20.5 ± 4.5
Chl a (mg/m^3)	11.34±6.37	2.90±1.45	8.95 ±2.54

3.1. Temperature

The mean temperature values in OFSF and AFSF stations of VGE ranged from 26.91°C (FP-2) to 31.33°C (FP-3) and from 28.75°C (FP-2) to 33.5°C (FP-3) 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 between OFSF and AFSF stations of all the farming periods were not significant (Table 2).

The maximum and minimum temperatures were observed in OFSF and AFSF stations of VGE during post monsoon and pre monsoon, respectively. The observed water temperature esteems harmonized with the trends in atmospheric temperature. Similar values were reported in VGE (Padmavathi & Satyanarayana, 1999; Vrao *et al.*, 2019. Chari *et al.*, 2020), which are corroborated with the results of our study.

3.2. P^H

The mean pH values in OFSF and AFSF stations ranged from 7.96 (FP-3) to 8.04 (FP-1 & FP-2) and from 7.75 (FP-2) to 8.43(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).

Anila Kumary *et al.*, (2007) reported that pH esteems change from acidic to alkaline when colloidal particles blend in with seawater and become coagulated. A slightly alkaline range in pH was observed at all the sampling stations (Table 2). pH values were relatively low in OFSF stations than in AFSF stations as the salinity increased downstream (Fig.1). Similar results reported by Pankaj et al. (2017) in Kali Estuary are corroborated with the results of our study. This is also evidenced by the negative correlation of pH with salinity in OFSF (Table 3) and AFSF stations (Table 4).

Table 2. Physico-chemical parameters of water in the Vasishta Godavari Estuary at outfall and away from shrimp farms during the discharge time of farming periods (FP) (Values along with 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 (°C)	28.91±0.53	26.91±1.54	31.33±0.97	29.12±0.25	28.75±0.64	33.5±0.40	29.05	30.46	1.89^{NS}
pH	8.04±0.03	8.04±0.25	7.96±0.17	8.43 ±0.15	7.75±0.05	8.33±0.24	8.02	8.17	1.91^{NS}
Salinity (ppt)	15.67±4.94	20.14±4.20	26.64±4.91	1.44±1.98	15.28±3.98	10.01±7.81	20.82	8.92	5.14**
DO (mg/l)	5.74±0.56	7.85±2.22	6.46±1.21	7.54±1.40	8.16±0.44	8.32±3.01	6.69	8.01	2.77**
BOD (mg/l)	1.03±0.56	1.54±0.89	1.42±0.60	1.99±0.52	2.18±1.57	1.2±2.70	1.36	2.17	2.85**
NO_2^- (mg/l)	0.031±0.004	0.069±0.059	0.12±0.11	0.027±0.003	0.047±0.003	0.108±0.206	0.08	0.06	0.512^{NS}
NO_3^- (mg/l)	1.39±0.16	0.41±0.11	0.82±0.19	2.14±0.30	0.61±0.09	0.84±0.26	0.88	1.2	1.73^{NS}
PO_3^{3-} (mg/l)	0.45±0.12	0.03±0.02	0.03±0.008	0.78±0.10	0.007±0.004	0.044±0.005	0.18	0.28	1.12^{NS}
SiO_4^{2-} (mg/l)	6.87±2.51	0.24±0.11	11.63±2.35	12.61±2.32	0.55±0.29	13.76±1.73	6.25	8.98	1.46^{NS}
NH_4^+ (mg/l)	0.009±0.006	0.005±0.001	0.007±0.001	0.004±0.003	0.003±0.001	0.004±0.001	0.01	0	2.85*
TSS (mg/l)	14.6±9.21	11.4±2.33	22.34±4.16	8.62±4.23	8.78±2.75	10.22±6.55	16.13	9.21	3.73**
Chl a (mg/m^3)	12.54±6.22	3.05±1.39	9.09±2.87	33.4±9.90	3.13±1.55	11.93±1.92	8.23	16.16	2.61*

NS – Not significant; * Significant at 5% level; **Significant at 1% level.

3.3 Salinity

The mean salinity values in OFSF and AFSF stations of VGE ranged from 15.67 ppt (FP-1) to 26.54 ppt (FP-3) and from 1.44 ppt (FP-1) to 15.28 ppt (FP-2) 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 considerable during all the periods of sampling in OFSF and AFSF stations, with higher bottom salinity values (Fig. 2 a, b; Fig. 3 a, b; Fig. 4 a, b). Salinity distinction among

Table 3. Correlation matrix for OFSF stations of Vashista Godavari Estuary

Variable	*Temperature*	*pH*	*Salinity*	*DO*	*BOD*	*NO$_2^-$*	*NO$_3^-$*	*PO$_4^{3-}$*	*SiO$_4^{2-}$*	*NH$_4^+$*	*TSS*	*Chl a*
Temperature	1											
pH	-0.89	1										
Salinity	0.63	-0.91	1									
DO	-0.6	0.18	0.23	1								
BOD	-0.17	-0.29	0.65	0.88	1							
NO$_2^-$	0.64	-0.92	0.99*	0.21	0.63	1						
NO$_3^-$	0.36	0.09	-0.48*	-0.96	-0.97*	-0.46	1					
PO$_4^{3-}$	-0.05	0.49	-0.80*	-0.76	-0.97*	-0.79	0.91	1				
SiO$_4^{2-}$	0.98	-0.81	0.51*	-0.71	-0.31	0.52	0.5	0.09	1			
NH$_4^+$	0.25	0.2	-0.58*	-0.92	-0.99*	-0.56	0.99	0.95	0.39	1		
TSM	0.98	-0.95	0.76*	-0.45	0	0.77	0.19	-0.22	0.94*	0.08	1	
Chl a	0.58	-0.15	-0.25	-0.99	-0.89*	-0.23	0.96	0.78	0.69	0.93	0.43	1

Note: * indicates significant correlations at 5 % level

Table 4. Correlation matrixfor AFSF stations ofVasishta Godavari Estuary

Variable	*Temperature*	*pH*	*Salinity*	*DO*	*BOD*	*NO$_2$-*	*NO$_3^-$*	*PO$_4^{3-}$*	*SiO$_4^{2-}$*	*NH$_4^+$*	*TSS*	*Chl a*
Temperature	1											
pH	0.42	1										
Salinity	0.08	-0.86	1									
DO	0.62	-0.44	0.83	1								
BOD	-0.99	-0.54	0.04	-0.51*	1							
NO$_2^-$	0.95	0.14	0.36	0.81	-0.91	1						
NO$_3^-$	-0.33	0.71	-0.96*	-0.94*	0.19	-0.58	1					
PO$_4^{3-}$	-0.42	0.64	-0.94*	-0.97*	0.29	-0.65	0.99	1				
SiO$_4^{2-}$	0.6	0.97	-0.73*	-0.24	-0.7	0.35	0.55	0.46	1			
NH$_4^+$	-0.1	0.85	-0.99*	- 0.84*	-0.02	-0.38	0.97	0.94	0.72	1		
TSM	0.99	0.29	0.22	0.72	-0.96	0.98	-0.45	-0.54	0.48*	-0.24	1	
Chl a	-0.18	0.81*	-0.99*	-0.88	0.05	-0.45	0.98	0.97	0.66	0.99	-0.32	1

Note: * indicates significant correlations at 5 % level

surface and bottom shows an increasing trend from head to mouth in both the estuaries (AFSF stations to OFSF stations), demonstrating that the Godavari estuary is like other Indian estuaries (Ramanadham and Varadarajulu 1975; Cherian *et al.*, 1975). High salinity values in OFSF stations over the AFSF stations during all the periods of sampling (Fig. 2 a, b; Fig. 3 a, b; Fig. 4 a, b) indicate pristine marine domination in the OFSF stations of middle and lower reaches of the estuary, which is witnessed by weak negative correlation of salinity with nitrate, phosphate, ammonium except silicate (Table 3). In AFSF stations, salinity was lowest in monsoon, showed an increasing trend from post monsoon followed by pre monsoon. The fresh water inflow from river impacted altogether, bringing down the saltiness during the monsoon. Salinity shows a strong negative correlation with nitrate, phosphate, silicate and ammonium (Table 3 & 4) indicates that these stations are dominated by fresh water (Lal, 1978; Edokpayi *et al.*, 2010; Usha *et al.*, 2015).

3.4 Dissolved Oxygen

The mean DO values in OFSF and AFSF stations of VGE ranged from 5.74 mg/l (FP-1) to 7.85 mg/l (FP-2) from 7.54 mg/l (FP-1) to 8.32 mg/l (FP-3). The difference between surface and bottom DO were set apart in AFSF stations than OFSF stations (Fig. 2 c, d; Fig. 3 c, d; Fig. 4 c, d) and were high in pre monsoon, which is attributed to the river discharge. 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 sampling periods (Fig. 2 c, d; Fig. 3 c, d; Fig. 4 c, d). The low DO concentration in FP-3 followed by FP-1 (Fig.2.c; Fig.3.c) of OFSF stations in lower and middle reaches of estuary might be either because of organic matter load discharged through the shrimp pond effluents (Hopkins *et al.*, 1993; Boyd

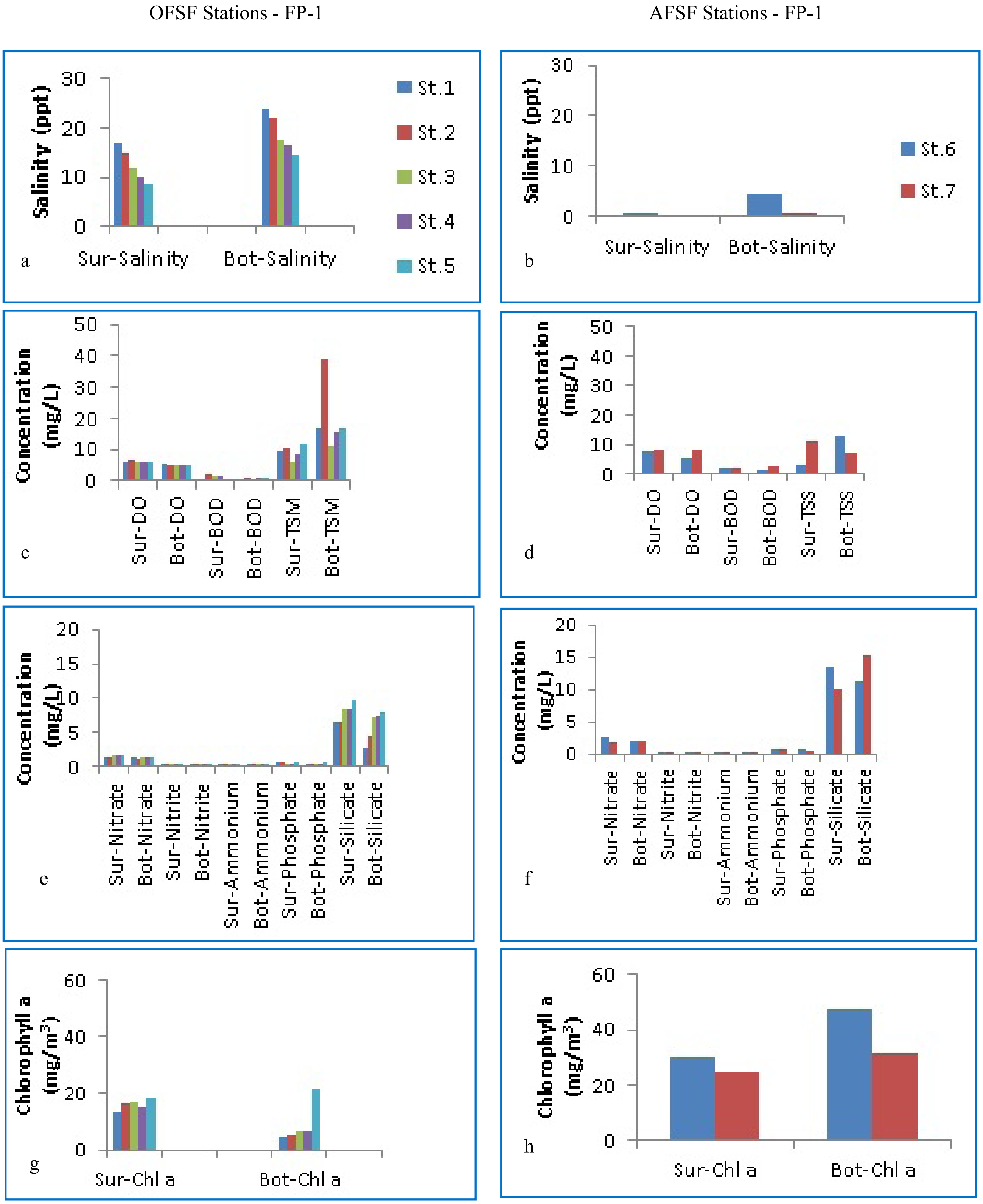

Fig. 2a-h. Physico-chemical parameters of surface and bottom waters of VGE during FP-1:
a & b. Salinity; c & d. Dissolved Oxygen, Biochemical Oxygen Demand and Total Suspended Solids;
e & f. Nutrients; g&h. Chlorophyll-a

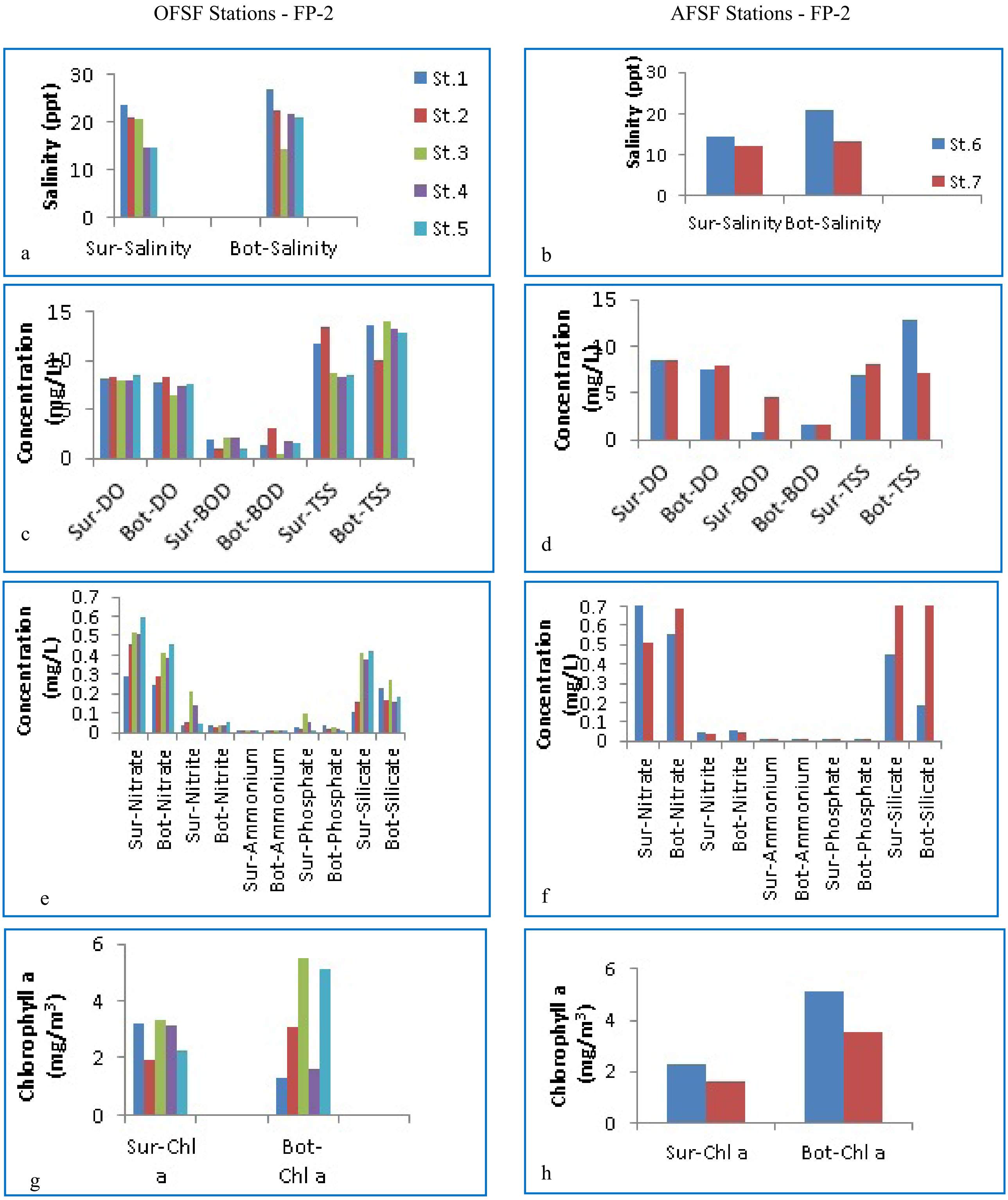

Fig. 3a-h. Physico-chemical parameters of surface and bottom waters of VGE during FP-2: a & b. Salinity; c & d. Dissolved Oxygen, Biochemical Oxygen Demand and Total Suspended Solids; e & f. Nutrients; g&h. Chlorophyll-a

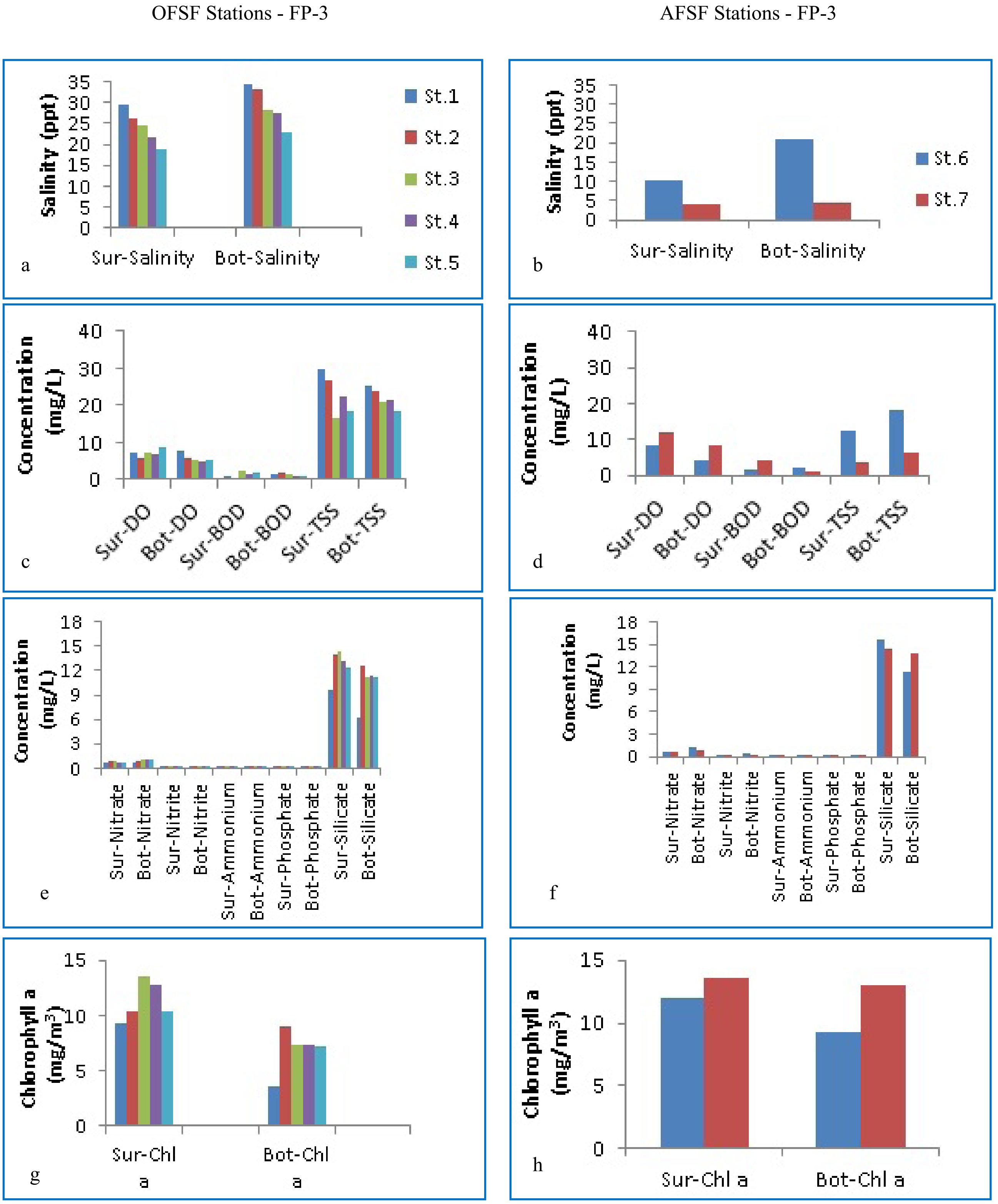

Fig. 4a-h. Physico-chemical parameters of surface and bottom waters of VGE during FP-3:
a & b. Salinity; c & d. Dissolved Oxygen, Biochemical Oxygen Demand and Total Suspended Solids;
e & f. Nutrients; g&h. Chlorophyll-a

2000; Miranda-Baeza *et al.,* 2007; Casillas-Hern´andez *et al*., 2007; Abdullai *et al*., 2008) or the influence of salinity and upwelling tides (Davis, 1975). This is like wise upheld by the negative correlation of DO with all nutrient species in OFSF stations (Table. 3), which shows that a relatively lower DO water mass was brought into the OFSF stations from the inner part of the estuary (Magni *et al*., 2002). However, relatively higher DO values in the AFSF stations could be attributed to the input of DO rich fresh water through river discharge.

3.5 BOD

The mean BOD values in OFSF and AFSF stations of VGE ranged from 1.03 mg/l (FP-1) to 1.54 mg/l (FP-2) and from 1.2 mg/l (FP-3) to 2.18 mg/l (FP-2) respectively. The surface and bottom differences of BOD were marked in AFSF stations than OFSF stations (Fig. 2 c, d; Fig. 3 c, d; Fig. 4 c, d). The BOD values of all the farming periods were highly significant between OFSF and AFSF stations ($p \leq 0.01$) (Table 2).

BOD is regularly utilized as a substitute for the degree of organic pollution of water (Sawyer *et al*., 2003) and gives a gauge of anthropogenic amount and natural biodegradable organic matter. Relatively higher BOD values were found in AFSF stations than in OFSF stations during all the periods of study in both the estuaries (Table 2), which may be due to the high amounts of wastewater from urban and agricultural activities, rich in organic matter entering into these regions (AL-Hejuje, 2017). However, a significant negative correlation of BOD with nitrate, ammonium and phosphate (Table 3) in OFSF stations in the middle and lower reaches of VGE indicates the availability of organic matter in these stations (Marisol *et al*., 1998) through the release of shrimp pond effluents rich in organic matter. Whereas, in AFSF stations in upper reaches of estuary, significant negative correlation of DO with BOD, nitrate, ammonium and phosphate (Table 4) was observed. Marisol *et al*. (1998) found negative correlation of DO with BOD, nitrate, ammonium and phosphate as organic matter is partially oxidized by oxygen, whilst nutrients are responsible for the eutrophication of fresh water in upper reaches, causing a further increase in organic matter concentration, which is corroborated with results of our study and supported by the relatively higher BOD values observed in AFSF stations than OFSF stations (Table 2).

3.6 TSS

The mean TSS levels in OFSF and AFSF stations of VGE ranged from 11.4 mg/l (FP-2) to 22.34 mg/l (FP-3) and from 8.62 mg/l (FP-1) to 10.22 mg/l (FP-3) respectively. The concentrations of TSS between surface and bottom water differ significantly at OFSF and AFSF stations (Fig. 2 c, d; Fig. 3 c, d; Fig. 4 c, 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 to be higher than AFSF stations with high values in bottom water (Fig. 2 c, d; Fig. 3 c, d; Fig. 4 c, d) 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 the course of shrimp pond effluent discharge (especially FP-3) due to the resuspension of bottom sediments of shrimp ponds and erosion of channel walls (Barraza-Guardado *et al*. 2013) and the absence of this during FP-1 may be diminished by monsoon discharge. However, in AFSF stations, levels of TSS were observed even though there was no discharge of pond effluents, showing the nearby connection between transient climate occasions and water quality (Trott and Alongi 2010).

3.7 Nutrients

The mean nitrite values in OFSF and AFSF stations ranged from 0.03 mg/l (FP-1) to 0.12 mg/l (FP-3) and from 0.02 mg/l (FP-1) to 0.1 mg/l (FP-3) respectively. There were no significant differences between surface and bottom nitrite concentrations 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 show up as transient varieties by the oxidation of ammonium or by the reduction of nitrate. The nitrite concentrations were observed low at all stations during all sampling periods. Nitrite levels above 0.1 mg/l in water bodies can be toxic (Wedemeyer, 1996). Concentrations of nitrite in OFSF stations were relatively high compared to AFSF stations though not much variation exists between OFSF and AFSF stations (Table 2; Fig.2 e, f; Fig. 3 e, f; Fig. 4 e, f), might be due to discharge of shrimp pond effluents, surface runoff and nutrient-rich, back water intrusion into OFSF stations of middle and lower reaches of estuary (Satpathy *et al*., 2010). This is corroborated by the positive correlation of salinity with nitrite (Table 3), 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 (You *et al*., 2016).

The mean values of nitrate in OFSF and AFSF stations ranged from 0.41 mg/l (FP-2) to 1.39 mg/l (FP-1) and from 0.61 mg/l (FP-2) to 2.14 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 (Fig.2 e, f; Fig. 3 e, f; Fig. 4 e, f), but marked differences were found in FP-2 both in OFSF and AFSF stations (Fig.3. e, 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 highest values during monsoon (FP-1) followed by pre-monsoon (FP-3), and post monsoon (FP-2) (Table 2). The highest monsoon values are due to fresh water influx. The negative correlation between salinity and nitrate both in OFSF stations (Table 3), and AFSF stations (Table 4) as reported by others (Choudhary and Panigrahy, 1991; Satpathy 1996a; Edokpayi *et al*., 2010) demonstrated that fresh water influx is the principle wellspring of this nutrient. However, especially in OFSF stations, the other nitrogenous nutrients except nitrite showed a negative correlation (Table 3) with salinity and a positive correlation with silicate, showing their allochthonous origin is responsible for stamped contrasts in surface and bottom values in FP-2.

The mean NH_4^+-N values in OFSF and AFSF stations ranged from 0.005 mg/l (FP-2) to 0.009 mg/l (FP-1) and from 0.003 mg/l (FP-2) to 0.004 mg/l (FP-1 & FP-3) respectively. NH_4^+-N concentration between surface and bottom did not differ significantly in OFSF and AFSF stations during all sampling periods (Fig.2 e, f; Fig. 3 e, f; Fig. 4 e, f). The mean NH_4^+-N values of all the farming periods were significant ($p \leq 0.05$) (Table 2).

The NH_4^+-N concentrations were observed low at OFSF and AFSF stations during entire study period (Table 2). The negative correlation of NH_4^+-N with salinity as reported by others (Satpathy *et al.,* 2010; George *et al.,* 2012) both in OFSF stations (Table 3) and in AFSF stations (Table 4) indicates that freshwater is the source of this nutrient into the study area, and not related to the aquaculture activities.

The mean phosphate values in OFSF and AFSF stations ranged from 0.03 mg/l (FP-2 & FP-3) to 0.45 mg/l (FP-1) and from 0.007 mg/l (FP-2) to 0.78 mg/l (FP-1) respectively. There was no noteworthy difference between surface and bottom water concentration of phosphate in OFSF and AFSF stations during all sampling periods (Fig.2 e, f; Fig. 3 e, f; Fig. 4 e, 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 relay on its concentration in the freshwater that blended in with the sea water within the sea-land interaction zone, phytoplankton-uptake addition through confined upwelling, and replenishment as a result of microbial deterioration of organic matter (Paytan and Mclaughlin, 2007). Phosphate showed a decreasing trend in OFSF and AFSF stations during all the periods of sampling with highest values during monsoon followed by pre and post monsoon seasons (Table 2). The highest values in AFSF stations and OFSF (FP-1) stations during monsoon are due to fresh water influx and mixing of fresh water with seawater accompanied by aquaculture effluents in middle and lower reaches of estuary respectively (Gouda and Panigrahy, 1995; Liu *et al*., 2009).

To differentiate the OFSF and AFSF stations, silicate concentration was measured. The mean silicate concentration in OFSF and AFSF stations ranged from 0.24 mg/l (FP-2) to 11.63 mg/l (FP-3) and from 0.55 mg/l (FP-2) to 13.76 mg/l (FP-3) respectively. Silicate concentration between surface and bottom differ significantly in OFSF and AFSF stations during all the farming periods (Fig.2 e, f; Fig. 3 e, f; Fig. 4 e, f). According to Patra *et al.,* (2010) silicate content of water fluctuates with water salinity and higher silicate content was recorded in low salinity area, which is corroborated with the results of our study. The mean silicate values of all the farming periods were significant ($p \leq 0.05$) in VGE (Table 2).

Silicate showed a decreasing trend from pre monsoon followed by monsoon and post monsoon both in OFSF and AFSF stations (Table 2). Higher silicate focuses were observed in pre monsoon in contrast to monsoon both in OFSF and AFSF stations, which are upheld by the negative correlation of salinity with silicate both in OFSF and AFSF stations (Table 3 & 4). This might be due to arrival 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 sensible to state that river discharge is high all through the study area.

3.8 Chlorophyll a

The mean chl a concentration in OFSF and AFSF stations ranged from 3.05 mg/m^3 (FP-2) to 12.54 mg/m^3 (FP-1) and from 3.13 mg/m^3 (FP-2) to 33.4 mg/m^3 (FP-1) respectively. Chl-a concentration between surface and bottom water differ significantly in OFSF and AFSF stations, which is more marked in monsoon season (Fig. 2 g, h; Fig. 3 g, h; Fig. 4 g, h). The mean chlorophyll values of all the farming periods were significant ($p \leq 0.05$) (Table 2).

Chl-a concentration in AFSF stations was found higher than OFSF stations during the study period (Table 2) without the intervention of whether it is surface or bottom. Chl-a concentration demonstrated 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 bounty, which is upheld by a strong positive correlation of pH with Chl-a (Table 4), showing the rapid growth of algae brought about by high concentrations of nitrogen and phosphorous released from ceaselessly dosed snare with river discharge (Zang *et al.,* 2011). In OFSF stations, an insignificant correlation of pH with Chl-a (Table 3) 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 (Burford, 1997).

4. Conclusion

The present study summarizes the environmental impact of shrimp pond effluent and phytoplankton biomass in a tropical wave dominated estuary with respect to 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 correlation analysis concludes that 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. The surpassed BOD values in AFSF stations than OFSF stations were due to the high amounts of wastewater from urban and agricultural activities, rich in organic matter, entering into these regions. The surpassed ionized ammonia concentrations in OFSF stations were not related to the aquaculture activities. High chlorophyll-concentrations in AFSF stations are due to higher phytoplankton abundance. The surpassed TSS levels in OFSF stations are due to the shrimp pond effluents discharge and resuspension of bottom sediments of shrimp ponds and erosion of channels walls. Our results conclude that some water quality attributes are altered by effluent discharge in outfall sites, but a comparison of water quality between OFSF and AFSF stations implies that the conditions at the out fall sites returned to ambient levels. Moreover, The VGE, which has been affected by aquaculture effluents, has some ability to acclimatize or transform nutrients derived from intermittent inputs from the shrimp ponds. The assimilative and/or dissimilative mechanisms were not examined, yet all things considered, a blend of cycles, in all likelihood mineralization and subsequent dissipation (for example: respiration, denitrification) by planktonic food webs, and dilution by river discharge, physical handling by tides, were the major mechanisms.

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Conflicts of Interest

No conflicts of interest.

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