Indian Journal of Geo Marine Sciences
Vol. 49 (1), January 2020, pp. 24-33

Variation of hydrochemical parameters with reference to geomorphological features in Godavari estuary, India

N.V.H.K. Chari*, Ch. Venkateswararao, R. Muralikrishna& K. Sivakrishna
Department of Physical chemistry, Nuclear Chemistry and Chemical Oceanography, School of Chemistry, Andhra University, Visakhapatnam-530003
[E-mail: harinaroju@rediffmail.com]

Received 25 May 2018; revised11 September 2018

In this study, seasonal observations of hydrochemical parameters were measured in the estuarine regions of Gautami Godavari (GGE) and Vasishta Godavari (VGE), which are surrounded by extensive mangrove swamps and closely spaced beach ridge-swale complex, respectively. A significant vertical stratification in the water column showed in the VGE region due to the strong influence of saline water intrusion. NO_2^- -N was higher and NO_3^- -N was lower in VGE during the end of the post monsoon season with reference to excretion by phytoplankton and uptake during the process of primary production respectively, which is also supported by higher concentrations of Chlorophyll a. Nutrients (NO_3^- -N, PO_4^{3-}-P and SiO_4^{2-}-Si) showed conservative behaviour with salinity in GGE, whereas, in the case of VGE absence of this is due to intrusion of saline water was significantly higher.

[Keywords: Chlorophyll a**;** Gautami Godavari; Nutrients; Salinity; Vasishta Godavari**]**

Introduction

Estuaries are highly dynamic, biologically diverse and highly productive ecosystems, support to survive more population, which depends on catchment[1,2]. Rapid increase in the population becomes a major concern for substantial requirement of alternative food. Therefore, the aquaculture has become a significant and rapidly growing component of world aquatic production. Mostly aquaculture ponds are found in and around the river and estuarine waters. The discharge of washings and effluents from these ponds are directly affecting the ecology of the adjacent water bodies. India is known as the second largest country for the aquaculture, about 95 % of the aquaculture; is based on the freshwater farming and the rest 5 % comprises of brackish and marine farming. Andhra Pradesh ranks first in coastal and second in fresh water aquaculture, situated around Godavari River. The River Godavari is India's second longest river after the Ganga. At Dowleswaram, it bifurcates into two main distributaries called Vasishta Godavari (VG) and Gowthami Godavari (GG). These are the western and eastern distributaries of the Godavari Esturine system and drains into the Bay of Bengal. Both the estuaries are influenced by anthropogenic runoff from small and large-scale industries, domestic, agriculture and aquaculture activities etc. The average width of the GG (~1200 m) was significantly higher compared to the VG (~900 m), so high volume of fresh water discharge (67 %) enters into the former estuary[3,4] from upstream during monsoon season. GG was surrounded by extensive mangrove swamps, which were intermixed by thin beach ridges appears to be a river dominated estuary. In contrast, Vasishta, with the closely spaced beach ridge plains seems to reflect a more wave-dominated system[5]. Because of this contrasting geomorphic features and anthropogenic activities, significant difference in biogeochemical processes may be taking place in these estuaries. In this regard the present study is proposed to address the hydro chemical parameters distribution in both the estuaries. To achieve our objective seasonal observations were done in both the estuaries from upstream to downstream.

Materials and Methods

Field works werecarried out in both the estuaries from upstream to downstream region during the end of the three seasons (October 2016, Monsoon; February 2017, Post monsoon; June 2017, Pre monsoon season) using mechanized boats. Water samples were collected fromsurface (< 1 m) and bottom (~ 5 or 10 m, based on column depth) by using Niskin Sampler at the three stations in each estuary

(Fig. 1) represents the upper estuary (UE, Stations 1 & 4), Middle Estuary (ME, Stations 2 & 5) and Lower Estuary (LE, Stations 3 & 6). 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 lid. Salinity was determined by the argentometric titration method and the pH was measured on Thermo Scientific Orion Star benchtop pH metre with accuracy of ± 0.01. For the determination of Chlorophyll a, water samples were filtered through GF/F filters and extraction 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[6].

Results and Discussion

The results of hydro-chemical parameters were shown in Table 1 & 2. The temperature of water ranged from 27.0 to 33.50 °C, lower temperatures were found during the end of the post monsoon in

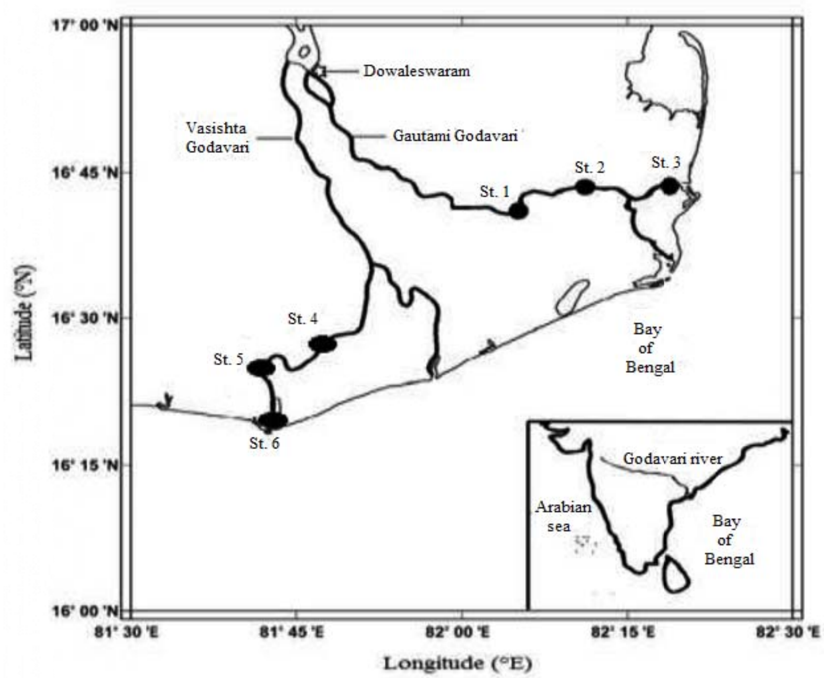

Fig. 1 — Station location map and sampling stations (•)

Table 1 — Summary of Hydrochemical parameters in Vasishta Godavari

	Monsoon			Post Monsoon			Pre Monsoon		
	Min	Max	Avg ± SD	Min	Max	Avg ± SD	Min	Max	Avg ± SD
Salinity	0.30	22.99	10.50±9.12	12.19	27.00	19.56±6.76	4.12	34.45	19.56±34.44
Temperature (°C)	29.00	30.00	29.25±0.42	27.00	29.50	28.17±0.88	30.50	33.50	32.17±1.21
pH	8.02	8.62	8.20±0.24	7.67	8.44	7.95±0.28	7.76	8.50	8.12±0.30
DO (µM)	160	265	207±45	200	265	243±23	165	270	229±38
Saturation (%)	69	103	85±14	90	115	106±8	77	152	110±25
NO3$^-$ -N (µM)	20.42	34.18	25.60±5.38	3.23	9.98	6.37±2.51	9.53	14.02	11.69±1.71
NH_4^+-N (µM)	0.13	1.19	0.54±0.41	0.18	0.44	0.30±0.12	0.15	0.45	0.30±0.13
NO_2^- -N (µM)	0.53	0.75	0.63±0.10	0.77	1.03	0.90±0.09	0.07	1.19	0.529±0.40
PO_4^{3-} -P (µM)	0.32	0.90	0.55±0.21	0.27	0.99	0.55±0.31	0.23	0.54	0.43±0.11
SiO_4^{2-} -Si (µM)	29.76	167.28	96.80±44.56	5.76	46.08	24.76±16.29	68.16	161.04	128.84±35.63
Chla (mg/m3)	4.76	31.34	17.61±10.11	1.27	5.51	3.07±1.53	3.65	14.45	10.26±4.16
DIN:DIP	34.24	80.42	53.19±16.54	8.54	29.37	16.71±8.57	21.79	46.71	30.99±8.52

Table 2 — Summary of Hydrochemical parameters in Gautami Godavari

	Monsoon			Post Monsoon			Pre Monsoon		
	Min	Max	Avg ± SD	Min	Max	Avg ± SD	Min	Max	Avg ± SD
Salinity	0.16	17.33	7.61±7.11	10.79	29.71	21.83±8.30	1.50	29.77	19.25±13.44
Temperature (°C)	29.00	31.00	30.00±0.63	29.00	30.00	29.46±0.41	29.50	30.50	30.33±0.41
pH	7.93	8.47	8.16±0.23	7.83	8.14	7.95±0.11	7.35	8.49	8.05±0.48
DO (μM)	185	311	242±51	186	233	215±19	218	270	248±17
Saturation (%)	78	124	99±17	78	109	96±10	98	125	110±12
$NO3^-$ -N (μM)	17.60	32.94	27.29±5.61	9.54	23.15	14.44±4.89	4.42	20.24	10.79±7.19
NH_4^+-N (μM)	0.30	1.85	1.15±0.69	0.15	0.80	0.42±0.22	0.15	1.20	0.55±0.41
NO_2^- -N (μM)	0.40	0.62	0.50±0.07	0.11	0.35	0.24±0.08	0.13	0.60	0.62±0.70
PO_4^{3-} -P (μM)	0.99	1.40	1.16±0.16	0.54	1.08	0.78±0.19	0.14	0.45	0.26±0.13
SiO_4^{2-} -Si (μM)	89.76	220.08	157.72±50.56	7.44	53.52	23.27±18.99	33.36	241.68	117.90±84.82
Chla (mg/m^3)	4.66	26.34	14.98±9.10	2.83	6.72	4.36±1.31	3.25	11.36	7.34±2.97
DIN:DIP	18.63	30.53	25.16±5.16	11.23	33.04	20.19±7.49	14.49	152.01	68.01±63.80

both the estuaries due to winter coolingreported earlier in these estuaries[7-10]. Salinity varied from 0.30 to 34.45 in VGE, whereas in the GGE ranged from 0.16 to 29.77. It showed increasing trend from UE to LE in both the estuaries during all the seasons (Fig. 2 a-f) due to terrestrial fresh water influence decreases and intrusion of saline water increases. However, significant low salinity water observed in our study in the UE of both the estuaries during the end of the premonsoon season due to the release of stored water by the irrigation department, Govt. of India from the dam which was located at upstream[11] (Discharge data during the study period included in the appendix Table 1). Temperature and salinity play major role in the density stratification in the aquatic environments. In this study, temperature did not show significant difference in the surface and bottom waters in both the estuaries. But, salinity showed significant differences between the surface and bottom waters were significantly high in the VGE (~5.88) throughout the study period than the GGE (~2.65 PSU). Previous study on VGE stated that the salinity gradient index was significant between the surface and bottom waters[7]. Therefore, salinity plays a major role in the density stratification in VGE, due to the intrusion of the marine water. In the case of GGE, which receives significantly high fresh water input compared to VGE during monsoon season leads to the less horizontal and vertical gradient in salinity. However, in the remaining seasons mixing in GGE was observed due to deep water column in the middle of the estuary[3,12].

Water pH ranged from 7.35 to 8.62 which showed (Fig. 3 a-f) significant decreasing trend from UE to LE in both the estuaries during the end of the monsoon season due to the removal of CO_2 during the process of photosynthesis[13] in the downstream. However, during the end of the post monsoon season pH increased from UE to LE in VGE, but in GGE significantly lower values in ME which might be due to bacterial respiration of organic matter released CO_2 in to the water column. This is also reported in the GGE, Grass Primary Production (GPP) to Respiration (R) ratio was <1 as production takes place only in the upper water column (~3 m) and respiration takes place in the entire water column[14]. During the end of the pre-monsoon season, pH showed opposite trend in these estuaries, which showed decreasing trend from UE to LE in VGE and vice versa in GGE. This could be due to *in situ* biological consumption associated primary production that leads to decrease of pH during no discharge period in VGE from upstream to downstream. Similar observations were also reported in other aquatic environments[15-17]. Whereas, in the case of GGE, increase of pH from upstream to down stream could be due to respiration of organic matter. This also reported in this estuary, community respiration (-30.7 mmolCm^{-2} d^{-1}) was significantly high compared to the other seasons[14].

Dissolved oxygen concentration ranged from 160 to 311 μM, which showed average lower concentration during the end of the monsoon and the pre-monsoon season in VGE than GGE. This is because of less volume of fresh water entered into in the VGE (~30 %) as compared to the GGE (~70 %) from dam during these seasons (Appendix, Table. 1). In contrast, DO was higher in VGE than GGE during the end of the post-monsoon season which may be due to respiration of organic matter that may take place in the later estuary (Table 1, 2). This also supports the lower pH conditions observed in the GGE, which may

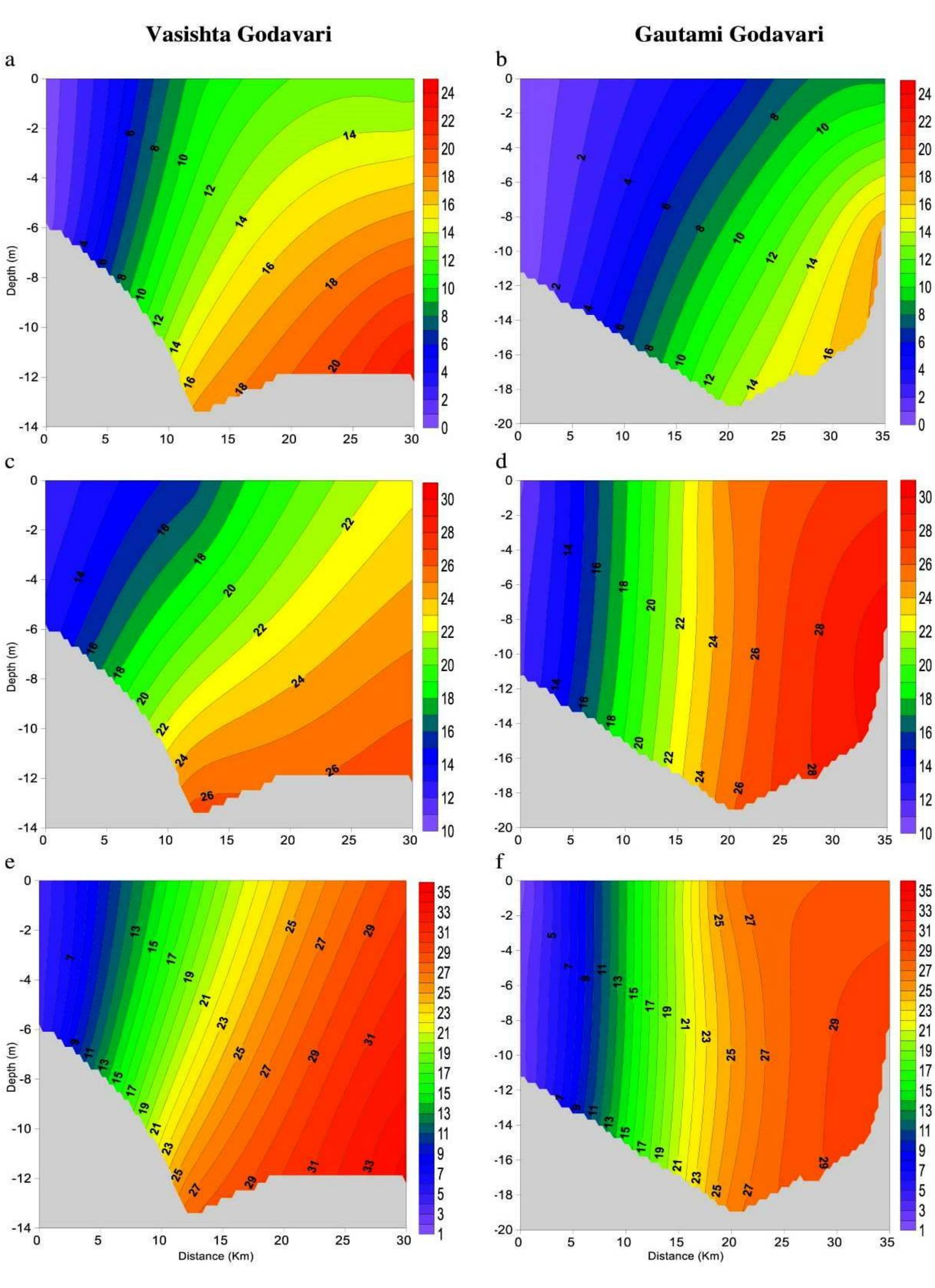

Fig. 2 — Seasonal distribution of salinity in the Vasishta and Gautami Godavari: a & b) Monsoon, c & d) Post monsoon, e & f) Pre monsoon season.

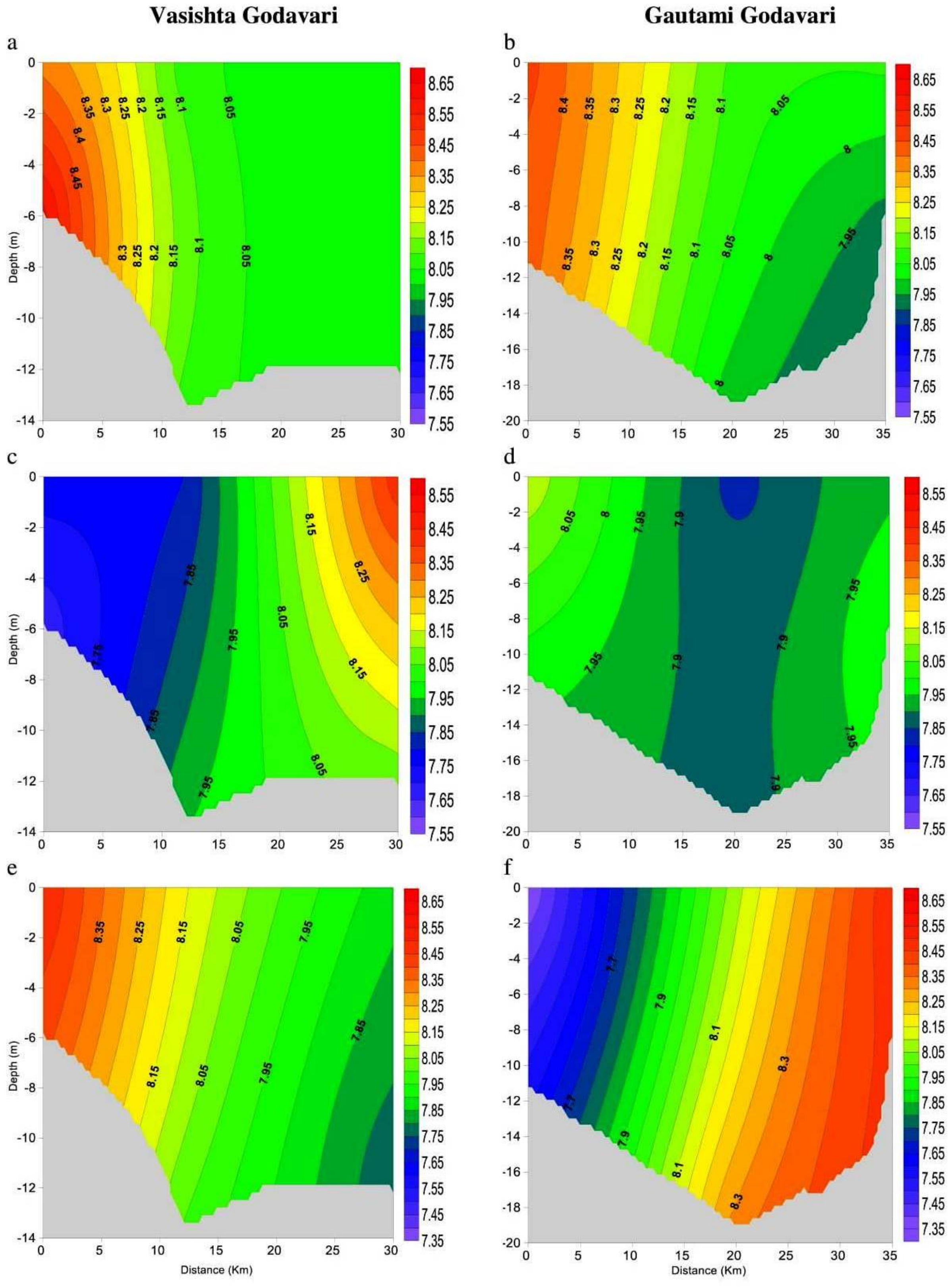

Fig. 3 — Seasonal distribution of pH in the Vasishta and Gautami Godavari: a & b) Monsoon, c & d) Post monsoon, e & f) Pre monsoon season.

be formed by the degradation of organic matter by utilization of dissolved oxygen. To differentiate the production and respiration of organic matter, oxygen saturation (%) was calculated[18] from the temperature, salinity and measured DO concentrations. DO saturation ranged from 69 to 124 %, which showed under saturation during the end of the monsoon season in VGE due to less fresh water discharge in this estuary. However, in the case of GGE, saturation was significantly high in the entire water column during the end of the premonsoon season due to increase of primary production. DO was less saturated in GGE than VGE during the end of the post monsoon in the entire water column. This may be because of production as well as respiration of organic matter[14] taking place in the former estuary. Earlier reports also stated that production was significantly high due to the addition of aquaculture farms drainage, which contains nutrients leading to increase of primary production in VGE[7]. Average DO saturation was significantly high in the VGE than GGE except during the end of the monsoon season.

NH_4^+-N concentration ranged from 0.13 to 1.85 µM, which did not show significant spatial variation in both regions, but observed higher concentration during the end of the monsoon season due to fresh water discharge from upstream during this season. However, in the other seasons this was lower concentrations due to utilization during the process of photosynthesis may be taking place. NO_2^- -N was ranged from 0.07 to 1.03 µM, which did not show significant trend during the end of the monsoon and pre-monsoon season in both the estuaries. However, during the post monsoon season significantly higher concentration in VGE was observed which could be due to bacterial oxidation of ammonia[19] or excreted by phyotoplankton[20]. NO_3^- -N ranged from 3.23 to 40.86 µM, which showed significant seasonal and spatial variation in VGE (Fig. 4-f) was lower during the end of the post monsoon and decrease from UE to LE. This may be due to uptake by phytoplankton in the process of photosynthesis or due to the intrusion of saline water, which contains lower concentrations[21-23]. In the case of GGE, higher concentrations in surface water than bottom waters during the end of the monsoon and post monsoon seasons due to fresh water discharge from upstream water and mineralization of organic matter may be taking place, respectively. This also supported by the earlier studies in this estuary that showed high concentration of NO_3^- -N during non-discharge season[14].

PO_4^{3-} -P ranged from 0.14 to 1.40 µM, which did not show significant seasonal and spatial variation, and lower concentrations in VGE may be due to less fresh water discharge and intrusion of high saline water taking place. However, in GGE decreasing gradually from the end of the monsoon to the pre-monsoon season due to decreasing fresh water discharge and biological uptake during the process of photosynthesis. SiO_4^{2-} -Si ranged from 5.76 to 241.6 µM in the study area, and decrease in concentration from UE to LE in the both the estuaries during all the seasons. This showed lower concentration during the end of the post monsoon season in both the estuaries than the other seasons due to uptake by phytoplanktons in the process of photosynthesis (Fig. 5c). Higher SiO_4^{2-}-Si concentrations were observed in UE during pre-monsoon season in both the estuaries due to release of fresh water stored in the dam for the irrigation process in low lying areas[11]. On an averege, higher SiO_4^{2-}-Si concentrations in GGE during the study period was due to high volume of fresh water discharge into the earlier estuary than the later from the upstream (Fig. 5d).

Chl a ranged from 1.27 to 31.34 mg/m^3 and showed significantly higher concentrations during the end of the monsoon season and premonsoon season in VGE due to nutrient rich fresh water inputs and *in situ* primary production, respectively (Table 1 & 2). However, in the case of GGE even though nutrients inputs from upstream and local inputs, lower Chl-a was observed due to the bacterial degradation of phytoplanktons. This was also evidenced by higher heterotrophy activity in this estuary[14]. DIN to DIP ratio ranged from 8.54 to 152.01 mg/m^3, which was significantly higher in the VGE during the end of the monsoon season due to less fresh water discharge with low concentrations of PO_4^{3-}-P leaching from the rocks during the process of weathering. However, in other seasons, higher in GGE was seen due to local anthropogenic inputs and mineralization of organic matter that releases nitrogen species in this environment. Salinity showed significantly negative correlation with nutrients NO_3^- -N, PO_4^{3-}-P and SiO_4^{2-} -Si (n=18, p=001, <0.0001 and <0.001, respectively) in GGE compared to VGE during the study period (Fig. 6a-c). This explains that the former estuary is dominated by freshwater than the later. This is also evidenced by GGE surrounded by intense mangrove region, which resists the intrusion of saline water.

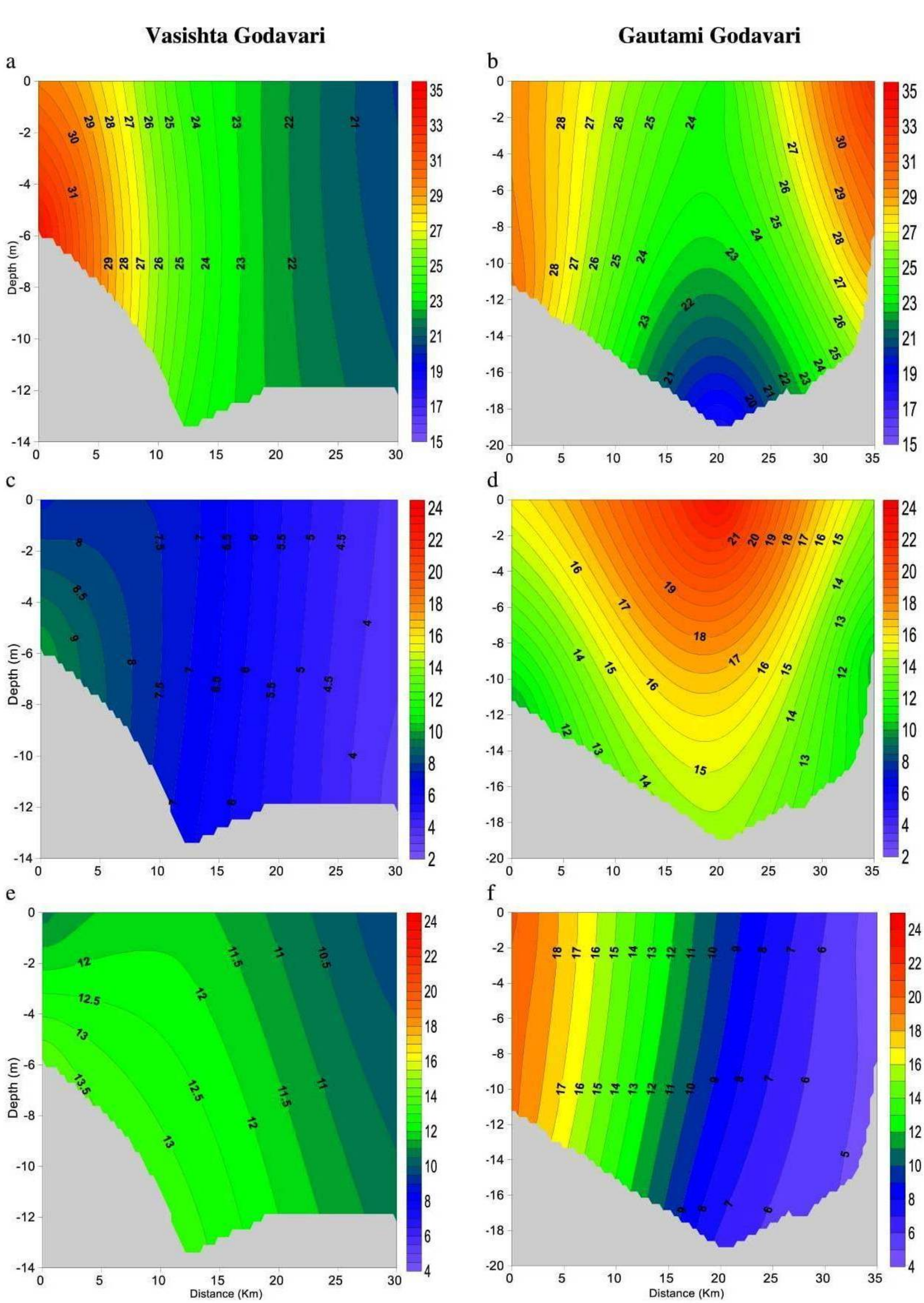

Fig. 4 — Seasonal distribution of NO_3^- -N (µM) in the Vasishta and Gautami Godavari: a & b) Monsoon, c & d) Post monsoon, e & f) Pre monsoon season.

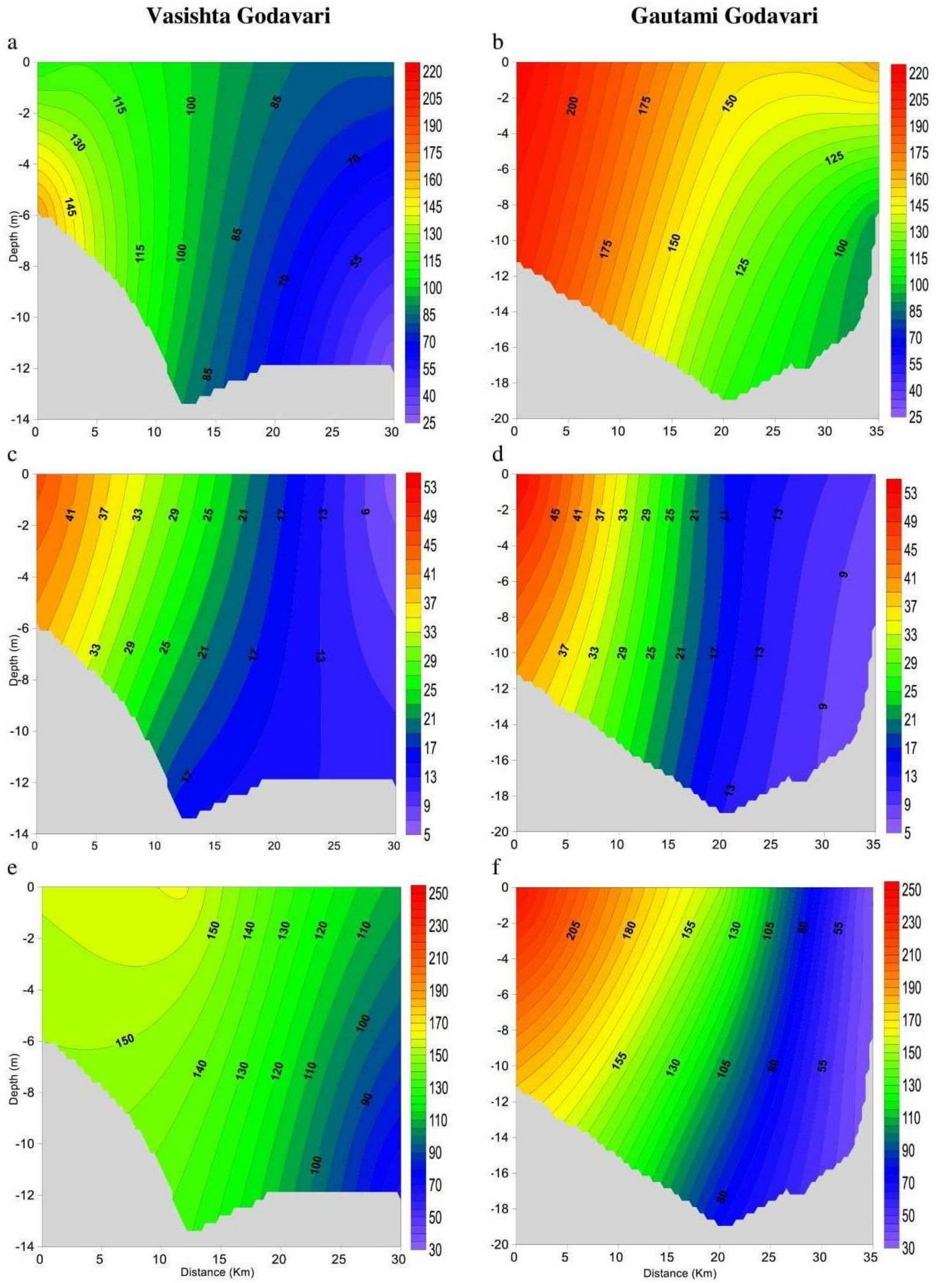

Fig. 5 — Seasonal distribution of SiO_4^{2-}-Si in the Vasishta and Gautami Godavari: a & b) Monsoon, c & d) Post monsoon, e & f) Pre monsoon seasons

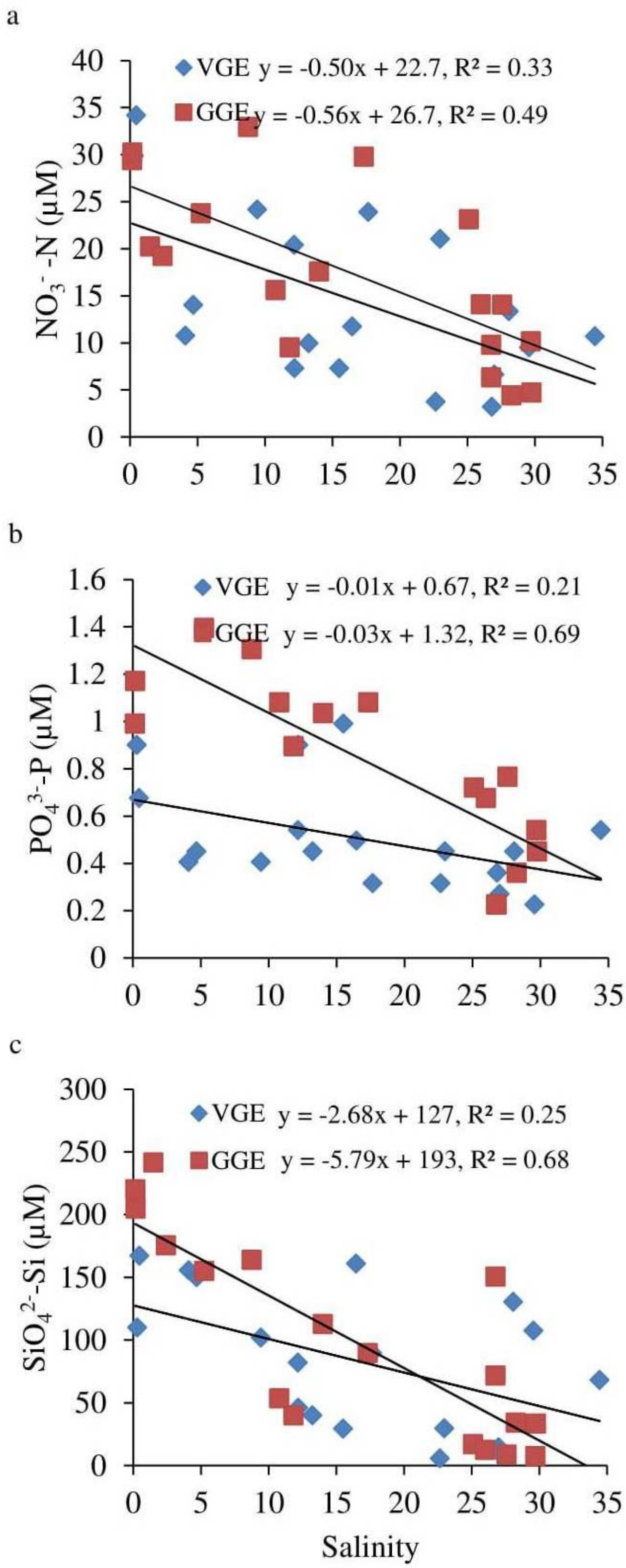

Fig. 6 — Correlation of a) NO_3^- -N b) PO_4^{3-}-P and c) SiO_4^{2-}-Si with salinity

Conclusion

Since the Gautami and Vasishta Godavari estuary have distinct geomorphological features, according to that significant differences in hydrochemical properties in the VGE. Density stratification was significant in VGE during the entire study period due to the intrusion of saline water. Even though fresh water discharge was less in VGE, significant primary production was higher compared to the respiration. Salinity showed non-conservative behaviour with nutrients in the entire study period in VGE. Further intense studies are required to study the aquaculture influences in this estuarine biogeochemistry.

Acknowledgement

This work was financially supported by the Department of Science and Technology, Science and Engineering Research Board to N.V.H.K. under grant No. SR/FTP/ES-56/2013. The authors acknowledge their Ph D Supervisor Prof. Nittala S. Sarma (Emeritus Scientist, CSIR) for providing instrumental facilities and suggestions.

References

1 Day, J. W., Hall, C.A.S., Kemp, W.M.,Yanez-Arancibia, A., *Estuarine Ecology*. John Wiley & Sons, Inc., (eds). New York, Chichester, Brisbane, Toronto, Singapore, 1989, pp. 558.

2 Costanza, R., Kemp, W.M., and Boynton, W.R., Predictability, scale and biodiversity in coastal and estuarine ecosystems: implications for management. *Ambio*, 1993, 22, 88–96.

3 Sridevi, B., Sarma, V.V.S.S., Murty, T.V.R., Sadhuram, Y., Reddy, N.P.C.,Vijayakumar, K., Raju, N.S.N., Jawahar Kumar, C.H., Raju, Y.S.N., Luis, R., Kumar, M.D., and Prasad, K.V.S.R., Variability in stratification and flushing times of the Gautami–Godavari estuary, India. *Ind. J. Ear. Syst. Sci.*, 2015, 124, 993–1003.

4 Kumar, A.R.S., Ramana Murthy, T.V., Malleswara Rao, M.M., Ranga Rao, V., and Reddy, B.S.R., Circulation and mixing process in Vasishta-Godavari estuary, Eastcoast of India. *Proc. Nat. Sym*, HACPO, 2005, pp 92-97

5 Rao, K.N., Saito, Y., Nagakumar, K.C.V., Demudu, G., Rajawat, A.S., Kubo, S., and Zhen, L., Palaeogeography and evolution of the Godavari delta, east coast of India during the Holocene: an example of wave-dominated and fan-delta settings. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2015, 440, 213-233

6 Grasshoff, K., Ehrhardt, M., Kremling, K. (Eds.), *Methods of Seawater Analysis*, third ed. VerlagChemie, Weinheim (pub), 1999, pp. 603.

7 SaiSastry, A.G.R., and P. Chandramohan., Physico-chemical characteristics of Vasishta- Godavari estuary, eastcoast of India: Pre-pollution status. *Ind. J. Mar. Sci*, 1990, 19, 42-46.

8 Ranga Rao, V., Ramana, Y.V., and Reddy, B.S.R., Salinity and current distribution in the Godavari estuary, east coast of India. *Ind. J. Mar. Sci*, 1988, 17, 14-18.

9 Reddy, B.S.R., and Ranga Rao, V., Seasonal vitiations in temperature and salinity in Gauthami-Godavari estuary. *Proc. Ind. Acad. Sci*. (Earth Planetaary. Science.). 1994, 103, 47-55.

10 Padmavathi, D., and Satyanarayana, D., Distribution of nutrients and major elements in riverine, estuarine and adjoining coastal waters of Godavari, Bay of Bengal. *Ind. J. Mar. Sci*, 1999, 28,345-354.

11 Sasidhar, N., Blue print for Godavari River utilisation in Andhra Pradesh. http://www.indiawaterportal.org/sites/indiawaterportal.org/files. pdf. 2009

12 Ramana, Y.U., Rao, V.R., and Reddy, B.S.R., Diurnal variation in salinity and currents in vasishta-Godavari estuary, east coast of India. *Ind. J. Mar. Sci*, 1989, 18, 54-59.

13 Rajasegar, M., Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *J. Environ. Biol.*, 2003, 24, 95-101.

14 Sarma, V.V.S.S., Gupta, S.N.M., Babu, P.V.R., Acharya, T., Harikrishnachari, N., Vishnuvardhan, K., Rao, N.S., Reddy, N.P.C., Sarma, V.V., Sadhuram, Y., Murty, T.V.R., and Kumar, M.D., Influence of river discharge on plankton metabolic rates in the tropical monsoon driven Godavari estuary, India. Estuar. *Coast. Shelf. Sci*., 2009, 85, 515–524.

15 Pradipta, R.M., Vishnu Vardhan, K., Robin, R.S., Charan Kumar, B., Sivaji, Patra., Raman, A.V., Nageswara Rao, and G., Subramanian, B. R., Distribution of dissolved inorganic carbon and net ecosystem production in a tropical brackish water lagoon, India. *Cont. Shelf. Res.*, 2013, 64, 75–87.

16 Bates, N.R., Best, M.H.P., and Hansell, D.A., Spatio-temporal distribution of dissolved in organic carbonand net community production in the Chukchi and Beaufort Seas. *Deep Sea Res*., 2005, 52, 3303–3323.

17 Hellings, L., Dehairs, F., and Damme, S.V.,2001. Dissolved in organic carbonina highly polluted Estuary(the Scheldt). *Limnol. Oceanogr*., 46, 1406–1414.

18 Green, E. J., and Carritt, D.E., New tables for oxygen saturation of seawater. *J. Mar. Res.*, 1967, 25, 140-147.

19 Knox, S., Whitfield, M., Turner, D.R., and Liddicoat, M.I., Statistical analysis of estuarine profiles: III. Application to nitrate, nitrite and ammonium in the Tamar estuary (S. W. England). *Estuar. Coast. Shelf Sci*., 1986, 22, 619–636.

20 Thasneem, T.A., Bijoynandan, S., and Geeta, P.N., Water quality status of Cochin estuary, India. *Ind. J. Mar. Sci*., 2018, 47, 978-989

21 Das, J., Das, S.N., and Sahoo, R.K., Semidiurnal variation of some physicochemical parameters in the Mahanadi estuary, east coast of India. *Ind. J. Mar. Sci*., 1997, 26, 323-326.

22 Gouda, R., and Panigrahy, R.C., Monthly variations of some hydrographic parameters in the Rushikulya estuary, east coast of India. Masagar-Bulletion *Nat. Inst. Oceanogr.*,1993, 26, 73-85.

23 Satpathy, K.K., Mohanthi, A.K., Natesan, U., Prasad, M.V.R., and Sarkar, S.K., Seasonal variation in physicochemical properties of coastal waters of kalpakam, east coast of India with special emphasis on nutrients. *Environ. Mon. Asses*., 2010, 164, 153-171.