Influence of river discharge on abundance and dissemination of heterotrophic, indicator and pathogenic bacteria along the east coast of India

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ABSTRACT

In order to examine the influence of discharge from different rivers from peninsular India and urban sewage on intensity and dissemination of heterotrophic, indicator and pathogenic bacteria, a study was carried out during peak discharge period along coastal Bay of Bengal. The coastal Bay received freshwater inputs from the river Ganges while Godavari and Krishna contributed to the south. Contrasting difference in salinity, temperature, nutrients and organic matter was observed between north and south east coast of India. The highest heterotrophic, indicator and pathogenic bacterial abundance was observed in the central coastal Bay that received urban sewage from the major city. Intensity and dissemination of heterotrophic, indicator and pathogenic bacteria displayed linear relation with magnitude of discharge. The coliform load was observed up to 100 km from the coast suggesting that marine waters were polluted during the monsoon season and its impact on the ecosystem needs further studies.

Keywords: River discharge, Heterotrophic bacteria, Coliforms, Pseudomonas, Salmonella, Vibrio
1. Introduction

Large quantities of fresh water influx ($1.6 \times 10^{12} \text{ m}^3 \text{ yr}^{-1}$) from the major rivers such as, the Brahmaputra, Cauvery, Ganges, Godavari, Irrawady, Krishna, and Pennar enters the Bay of Bengal (Rao, 1985; Subramanian, 1993). The typical yearly discharges are incredibly far above the ground for the Brahmaputra-Ganges and comparatively stumpy for the Pennar and Cauvery (Rao, 1985). During summer, large fresh water discharge substantially lowers the salinity and also reduces the intensity of upwelling (Shetye et al., 1991). According to recent estimates, the annual total continental runoff into the Bay of Bengal (BoB) is about $2,950 \text{ km}^3$, which is more than half that into the entire tropical Indian Ocean (Sengupta et al., 2006). A large proportion of the population lives near the coastal regions (Scialabba, 1998), hence contamination of marine habitats with human pathogens is documented as a noteworthy ecological menace to human well being. There are several pathogenic microbes, which are capable of causing dreadful diseases such as cholera, diarrhea, dysentery, typhoid fever. Pathogenic bacteria in marine water can cause illness by means of recreational activities in the coastal waters and fouled marine foodstuff. Each year, $\sim$50 and 120 million acute respiratory and gastrointestinal infections occur worldwide due to recreational activities in the coastal waters (Viau et al., 2011). Marine fauna also affected by the allochthonous microbial contamination to the seawater (Gulland and Hall, 2007) and these pathogenic microbes propagate in the host and re-enter the environment, cause zoonoses (Stewart et al., 2008) and disseminate to far distances (Nagvenkar and Ramaiah, 2009). The routine assessment of coastal water in terms of microbial load, especially the coliform and pathogenic bacteria, has a vital position in marine pollution studies, as this gives an unswerving consequence of pollution on human health and also other marine biota. Hence it is crucial to observe microbial load in marine environments to warrant the wellbeing of coastal water for recreational purpose and fishing as well. There are several sources of microbial contamination of marine waters, like discharge of domestic waste directly to coastal regions, sewage effluents, bathers themselves, seabirds, ballast water discharges, freshwater discharges from rivers contaminated with human activities (agricultural, farm industry and municipal surface runoff) during monsoon season, fisherman activities, discharge of waste from transport ships, recreational use, domestic and wild animals in the coastal areas. Allochthonous microbes in the marine waters present valuable tracers of contamination, such as *Edwardsiella* spp., *Enterobacter* spp., *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella* spp., *Salmonella* spp., *Shigella* spp., *Staphylococcus aureus* and hepatitis viruses, etc (Griffin et al., 1999; Mote et al., 2012; Ramaiah and Chandramohan,
1993; Ramaiah and De, 2003; Stewart et al., 2008; Viau et al., 2011), can survive in marine habitat from one to several weeks (Nagvenkar and Ramaiah, 2009) and elevated magnitude of these microbes not only stay alive but also dominate autochthonous microbes, which may results in objectionable marine habitat disparity (Colwell et al., 1981; Huq et al., 1984). Some pathogens in the marine waters are autochthonous to the marine environments, such as bacteria related to the genus *Vibrio* which cause fatal or opportunistic infections to humans. Illness caused by *Vibrio* bacteria are recognized to be coupled with either eating of marine foodstuffs or in contact to marine waters like recreational use. Only by examining their dispersion, it is possible to examine the dominant regional sources of pollution and the various disease threats. Subgroups non-O1 and O-139 of *Vibrio cholera*, found in coastal waters in endemic areas of cholera, and inhabit copepods, which feeds on phytoplankton. Based on this it is presumed that elevated abundance of phytoplankton might result in lofty abundance of copepods with *Vibrio cholerae*, which ultimately escalate the risk of cholera epidemics in coastal human populations.

To measure the sanitary value of drinking and recreational waters, indicator bacteria are frequently used. Presence of these bacteria indicates likely incidence of pathogenic bacteria, such as *Salmonella* (OECD, WHO 2003). Generally total coliforms (TC), faecal coliforms (FC), *Escherichia coli* and enterococci (ENT) were used as indicator bacteria. Heterotrophic bacterial abundance is also used often as general water quality indicator. According to several national legislations and international guidelines for drinking water quality insist that *E. coli* must be absent in a 100 ml water sample (WHO 2004), these limits for bathing water are higher according to the European Directive 2006/7/CE, and if the *E. coli* levels exceed 900 CFU/100 ml and/or ENT exceed 330 CFU/100 ml indicates that the coastal waters are not safe for the recreational purposes.

The spatial distribution pattern of pathogenic microbes is required to evaluate the possible risk to the human well being. But scarce information is available about variations in contribution of pathogenic bacteria by different rivers to coast and their dispersion towards offshore. Our motivation to this study is to analyze the abundance and distribution pattern of heterotrophic, pollution indicator, and human pathogenic bacteria along the east coast of India during peak discharge period, account contribution from different Indian rivers to coast and examine how far these bacteria disperse towards offshore from the source region.
2. Description of study area and materials and methods

2.1. Study area

The North Indian Ocean (NIO) is a distinct ocean in terms of its geographical location, as it is semi-enclosed and closed in the north and opened to south Indian Ocean at the southern boundary. The Bay of Bengal is the north eastern part of the NIO with a positive water balance as the precipitation and river runoff far surpasses evaporation, which results in low surface salinities and sturdy stratification (Varkey et al., 1996). Seasonality in the Bay of Bengal is due to the extreme meteorological forcing, known as monsoon. About 80% of the precipitation is received during SW monsoon period (June to October) resulting in maximum discharge from the rivers to the Bay of Bengal.

The objective of this work is to test the hypothesis that rivers bring heterotrophic, indicator and pathogenic bacteria to the coastal Bay of Bengal, however, their abundance and contribution may be river dependent. In order to examine the same, samples were collected onboard ORV Sagar Nidhi (#SN 42) along the east coast of India during 23rd July-10th August 2010, representing the peak river discharge period, covering off major rivers viz., Krishna, Godavari, Mahanadi and minor rivers like Vamsadhara, Hyadri. In addition to this, sampling was also conducted at off Visakhapatnam (transect V) where no discharge occurs to examine the impact of discharge. The present study area was divided into south-east (SE) coast of India consisting of Krishna south (KS), Krishna north (KN), Godavari south (GS) and Godavari north (GN) transects, and northeast (NE) coast includes Vamsadhara (VD), Hyadri (HD), Mahanadi south (MS) and Mahanadi north (MN) transects (Fig. 1). Samples were collected from a total of 72 stations along 9 transects (8 stations along each transect) covering both south and north of riverine mouths (Fig.1). The water samples collected at 8 stations in each transect from close to coast to 16.2 to 110.47 km offshore. The distance from the coast to offshore varied as the water column depth of 1000m was taken as the last station in this study.
2.2. Sampling and methodology

Low saline water normally occupies in the upper 10 m of water column along the coastal Bay of Bengal (Sarma et al., 2013). Hence samples were collected from ca. 1 m and 10 m below the surface using Niskin (10 L capacity, General Oceanics, USA) samplers attached to a rosette system. The temperature and salinity of water were obtained using the Conductivity, Temperature and Depth profiler (Sea Bird Electronics, USA). Water samples were collected for dissolved oxygen and nutrients in glass and plastic bottles respectively. Dissolved oxygen (DO) was analyzed by Winkler titration method (Strickland and Parsons, 1972), whereas dissolved nutrients such as the ammonium, nitrate and nitrite were done following the standard spectrophotometric procedures (Grasshoff et al., 1983). Chlorophyll-a was measured by filtering the water sample of about one liter through glass fiber filter (Whatman) and Chl-a from the phytoplankton biomass retained on the filter was extracted with N,N-dimethyl formamide at 4 °C in dark for 12 h, and measured spectrofluorometrically following Suzuki and Ishimaru (1990). Suspended particulate matter (SPM) concentration in the water sample was analyzed by filtering the water sample of about one liter through the pre-weighed 0.22 μm filter (Millipore), dried at 40 °C and reweighed to quantify SPM (mg L⁻¹) retained on the filter. Dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) were determined by a high-temperature catalytic oxidation method and chemiluminescence method respectively (Benner and Hedges, 1993; Spyres et al., 2000) using a Shimadzu TOC 5000A. Before the analysis, samples were acidified (pH <2) using 5% phosphoric acid and purged with CO₂ free air for 5 min to eliminate inorganic carbon, and then 50 μl was directly injected into the vertical furnace, which contained a standard platinum catalyst at a temperature of 720 °C. The released carbon dioxide after oxidation of the DOC was measured using non-dispersive infrared detection. Standardization was carried out every set of samples using potassium hydrogen phthalate. Particulate organic carbon (POC) and Particulate nitrogen (PN) were analyzed using an elemental analyser attached to the Isotopic Ratio Mass Spectrometer (Sarma et al., 2012). About 1 to 2 L of water sample was filtered through the pre-combusted glass fiber filter (GF/F), followed by overnight drying at 40 °C. Filters were exposed to hydrochloric acid fumes to remove the particulate inorganic carbon.

About 100 ml of sample was sub-sampled in to a pre-sterilized bottle for bacterial analysis. All samples were collected with precautions required for microbiological analysis, and analyzed immediately onboard. The bacteriological examinations were done onboard laboratory following Nagvenkar and Ramaiah (2009) for the enumeration of heterotrophic, indicator and few pathogenic
bacteria. The different selective media’s used for the specific bacterial groups. Heterotrophic bacterial counts were determined on nutrient agar (NA), enumeration of coliforms on McConkey agar, Vibrio spp. on Thiosulphate citrate bile salts sucrose (TCBS) agar, Pseudomonas spp. on Cetrimide agar, Salmonella spp. and Shigella spp. on Salmonella Shigella (SS) agar. The specific colonies (unique to the organism of interest) on the respective agar media were quantified and the results were expressed in colony forming units (cfu ml\(^{-1}\)) according to Nagvenkar and Ramaiah (2009). Colonies of Pseudomonas aeruginosa on Cetrimide agar appear pigmented blue, blue-green or non-pigmented. Colonies exhibiting fluorescence at 250nm and a blue green pigmentation are considered as presumptive positive. Colonies of Salmonella spp. on SS agar grow well and appear colourless with black centre and Shigella spp. grows well and appear colourless.

2.3. Statistical analyses of data

Student t test was conducted for all the parameters to estimate the significance of variance between SE and NE regions using STATISTICA version 5.0.

3. Results

3.1. Physicochemical properties

Physical and biogeochemical properties showed significant north-south variations along the coastal Bay of Bengal due to discharge from various rivers. The surface water salinity varied between 21 and 34 psu along the east coast of India and relatively lower salinities was observed in the NE than the SE coastal region due to huge fresh water discharge from Ganges river to the former zone (Fig. 2a; Sarma et al., 2012). Temperature in the water column ranged between 26 °C and 30.1 °C, and higher temperatures were observed towards the NE than SE region (Fig. 2b). The SPM, DO and Chl-a varied from 5.6 to 90 mg/L, 120 to 221 µmol kg\(^{-1}\), and 0.3 and 4.5 mg m\(^{-3}\) respectively with relatively higher concentrations in the SE than NE region (Fig. 2c, d, 3a). Similarly DOC, POC, DON and PN concentrations varied from 103 to 253 µMC, 1.99 to 26.07 µMC, 5.9 to 49.0 µMN and 0.13 to 8.9 µMN with high concentrations in the NE than SE region (Fig. 3b, c, d, e). In contrast, DIN ranged from 0.1 to 9.6 µMN with high concentrations in the SE than NE region (Fig. 3f). The significant north-south variations in physical associated with biogeochemical properties along the east coast of India were mainly driven from discharge from various rivers with different characteristics (Sarma et al., 2012 and Rao and Sarma, 2013).
3.2. Discharge influence on the bacterial counts

The heterotrophic bacterial counts (HBC), total coliform counts (TCC), *Pseudomonas*, *Salmonella* and *Vibrio* counts ranged from $1.0$ to $3.2 \times 10^3$, $0$ to $2.3 \times 10^3$, $0$ to $2.5 \times 10^3$, $0$ to $0.04 \times 10^3$ and $0$ to $0.1 \times 10^3$ cfu ml$^{-1}$ respectively along the east coast of India (Figs. 4-8). Relatively higher counts of all these groups were noticed along V transect where major city, Visakhapatnam, was located. On the other hand, the lowest counts were noticed along KN transect that receives discharge from river Krishna (Figs. 4-8). Relatively higher counts were noticed in the NE coast than SE coast of India however they are statistically not significant. The region influenced by discharge from Godavari river contained relatively higher counts of all groups measured than region influenced by Krishna suggesting that former river brings more bacteria to the coastal Bay of Bengal than latter. The coliform counts were observed in the entire study region at all stations, except along KS and KN transects where it was observed up to the distance of 3.26 km from the coast and no counts were noticed along KN transect (Fig. 5). Similarly *Pseudomonas* bacterial counts were observed in the entire study region except along transect KN (Fig. 6). *Salmonella* counts are observed mostly in the stations near to the coast and they were present either at surface or 10m depth (Fig. 7).

4. Discussion

Significant spatial variations were noticed between SE and NE coast of India due to discharge from different rivers. The rivers opened to the NE region brought relatively low suspended matter that facilitated high phytoplankton biomass and consumption of nutrients (Sarma et al., 2012; 2013). In contrast, high suspended matter in the SE region hindered phytoplankton growth that lead to accumulation of nutrients in the upper water column. Though no significant differences in POC concentrations were observed in the NE ($9.8 \pm 4.0 \mu$MC) and SE ($9.05 \pm 5.73 \mu$MC) region, however, dominant marine source contributed to POC pool was observed in the former whereas terrestrial sources (mainly C3 plants) in the latter region (Krishna et al., 2013) suggesting that more labile carbon is available in the former than latter region. The distribution of heterotrophic bacterial load along the coastal Bay of Bengal illustrated that relatively low heterotrophic bacterial (HB) abundance was observed along KN transect compared to other transects. Such low heterotrophic bacterial count is confined close to the coast at off river Krishna (KN and KS transects) due to low discharge (577 m$^3$/s) compared other rivers mainly Godavari (3,505 m$^3$/s), Mahanadi (2,121 m$^3$/s) and Ganges (>14,000 m$^3$/s) (Sarma et al., 2014) (Fig. 4). Though discharge rate is lower for Hyadri and Vamsadhara than even Krishna, the
heterotrophic bacterial abundance was higher along the VD and HD transects, that could be due to major input from the Ganges. The highest heterotrophic bacterial counts of $3.2 \times 10^3$ cfu/ml (Fig. 4) was observed along transect V, which is not influenced by the river water discharge, however highly influenced by the recreational use, shipping industry, fishery activities, domestic, and industrial sewage and it is consistent with other reports along coastal water of India (Clark et al., 2003; Ramaiah and Chandramohan, 1987; Nagvenkar and Ramaiah, 2009; Patra et al., 2009; Knight, 2012; Robin et al., 2012; Rodrigues et al., 2011). The prevalence of the heterotrophic bacterial count was 98% in the entire study region. However, our results are higher than the South off Gujarat coast (Mohandas et al., 2000) and Tamil Nadu coast (Venkateswaran and Natarajan, 1987) but lower than Port Blair bay of Andamans (Nallathambi et al., 2002), Marmugao Bay and Zuari (Nagvenkar and Ramaiah, 2009), Port region of Bhavanagar (Abhay Kumar and Dube, 1995) and Mumbai coastal waters (Ramaiah et al., 2004).

Coliforms survive in sea water for several weeks (Patti et al., 1987; Piccolomini et al., 1987) and are the dominant bacteria in the waste water, and their presence in natural water is an indicator of water pollution. The prevalence of the TCC was 75% in the study region and such high number indicates the presence of other pathogenic bacteria and some may be viable but non culturable state due to several deleterious effects in the marine environment (Rozen and Belkin, 2001; Robin et al., 2012). Similar to the HBC, the total coliform load is relatively higher near to coast than offshore (Fig. 5). But due to low discharge and less influence of the coastal pollution in the SE coast of India, off Krishna River, TCC was observed only close to the coast up to 3.6 km (Fig. 5). The highest count was observed along transects V and VD (Fig. 5) as these regions were highly influenced by several anthropogenic activities, and it is consistent with the studies carried out in other habitats (Clark et al., 2003; Ramaiah and Chandramohan, 1987; Nagvenkar and Ramaiah, 2009; Patra et al., 2009; Knight, 2012; Robin et al., 2012; Rodrigues et al., 2011). Interestingly TCC in the study regions were significantly lower than coastal waters off Mumbai ($10^3$ to $10^4$ ml) (Ramaiah et al., 2004).

The distribution pattern of *Pseudomonas* spp. followed HBC and TCC in the study region (Fig. 6). The prevalence of the *Pseudomonas* spp. count was 80% in the study region and was found both in surface and 10 m depth at most of the stations sampled in this study (Fig. 6). This suggests the influence of discharge and also the extensive anthropogenic activities due to huge traffic of shipping, fishing and untreated discharge of sewage from the coastal cities carry wastes and other pollutants in to the coastal
waters. The high PC in coastal waters were also noticed earlier in the Orissa coast i.e., off Rushikulya, Mahanadi and Baitarini Rivers (Patra et al., 2009).

*Salmonella* spp. were observed only at few stations (11 out of 72; 12 samples out of 144 samples including surface and 10 m depth water), the prevalence rate of *salmonella* spp. is 7% in the study region (Fig. 7). *Salmonella* spp. count was observed mostly close to the coast. *Salmonella* spp. count was observed only along transect VD in the off-shore region (Fig. 7) that could probably due to fisherman activities or discharge from the transport ships. *Salmonella* spp. counts were not detectable along KN, GN and V transects (Fig. 7). *Salmonella* spp., has been reported from the coastal waters previously (Venkatswaran et al., 1989; Hatha et al., 2004; Clark et al., 2003; Ramaiah and Chandramohan, 1987; Nagvenkar and Ramaiah, 2009; Patra et al., 2009; Knight, 2012; Robin et al., 2012; Rodrigues et al., 2011). Though *Shigella* spp., counts were very low in the present study, however, there are several reports of their presence in the Indian coastal waters (Venkatswaran et al., 1989; Hatha et al., 2004; Clark et al., 2003; Ramaiah and Chandramohan, 1987; Nagvenkar and Ramaiah, 2009; Patra et al., 2009; Knight, 2012; Robin et al., 2012; Rodrigues et al., 2011).

*Vibrio* spp. were observed only at few stations (11 out of 72 in surface waters; 15 out of 72 in 10 m depth waters) (Fig. 8). *Vibrio* spp. counts were observed relatively less in coastal (9) than off-shore regions (17) (Fig. 8). The prevalence of *Vibrio* is 25% in the study region. *V. cholerae* was dominant than *V. parahaemolyticus* in the study region and their counts are lower than earlier reports from east coast (Nair et al., 1980) and west coast of India (Pradeep and Lakshmanperumalsamy, 1986; Lokabharathi et al., 1987), Mediterranean Sea (Baffone et al., 2001; Barbieri et al., 1999; Dumontet et al., 2000; Hervio-Heath et al., 2002; Maugeri et al., 2006; Masini et al., 2007).

Heterotrophic viable bacterial counts along the east coast of India showed significant variations with reference to physical and biogeochemical parameters in the study region. Water temperature linearly correlated with VC ($r^2=0.40$, $p<0.001$) and PC ($r^2=0.39$, $p<0.001$) (Table 1), as high temperature is favorable for their growth. TCC and PC did not display any relation with salinity indicating that their tolerance at high salt content. Dissolved oxygen showed a linear correlation with TCC ($r^2=0.25$, $p<0.05$) and PC ($r^2=0.27$, $p<0.05$) (Table 1) suggesting that oxygen saturation is more in the surface waters for bacterial metabolism. Heterotrophic bacterial counts (HBC) showed a linear correlation with dissolved organic carbon, a better correlation is observed with TCC ($r^2=0.35$, $p<0.01$), PC ($r^2=0.31$, $p<0.05$), SaC ($r^2=0.42$, $p<0.001$) (Table 1) indicating that these heterotrophic bacterial biomass increased with
availability of organic matter, which act as substrate for their growth and metabolism. Recently Krishna et al. (2013) noticed that dominant contribution of organic matter from terrestrial sources in the SE region while marine sources in the NE region based on the stable isotopic composition of carbon. The linear relation of DOC with HBC, TCC, PC and SaC further suggested that both marine and terrestrial organic carbon satisfied their carbon needs and oxidized organic matter to CO₂ efficiently. Recently Sarma et al. (2012) reported that coastal Bay of Bengal is acting as a source for atmospheric CO₂ and biological processes are important. Though dissolved organic nitrogen did not showed any correlation with the HBC but dissolved inorganic nitrogen showed a significant inverse correlation with TCC ($r^2=0.32$, $p<0.05$), VC ($r^2=0.36$, $p<0.001$), PC ($r^2=0.35$, $p<0.01$) (Table 1) indicating that inorganic nitrogen is easily preferred nitrogen source for growth of viable bacteria than the organic nitrogen.

Our study suggests that rivers brought significant amount of viable bacteria to the coastal Bay of Bengal however their abundance is proportional to the magnitude of discharge. Relatively lower counts were noticed at off Krishna River as this river discharges relatively lower rate compared to other rivers. The influence of release of domestic or industrial pollution on viable bacterial counts dominated river derived sources as indicated by higher counts at off Visakhapatnam city. The relation with temperature suggests that enhanced stratification due to freshwater discharge increased the upper ocean temperature that promoted growth of the bacteria. In addition to this, rivers also brought significant amount of terrestrial organic matter and nutrients and the latter promoted organic matter production in the coastal waters. Both the sources (in situ produced and terrestrial) of organic matter was efficiently utilized by the bacteria as a food source that lead to the coastal Bay of Bengal acted as a mild source of CO₂ to atmosphere.

5. Conclusions

Heterotrophic bacterial counts showed significant spatial variations along the east coast of India due to variable sources of freshwater from different rivers. Relatively higher heterotrophic bacterial abundance was noticed in the NE coast of India which received major discharge from Ganges than SE coast of India that received inputs from peninsular region. Indicator bacterial abundance were higher in the entire study area and were noticed up to 40-110 kms from the coast, except off Krishna river where discharge was relatively low compared to other rivers. Coliforms as well as other potentially pathogenic bacteria were detected in high numbers in the entire study region. The presence of Vibrio spp., Salmonella spp. and Pseudomonas spp. in the coastal waters is alarming, even though their abundance was low. The
coastal contamination due to enteric bacteria leads to quality deterioration of marine resources that pose a human health hazard and subsequent economic loss. Higher abundance of different bacteria was observed off Visakhapatnam city due to the intensive anthropogenic activities. Besides highlighting significant correlations between the coliform group and certain pathogenic bacteria at many locations, this study suggested that both organic matter brought by the rivers and in situ produced through phytoplankton supported their carbon needs in the coastal Bay of Bengal. Modification of river discharge is possible in future due to variations in intensity of monsoon and construction of more dams on the rivers and it may have significant impact on supply of organic matter and bacteria to the coastal regions. Further studies are required to examine how variations of such condition influence coastal bacterial abundance and its impact on the other components of the ecosystem.

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References:


Legends to the Figures:

Fig. 1. Sampling locations in the east coast of India. Isobaths of 50, 250 and 1000 m were also shown. Acronyms K, G, VD, HD, M stands for rivers Krishna, Godavari, Vamsadhara, Hyadri and Mahanadi, V stands for Visakhapatnam, whereas N and S attached to the river name represent north and south of the mouth of the river, respectively. Transect names and river names are given in white.

Fig. 2. Distribution of (a) salinity (psu), (b) temperature (°C), (c) suspended particulate matter (mg L⁻¹), and (d) dissolved oxygen (µM) in the east coast of India.

Fig. 3. Distribution of (a) Chl-a (mg/m³), (b) dissolved organic carbon (µM), (c) particulate organic carbon (µM), (d) dissolved organic nitrogen (µM), (e) particulate nitrogen (µM) and (f) dissolved inorganic nitrogen (µM) in the east coast of India.

Fig. 4. Heterotrophic bacterial counts (cfu ml⁻¹) in different transects from surface (a) and 10m depth waters (b) in the east coast of India.

Fig. 5. Indicator bacterial counts (cfu ml⁻¹) in different transects from surface (a) and 10m depth waters (b) in the east coast of India.

Fig. 6. *Pseudomonas* spp., counts (cfu ml⁻¹) in different transects from surface (a) and 10m depth waters (b) in the east coast of India.

Fig. 7. *Salmonella* spp., counts (cfu ml⁻¹) in different transects from surface (a) and 10m depth waters (b) in the east coast of India.

Fig. 8. *Vibrio* spp., counts (cfu ml⁻¹) in different transects from surface (a) and 10m depth waters (b) in the east coast of India.
Table 1. Rank correlation matrix (Spearman’s $r_s$) of biogeochemical parameters measured in east coast of India.

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(***) = $P<0.001$, (**) = $P<0.01$, (*) = $P<0.05$

TEMP, temperature; SAL, salinity; CHL, chlorophyll; DO, dissolved oxygen; DOC, dissolved organic carbon; DIN, dissolved inorganic nitrogen; DON, dissolved organic nitrogen; SPM, Suspended particulate matter; POC, particulate organic carbon; PN, particulate nitrogen; HBC, heterotrophic bacterial count; TCC, total coliform count; VC, Vibrioc count; SaC, Salmonella count; PC, Pseudomonas count.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5 

(a) Log scale: cfu ml⁻¹

(b) Log scale: cfu ml⁻¹

KS, KN, GS, GN, V, VD, HD, MS, MN

Stn1, Stn2, Stn3, Stn4, Stn5, Stn6, Stn7, Stn8
Fig. 7
Fig. 8