

Occurrence and seasonal variation in distribution of fecal indicator bacteria in Tapi estuary along the West coast of India

Sunil Borade[#], Rutuja Dhawde[#], Ayushi Maloo, Gajbhiye S N & Syed G Dastager^{*}

CSIR-National Institute of Oceanography, Regional Center, Lokhandwala Road, Mumbai 400 053, India
[E-mail: sdastager@nio.org]

Received 23 June 2012; revised 25 October 2012

Distribution and occurrence of fecal indicator bacterial in nine different locations along the inner to coastal areas of Tapi estuary during three different seasons like, post-monsoon, pre-monsoon and monsoon were analyzed for the period of one year. It was found that monsoon was inhabited by the highest number of investigated bacteria, while lower numbers of them were found in other two seasons. Concentrations of fecal microorganisms in sediment were found to be significantly high. Overall percentage occurrence for the enteric bacteria in water and sediment were maximum accounted for fecal coliforms (64%), and moderate for *Pseudomonas aeruginosa* (22.2%). Higher microbial populations were recorded in stations close to coastal areas and inner estuarine as compared to middle and outer area of Tapi, while according to the analysis of surface water the highest degree of pollution was reached on its estuary. Bacterial populations showed strong correlations with biological oxygen demand and negative relationship with salinity, indicating the dominating influence of human activities resulting fecal pollution in the estuarine area.

[**Keywords:** Fecal indicators, Tapi estuary, Correlation, BOD]

Introduction

Human fecal material is generally considered to be the greater risk to human health, as it is more likely to contain human enteric pathogens, which may pose serious health-hazards to the exposed human population¹⁻². In the estuaries and coastal environments the levels of fecal-indicator bacteria and enteric pathogens are mainly influenced by point sources (such as discharge of effluents from Wastewater Treatment Plants [WWTP], domestic garbage), and the nature of the watershed. Soil leaching and surface runoff also contribute substantially to the fecal pollution of the environment³. In estuarine, the survival of fecal microorganisms is mainly by their association with particles, which have a complex hydrodynamic behavior affected by tidal cycles and river flow⁴.

Worldwide coliforms bacteria are used as an indicators of fecal contamination and hence, the possible presence of disease causing organisms⁵⁻⁸. The extent of fecal pollution increases during monsoon and post monsoon mainly due to land drainage. Furthermore, it has been shown that in tropical aquatic environments, classical fecal indicators are suspected to be proliferated and thus be detectable at levels which do not reflect

the original extent of fecal contamination and they become an autochthonous part of the aquatic microbial community in the tropical waters⁹⁻¹⁰. From the sanitary standpoint, presence of pathogenic microorganisms in the aquatic environment is related to their ability to resistance and survival to the different natural factors of stress, such as low temperature, low or high pH, high salinity, and scarce organic matter and nutrients¹¹.

The bacteriological parameters of different river systems have been studied by various groups and many concerns have been raised recently about the pathogens originating from rainfall runoff¹²⁻¹⁵. Seawaters along the Indian coasts are classified by Central Pollution Control Board of India (CPCB) as fit for commercial fishing, contact recreation and bathing activities when the FC is <100 CFU/mL. Whereas, the USEPA sets FC limits of 200 CFU/mL natural waters for recreational purposes¹⁶. Indicator organisms are often used as a tool to identify the contaminant sources. Therefore, it is important to understand the potential and limitations of these indicator organisms before realistically implementing guidelines and regulations to safeguard our water resources and public health.

The estuary of the Tapi river is 25 km long though the river which is originating in the Multan ghats of Madhya Pradesh, India, runs over a distance of 720 km and passes through three states, Madhya Pradesh, Maharashtra and Gujarat. The estuary receives an annual average river runoff of 7,686 million m³ with annual ground water flow of 18,000 million m³. The seasonal monsoonal discharge effectively flushes the estuary on a yearly cycle. Hazira-Kawas region on the north-western bank of the Tapi estuary is one such area which is largely consisted on marshy, low productive waste land which has become a major industrial zone for petrochemical, fertilizer, steel and power industries. These industries release their treated effluents along with the domestic waste water from townships in the lower segment of Tapi estuary. However, it is important to document the current levels of occurrence and seasonal distribution of microbial indicators as well as pathogenic bacteria to provide the levels of microbial hazards in the Tapi estuarine.

Materials and Methods

The study area is situated in the west coast of Gujarat, India. Water and sediment samples were collected from twelve different sampling sites of Tapi estuary. This estuary drains and receives enormous quantity of land materials, urban and rural sewage effluents, industrial and agricultural wastes throughout the years.

A seasonal sampling were undertaken during 2011 representing, post-monsoon (January), pre-monsoon (May) and monsoon (August). Study area were divided into four parts in which inner estuary constituted two sampling sites like stations 1 and 2, middle estuary in station 3, outer were stations 4, 5, 6, 7 and coastal area with stations 8 and 9 as shown in Fig. 1. One liter of water sample from each location was collected in to pre-sterilized bottles, while sediment samples were collected by using an alcohol rinsed, air-dried Ven-Van grab. All collected samples were aseptically transferred into new polyethylene bags using a sterile spatula and preserved in an icebox until they transported to the laboratory for further analysis. Water quality parameters such as temperature, salinity, pH, dissolve oxygen (DO), biological oxygen demand (BOD) and nutrients like ammonia, nitrate, nitrite and phosphate concentrations were also monitored for their impact on microbial count for all three seasons.

Enumeration of bacteria was carried out by using standard procedures, water sample and sediment samples were prepared in 50% of aged sea water separately and then serially diluted using the same diluents. Standard spread plate technique was adopted for enumeration of Total Viable Count (TVC), fecal pollution indicator (total and fecal coliforms), *Escherichia coli* (ECLO), *Shigella* (SHLO), *Salmonella* (SLO), *Proteus Klebsiella* (PKLO), *Vibrio cholerae* (VCLO), *Vibrio parahaemolyticus*

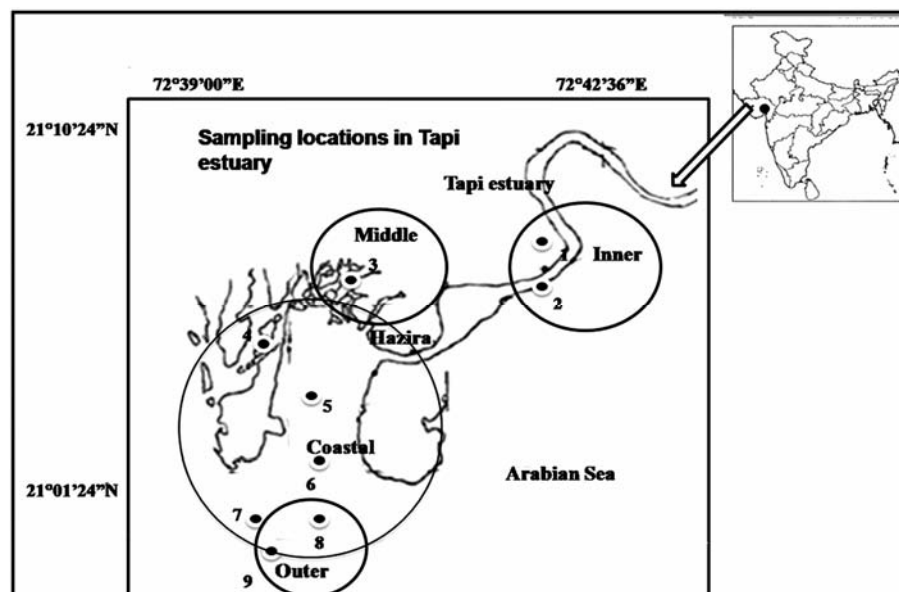


Fig. 1—Map showing inner, middle, coastal and outer sampling location of Tapi estuary.

(VPLO), *Pseudomonas aeruginosa* (PALO) and *Streptococcus fecalis* like organisms (SFLO) (APHA, 1995). Nutrient agar prepared in 10% seawater was used for enumerating TVC. Total coliforms (TC) were enumerated using MacConkeys agar which was incubated for 24 h at 37°C. All colonies showing pink-red colour were counted as total coliforms. Fecal Coliforms (FC) were enumerated using m-Fc agar with rosolic acid as an indicator and incubated at 44.5°C for 24 h. Typical blue-green colonies were counted for fecal coliforms. ECLO were enumerated on M7Hrhc agar with yellow color colonies. For enumeration of SHLO, SLO and PKLO were grown on xylose lysine deoxycholate agar (XLD) for 24 h at 37°C. Colonies with Pink/red coloration were enumerated as SHLO, pink with black centered colonies as SLO, and yellow mucoid colonies as PKLO respectively. While, yellow colonies with <2 mm diameter were quantified as VCLO and green colonies as VPLO on thiosulphate citrate bile salts sucrose agar (TCBS). All colonies growing on *Pseudomonas* agar with glycerol were enumerated as PALO and the maroon colonies were enumerated using SFLO on M-Enterococcus agar.

Physico-chemical properties like, atmospheric and surface water temperatures were measured using standard mercury filled centigrade thermometer, pH was measured on a microprocessor-based pH

analyzer, DO was determined by modified Winkler's method and biological oxygen demand (BOD) was done by using direct seedling method¹⁷. The analysis procedure for total phosphorus, nitrate, nitrite and ammonia were adopted from methods described by Parsons *et al*¹⁸.

All results were analyzed statically by Pearson correlation analysis. And correlation matrix of microbial population and physico-chemical parameters were analyzed with the help of STATICA 7.0 software.

Results

Microbiological analysis

The overall microbial counts in water and sediment samples of Tapi estuary were given in Table 1. Total viable counts (TVC) in water and sediment samples were highest during monsoon and lowest during pre-monsoon as shown in Fig. 2 A and 2 B. Total coliforms (TC) and fecal coliforms (FC) counts were relatively higher in monsoon season as compared to post monsoon and pre-monsoon. Occurrence and distribution of different faecal and enteric pathogens were given in Tables. 2 and 3. Overall positive occurrences of fecal indicator bacteria were 64% for fecal coliforms during post monsoon. Coastal areas harbors the highest distribution of TC and FC as compared to inner, middle and outer sites of sampling area

Table 1—Total microbial count in different seasons of Tapi estuary during 2011

Types of bacteria	Microbial counts					
	Water (cfu/ml)			Sediment (cfu/g)		
	Postmonsoon Min-Max (Average)	Premonsoon Min-Max (Average)	Monsoon Min-Max (Average)	Postmonsoon Min-Max (Average)	Premonsoon Min-Max (Average)	Monsoon Min-Max (Average)
TVC ^a	41-112 (68)	26-88 (50)	39-216 (95)	31-80 (51)	21-65 (31)	36-105 (59)
TC ^b	ND ^m -109 (38)	ND-170 (42)	ND-470 (131)	ND-3000 (1125)	ND-8000 (4625)	ND-5000 (1125)
FC ^c	ND-90 (26)	ND-200 (29)	ND-360 (94)	ND-1000 (562)	ND-7000 (2000)	ND-2000 (500)
ECLO ^d	ND-20 (5)	ND-80 (16)	ND-260 (67)	ND-1000 (250)	ND-4000 (1000)	ND-1000 (250)
SHLO ^e	ND-110 (15)	ND-50 (9)	ND-20 (6)	ND	ND-8000 (2625)	ND
SLO ^f	ND-80 (16)	ND	ND	ND	ND	ND
PKLO ^g	ND-90 (56)	ND-210 (56)	ND-170 (54)	ND-1000 (63)	ND-9000 (5437)	ND-1000 (125)
VLO ^h	ND-110 (30)	ND-210 (37)	ND-220 (66)	ND-1000 (313)	ND-18000 (7562)	ND-6000 (875)
VPLO ⁱ	ND-80 (14)	ND-50 (12)	ND-20 (8)	ND	ND-8000 (2750)	ND-3000 (750)
VCLO ^j	ND-110 (16)	ND-160 (25)	ND-210 (58)	ND-1000 (313)	ND-16000 (4812)	ND-3000 (375)
PALO ^k	ND-50 (12)	ND-160 (18)	ND-210 (40)	ND-3000 (313)	ND-1000 (250)	ND
SFLO ^l	ND-10 (2)	ND	ND	ND	ND	ND

Note: ^a Total viable counts, ^b Total coliforms, ^c Fecal coliforms, ^d *Escherichia coli* like organisms, ^e *Salmonella* like organisms, ^f *Shigella* like organisms, ^g *Proteus Klebsiella* like organisms, ^h *Vibrio* like organisms, ⁱ *Vibrio cholera* like organisms, ^j *Vibrio parahemolyticus*, like organisms, ^k *Pseudomonas aeruginosa* like organisms, ^l *Streptococcus fecalis* like organisms ^m none detected.

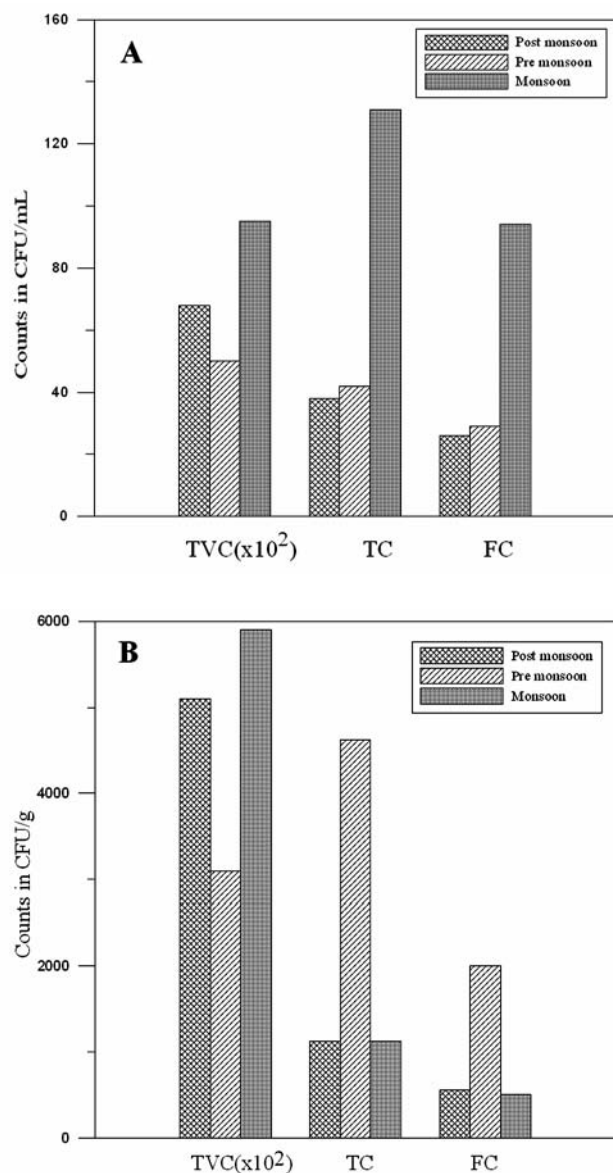


Fig. 2—Population density of Total Viable Count (TVC), Total Coliforms (TC) and Fecal Coliforms (FC) in (A) water and (B) sediment samples of Tapi estuary during different season.

(Table 3). Presence of fecal coliforms in the coastal waters indicates that the fecal contamination is from the human and animal sources. The overall highest occurrence of enteric pathogens like *Escherichia* (ECLO), *Shigella* (SHLO), *Proteus Klebsiella* (PKLO), *Vibrio parahemolyticus* (VPLO) and *Vibrio cholerae* like organism (VCLO) were found to be 52%, 37%, 74.1%, 59.2% and 48.1% during pre monsoon (Table 2). Highest pathogenic bacteria occurrence for *Salmonella* (SLO) and *Pseudomonas aeruginosa* like organism (PALO) were found to be 8% and 36% respectively

during post monsoon season. In coastal areas showed highest load of ECLO, PKLO and PALO, while middle estuarine area indicates maximum load of enteric bacteria like SHLO, and VPLO and in inner estuary waters *Vibrio cholerae* like organism were recorded maximum (Table 3).

Physico-chemical parameters and nutrients

The values in the Table 4 showed the physico-chemical parameters and nutrients available in different sampling sites of Tapi estuary. Temperature range varied from 23.4°C to 32.6°C, which indicates that maximum temperature was recorded at inner estuary particularly during pre monsoon season. While, pH varied from 7.5 to 8.2 with maximum pH was observed at coastal areas during post monsoon seasons. Salinity was observed from 14.0 to 32.4 ppt. Highest salinity was detected in coastal areas during monsoon seasons. Dissolved oxygen (DO) was 0.0 to 5.2 mL/L and no DO was recorded in inner estuary during pre-monsoon. Biological oxygen demand (BOD) was 0.0 to 96.5 mg/L, no BOD was recorded at middle estuary during post and pre monsoon seasons. Nutrients like ammonia, nitrate, nitrite and phosphate concentration were recorded maximum of 50.3, 142.8, 142.8 and 7.9 µmol/L particularly during post-monsoon and pre-monsoon seasons. Inner estuary showed higher amount of ammonia and phosphate, whereas coastal areas accounts for high amount of nitrate and nitrite (Table 4).

Correlation of physico-chemical parameters and the microbial population

The correlation among the microbial population and the physico-chemical parameters were presented in Table 5. Correlation matrix showed a very strong relationship of BOD with almost all the microbial populations. This clearly infers that, the microbial populations in the Tapi estuarine waters contribute the biological oxygen demand. A negative relationship of salinity exists with the bacterial populations like total viable count, total coliforms, fecal coliforms and *Vibrio* like organisms. Positive correlation was observed for temperature and pH with *Shigella*, *Salmonella*, *Vibrio parahemolyticus* and *Streptococcus fecalis* like organisms.

Table 2—Seasonal variation in distribution of enteric bacteria in water and sediment of Tapi estuary

Types of Bacteria	Samples								
	Number of samples analyzed (water + sediment)			Positive occurrence			Occurrence (%)		
	Post	Pre	Monsoon	Post	Pre	Monsoon	Post	Pre	Monsoon
<i>Fecal coliforms</i>	25.0	27.0	25.0	16.0	14.0	12.0	64.0	52.0	48.0
<i>E. coli</i>	25.0	27.0	25.0	11.0	14.0	10.0	44.0	52.0	40.0
<i>Shigella</i> spp.	25.0	27.0	25.0	9.0	10.0	9.0	36.0	37.0	36.0
<i>Salmonella</i> spp.	25.0	27.0	25.0	2.0	Nil	Nil	8.0	Nil	Nil
<i>Proteus</i> and <i>Klebsiella</i> sp.	25.0	27.0	25.0	6.0	20.0	7.0	24.0	74.0	28.0
<i>V. parahemolyticus</i>	25.0	27.0	25.0	6.0	16.0	5.0	24.0	59.2	20.0
<i>V. cholerae</i>	25.0	27.0	25.0	9.0	13.0	5.0	36.0	48.1	20.0
<i>P. aeruginosa</i> .	25.0	27.0	25.0	9.0	6.0	2.0	36.0	22.2	8.0

Note: All the values are taken as an average of two readings

Table 3—Distribution of enteric pathogens in different areas of Tapi estuary

Types of Bacteria	Stations											
	Number of samples analyzed (water + sediment)				Positive occurrence				Occurrence (%)			
	Inner	Middle	Outer	Coastal	Inner	Middle	Outer	Coastal	Inner	Middle	Outer	Coastal
<i>Fecal coliforms</i>	5.0	3.0	10	5.0	4.0	2.0	6.0	3.0	75.4	53.3	56.0	77.4
<i>E. coli</i>	5.0	3.0	10	5.0	4.0	2.0	4.0	3.0	69.0	53.3	43.3	65.2
<i>Shigella</i> spp.	5.0	3.0	10	5.0	3.0	2.0	5.0	1.0	62.8	53.	50.0	28.9
<i>Salmonella</i> spp.	5.0	3.0	10	5.0	Nil	Nil	0.3	Nil	0.0	0.0	3.3	0.0
<i>Proteus</i> and <i>Klebsiella</i> spp.	5.0	3.0	10	5.0	3.0	2.0	4.0	2.0	49.0	6.6	40.0	50.6
<i>V. parahemolyticus</i>	5.0	3.0	10	5.0	3.0	2.0	4.0	2.0	49.0	53.3	40.0	36.0
<i>V. cholerae</i>	5.0	3.0	10	5.0	3.0	2.0	3.0	1.0	56.6	53.3	30.0	28.9
<i>P. aeruginosa</i>	5.0	3.0	10	5.0	3.0	0.3	0.3	2.0	49.0	11.0	3.3	71.7

Note: All the values are taken as an average of two readings

Table 4—Physico-chemical parameters and nutrients in different areas of Tapi estuary

Parameters	Postmonsoon				Premonsoon				Monsoon			
	Inner	Middle	Outer	Coastal	Inner	Middle	Outer	Coastal	Inner	Middle	Outer	Coastal
Temp (°C)	27.3	23.9	23.9	23.4	32.6	30.1	24.6	30.2	28.4	27.8	29.1	29.2
pH	7.6	7.7	8.0	8.2	7.5	7.8	7.8	8.1	8.1	8.0	8.2	8.1
Salinity (ppt)	14.3	26.6	31.1	32.7	0.1	10.3	21.8	31.5	10.5	28.8	32	32.4
DO (ml ⁻¹)	0.1	2.1	4.1	4.8	0.0	3.1	5.1	5.2	4.5	4.7	4.5	4.4
BOD (mg ⁻¹)	0.0	0.0	1.3	4.6	96.5	0.0	4.5	3.1	3.9	2.0	2.0	1.5
NH ₄ ⁻ - N(μmol ⁻¹)	50.3	40.3	11.6	3.7	40.6	6.4	1.2	1.0	31.0	13.1	7.7	19.9
NO ₃ ⁻ - N(μmol ⁻¹)	2.8	17.2	17.6	22.6	5.6	142.8	25.1	52.6	35.0	46.0	26.6	36.7
NO ₂ ⁻ - N(μmol ⁻¹)	0.2	2.0	1.3	0.5	1.2	15.5	4.3	1.4	1.0	3.9	2.6	5.8
PO ₄ ⁻ - P(μmol ⁻¹)	1.2	1.0	1.7	2.1	7.9	3.6	2.6	2.7	1.8	4.8	2.4	1.3

Note: All the values are taken as an average of surface and bottom water

Table 5—Correlation matrix of water quality parameters with microbial populations of Tapi estuary

	TVC	TC	FC	ECLO	SHLO	SLO	PKLO	VLO	VPLO	VCLO	PALO	SFLO	Temp	pH	Salinity	DO	BOD
TVC	1.000																
TC	0.833*	1.000															
FC	0.796*	0.988*	1.000														
ECLO	0.735*	0.967*	0.985*	1.000													
SHLO	-0.253	0.125	0.220	0.346	1.000												
SLO	-0.285	0.088	0.188	0.304	0.947*	1.000											
PKLO	0.667**	0.851*	0.880*	0.883*	0.328	0.307	1.000										
VLO	0.619**	0.855*	0.891*	0.886*	0.292	0.231	0.873*	1.000									
VPLO	-0.165	0.185	0.295	0.401	0.941*	0.948*	0.451	0.380	1.000								
VCLO	0.696*	0.941*	0.972*	0.965*	0.336	0.322	0.916*	0.930*	0.411	1.000							
PALO	0.602**	0.895*	0.943*	0.952*	0.450	0.431	0.909*	0.898*	0.419	0.980*	1.000						
SFLO	-0.284	0.080	0.179	0.293	0.942*	0.998*	0.305	0.224	0.939*	0.319	0.424	1.000					
Temp	0.260	0.121	0.221	0.325	0.917*	0.989*	0.347	0.280	0.945*	0.358	0.459	0.986*	1.000				
pH	0.290	0.087	0.186	0.300	0.942*	0.999*	0.300	0.227	0.938*	0.321	0.429	0.998*	0.990*	1.000			
Salinity	-0.428	-0.100	-0.031	0.081	0.826*	0.921*	0.042	-0.090	0.783*	0.077	0.184	0.926*	0.897*	0.987*	1.000		
DO	0.296	0.085	0.179	0.295	0.938*	0.996*	0.280	0.210	0.921*	0.312	0.418	0.995*	0.985*	0.998*	0.937*	1.000	
BOD	0.174	0.121	0.233	0.238	0.570**	0.692*	0.437	0.319	0.720*	0.396	0.488	0.689*	0.740*	0.691*	0.554**	0.666**	1.000

Note: *- significant at 0.01 level, **- Significant at 0.05 level

Discussions

The present investigations showed the higher microbial counts with seasonal occurrence and distribution in Tapi estuary, along west coast of India, Natural characteristics of the coastal ecosystem has led to dreadful changes due to an increased use of coastal waters and the adjacent water bodies for waste disposals. Untreated sewage discharges and industrial effluents carries high load of pathogenic bacteria especially enteric groups and pose the threat to human health¹⁹. Generally the occurrences of microbial load were more in the sediment samples when compare with the water columns, present observations were quite similar with the findings of Nagvenkar and Ramaiah²⁰. Enhanced survival of stressors, such as sunlight, predation and increased availability of nutrients leads to high bacterial load in the sediments observed by Criag *et al*²¹. Our study showed higher microbial counts in monsoon season as compared

with post-monsoon and pre-monsoon seasons. These observations were very well supported by the similar observation made for higher bacterial populations during heavy rain falls²². Total coliforms and fecal coliforms were found to be high in monsoon season than their respective levels found in the post-monsoon and pre-monsoon seasons, which clearly suggests that, the role of precipitation on the sources and the extent of microbial pollutions. Sood *et al*²³ has made quite similar observations in Gangetic river. The sampling locations were being an estuarine and the availability of variable salinity may influence the total coliforms and fecal coliforms to get adapted and survive for a longer periods which results for higher counts²⁴. Overall, fecal coliforms counts studied in the present investigation were beyond the permissible limits of Central Pollution Control Board of India. Higher incidence of total coliforms compare to fecal coliforms and streptococcus fecalis were not

surprising, since total coliforms can originate from non fecal sources and they got narrowed down to the fecal coliforms and fecal streptococci²⁵. However, fecal streptococcal counts in Tapi estuarine water samples were lesser than those of Cherai beach, Kerala and Cochin backwaters, and could not be related to seasons contrary to earlier reports were higher counts recorded during monsoon and post-monsoon²⁶. Presence of different enteric pathogens like *Escherichia coli*, *Shigella*, *Salmonella*, *Proteus Klebsiella*, *Vibrio parahemolyticus*, *Vibrio cholerae*, and *Pseudomonas aeruginosa* like organism were also incorporated in the present study. *Salmonella* and *Shigella* were pathogens that are distributed worldwide and transmitted mainly through food and water ingestions²⁷. Pathogenic bacteria for human health concern have been studied mostly for their survival in the river environment, their presence in recreational water renders that water is unfit for human use for any purpose²⁸. *V. cholerae* and *V. parahemolyticus* most common species observed in marine environments. The higher influence of the marine environment provokes bacterial inactivation of the allochthonous microbiota from sewage discharges, except for the halotolerant microorganisms. Present study reflects their overall percentage occurrence for *Escherichia coli* (65.2%), *Proteus Klebsiella* (50.6%) and *Pseudomonas aeruginosa* (71.7%) in coastal waters as compared to inner, middle and outer areas of Tapi estuarine and their presence in water columns is of serious concern. It indicated the increase in the human induced activities in the near coastal zone and riverine discharges sources. The common practice is that settlements along the Tapi estuarine water discharge due to domestic effluents into the estuaries, apart from such daily discharges of untreated sewage effluents deliberately and incidentally at various locations, the sewer flows during low tide times increased the amount of effluents leading to higher concentrations of sewage pollution indicator bacteria in the estuarine environments.

Several investigators have examined the distribution of indicator and human pathogenic bacteria as well as certain viruses in coastal waters with a view to quantify and understand their relationships and their relevant environmental factors²⁹⁻³¹. Fluctuation in river water temperature usually depends on the season, geographic location, sampling time and temperature of effluent entering to the stream. Temperature and pH showed good

correlations with microbial populations as both are limiting factors for the survival of bacteria in the environment. Salinity shows negative relationships with microbial population indicates that, the source of bacterial population is riverine as salinity plays a key role in the biological process³². Dissolved oxygen shows a correlation with *Shigella*, *Salmonella*, *Vibrio parahemolyticus* and *Streptococcus fecalis* like organisms, while Biological oxygen demand shows a strong correlation with *Shigella*, *Salmonella*, *Vibrio parahemolyticus* and *Streptococcus fecalis* like organism which may indicate the influence of human settlements and mixing of untreated sewages³².

Conclusion

Fecal pollution indicator bacteria such as total coliforms, fecal coliforms and fecal streptococcus have been used as a model for study the presence of pathogenic microorganisms. Present investigation dealt with the seasonal variation and distribution of microbial counts in Tapi estuary, which reveals the higher microbial count and indicates the influence of human activities and mixing of domestic untreated sewage with estuarine environment. Baseline data generated on microbiological quality of Tapi estuary water sample may serve as a biomonitoring and comparisons analysis for other coastal studies. Data may be useful for decision makers and resource managers working with environmental planning and management of coastal areas to implement the proper treatment procedure for waste waters and effluents before discharging into the estuarine and to avoid various human diseases outbreaks.

Acknowledgements

Author thanks Dr S R Shetye, Director, National Institute of Oceanography for facilities and encouragement. Syed G. Dastager is acknowledging the Council of Scientific and Industrial Research (CSIR), New Delhi, India, supported from the grants under OLP1209 and GAP 2045. This is NIO contribution number XXXX.

References

- 1 Scott T M, Salina, Portier K M, Rose J B, Tamplin M L, Farrah S R, Koo A & Likasik J, Geographical variation in ribotype profiles of *Escherichia coli* isolates from human, swim, poultry, beef and dairy cattle in Florida. *J. Appl. Environ. Microbiol.* 69 (2003) 1089-1092.
- 2 Dionisio L P C, Rosado E G, Lopez-cortes L, Castro D & Borrego J J, Microbiological and sanitary quality of

- recreational seawaters of Southern Portugal. *Water. Air. Soil Poll.* 138 (2002) 319-334.
- 3 Aikten M N, Impact of agricultural practices and river catchment characteristics on river and bathing water quality. *Wat. Sci. Technol.* 48 (2003) 217-224.
 - 4 Rodrigues V, Ramaiah N, Karti S & Somant D, Long term variations in abundance and distribution of sewage pollution indicator and human pathogenic bacteria along the central coast of India. *Ecol. Indicator.* 11 (2011) 318-327.
 - 5 El-Naggar M M A & Farag A M, (2005) Spatial and temporal variability of saprophytic and water quality bacteria along the coast of Aqabaa, Suez gulfs and Red sea-Egypt. *Egyptian. J. Aqua. Res.* 31 (2005) 157-169.
 - 6 Baghel V, Gopal K, Diwedi S & Tripathi R D, Bacterial indicators of fecal Contamination of the Gangetic river system at its source. *Ecol. Indicat.* 5 (2005) 49-56.
 - 7 Tyagi V K, Chopra A K, Kazmi AA & Kumar A, (2006) Alternative microbial indicators of fecal pollution: Current perspective. *Iran. J. Environ. Health Sci. Engineering.* 3 (2006) 205-21.
 - 8 Sabae S Z, (2006) Spatial and temporal variability of saprophytic bacteria, fecal indicators and the nutrient cycle bacteria in lake bardawil, Sinai, Egypt. *Int J Agricul Biol.* 8 (2006) 178-185.
 - 9 Desmarais T R, Solo-Gabriele H M & Palmer C J, Influence of soil on fecal indicator organims in a tidally influenced subtropical environment. *J. Appl. Environ. Microbiol.* 68 (2002) 1165-1172.
 - 10 Byamukama D, Mach R L, Kansime F, Manafi M & Farnleitner A H, Discrimination of efficacy of fecal pollution detection in different aquatic habitats of a high altitude tropical estuary, using presumptive coliforms, *Escherichia coli* and *Clostridium perfringens* spores. *J. Appl. Environ. Microbiol.* 71 (2005) 65-71.
 - 11 Haller L, Pote J, Loizeau J L & Wildi W, Distribution and survival of fecal indicator bacteria in the sediment of the Bay of vidy, lake Geneva, Switzerland. *Ecol. Indicat.* 9 (2009) 540-547.
 - 12 Badra B, Mukherjee S, Chakarborty R & Nanda A K, Physiochemical and bacteriological investigation on the river Torsa of North Bengal. *J. Environ. Biol.* 24 (2003) 125-133.
 - 13 Arvanitidou M, Kanellou K & Viagiona DG, Diversity of Salmonella spp. and Fungi in northern Greek rivers and their correlation to fecal pollution indicators. *Environ. Res.* 99 (2005) 278-284.
 - 14 Ferguson C, Husman AMD, Altavilla N, Deere D & Ashbolt N, Fate and transport of surface water pathogens in watersheds. *Crit. Revie. Environ. I Sci. Technol.* 33 (2003) 299-361.
 - 15 Smith J E & Perdek J M, Assessment and management of watershed microbial contaminants. *Crit. Rev. Environ. Sci. Technol.* 34 (2004) 109-139.
 - 16 United States Environmental Protection Agency (USEPA), Recommended protocols for microbiological studies in Puget Sound. Puget Sound Estuary Program, Puget Sound Monitoring Program. USEPA, Region 10. Office of Puget sound, Settle (1986), WA.
 - 17 APHA, standards methods for the examination of water and waste water. 18th edn, American Public Health Association, Washington, DC (1995) USA
 - 18 Parsons RP, Maita Y & Lalli CM, A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press (1992) Oxford.
 - 19 Lipp EK, Farrah SA & Rose JB, Assessment and impact of microbial fecal pollution and human enteric pathogens in a coastal community. *Mar. Poll. Bull.* 42(2001) 286-293.
 - 20 Nagvenkar GS & Ramaiah N, Abundance of sewage-pollution indicator and human pathogenic bacteria in a tropical estuarine complex. *Environ. Monit. Asses.* 155 (2009) 245-256.
 - 21 Craig D L, Fallowfield H J & Cromar N J, Enumeration of fecal coliforms from recreational coastal sites: evaluation of techniques for the separation of bacteria from sediments. *J. Appl. Microbiol.* 93 (2002) 557-565.
 - 22 Ramaiah N, Rodrigues V, Alvares E, Rodrigues C, Baksh R, Jaya S & Mohandas C, Sewage-pollution indicator bacteria, Research Publishing Services, Chennai, India. (2007) pp. 115-120.
 - 23 Sood A, Singh K D, Singh P & Sharma S, Assessment of bacterial indicators and physicochemical parameters to investigate pollution status of Gangetic river system of Uttarakhand (India). *Ecol. Indicator.* 8 (2008) 709-717.
 - 24 La Rosa T, Mrito S, Marino A, Alonzo V, Maugeri T L & Mazola A, (2001) Heterotrophic bacterial community and pollution indicators of mussels- farm impact in the gulf of Gaeta (Tyrrhenian sea). *Marine Environ. Res.* 52 (2001) 301-321.
 - 25 Kistemann T, Claben T, Koch C, Dangendorf F, Fischeder R, Gebel J, Vacata V & Exner M, Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff. *J. Appl. Environ. Microbiol.* 68 (2002) 2188-2197.
 - 26 Vaidya SY, Vala A K & Dube H C, Bacterial indicators of fecal pollution at Bhavnagar coast. *Ind. J. Microbiol.* 41 (2001) 37-39.
 - 27 Rosenfeld L K, Mc Gee C D, Robertson G L, Noble M A & Jones B H, Temporal and spatial variability of fecal indicator bacteria in the surf zone off Huntington beach, CA. *Marine Environ. Res.* 61 (2000) 471-493.
 - 28 Kim G, Choi E & Lee D, Diffuse and point pollution impacts on the pathogen indicator organism level in the Geum River Korea. *Sci. Total Environ.* 350 (2005) 94-105.
 - 29 Ruiz G M, Rawlings T K, Dobbs FC, Drake L A, Mudullay T, Huq A & Colwell R R, Global spread of microorganisms by ships. *Nature.* 408 (2000) 49-50.
 - 30 Pathak S P & Gopal K, Rapid detection of *Escherichia coli* as an indicator of fecal pollution in water. *Ind. J. Microbiol.* 41 (2001) 139-151.
 - 31 Patra A A, Acharya B C & Mahapatra A, (2009) Occurrence and distribution of bacterial indicators and pathogens in coastal waters of Orrisa. *Ind. J. Marine Sci.* 38 (2009) 474-480.
 - 32 Ajithkumar TT, Thangaradjou T & Kannan L, Physico-chemical and biological properties of the Muthpettai mangrove in Tamil Nadu. *J. Mar. Biol. Assess. India.* 48(2006) 131-138.