such bench cultivated paddy fields have contributed to the increase of pore pressure resulting in mud flows. Thus, Malin landslides are the cumulative effect of tectonism and anthropogenic activities.

In such tectonically active and anthropogenically invaded Malin area, detailed studies are required on large scale to mitigate landslides, involving (i) Mapping of lineaments using aerial photographs and multidated satellite images bringing out the time series growth and modification of the fractures, (ii) detailed structural mapping, (iii) GPS-based monitoring of the cracks/fractures, (iv) detailed geomorphic mapping, (v) land use/land cover mapping using multidated satellite images, change detection in land use/land cover vis-à-vis rainfall and landslides, (vi) clay mineralogy, (vii) geotechnical investigations, etc. Working out the factor of safety and integration of all would give a viable direction to mitigating landslides in the area.

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Water quality index of estuarine environment

The estuarine environment is characterized by constant churning of freshwater from the river with marine water, which may be challenged by modifications in water quality. Aquatic animals living in such a challenged estuarine environment should be able to match appropriate changes with their physiological requirements. It is observed that estuarine environment is polluted by discharges of domestic sewage and industrial effluents besides other anthropogenic activities including agricultural runoff[1]. These discharges bring considerable amount of pollutants that may cause undesirable changes in the water quality which ultimately cause pollution. Such pollution is a serious threat not only to the aquatic organisms but also to the downstream water users.

Conventionally, pollution status of water resources including estuary can be determined by assessing water quality parameters (WQP) *in situ* and *ex situ*. However, computation of water pollution index (WPI) based on WQP provides relatively precise information on the extent of pollution. The use of WPI is an important tool as it is stretched analysis. Therefore, it has wide applications as the indicator of the quality of sea water[2] and river waters[3–5] as well as drinking water[6]. The water quality of Kollidan estuary[7], Mahi estuary[8,9], Devi estuary[10] and Tapi estuary[11,12] was studied earlier. These studies inferred that these lotic ecosystems are polluted by domestic sewage, industrial effluents and other anthropogenic activities. Further, developmental activities are also reported to affect the riverine, estuarine, coastal and marine environments[13,14].

The WPI is helpful to summarize a large amount of water quality data into simple terms which is one of the most effective ways to communicate information on water quality trends to guide policy makers on effective restoration, conservation and management of water resources. The WPI of Borska Reka river shows increasing organic pollution which results from domestic discharges[15]. Similarly, the coastal environment of Mumbai is affected by local inputs of sewage from drainage, anthropogenic activities and industrial discharges through creeks, rivers and sewage outfall points[16]. Likewise, WQP and pollution index of Danube–Tisa–Danube canal system of Serbia[17] and Woji river, Nigeria[5] were studied and various causes of pollution were underlined.

This study deals with WQP vis-à-vis WPI of Tapi estuary, Gujarat to assess the pollution status which may be helpful to improve the water quality management and policy making to conserve this estuarine ecosystem.

The Tapi estuary is one of the major estuaries of west coast river systems of India and situated at 21°40′N and 72°40′E. Hazira sampling station selected for this study is located on the southern bank of Tapi estuary, which is 8 km away from Surat city (Figure 1).

For the analysis of WQP, the water samples were collected and preserved in pre-rinsed plastic bottles at monthly intervals during January 2011–June 2011. The samples were filtered prior to analysis. Although temperature, pH and dissolved oxygen (DO) were analysed *in situ*, the conductivity, turbidity, nitrate-nitrogen, nitrite-nitrogen, phosphate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, fluoride and chloride were analysed in the Research Laboratory, Department of Aquatic Biology, VNSGU, Surat. For the preservation and analysis of the water samples, the standard methods were followed[18,19].

As WPI represents the sum of the ratio between the observed parameters and regulated standard values, the WPI of Tapi estuary was calculated from the

Table 1. Water quality parameters of estuarine environment

Parameters	January	February	March	April	May	June	Minimum	Maximum	Average	SE
Temperature (°C)	21.00	23.00	24.00	27.00	29.00	30.00	21.00	30.00	25.17	1.25
Turbidity (NTU)	64.00	65.65	68.00	76.10	82.00	87.00	64.00	87.00	73.79	3.84
pH	8.10	8.00	7.80	7.50	7.90	7.40	7.40	8.10	7.78	0.11
DO (mg/l)	1.20	2.00	2.40	0.80	4.00	6.00	0.80	6.00	2.73	0.80
BOD (mg/l)	0.50	1.40	2.90	0.40	2.00	2.40	0.40	2.90	1.60	0.45
COD (mg/l)	780.00	760.00	852.00	140.00	664.00	800.00	140.00	852.00	666.00	108.18
Nitrate-N (mg/l)	0.44	0.70	0.21	0.78	54.46	46.79	0.21	54.46	17.23	10.61
Nitrite-N (mg/l)	0.27	0.18	0.17	0.79	3.21	3.05	0.17	3.21	1.28	0.59
Phosphate (mg/l)	0.26	0.18	0.17	0.28	0.88	0.39	0.17	0.88	0.36	0.11
Conductivity (mS)	0.99	0.99	12.47	0.95	0.99	0.98	0.95	12.47	2.89	1.92
Ammonia (mg/l)	0.47	0.19	0.18	0.19	1.59	0.95	0.18	1.59	0.60	0.23
Fluoride (mg/l)	1.14	0.13	0.02	0.01	0.01	0.02	0.01	1.14	0.22	0.18
Chloride (mg/l)	7,702.61	7,764.78	11,771.35	14,059.61	6,340.82	7,404.20	6,340.82	14,059.61	9,173.90	1,237.27

DO, Dissolved oxygen; BOD, Biochemical oxygen demand; COD, Chemical oxygen demand.

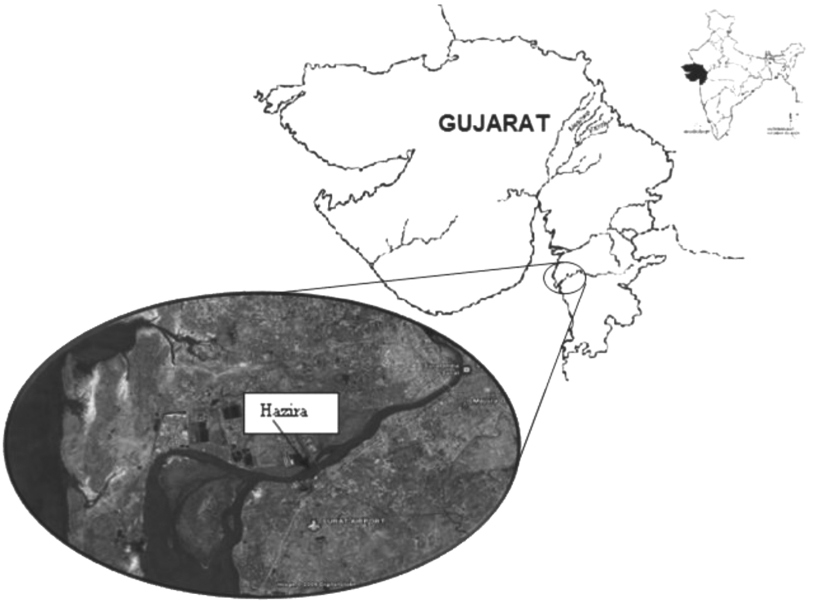

Figure 1. Map of the study area (Hazira sampling station, Tapi estuary).

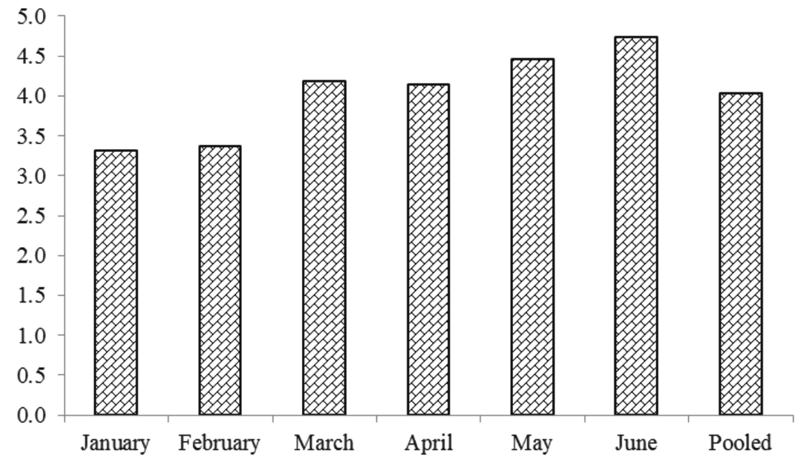

Figure 2. Graphical presentation of monthly water pollution index variations.

observed values of WQP following the equation[3]

$$\text{WPI} = \sum(C_i/\text{SFQS}) \times (1/n),$$

where C_i represents the average monthly concentration of the analysed WQP, SFQS represents the standard values of the water quality and n indicates the number of analysis. Data analysis and graphical presentations were done with Microsoft Excel 2008.

The conventional approach of presenting WQP in varying units is accepted by environmentalists and experts of water resources. Here, maximum temperature, turbidity and DO were observed (30.00°C, 87.00 NTU and 6.00 mg/l) during June, whereas these were minimum (21.00°C, 64.00 NTU and 0.80 mg/l) during January, respectively (Table 1). The BOD, COD and conductivity were high (2.90 mg/l, 852.00 mg/l and 12.47 mS) and low (0.40 mg/l, 140.00 mg/l and 0.95 mS) in March and April respectively (Table 1). The major elements of chemical parameters including nitrate-N, nitrite-N, phosphate and ammonia were found maximum (54.46, 3.21, 0.88 and 1.59 mg/l) during May and minimum (0.21, 0.17, 0.17 and 0.18 mg/l) during March (Table 1). The maximum quantity of fluoride (1.14 mg/l) and chloride (14,059.61 mg/l) was observed during January and April respectively; whereas these were observed minimum (0.01 and 6340.82 mg/l) during May (Table 1). Average values of WQP were compared with prescribed units of water quality standards from which it is evident that temperature (25.17°), pH (7.78), nitrite-N (1.28 mg/l), BOD (1.60 mg/l), DO

Table 2. Average values of water quality parameter and water pollution index (WPI) of estuarine environment

Parameters	Average	Quality standards	Reference	Ratio of observed and standard parameters (C_i/SFQS) × (1/n)
Temperature (°C)	25.170	30	20	0.143
Turbidity (NTU)	73.790	10	20	1.230
pH	7.780	8.3	20	0.156
DO (mg/l)	2.730	4	20	0.114
BOD (mg/l)	1.600	30	20	0.009
COD (mg/l)	666.000	250	20	0.444
Nitrate-N (mg/l)	17.230	10	20	0.287
Nitrite-N (mg/l)	1.280	10	20	0.021
Phosphate (mg/l)	0.360	0.1	20	0.002
Conductivity (mS)	2.890	2.25	21	0.079
Ammonia (mg/l)	0.600	5	21	0.020
Fluoride (mg/l)	0.220	15	21	0.002
Chloride (mg/l)	9,173.900	1000	21	1.529
		WPI = $\sum$ (C_i/SFQS) × (1/n)		4.035

Table 3. Classification of water pollution levels on basis of water pollution index (WPI)[2]

Class	Characteristics	WPI
I	Very pure	<0.3
II	Pure	0.3–1.0
III	Moderately polluted	1.0–2.0
IV	Polluted	2.0–4.0
V	Impure	4.0–6.0
VI	Heavily impure	>6.0

(2.73 mg/l), ammonia (0.60 mg/l) and fluoride (0.22 mg/l) were well within the limits, whereas turbidity (73.79 NTU), COD (666.00 mg/l), nitrate-N (17.23 mg/l), phosphate (0.36 mg/l), conductivity (2.89 mS) and chloride (9,173.90 mg/l) exceeded the limits of water quality standards prescribed by Moor[20] and CPCB[21] (Table 2). Results further show that comparative low value of DO and high values of nitrate-N, turbidity and COD during the study depicts distribution of inorganic contents in estuarine environment that may occur due to discharge by industries and anthropogenic activities. Similar findings on water quality of Tapi estuary were described earlier and it is considered as polluted with input sources from industries, domestic and anthropogenic[11,12,22] activities. Results on water quality and water quality index of River Cauvery (Tamil Nadu) exhibited the pollution status and confirm urbanization along the river banks to be the main cause of pollution[23]. In this study, WPI was minimum (3.3) during January and maximum (4.7) during June with an average of 4.035 (Table 2 and Figure 2). WPI values further show that Tapi estuary can be assigned V category (Table 3), which is considered valid for impure resource. Findings on water quality and overall indices of pollution were stated earlier for Borska Reka river, Serbia[15] and in the upstream of Zuari river's estuarine region of Goa[24] and these are considered slightly polluted due to domestic wastes and anthropogenic activities. Results of this study corroborates with the findings on Cauvery river[23], Zuari estuary[24] and Garganrood river[25] for the water quality and WPI. Based on the findings of this research, it can be inferred that the seasonal variations are influenced directly by various anthropogenic activities and industrial effluents, being the main causes for pollution.

This study summarizes the pollution status of the Tapi estuary on the basis of physico-chemical parameters which is further confirmed by the computed values of WPI. Low values of DO and high values of nitrate-N, turbidity and COD show the distribution of inorganic contents in this aquatic environment that may be influenced by discharges from industries and anthropogenic activities in and around the estuarine zone.

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