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Application of WQI Technique for the Classification of Water Quality: Mahanadi River-estuarine System, India – A Case Study

Sanjay Kumar Sundaray*, Binod Bihari Nayak[1] and Dinabandhu Bhatta[2]

*Department of Chemistry, S.C.S. (Autonomous) College, Puri - 752 001, Orissa, India
[1]Regional Research Laboratory, Bhubaneswar - 751013, Orissa, India
[2]Department of Chemistry, Utkal University, Bhubaneswar - 751004, Orissa, India
✉ sanjay_sundaray@yahoo.com

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Abstract: Water Quality Index (WQI) plays an important role in interpreting the information on water quality trends of a water body and was used to denote degradation of river water quality. WQI technique was applied for the classification of Mahanadi river-estuarine waters with respect to three major use purposes. WQI representing importance of the variables was studied with respect to suitability of river water for drinking, aquatic lives and irrigation purposes for 31 different stations of the river during six different seasons (pre-monsoon, monsoon and post monsoon during 2001–02 and 2002–03). In the formulation of a WQI, the importance of various parameters (pH, EC (electrical conductance), DO (dissolved oxygen), BOD (biochemical oxygen demand), TDS (total dissolved solids), turbidity, SO4, chloride, nitrate, sodium, calcium, magnesium, alkalinity and hardness) depends on the intend use of water. The results of different WQI produce similar trend but different index values as well as some different remarks. The present study reveals that the water quality of Atherbanki creek irrespective of seasons, is quite unsuitable for all the three purposes, which may be due to the combined impact of municipal effluent from Paradip township, industrial effluents from industries like PPL** and also saline influence. The application of a WQI to the Mahanadi river allows a water quality classification both spatial and temporally, that is reproducible within the river by means of uniform, objective criteria. Such an approach permits the identification of stretches of river that may require urgent measures in order to restore minimal water quality uses for different purposes, and can be applied beyond the Mahanadi river.

From the present observation, it can be concluded that three major townships (Sambalpur, Cuttack and Paradip) in the basin produce negative impact on the Mahanadi river water quality, particularly serious after the city sewage discharge. Effective pollution control measures must be taken in the near future.

Key words: WQI, drinking, irrigation, aquatic lives, Mahanadi river, India.

Introduction

Rivers due to their role in carrying off the municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution. Since, rivers constitute the main inland water resources for domestic, industrial and irrigation purposes, it is imperative to prevent and control the river pollution and to have reliable information on the quality of water for effective management. The chemistry of water is an important factor determining its use for domestic, irrigation or industrial purposes. Due to spatial and temporal variations in water chemistry a monitoring programme

*Corresponding Author
**All location abbreviation given in Table 2.

that will provide a representative and reliable estimation of water quality of surface waters is necessary (Chapman, 1992: Simeonov et al., 2002).

However, accurate and timely information on the quality of water is necessary to shape sound public policy and implement the water quality improvement programmes efficiently. Various governments, industries, political decision makers, non-technical water managers and the general public usually has neither the time nor the training to study and understand a traditional technical review of water quality data. A number of indices have been developed to summarize water quality data in an easily expressible and understandable format (Couillard and Lefebvre, 1985). Water quality indices are intended to provide a simple and understandable tool for managers and decision makers on the quality and possible users of a given water body. Basically, a water Quality Index (WQI) attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Miller et al., 1986; Bordalo et al., 2001).

A WQI may be defined as a rating reflecting the composite influence on overall quality of a number of individual characteristics or water quality parameters (Tiwari and Ali, 1987). The WQI techniques are the appropriate tool for a meaningful data reduction and interpretation of multi-constituent chemical and physical measurements (Tiwari et al., 1986; Nayak and Purohit, 1996; Tiwari and Nayak, 1998; Mishra and Patel, 2001(a), (b), 2002; Abraham and Beegum, 2001; Swain et al., 2002). This technique makes the information more easily and rapidly interpretable than a list of numerical values. Consequently, a WQI is a communication tool for transmitting information. It also permits to assess changes in water quality and to identify water trends (Chapman, 1992).

Study Area

Geographical Setting

The Mahanadi river system is the third largest in the Indian peninsula and the largest river in Orissa. The basin (80°30′–86°50′ E and 19°20′–23°35′ N) extends over an area of approximately 141,600 km^2, has a total length of 851 km and an annual runoff of 50 × 10^9 m^3 with a peak discharge of 44,740 M^{3}S^{-1} (Konhauser et al., 1997; Chakrapani and Subramanian, 1990; Sundaray et al., 2006). The basin is characterised by a tropical climate with average annual rainfall of 142 cm (NWDA, 1981) with 90% occurring during the SW monsoon. The river begins in the Baster hills of Madhya Pradesh flows over different geological formations of Eastern Ghats and adjacent areas and joins the Bay of Bengal after dividing into different branches in the deltaic area. The main branches of River Mahanadi meet Bay of Bengal at Paradip and Nuagarh (Devi estuary) (Figure 1). The tidal estuarine part of the river covers a length of 40 km and has a basin area of 9 km^2. Based on physical characteristics, the estuary has been characterized as a partially mixed coastal plain estuary.

Geology of the Basin

The basin geology is characterised by the pre-cambrians of Eastern Ghats consisting of rock types as khondalites, charnockites, leptynites, granites, gneisses, etc., the limestones, sandstones and shales of the Gondwanas, and the coastal tracts constituted by the recent deltaic alluvium of the river with littoral deposits. The basin lithology consists of granite suite (34% of the basin area), Khondalite suite (7%), charnockite suite (15%), limestone, shale of lower gondwana (17%), sandstone, shale of upper gondwana (22%) and coastal alluvium (5%). A part of the richest mineral belt of the sub-continent consisting of Fe ore, coal, lime-stone, dolomite, bauxite, Pb and Cu deposits fall within the basin (Chakrapani and Subramanian, 1990).

Anthropogenic Setup of the Area

The river serves as a major source of domestic water supply of the Cuttack (population about 50 million), Sambalpur (population about 20 million) cities and indirectly to Paradip (population about 15 million) through Taladanda canal. In addition to the above three major urban settlements, there are a number of rural and minor urban settlements which depend upon the river for their domestic water consumption. The annual water abstraction for domestic consumption in the basin is 826.85 Mm^3 (Table 1).

Irrigational use accounts for about 87% of the total organized water usage in the basin. The river serves as a major source of water supply of about 13,590.17 km^2 irrigation area in the basin (Table 1). Agriculture is the most important economic activity within the basin and agricultural land use constitutes the most significant aspect in comparison to the other forms of land use. The cultivated area (69,654.57 km^2) of the basin accounts for 49.39% of the total basin area, where 13% of the basin area is cultivated more than once in a year (CPCB, 2000). Subsequently the river receives back the untreated domestic waste water from Sambalpur, Bauda, Cuttack, Choudwar, Jagatpur and Paradip cities of Orissa state and effluents from some industries (fertilizer, paper, textile distilleries and others) directly during its course (Radhakrishna, 2001; Sundaray et al., 2006). It also

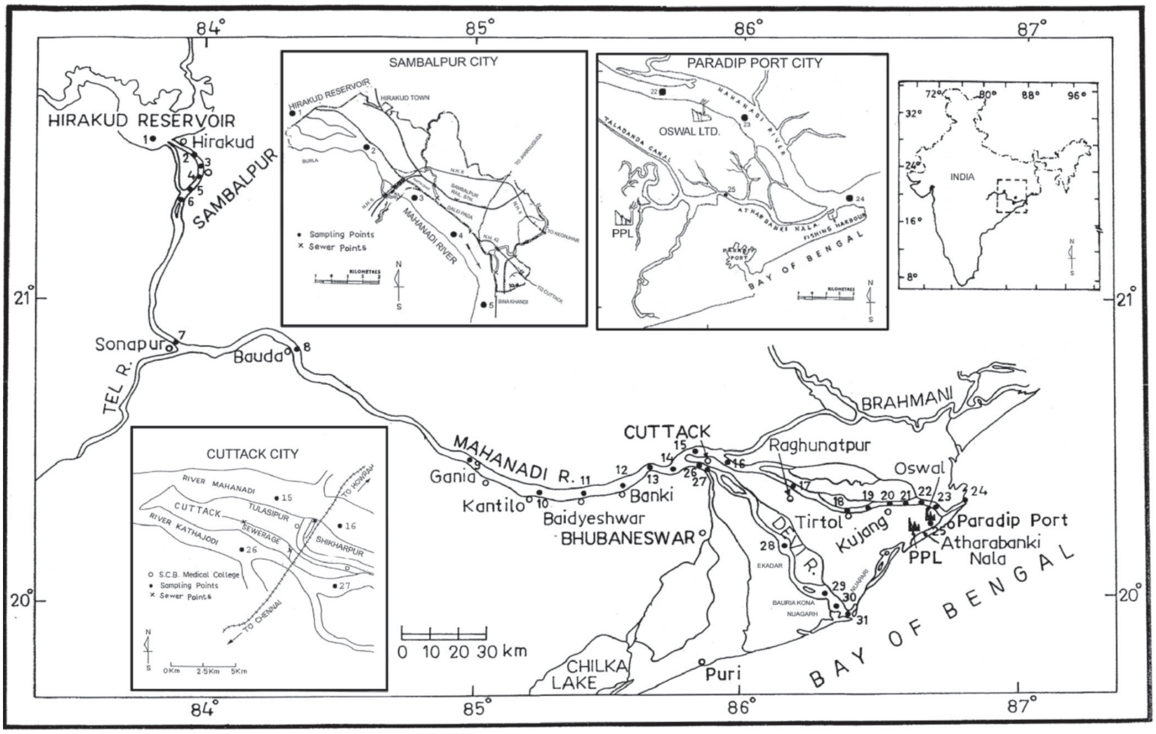

Figure 1: Map showing station locations.

Table 1: Land use characterisrics and water abstraction in Mahanadi river basin

Total basin area	km^2	141600
Total population of the basin		26321362
Cultivated area in the basin area	km^2	69654.57
% of cultivated area to total basin area	%	49.39
Irrigated area in the basin	km^2	13590.17
Total annual river water abstraction (for all purposes) in the basin	Mm^3	18745.87
Annual River water abstraction for agriculture	Mm^3	17830.09
Annual River water abstraction for domestic consumption	Mm^3	826.85
Annual River water abstraction for industries	Mm^3	88.94
Total river water abstraction (for all purposes) in the basin	Mm^3/year	18745.87
% of river water abstraction to total water abstraction in the basin	%	95.11
Waste water return from agriculture	Mm^3/year	2159.93
% of waste water return from irrigated field to total water use for agriculture	%	12
Waste water generated from urban	Mm^3/year	169.074
Waste water generated from rural	Mm^3/year	299.89
% of domestic waste water generated to total water use for domestic purposes	%	62.5
Waste water generated from industries	Mm^3/year	80.738
% of industrial waste water generated to total water use for industries	%	90
Total waste water generated	Mm^3/year	2710.63

Ref: CPCB, 2000 and NWDA, 1981

receives large amount of agricultural runoff along its course. Human influences are pronounced at three major urban settlements on the banks of the river (Figure 1), where the proliferation of industries and sewer discharges are prominent.

The details of location of sewer and industrial effluent discharge point along with their main product, volume of effluent and their pollutant characteristics are presented in Table 2.

Literature Review and Thought Process

Numerous works were carried out on the role of different urban and industrial effluents upon the water quality of Mahanadi river and estuarine systems (Upadhayay, 1988; Chakrapani and Subramanian, 1990; Chakrapani and Subramanian, 1993; Das et al., 1997; Nanda and Tiwari, 2001; Radhakrishna, 2001; Nayak et al., 2001; Das, 2003; Sundaray et al., 2005; Sundaray et al., 2006), but no study has been carried out on the application of WQI

Table 2: List of major municipal township and industries along with their pollutant characteristics on the Mahanadi River basin

Sl. No.	*Major sewage/ industries*	*Location*	*Product*	*Approx. Vol of waste water discharge*	*No. of treatment plant*	*Main pollutant*
1	Sambalpur Township	U/s of st. 4 & 5 at Binakhandi, Sambalpur	—	264.54 M m^3/year	Nil	Nutrients, BOD, Oil, Heavy metals, Pathogenic becteria
2	Cuttack Township	U/s of st.16 at shikharpur & U/s of st.27 Khathjodi down, Cuttack	—	708.944 M m^3/year	Nil	Nutrients, BOD, Oil, Heavy metals, Pathogenic bacteria
3	Paradip Township	U/s of st. 25 at Atharbanki, Paradip	—	—	Nil	Nutrients, BOD, Oil, Heavy metals, Prathogenic becteria
4	Indian Aluminium Co, Hirakud	U/s of st. 4 at Sambalpur	Aluminium	560 m3/day	Nil	Flouride, COD
5	Hirakud Industrial Works, Hirakud	U/s of st. 4 at Sambalpur	Engineering Goods	80 m^3/day	Nil	Oil, Grease, SS, COD
6	Hira cables, Hirakud	U/s of st. 4 at Sambalpur	Aluminium Conductor	72 m^3/day	Nil	pH, Oil and Grease, SS, COD
7	Re-rolling mills, Hirakud	U/s of st. 4 at Sambalpur	Contingand Forging	156 m^3/day	Nil	SS, BOD
8	IPINIT vanaspati, Jagatpur, Cuttack	U/s of st.16 at Shikharpur, Cuttack	Vanaspati, Soap stock	80 m^3/day	Nil	SS, BOD
9	Tatagarh Paper mills Choudwar, Cuttack	U/s of st.16 at Shikharpur, Cuttack0	Pulp & Paper	—	Nil	BOD, COD, SS, pH
10	Orissa textiles mills, Choudwar,Cuttack	U/s of st.16 at Shikharpur, Cuttack	Cotton Textiles	1507 m^3/day	Nil	pH, BOD, dyes
11	Central Orissa Straw Boards, Jagatpur, Cuttack	U/s of st.16 at Shikharpur, Cuttack	Paper & Duplex Boards	181.5 m^3/day	Nil	BOD, COD, SS, pH
12	Paradip Phosphates Ltd, Paradip	U/s of st. 25 at Atharbanki, Paradip	Fertiliser & Diammonium Phosphate	3264 m^3/day	One	pH, BOD, Nutrients, Flouride
13	Oswal Fertiliser Ltd, Paradip	U/s of st.23 at Oswal down, Paradip	Fertiliser & Diammonium Phosphate	4085 m^3/day	One	pH, BOD, Nutrients, Flouride
14	East Coast Brewaries & Distilleries Ltd, Paradip	U/s of st.25 at Atharbanki, Paradip	Breweries	376 m^3/day	Nil	BOD, SS, pH, Mineral acids, Sugars

Ref: CPCB, 2000

technique for the evaluation of water quality with reference to suitability for aquatic lives consumption and agricultural purposes.

In recent years, various statistical procedures based on water quality index have been used to formulate environmental classification. Research has been carried out in many parts on the application of WQI technique for the evaluation of water quality. The WQI approach has many variations in the literature and comparative evaluations have been undertaken (Singh and Anandh, 1996; Tyagi et al., 2003; Tiwari et al., 1986 Malathi et al., 1998; Alexander et al., 1999; Merlin et al., 2001; Cude, 2001; Harkins, 1974; Inhaber, 1976; Stoner, 1978; Ott, 1978; Dunnette, 1979; Lohani, 1981; Miller et al., 1986; Chapman, 1992; Rauch et al., 1998; Shanahan et al., 1998; Somlyody et al., 1998; Gilianovic, 1999; Pesce and Wunderlin, 2000). The use of an index to 'grade' water quality is a controversial issue among water quality scientists. Numerous WQI have been developed, with different countries having different WQI. Canadian council of ministers of the environment water quality index (CCMEWQI) has been utilized in Canada (http: //www.waterquality). The national sanitation foundation's water quality (NSFWQI) has been utilized in United States (http://.bcn.). The DOE water quality (DOEWQI) has been utilized in Malaysia (DOE, 2001; Sari and Omar, 2008). There are also other WQI like Oregon water quality index (OWQI) (http://www.deq; Cude, 2001), Iowa water quality index (IWQI) (IOWA, 2006), Scottish WQI (SDD,1976; Bordalo et al., 2001), National science foundation water quality indices (Ott, 1978; Mathuthu et al., 1993; Jonnalagadda and Mhere, 2001) has been utilized by different workers.

All these water quality indices incorporate data from multiple selected water quality parameters into a mathematical equation that rates the health of a river with a single number. The selection of parameters for calculation of WQI is different for different WQI. Furthermore, the standard/permissible values of selected parameters are also different from one another, as different countries have different values of water quality standards.

In the present study weighted arithmetic method (Tiwari and Ali, 1987) has been used for calculation of WQI as a way of beginning the ongoing dialogue needed for the community to better understand the complex issues of the local water quality. This method was widely adopted by various workers for evaluating the water quality (Nayak and Purohit, 1996; Tiwari and Nayak, 1998; Abraham and Beegum, 2001; Mishra and Patel, 2001(a), 2002; Swain et al., 2002; Chatterjee and Raziuddin, 2002; Pattajishi and Rout, 2003).

It is the normal practice that WQI is applied to assess the water quality with reference to suitability for human consumption purposes. Considering the impact on aquatic lives and agriculture by the water quality, it is felt that WQI technique should be applied separately on the basis of importance of parameters responsible for different uses. Thus in order to assess the water quality for three different uses (drinking, aquatic lives propagation, agricultural use) of river Mahanadi, three WQI have been applied separately to six seasonal data sets.

Materials and Methods

Sampling and Analytical Methods

The water samples were collected from 31 stations along the course of Mahanadi river system starting from Hirakud reservoir to the estuary points i.e., at Paradip and Nuagarh (Figure 1). Field visits were made for three different seasons, viz., pre-monsoon (February–May), monsoon (June–September), post monsoon (October–January) during the session 2001–02 and 2002–03. In each season, sampling was carried out for three to four times and samples were collected at three points (¼, ½ and ¾) across the river width at a depth of 20–30 cm from water surface, with the help of country boats during each sampling time. The mean value was taken for the evaluation. The onboard measurements of pH and electrical conductance (EC) as well as fixation of dissolved oxygen (DO) were carried out immediately after the collection of sample. Other parameters such as total dissolved solids (TDS), turbidity, chloride, SO_4^{2-}, NO_3–N, hardness, alkalinity, Na, Ca and Mg were analysed following standard guidelines and procedures (APHA, 1998; Vogel, 1961). DO and BOD were measured using Winkler's method. Turbidity was determined by Nephelometric method. Each analysis was done in triplicate and the mean value was taken. The analytical data quality was ensured through careful standardization, procedural blank measurements, spiked and duplicate samples.

Data treatment and Water Quality Index

The WQI is a mathematical technique used for transforming large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts (Stambuk-giljanovic, 1999).

In the present study, three different water quality indices for different areas of Mahanadi river estuarine systems were calculated for determining the suitability of river water for the respective purposes, i.e., for human consumption (drinking), for aquatic lives propagation and for irrigation purposes. In the formulation of a WQI, the importance of various parameters depends on the intend use of water.

For the calculation of WQI, the following equations have been used in different steps.

STEP I: Unit weight (W_i) for various parameter is inversely proportional to the recommended standard (S_i) for the corresponding parameter.

$$W_i = \frac{K}{S_i} \quad (1)$$

where K = proportionality constant and $K = 1$ for sake of simplicity

S_i = standard permissible value of i_{th} parameter and

W_i = unit weight of i_{th} parameters.

STEP II: Quality rating $q_i = 100 \times \frac{V_i - V_{io}}{S_i - V_{io}}$ (2)

where V_i = measurement value of i_{th} parameter of water sample,

V_{io} = ideal value of i_{th} parameter of pure water and

S_i = standard permissible value of i_{th} parameter.

Since in general, the ideal value $V_{io} = 0$ (zero) for the suitable water for most parameters (except pH and DO which is 7.0 mg/l and 14.6 respectively), The above equation (2) assumes the simple form for these parameters:

$$q_i = 100 \times \left(\frac{V_i}{S_i}\right) \quad (3)$$

Equations 2 and 3 ensure that $q_i = 0$, if the i_{th} parameter is totally absent in the polluted water and $q_i = 100$, if the amount of this parameter is just equal to its permissible value (for human consumption (drinking), aquatic lives consumption and irrigation purposes).

For pH, the ideal value is 7.0 (for neutral water). The permissible value (in case of sample has pH > 7.0) is 8.5 for drinking and aquatic lives consumption and 9.0 for irrigation purposes, where as in case of sample pH < 7.0, it is 6.5 for drinking and aquatic lives consumption and 5 for irrigation purposes.

For DO, the ideal value may be taken as 14.6 mg/l. The permissible is 6.0 mg/l for drinking purposes and 4.0 mg/l for aquatic lives consumption.

STEP III: The overall water quality Index was calculated by the following relation

$$\text{WQI} = \frac{\sum_{i=1}^{i=n} q_i W_i}{\sum_{i=1}^{i=n} W_i} \quad (4)$$

Water quality index scores for human (drinking) consumption purposes, were determined from fourteen most important parameters: pH, EC, DO, BOD, TDS, turbidity, SO_4, chloride, nitrate, sodium, calcium, magnesium, alkalinity and hardness. Whereas eight important parameters (pH, EC, TDS, SO_4, chloride, Sodium (%), calcium and magnesium) were taken for evaluation of WQI with respect to irrigational purposes. Future pH, DO and BOD were considered the most important parameters and measured WQI for aquatic lives propagation purposes. The 'standards' (permissible) values recommended by ISI (1974, 1983), ICMR (1975), CPCB (1982) and WHO (1984), were adopted for this purposes. The status of water qualities based on WQI is classified in Table 3.

Table 3: Status of water qualities based on Water Quality Index (WQI) (Tiwari and Ali, 1987)

WQI	*Status*
0 - 25	Excellent
25 - 50	Good
50 - 75	Poor
75 - 100	Very poor
> 100	Unsuitable

Results and Discussion

The Mahanadi river is extensively used for irrigation and is the main drinking water resource in the basin area. A systematic study on the river water quality is of great necessity and significance. The hydro-chemical characteristics of water determine its usefulness for agricultural, municipal, industrial and domestic water supplies. The evaluation of water quality is not an easy task particularly when different criteria for different uses are applied. WQI plays an important role in interpreting the information on water quality trends of a water body. Although the weighted arithmetic method (Tiwari and Ali, 1987) was implemented, in this study the three different WQI were carried out separately in order to account the water quality status with respect to drinking, agricultural use and aquatic lives propagation.

The minimum, maximum, mean and standard deviation values of physico–chemical parameters of Mahanadi river estuarine systems in 31 different stations during pre-monsoon, monsoon and post monsoon seasons are incorporated in Table 4. The results of WQI for three different purposes (human consumption, agricultural use and aquatic lives propagation) of Mahanadi river estuarine systems during 2001–02 and 2002–03 sampling periods are presented in Table 5.

WQI for Drinking Water Purposes

The WQI values of Mahanadi river for human consumption (drinking) purposes varied from 33.0 to 396.0 during pre-monsoon, 55.8 to 205.4 during monsoon and 36.9 to 284.3 during post monsoon season for 2001–02 and from 34.2 to 378.8, 72.4 to 286.2 and 43.7 to 261.2 during the respective three different seasons for the 2002–03 sampling period. During the monsoon season 45% of the WQI values were higher than 100, whereas the number decreased to 31(%) and 24(%), during pre-monsoon and post monsoon seasons respectively.

Considering that the river is a source of drinking water, the pollution potential gains significance. The present study demonstrates that overall water quality of up stream stations (except some polluted stations) of Mahanadi river was good with respect to human consumption, particularly during pre-monsoon and some extent to post monsoon seasons. However, water of polluted stations (Stn. 4, 5, 15, 16 and 27) and estuarine stations (Stn. 20–25 and 29–31) were unsuitable, which is reflected by higher WQI values (Figure 2a). But their magnitudes were varying temporally. The spatial as well as temporal variation of WQI values are due to variation in physico–chemical characteristics of river water. Irrespective of seasons, the higher values of WQI was found at polluted stations like Stn. 4 and 5 (Sambalpur down) and 15 (Tulasipur), 16 (Shikharpur) and 27 (Kathajodi down), which are mainly due to the proximity of the effluent discharge point from Sambalpur and Cuttack town respectively. The higher value of WQI in the estuarine regions is due to the contribution of saline sources.

Temporal variation reveals that during monsoon season, all fresh water (except estuarine stations) samples showed high peak values of WQI, whereas in estuarine stations (Stn. 20–25 and 29–31) salinity (saline contribution) of the waters are getting diluted by the fresh water discharge through the river (Figure 2a). In case of monsoon season, it is obvious that the river (Mahanadi) water were poor and unsuitable for drinking purpose; this may be due to the influx of massive agricultural runoff from land drainage. Among the stations, irrespective of seasons highest WQI value (205.4–396.0) was found at station 5 (Atharbanki creek), which reflects the combined impact of municipal effluent from Paradip township, industrial effluents from industries like PPL and also saline influence.

Similar seasonal trends of WQI (for drinking purposes) have been reported in river Jhelum, Kashmir, India (Tiwari et al., 1986), some rivers of south east Asia (Palupi et al., 1995), river Suqia, Argentina (Pesce

Table 4: Physico-chemical parameters with ranges average value in 31 different stations of Mahanadi river systems during three different seasons (both 2001-02 and 2002-03 sessions)

Parameters	*Pre-monsoon*				*Monsoon*				*Post monsoon*			
	Min	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*
pH	3.23	8.16	7.39	0.81	4.89	8.08	7.43	0.44	4.55	8.10	7.48	0.57
EC	124.8	26748.0	4665.2	8027.4	127.2	14402.5	583.4	1737.1	124.8	15047.3	1935.3	3994.7
DO	3.40	8.10	7.06	0.84	5.37	8.95	7.79	0.83	4.25	8.45	7.31	0.96
BOD	0.29	6.55	1.62	1.46	0.18	6.27	0.97	0.85	0.22	5.10	1.25	0.99
TDS	72.7	13845.0	2461.3	4204.6	61.4	7301.5	311.7	907.4	64.8	8627.4	996.8	2120.8
Cl	9.93	13152.0	1572.2	3042.4	4.3	4413.5	156.4	620.8	7.0	5977.8	639.9	1418.4
SO_4	1.29	289.20	56.43	71.75	1.58	360.50	17.09	53.75	5.50	219.50	39.87	57.32
NO_3-N	0.080	2.830	0.601	0.613	0.260	3.730	0.665	0.604	0.260	2.90	0.576	0.535
Hardness	86.90	3437.51	592.38	889.16	48.72	1575.00	167.00	274.84	34.36	1742.16	337.13	535.76
Alkalinity	21.0	193.0	87.9	25.7	28.0	98.0	72.1	12.7	23.0	152.0	83.2	18.6
Na	9.5	6275.0	857.2	1591.3	7.30	2643.0	162.25	478.42	5.60	2923.0	498.55	910.06
K	1.94	258.80	40.80	67.89	1.93	117.80	10.93	22.93	1.39	132.20	24.26	39.72
Ca	18.82	200.00	48.04	43.99	10.28	113.30	21.74	17.33	6.20	115.80	25.10	31.31
Mg	8.80	714.00	114.70	189.67	4.20	313.98	27.39	56.70	3.80	353.10	66.70	111.48

Units: DO, BOD, TDS, Cl, SO_4, NO_3, Hardness, Alkalinity, Na, K, Ca and Mg are in mg/l; EC is in µ S/cm

Table 5: Water quality Index values for all three purposes in 31 different stations of Mahanadi river systems during six different seasons of 2001-02 and 2002-03

	2001-02									2002-03								
	Drinking			*Agriculture*			*Aquatic lives*			*Drinking*			*Agriculture*			*Aquatic lives*		
St. No.	*Pre-mon*	*Mon-soon*	*Post-mon*	*Pre-mon*	*Mon-soon*	*Post-mon*	*Pre-mon*	*Mon-soon*	*Post-mon*	*Pre-mon*	*Mon-soon*	*Post-mon*	*Pre-mon*	*Mon-soon*	*Post-mon*	*Pre-mon*	*Mon-soon*	*Post-mon*
1	33.0	55.8	39.1	21.6	22.5	20.7	34.6	30.5	33.1	45.4	72.4	57.7	14.9	20.9	28.8	36.8	34.5	42.4
2	46.7	88.4	44.9	27.3	29.5	27.7	40.8	38.8	37.2	48.9	89.4	46.5	23.1	24.4	38.9	43.4	34.8	41.1
3	76.1	101.1	75.9	23.7	24.0	19.1	48.1	42.3	43.4	65.5	114.9	53.7	20.6	20.8	22.9	44.5	38.1	38.2
4	96.6	107.9	82.0	13.3	16.5	15.8	49.5	39.8	46.1	56.2	117.2	75.8	21.3	19.2	30.4	42.7	38.8	46.7
5	119.6	115.7	85.9	26.1	15.5	16.4	63.3	40.8	45.4	94.6	140.4	121.4	19.1	21.6	20.1	53.0	54.2	54.5
6	53.5	87.6	60.5	35.5	32.5	37.1	47.4	46.5	47.1	70.5	111.1	90.4	26.5	14.2	33.3	49.9	43.6	54.6
7	40.4	93.9	47.4	27.8	30.8	27.2	40.7	37.4	39.3	46.8	79.3	50.7	23.3	12.5	31.4	39.4	31.0	39.2
8	38.0	92.9	52.6	30.0	36.6	28.6	40.3	38.4	41.4	34.2	82.5	43.7	23.9	16.6	27.6	36.8	31.2	35.9
9	42.0	79.4	49.1	26.8	35.4	31.7	41.7	37.5	42.1	38.8	97.5	44.8	25.2	13.9	25.4	37.5	33.0	37.0
10	44.8	89.8	51.3	28.0	34.8	32.8	43.0	35.5	40.3	37.4	85.0	47.7	23.9	10.0	29.2	36.8	28.8	39.3
11	42.4	72.3	44.8	30.6	29.8	30.9	40.9	34.6	40.0	36.9	90.2	55.3	21.9	14.4	23.7	35.2	31.9	36.8
12	35.7	95.1	48.3	30.9	33.2	35.3	40.3	36.5	43.0	38.2	82.0	50.0	26.8	15.1	24.9	39.5	32.5	39.6
13	45.2	95.8	49.0	26.5	28.8	25.6	40.6	36.9	39.8	50.7	95.6	69.6	28.4	18.3	42.9	40.9	34.3	47.4
14	57.1	103.1	36.9	33.3	31.2	27.2	45.1	37.7	37.7	58.8	124.9	75.3	27.6	23.7	47.1	40.4	39.5	46.9
15	88.1	129.2	62.1	46.8	24.8	38.8	63.2	44.3	54.3	98.9	131.9	75.4	27.9	28.4	45.2	54.6	47.8	50.9
16	143.4	151.2	115.9	21.4	13.9	17.2	67.2	47.7	57.1	115.8	168.7	123.2	26.2	29.3	51.3	61.6	57.6	63.2
17	55.4	117.9	53.2	32.5	36.1	31.5	48.2	41.6	45.8	49.8	95.0	57.4	24.4	25.2	43.2	42.9	40.0	45.9
18	53.2	91.5	41.0	28.9	30.3	26.8	44.3	37.2	37.4	65.6	98.2	62.7	31.0	21.6	31.4	45.0	39.0	43.7
19	65.0	107.1	40.5	32.4	34.4	34.4	47.1	39.2	39.2	57.5	109.4	61.7	34.6	26.5	34.9	44.9	38.9	43.0
20	84.1	112.1	51.3	50.0	30.7	40.0	48.3	36.2	39.3	80.2	99.3	66.6	54.0	24.8	47.0	46.5	39.6	45.3
21	125.7	91.5	75.6	74.4	34.6	49.0	46.9	34.7	40.6	164.6	96.8	86.9	79.7	37.0	62.2	48.2	42.6	47.5
22	168.1	104.4	108.3	101.9	45.6	72.0	45.5	42.2	45.1	156.4	96.0	103.3	85.0	40.8	82.1	49.9	42.9	50.4
23	203.0	125.6	151.3	110.5	27.8	42.0	53.3	41.6	47.1	221.7	127.1	121.5	81.8	52.1	53.4	51.6	53.3	42.3
24	213.0	131.4	146.6	142.0	60.4	68.4	51.2	43.9	44.5	208.5	121.8	140.4	114.2	68.7	77.0	55.7	54.7	45.9
25	396.0	205.4	284.3	252.4	95.8	145.0	217.3	95.4	145.9	378.8	286.2	261.2	255.7	167.6	181.3	239.6	153.7	168.6
26	56.5	102.8	53.3	32.4	29.4	34.4	50.0	36.4	42.5	49.4	99.0	76.3	22.1	25.3	20.9	44.5	42.1	41.1
27	223.2	126.4	136.0	65.0	20.6	23.7	117.4	23.8	64.4	227.3	167.8	152.5	32.6	13.1	25.8	79.2	56.8	42.4
28	75.8	95.4	74.2	47.7	27.6	40.5	54.0	35.1	46.0	85.2	96.7	60.6	33.3	25.6	25.1	45.8	40.0	39.2
29	84.5	84.0	73.2	68.6	36.3	61.8	48.8	36.4	46.4	69.7	103.2	82.4	57.5	37.5	50.7	44.8	43.9	42.0
30	114.1	81.4	94.0	96.0	49.2	77.3	48.5	40.8	48.4	125.0	80.1	89.1	85.5	52.1	68.3	48.0	44.3	41.4
31	163.2	86.5	118.9	127.7	62.8	101.1	49.9	39.7	45.6	189.7	82.5	123.2	133.6	63.3	100.6	48.6	42.6	46.4

and Wunderlin, 2000), river Bangpakong eastern Thailand (Bordalo et al., 2001) and some rivers in Asansol industrial area, West Bengal (Chatterjee and Raziuddin, 2002).

When comparing with other rivers of India (Table 6), it was found that our present study results are almost higher WQI values for drinking purpose than other results. Hence Mahanadi river was considered as one of the polluted rivers of India.

WQI reflects the overall quality of the water based on all the parameters facilitated their classification. According to WQI classification, waters of polluted stations (Stn. 4, 5, 15, 16 and 27) and estuarine stations (Stn. 20–25 and 29–31) were unsuitable for human consumption. However, up stream water samples (except some polluted stations) of Mahanadi river was good and can be used for drinking purposes, particularly during pre-monsoon and to some extent during post monsoon but after being disinfected.

WQI for Agricultural Use

Rivers play an important role in human development and are important natural potential sources of irrigation water. Agriculture is the most important economic activity within the basin and agricultural land use constitute the most significant aspects in comparison to the other forms of land use. The quantity of water utilized for irrigation is quite large, particularly in comparison to quantity used for community, industrial and other beneficial purposes. Irrigational use accounts for about

87% of the total organized water usage in the basin. The river serves as a major source of water supply of about 13590.17 km^2 irrigation area in the basin.

The WQI for agriculture in water of Mahanadi river was reported to be in the range of minimum 13.3, 13.9 and 15.8 and maximum of 252.4, 95.8, 145.0 during 2001–02, whereas it ranged from 14.9, 10.0 and 20.1 to 255.7, 167.6, 181.3 during 2002–03 sampling periods for pre-monsoon, monsoon and post monsoon seasons respectively.

The present results suggest that no seasonal trend of variations was remarked along the fresh water regions (except estuarine samples). However, in the estuarine region (Stn. 20–25 and 29–31) comparatively low WQI values were found during monsoon season, which may be attributed to the dilution effect (Figure 2b).

The spatial variations of WQI for irrigation show similar trend as in case of WQI for human consumption. Like WQI for human consumption, irrespective of seasons the values of WQI for agriculture was recorded higher in the estuarine samples (Stn. 20–25 and 29–31) as compared to other samples (Figure 2b), which is attributed to high salinity in the estuarine regions. These high WQI values reflect that the waters in the estuarine region are unsuitable for irrigation.

Table 6: Comparison of WQI (drinking purpose) values of some Indian Rivers with our present study

Name of the River	*Location/sampling site*	*WQI*	*Reference*
Ganga	Gharhmukteswar	25.5	Pattajioshi, 2003
Solani	Roorke	70.8	Pattajioshi, 2003
Brahamaputra	Gawuhati	81.6	Pattajioshi, 2003
Ravi	Chamba	63.7	Pattajioshi, 2003
Gandak	Hajipur	83.3	Pattajioshi, 2003
Jhelum	Mirpur	92	Pattajioshi, 2003
Hooghly	Calcutta	93.2	Pattajioshi, 2003
Godavari	Nanded	86.3	Pattajioshi, 2003
Krishna	Vijayawada	86.5	Pattajioshi, 2003
Mahanadi	Sambalpur	112.9*	Present study
Mahanadi	Cuttack	172.2*	Present study

* Average value of six seasons

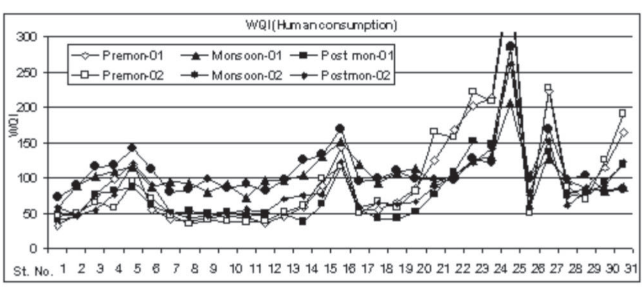

Figure 2a: WQI for human consumption.

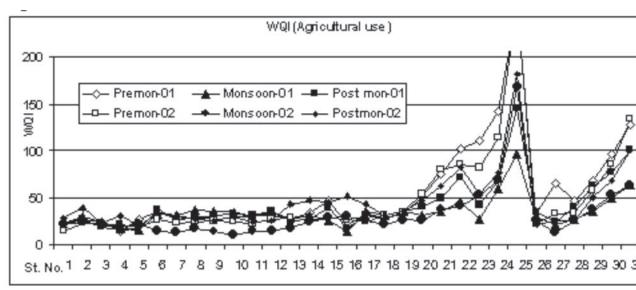

Figure 2b: WQI for agricultural use.

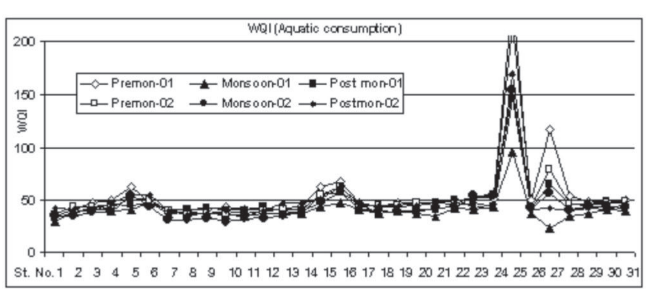

Figure 2c: WQI for aquatic life consumption.

Among the stations, irrespective of seasons highest WQI value (95.8–255.7) was found at station 25 (Atharbanki creek) and quite unsuitable for irrigation, which may be due to impacts of acidic effluents from fertilizer plants situated upstream of the station at Paradip (Sundaray et al., 2006).

According to WQI classification, all the fresh water zone samples (except estuarine samples) of the study area are of 'excellent to good' category for irrigation and are suitable to irrigate all soils for semi-tolerant and tolerant as well as sensitive crops.

WQI for Aquatic Lives Propagation

For the existence of aquatic lives in river water, pH, DO and BOD are three important parameters to assess the water quality. The value of WQI for aquatic lives in the Mahanadi river estuarine system (except Atharbanki station; Stn. 5) ranged from 34.6 to 117.4 (average 55.4), 23.8 to 95.4 (average 40.3) and 33.1 to 145.9 (average 47.30) in pre-monsoon, monsoon and post monsoon respectively during 2001–02 sampling period, whereas its values varied from 35.2 to 239.6 (average 52.5), 28.8 to 153.7 (average 44.7) and 35.9 to 168.6 (average 48.3) during 2002–03 for the respective three different seasons.

There are no significant spatial and temporal variations of WQI for agriculture observed in the Mahanadi river estuarine systems (Figure 2c).

Almost all water samples of Mahanadi river during the study period fall in the good quality categories for survival of aquatic lives. Few of the samples mainly from Sambalpur down (Stn. 5), Tulasipur (Stn. 15), Shikharpur (Stn. 16), Kathajodi down (Stn. 27) and Atharbanki creek (Stn. 25) fall in the poor to unsuitable categories.

The very high WQI value (95.4–239.6) at Atharbanki station (Stn. 25) reflects that the water quality was very critical for survival of aquatic lives. This high WQI value indicating the source is from localised anthropogenic input rather than river runoff/saline influence. This Atherbanki creek receives industrial effluents from fertilizer plants like PPL along with municipal sewage from Paradip township. It is observed in our previous study that industries like fertilizer plant at Paradip discharge acidic effluents into the river. In addition to this influx of high organic load from the sewage of Paradip Port Township, influx of effluents from fertilizer industries were confirmed by Sundaray et al. (2006). This very acidic character of water increases the values of WQI for aquatic lives. Further these values were increased by a low DO and high BOD values, which may attribute to influxes of organic pollutants into Atherbanki creek (Das et al., 1997; Pradhan et al., 1998; Nayak et al., 2001; Sundaray et al., 2006). Dissolved oxygen, which is critically important for aquatic life, drastically lowered at this station due to the oxidation of organic sewage. Comparatively higher values of WQI were found in stations 5 (downstream of Sambalpur town sewage discharge point), stations 15 and 27 (downstream of sewage discharge point of Cuttack city), station 16 (near effluent discharge point of Cuttack hospital) during all the respective three seasons, which may be due to the above similar reasons (Patnaik et al., 1997; Nanda and Tiwari, 2001).

Conclusion

Three major townships in the basin produce negative impact on the Mahanadi river water quality, particularly serious after the city sewage discharge. The results of different WQI produce similar trend but different index values as well as some different remarks. WQI reflects the overall quality of the waters based on all the parameters that facilitated their classification. According to WQI classification, estuarine samples (Stn. 20–25 and 29–31) were unsuitable for human consumption as well as agricultural use (Figure 3). However, up stream

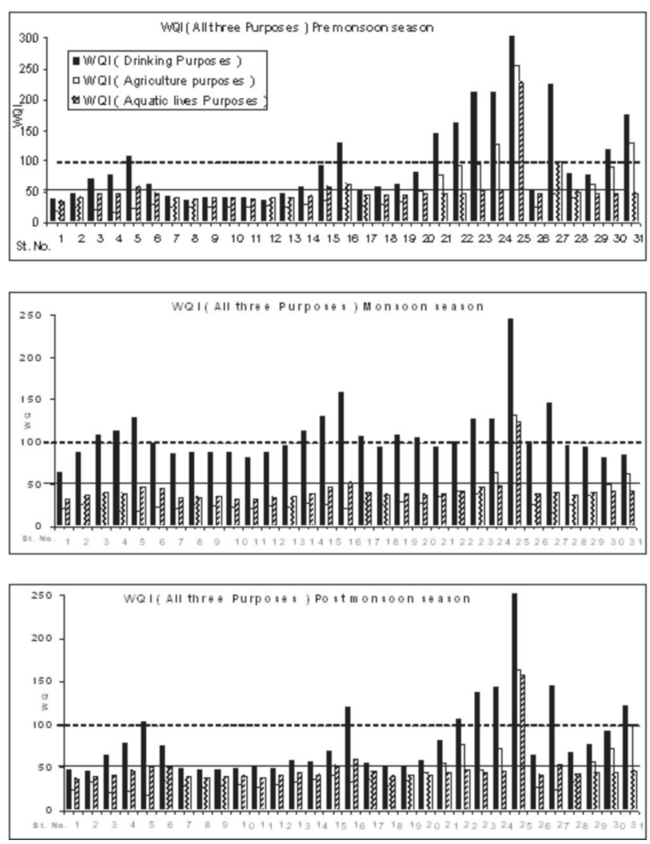

Figure 3: WQI seasonal variations.

water samples (except some polluted stations) of Mahanadi river was good and can be used as drinking purposes, but after being disinfected and are suitable to irrigate all soils for semi-tolerant and tolerant as well as sensitive crops, particularly during pre-monsoon and some extend to post monsoon seasons. The waters of some polluted stations (Sundaray et al., 2006) like Daleipada (Stn. 4), Sambalpur down (Stn. 5), Chipilima (Stn. 6) and Tulasipur (Stn. 15), Shikharpur (Stn. 16), Kathajodi down (Stn. 27) are quite unsuitable for human consumption. This is due to the proximity of the effluent discharged from Sambalpur and Cuttack respectively. The present study reveal that the water quality of Atharbanki creek irrespective of seasons is quite unsuitable for all the three purposes, i.e. (for human consumption, agricultural use and aquatic lives propagation), which may be due to the combined impact of municipal effluent from Paradip township, industrial effluents from industries like PPL and also saline influence.

From the present observation, it can be concluded that the water quality of river Mahanadi is under stress of severe pollution in some downstream stations and effective pollution control measures must be taken in the near future.

The application of a water quality index to the Mahanadi river allows a water quality classification both spatial and temporally that is reproducible within the river by means of uniform, objective criteria. Such an approach permits the identification of stretches of river that may require urgent measures in order to restore minimal water quality uses for different purposes, and can be applied beyond the Mahanadi river.

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