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Evaluation of Water Quality Index of Damodar River for Drinking Purpose Using Computer Programming

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Abstract: The objective of the study is to evaluate and compare the water quality of river Damodar for drinking purposes using Water Quality Index (WQI) and Sensitivity Index (SI) respectively. WQI gives information about spatial and seasonal variations of pollution load and to classify river water into five classes: *Excellent, Acceptable, Slightly polluted, Polluted* and *Heavily polluted* for drinking purposes. However, SI gives an idea about whether quality of water is increasing or decreasing at same point during subsequent monitoring. Both were estimated using two separate computer programs; written in C language based on the eleven water quality parameters such as pH, DO, BOD_5, TDS, TSS, Cl^-, NO_3^-- N, SO_4^{2-}, THARD, T- alkalinity, and T-coliform. A total 76 water samples were collected from 19 sampling points of a stretch D/S Tenughat dam to D/S Barakar river in mid-upper Damodar Valley to estimate spatial and seasonal variations in water quality for the year 2010. The values of WQI were found in the range of 66.2-75.6 in summer, while it was 55-76.0 in winter, affected mainly due to high values of total coliform, TSS and pH, exceeded the tolerable limits of IS:10:500 (1993) at almost all the sampling points. The results indicate that all sampling points were falling in the *Acceptable* (C2) to *Slightly polluted* (C3) range, except at Garga Nalla [*Polluted* (C4) category]. This study demonstrates the application of WQI using computer programming tool for quick assessment of water quality of any water body and also can be used for effective water quality management.

Key words: Damodar river, water quality index, sensitivity index, water quality management.

Introduction

The incessant growth of Damodar river basin population, the expansion of economic activities and intensive urbanization process over the last three decades have led to the rapid degradation of the region's natural resources, particularly its water resources. People living in the river Damodar watershed are gradually facing health problems as the river and its tributaries are the only source of drinking water for them. Therefore, appropriate water quality assessment is needed for water resource utilization for various beneficial uses like drinking, bathing, agriculture, public water supplies, fish culture, industry etc. in any watershed scale. Water pollution in this area is mainly caused due to point sources such as coal mining activities, domestic and industrial waste, mine rejects and toxic effluents and high concentration of dissolved solids mostly at downstream of coal industries (Tiwary and Dhar, 1994). Due to high carrying capacity of the river, the water is still not so much polluted as it is usually projected in earlier studies (George et al., 2010). The river water is still utilised for domestic and industrial purposes.

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The water quality of river under natural conditions is influenced by a number of factors, such as topography, geology, climate, population, anthropogenic factors and disturbance due to pollution and other human interferences such as construction of dams, and reservoirs, channelization, industrialization, urban sprawl, land use development throughout the drainage basin, etc. (Carpenter et al., 1998; Simeonov et al., 2003). Water quality rarely remains static, so quality data are needed specifically as it in space and time and even fluctuates surprisingly during a day. Thus, it is necessary to periodically monitor the surface water quality to get proper information about variation of individual water quality parameters (Dixon and Chiswell, 1996) and their comparison with the water quality guidelines for different uses or overall health of the river.

WQI is a useful tool to compare spatial and seasonal variations in water quality. It could also be considered to give a criteria for surface water classification viz., Excellent[1], Acceptable[2], Slightly polluted[3], Polluted[4] and Heavily polluted[5] for drinking purpose based on the use of standard parameters for water quality assessment (Prati et al., 1971; Smith, 1990; Nives, 1999; Pesce and Wunderlin, 2000; Cude, 2001; Jonnalagadda and Mhere, 2001; Sargaonkar and Deshpande, 2003; Chauule et al., 2009).

Normally, for computing WQI three steps are followed: first step is normalization where each parameter is expressed on a 0-100 scale Rivers with WQI values between 0-40, 40-60 and 60-80 indicates Heavily polluted, Polluted and Slightly polluted respectively, while waters of Acceptable and Excellent quality have WQI values of 80-100, and 100, respectively. The second step is to apply a weighting factor in accordance with the importance of the parameter as an indicator of water quality for drinking purpose (Nives, 1999; Pesce and Wunderlin, 2000; Jonnalagadda and Mhere, 2001) and then in the third step, all of the sub-indices are aggregated by a linear sum specific aggregation function in terms of computer program to evaluate the overall WQI values of the river. Further, SI can also illustrate increasing or decreasing trends in water quality of the stream with reference to its intended uses.

Many researchers (Horton, 1965; Bhargava, 1983, 1985; Tiwary and Mishra, 1986; House, 1989; Smith, 1989; Nives, 1999; Pesce and Wunderlin, 2000; Swamee and Tyagi, 2000; Cude, 2001; Jonnalagadda and Mhere, 2001; Sargoankar and Deshpande, 2003; Said et al., 2004) have developed their own rating schemes during the last four decades. Some of the water quality indices that have been also frequently employed in public domain for the purpose of water quality assessment are the National sanitation foundations water quality index (NSFWQI), British Columbia water quality index (BCWQI), Canadian water quality index (CWQI), Oregon water quality index (OWQI), and Florida stream water quality index (FWQI) (Said et al., 2004, Kannel et al., 2007). The Overall index of pollution (OIP) method was developed by Sargaonkar and Deshpande (2003), based on measurements and subsequent classification of pH, turbidity, DO, BOD, THARD, TDS, T-coliform, arsenic and fluoride. The authors have also considered Indian and other international standards, such as World Health Organization (WHO) and European Community (EC) Standards for Indian rivers to classify surface water quality as *Excellent, Acceptable, Slightly polluted, Polluted* and *Heavily polluted* for drinking purposes. All the above methods have some advantages and disadvantages for assessing water quality in river systems.

This paper presents a quick assessment approach to evaluate WQI through an arithmetic weighted mean and SI of river Damodar for summer (May-July) and winter (January-February) season, 2010 for drinking purposes using computer program. (Appendix).

Materials and Methodology

Study Area

The Damodar river basin (DRB) is one of the richest mineralised zones of the country with a high growth potential as evident from mining and industrial development, demographic and urban growth extending over an area of 23,170 sq. km. in the states of Jharkhand and West Bengal. The geographical boundary of the basin lies between 22°15’ N to 24° 30’ N latitude and 84°45’ E to 88° 30’ E longitude (Figure 1), and mainly drained by the Damodar river. It has a number of tributaries and subtributaries, such as Barakar, Konar, Garganalla,

[1]Excellent means water quality is pristine – Class C1.
[2]Acceptable needs only disinfection – Class C2.
[3]Slightly polluted requires filtration and disinfection – Class C3.
[4]Polluted requires special/auxiliary treatment and disinfection – Class C4.
[5]Heavily polluted water cannot be used for any purpose – Class C5.

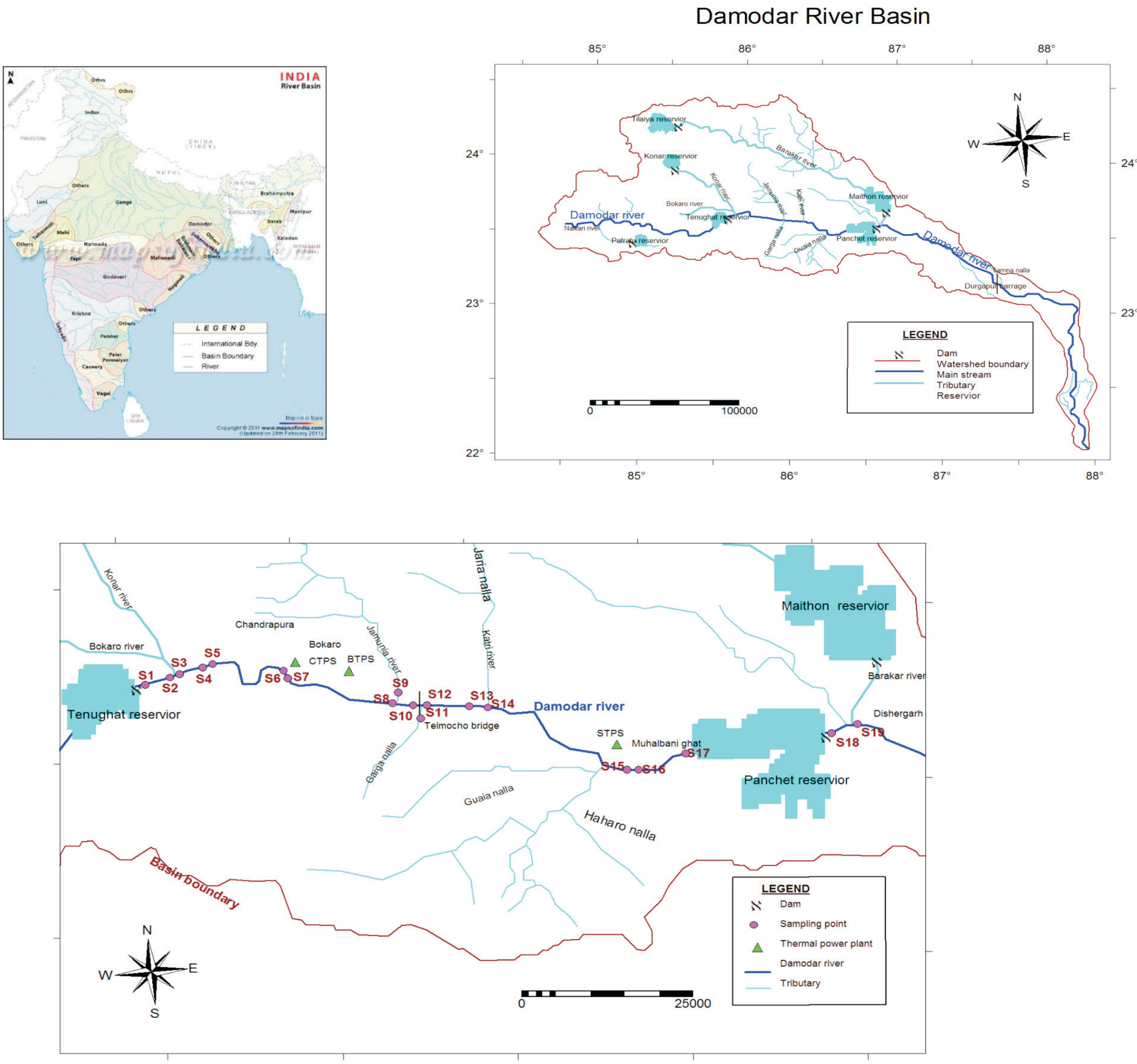

Figure 1: Map showing the study area and location of sampling points (S1….S19) in DRB.

Jamunia, Khudia, Katri, Nunia and Tamla Nalla and also has five reservoirs, two are located on Damodar river at Tenughat and Panchet, two on Barakar river at Tilaiya and Maithon and one on Konar river, a tributary of the Damodar. The region is richly endowed with mineral resources of coal, mica and bauxite; industrial activities comprising about 311 coal mines, 182 non-coal mines, 78 urban centres and 82 other industrial centres have grown up in this region (http://www.envfor.nic.in/divisions/cltech/Damodar/1.1htm).

The upper Damodar valley with its dry climate and sloping terrain is very rich in mineral resources while the lower valley which impinges into the deltaic region of West Bengal is predominantly an agricultural land (Singh et al., 2007). The basin experiences tropical climate, and an average maximum temperature of 43°C, 28°C and average minimum of 30°C, 2°C in summer and winter seasons respectively. Annual rainfall over the basin varies between 765 and 1607 mm with an average of 1200 mm, which is the main source of water to the river, the other inflow comes from the drainage of mines being discharged to facilitate the mining operation. Besides mining, coal-based industries like coal washeries, coke oven plants, coal-fired thermal power plants, steel plants and other related industries in the region also greatly impact towards degradation of the environmental quality i.e. surface water quality (Tiwary and Dhar, 1994). As a consequence of underground mining huge volume of polluted water, flooded in the mines, are discharged into the river and its tributaries. Mine and runoff water from overburden dumps of the opencast mines contaminates the surface water quality in the vicinity of mining sites.

The study area includes a stretch of about 110 km from D/S of Tenughat Dam to D/S of Barakar river with confluence of Damodar. The study area was divided into different stretches, which includes bridges, confluence points of tributaries, downstream of industrial effluents discharge point to obtain representative samples to assess the impact of anthropogenic activities on water quality of Damodar river. Also each stretch receives wastewater from industries, coal washeries, mine water and municipal sewage, throughout its course and tributaries like Konar river, Garganalla and Jamunia river, join the river carrying various types of waste including domestic and industrial (Figure 1), description of the sampling points are summarized in Table 1.

Data Collections and Analytical Methods

The monitoring network and sampling strategy were designed to cover a wide range of determinants at key sites, which accurately represent the water quality of the river system accounting for tributary and inputs from drains that have impact on downstream water quality. A total 76 water samples were collected during summer (May-July) and winter (January-February) for the year 2010 from 19 sampling points (Figure 1). The interval between the visits to any sampling point was never less than 15 days and each sampling point was visited at least twice. The water quality parameters include pH, DO, BOD_5, THARD, T-Alkalinity, TDS, TSS, Cl^-, NO_3^--N, SO_4^{2-} and T-coliform which were considered as significant indicator of surface water quality in the present study.

The water samples were collected in pre-cleaned, non-reactive plastic bottles from representative sampling points in each area which was carried out as per standard sampling methods (American Public Health Association (APHA), 1998). The pH value of water samples were measured by OrionATI ion analyzer EA 960. Samples for BOD and DO were collected separately in 300 ml BOD (glass) bottles. BOD was determined as per the Standard Methods (APHA, 1998). TSS and TDS were separated by filtering the water through 0.42 mm Watmann filter paper and determined according to standard procedures. Nitrate was determined photometrically by measuring the intensity of the yellow colour developed by the reaction of Brucine with nitrate. Sulphate and total coliform were determined by gravimetric and multiple tube fermentation (presumptive) method respectively, according to Standard Methods (APHA, 1998). The results of analysed samples are shown in Tables 2 and 3.

Indexing Approach

In this study, WQIs were estimated through following steps: first, the rating scale has been assigned to the parameters, which is also assigned weighed to water quality variables, to denote each variable's importance to the overall water quality. Second, larger weight value (W_i) implies greater importance of the variable (shown in Table 5).

The rating scale (q_i) for the eleven water quality parameters considered are given in Table 4. It can be expressed by assigning the values for the parameters in five classifications such as *Excellent, Acceptable, Slightly polluted, Polluted* and *Heavily polluted.* The quality rating q_i ranges 0-100. Finally, the sub-index aggregation of WQI mathematically combines sub-indices to an overall index value. The aggregation function of WQI, given by the following equation, is based on the linear sum aggregation function:

$$WQI = \Sigma\, (q_i \times W_i)_n$$

And, the concentrations (levels/ranges) of these parameters in the specified classes are defined as per CPCB standards/criteria and IS: 10500 (Table 5). The parameters and classes not included in the CPCB standards are defined by Sargaonkar and Deshpande (2003) for Indian rivers (Table 4).

WQI Calculation

The unit weight of each parameter is calculated as follows:

Weight assigned to independent parameter = W

Unit weight of independent parameter = W_i

Unit weight (Wi) = Weight assigned to parameter/Sum of weights of all parameters

Therefore, $$W_i = W/\Sigma W \quad (1)$$

Assume $$\Sigma W_i = 1$$

Degree of pollution rating (q_i) is considered as follows:

Excellent = 100; Acceptable = 80-100

Slightly polluted = 60-80; Polluted = 40-60

Heavily polluted = < 40

Sub-index (SI_i) value for each variable calculated as Eq. 2:

$$\text{Sub index } (SI_i) = q_i \times W_i \quad (2)$$

SI_i is the sub-index of i^{th} parameter, q_i is the rating based on concentration of the i^{th} parameter and n being the number of parameters.

Therefore, water quality index (WQI) for 'n' parameters can be calculated as:

$$WQI = \Sigma\, (SI_i)_n \text{ or } WQI = \Sigma\, (q_i \times W_i)_n \quad (3)$$

Table 1: Description of sampling points along Damodar river and its tributaries

S.No	*Sampling point*	*Code*	*Distance from Tenughat Dam (km)*	*Description of sampling points monitored*
1.	Damodar river, D/S Tenughat Dam	S1	0.3	Sampling point (23° 44'47'' N 85° 55'17'' E elev. 754 ft) is near to the temporary bridge, which is downstream location from Tenughat Dam.
2.	Damodar river, U/S confluence of Konar river	S2	12.0	Sampling point (23°45'20''N 85°55'10''E elev. 664 ft) is upstream of Damodar river confluence with Konar river. The water from this area is used for drinking and bathing.
3.	Damodar river, D/S confluence of Konar river	S3	12.2	Sampling point is downstream of Damodar river confluence with Konar river. The water from this area is used for drinking and bathing.
4.	Damodar river, U/S of Kargali coal washery	S4	22.0	Sampling point (23° 46'10''N 85°58'10''E elev.654 ft) is upstream of a temporary bridge near water treatment plant of Kargali coal washery. The water from this area is mainly used for bathing, fishing etc.
5.	Damodar river, D/S of Kargali coal washery	S5	22.2	Sampling point is 200 m downstream from S4 and activities observed are bathing, swimming, fishing etc.
6.	Damodar river, U/S **CTPS, Chandrapura	S6	30.0	Sampling point is near ash pond of Chandrapura Thermal Power Station. Activities mainly observed are washing, cleaning, bathing etc.
7.	Damodar river, D/S **CTPS, Chandrapura	S7	30.2	Sampling point is 200 m downstream from S6 and activities observed bathing, fishing etc.
8.	Damodar river, U/S Confluence Jamunia river	S8	41.5	Sampling point (23°41'42''N 86° 10'18'' E elev. 535 ft) is located at downstream of CTPS, Chandrapura.
9.	*Jamunia river	S9	43.0	Sampling point is near the bridge and it is 2 km upstream from the confluence point of Damodar river with Jamunia.
10.	Damodar river, U/S Telmocho bridge	S10	44.2	Sampling point (23°43'14''N 86°12'44''E elev.503 ft) is near Telmocho bridge on Bokaro-Dhanbad border and it is upstream of Damodar river confluence with Garga Nalla.
11.	*Garga Nalla U/S Telmocho bridge	S11	43.5	Garga Nalla is mainly carrying effluent of Bokaro steel plant and Domestic sewage from Bokaro. Sampling point is near the confluence point of Damodar river with Garga Nalla.
12.	Damodar river, D/S Telmocho bridge	S12	44.4	Sampling point (23° 44'48''N 86°12'34'' E elev. 496 ft) is 200 m downstream from S10. The water is used for domestic usage like washing, cleaning, bathing etc.
13.	Damodar river, near Jamadoba pump house	S13	66.0	Sampling point is near bridge nearby Jamadoba coal washery, Tata Iron & Steel company Ltd. and received domestic waste from Dhanbad and Jharia.
14.	Damodar river, near Domgarh Ghat (Sindri)	S14	81.0	Sampling point (23° 38' 50''N 86° 29'34'' E elev. 501 ft) is near the BIT, Sindri and receive effluent from Patherdih and Sudamdih coal washery.
15.	Damodar river, U/S Muhalbani Ghat	S15	95.0	Sampling point (23° 39'57'' N 86° 25'10'' E elev. 554ft) is near the Muhalbani bridge. The water from this area is used for drinking, fishing, bathing, etc.
16.	Damodar river, D/S Muhalbani Ghat	S16	95.2	Sampling point is near Muhalbani bridge. The water from this area is used for drinking, fishing, bathing, etc.
17.	Damodar river, U/S Panchet Dam	S17	106.2	Sampling point (23° 40'10''N 86°44'14'' E elev. 386 ft) is near the Panchet Dam.
18.	Damodar river, D/S Panchet Dam	S18	106.4	Sampling point is 200 m downstream from S17 and activities observed are bathing, swimming, fishing etc.
19.	Damodar river, D/S Barakar river, Disergarh.	S19	110.2	Sampling point is downstream of confluence point of Damodar river with Barakar river at Disergarh.

* Tributary of Damodar river ** CTPS: Chandrapura Thermal Power Station

Table 2: Water characteristics at different sampling points and WQI of the Damodar river in winter season, 2010

		Sampling Code																		
S.No	Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
1.	pH	8.4	6.8	6.7	7.2	7.4	8.7	8.4	6.7	7.4	8.76	8.2	7.75	8.9	7.6	7.2	7.34	8.3	7.9	7.9
2.	THARD	76	84	78	76	80.2	132	120	92	130	137	154	158	158	178	298	282	130	130	92
3.	BOD_5	0.7	1.2	4.4	4.6	4.2	0.5	2.9	3.4	3.4	2.5	11.4	6.6	1.6	6.8	4.8	6.8	3.2	1.8	1.3
4.	T-Alkalinity	280	280	290	230	282	320	370	364	260	420	300	280	230	270	344	314	340	360	330
5.	DO	7.4	7.2	6.8	6.0	7.1	8.5	8.4	6.6	6.0	8.1	6.0	7.0	8.5	5.0	5.4	5.0	7.0	8.0	9.1
6.	TDS	122	141	540	284	306.4	134	187.6	240	200	134	1278	265.6	340.8	332	248	218	246	240	256
7.	TSS	90	170	144	122	102.4	21.2	94.4	162	210	121.2	540	78.4	32.8	54	52	42	130	159	38
8.	Cl-	25.3	8.2	8.8	8.4	10.2	26.9	28.4	29.2	30.5	25.9	54.2	34.08	25.6	18.9	25.8	247	36.9	42.6	34.1
9.	NO_3^-	1.7	12.2	4.1	4.4	3.6	3.7	4.6	3.2	11.6	11.4	23.4	17.4	2.04	8.52	13.4	12.6	7.46	7.6	26.8
10.	SO_4^{--}	5.59	18.7	124.4	12.41	14.4	24.7	43.6	46.2	70.2	29.6	142.4	24.68	74	74.82	74.06	68.1	42	48.3	18.8
11.	T-Coliform	4	93	240	240	240	93	240	240	240	240	1100*	120	460	460	460	1100	460	460	460
WQI		74.8	74.7	68.2	69.5	72.2	76.0	72.4	69.5	69	72	55	70	72.2	69.6	69.5	69	69.5	72.2	72.8
Class		C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4	C3	C3	C3	C3	C3	C3	C3	C3

Note: All the units are in mg/L, except pH, total coliform * Three times dilution

Table 3: Water characteristics at different sampling points and WQI of the Damodar river in summer, 2010

		Sampling Code																		
S. No.	Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
1.	pH	8.6	6.5	6.7	8.3	7.2	6.0	6.1	6.9	7.8	8.0	8.1	8.3	8.0	8.0	7.9	9.2	7.9	7.8	7.7
2.	THARD	74	88	72	76	78	110	268	84	110	90	134	88	152	123	102	101	127	125	126
3.	BOD_5	3.1	3.0	4.3	4.6	2.2	1.6	2.8	3.1	3.4	3.2	17.2	7.1	3.6	4.9	3.6	12	12.2	4.1	2.2
4.	T-Alkalinity	240	220	250	230	235	220	245	245	260	230	300	240	280	230	260	260	220	220	230
5.	DO	7.4	7.8	6.8	7.2	6.8	6.3	5.4	6.2	6.0	8.0	3.7	6.2	6.0	5.4	5.9	5.8	6.2	4.7	6.8
6.	TDS	215	240	480	708	720	493	1153	178	200	190	1450	270	194	215	310	520	144	130	110
7.	TSS	118	170	190	275	305	160	170	290	310	125	430	386	170	92	423	180	130	159	176
8.	Cl-	21	23.5	22.5	22	24.5	20.5	18.5	34	30.5	28.5	59	31	31.5	30	44	34	33	32	28.5
9.	NO_3^-	25.1	12.5	14.1	17.6	13.8	9.5	22.4	11.3	19.6	13.3	23.4	15.4	15.2	14.4	17.2	17.4	13.2	12.8	14.7
10.	SO_4^{--}	17.9	18.9	88.47	93.41	88.7	64.2	80.4	96.4	73.6	63.4	142.4	104	106	120	89.9	107	60.5	52	25.5
11.	T-Coliform	4	93	460	240	240	93	93	240	240	93	1100*	120	240	93	1100	1100	460	460	460
WQI		70.2	72.2	69.6	70.8	68.2	70.0	66.6	70.6	70	74.2	66.2	69.6	68	70.0	70.6	75.6	71.0	69.0	70.0
Class		C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3

Note: All the units are in mg/L, except pH, total coliform * Three times dilution

Table 4: Ranges of water quality parameter values based on Sargaonkar and Deshpande's developed classification scheme for Indian rivers

S. No	*Classification*	*Excellent C1*	*Acceptable C2*	*Slightly polluted C3*	*Polluted C4*	*Heavily polluted C5*
	Rating Parameters	100	80	60	40	0
1.	pH	6.5-7.5	6.0 - < 6.5	5.0 - < 6.0	4.5 - < 5	< 4.5 - ≥ 9.5
2.	THARD (mg/L)	< 300	300 - ≤ 400	400- ≤ 500	500 - ≤ 600	> 600
3.	BOD_5 (mg/L)	≤ 1.5	1.5 - ≤ 3	3 - ≤ 6	6 - ≤ 12	> 12
4.	T-Alkalinity (mg/L)	≤ 200	200 - ≤ 325	325 - ≤ 450	450 - ≤ 600	> 600
5.	DO (mg/L)	> 7.0	5.1 - 7.0	4.1 - 5.0	3.0 - 4.0	< 3.0
6	TDS (mg/L)	≤ 500	500 - ≤ 1500	1500 - ≤ 2100	2100 - ≤ 3000	> 3000
7.	TSS (mg/L)	≤ 30	30 - ≤ 60	60 - ≤ 80	80 - ≤ 100	> 100
8.	Cl^- (mg/L)	≤ 150	151 - ≤ 250	251 - ≤ 600	601 - ≤ 800	> 800
9.	NO_3^- (mg/L)	≤ 20	20 - ≤ 45	45 - ≤ 50	50 - ≤ 100	> 100
10.	SO_4^{2-} (mg/L)	≤ 150	151 - ≤ 250	250 - ≤ 400	400 - ≤ 1000	> 1000
11.	T-Coliform (MPN/100 mL)	≤ 50	51 - ≤ 500	501 - ≤ 5000	5001 - ≤ 10,000	> 10,000

Table 5: Water quality parameters standards recommended by IS:10500 (1993) and weight assigned

S. No	*Water quality parameter*	*Maximum permissible limit*	*Highest Desirable Limit*	*Weight (W)*	*Unit weight (W_i)*
1.	pH	No Relaxation	6.5-8.5	4	0.13
2.	THARD	600	300	2	0.07
3.	BOD_5	-	-	4	0.13
4.	T-Alkalinity	600	200	3	0.10
5.	DO	-	-	4	0.13
6	TDS	2000	500	2	0.07
7.	TSS	-	-	2	0.07
8.	Cl^-	1000	250	1	0.03
9.	NO_3^-	No Relaxation	45	3	0.10
10.	SO_4^{2-}	400	200	1	0.03
11.	T-Coliform	-	-	4	0.13
Sum				$\Sigma W = 30$	$\Sigma W_i = 0.99 \sim 1$

Note: All units are in mg/L except pH and total coliforms.

The computed WQI values were classified into five types, Excellent to Heavily polluted as described above.

Sensitivity Index (SI)

Sensitivity Index is applied to compare the water quality for two subsequent monitoring at the same point. The SI>0 means water quality has improved or vice versa. Equation (4) is used to estimate SI.

$$SI = WQI_i - WQI_{i-1}/WQI_i \ (i = 1, 2 \ldots n) \quad (4)$$

where SI is the sensitivity index, WQI_i is the water quality index in subsequent monitoring and WQI_{i-1} is water quality index in previous monitoring.

Computer Program

Two computer programs were written to estimate the overall WQI and SI for any river system in general. First program gives information about degree of pollution, whereas, second gives variation in degree of pollution as increases or decreases between two values of water quality indices (Appendix).

Results and Discussion

To assess the suitability of the river water for drinking and public health purpose, the water characteristics of the samples analysed were compared with the prescribed IS:

10500 (1993) (Table 5) and results are shown in Tables 2 and 3 for the year 2010 for both summer and winter seasons. A critical observation of Tables 2 and 3 reveals that the water from none of these sampling points was fit for human consumption directly; most of the stretches during both the seasons were falling under *Acceptable to Slightly polluted* range. This could be mainly due to lower discharge of municipal wastes and effluent from most of the coal washeries. However, water should be disinfected by chlorination before using for drinking purpose.

The results show that water of Damodar river is mildly acidic to alkaline in nature. The pH values lies between 6.7-8.9 during winter and 6.1-9.2 in summer. The water is slightly alkaline due to higher pH of the effluents being regularly disposed off by the various industries, such as coke making plants, thermal power plant, coal washing, and steel plants established on the bank of the river. The value of total coliform (MPN/100 mL) were found to be higher as prescribed IS: 10:500 and Central Pollution Control Board (CPCB), New Delhi norms for drinking purpose. Higher coliform counts clearly indicate inadequate sanitation facilities along these stretches. Hence, it is suggested that as the MPN values are greater, proper treatment, like disinfection etc., should be strictly followed, if used for drinking purpose. Highest number of coliform was found in Garganalla (S11) and lowest at D/S of Tenughat dam (S1).

TDS was found to be within the desirable limit of 500 mg/L, except at few sampling points like D/S confluence of Konar river (S3), D/S of Kargali coal washery (S5), D/S of CTPS, Chandrapura (S7) and Garganalla (S11), mainly due to direct discharge of fly-ash and organic pollutants from nearby thermal power plants.

The DO level was found to be sufficient for the planktons to survive and various physiological activities. This could be because the water flows through the rocky surface thus increasing DO level due to high aeration. Generally, the lowest acceptable levels of DO is about 4.5 mg/L for fish and other life and 3 mg/L for recreational uses.

The value of THARD was found to be lower than 600 mg/L, which is the maximum permissible limit as per IS: 10500 (1993) at each of sampling point. Hardness has no known adverse effect on health but it can prevent formation of lather with soap and increases the boiling point of water. High THARD may cause the encrustation on water supply distribution systems. There is some evidence that drinking extremely hard water might lead to an increased incidence of Urolithiasis (Bokiana, 1965).

The observed ranges of WQI for summer and winter seasons were 66.2-75.6 and 55-76.0 respectively. Figure 2 shows marginal improved water quality in summer season as compared to winter season, due to comparatively less amount of runoff from mine area or watershed land cover. The highest value of WQI obtained was 74.8 at D/S of Tenughat dam (S1), while lowest value observed was 55 for Garganalla (S11), which shows polluted water in the all sampling points. This could be because effluent of Bokaro thermal power plant as well as domestic sewage from Bokaro city is discharged into the river at this point.

Conclusion and Recommendation

The detailed investigation from the present study indicates the water quality parameter for both seasons were found within the desirable limits, except pH, TSS and T-coliform. The overall WQIs indicated that although the surface water quality at all sampling points, except Garganalla (S11) were in the range of *Acceptable to Slightly polluted*, which indicates that disinfection is essential if the source is to be used for drinking purpose.

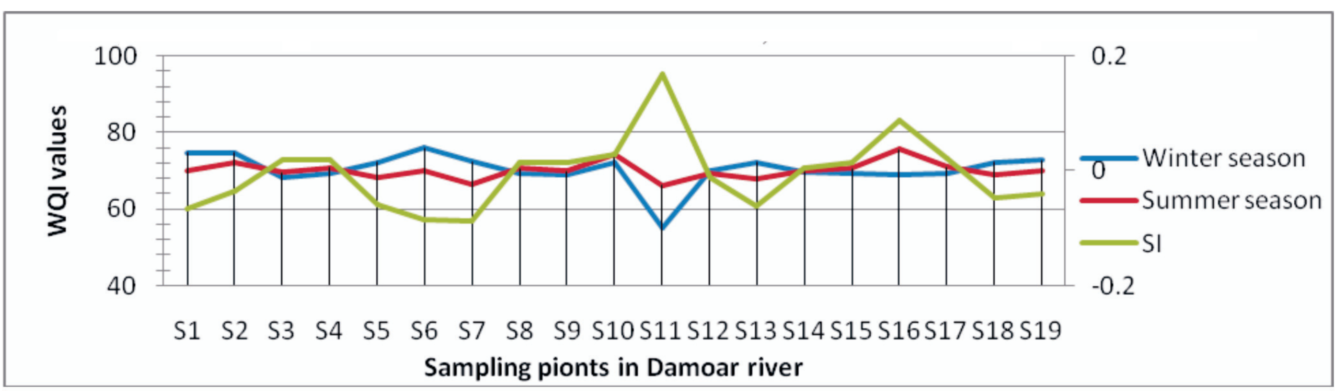

Figure 2: Comparison of WQI values and SI with respect to winter season.

A robust quick assessment tool for water quality management in the form of WQI programme is discussed, which can normally be used to evaluate overall WQI values in term of pollution load. Therefore, it is very useful for assessing water quality status of any water system and can be used as a powerful tool in formulating the pollution control strategies in terms of treatment required at different levels. On the basis of WQI values, it is suggested that proper treatment must be provided before using it for drinking purpose. Further, it is essential to create awareness among the people to maintain the cleanness of water at their highest level to lead a better life.

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Appendix

Programs for calculation of water quality index (WQI)

A. Computer Program No. 1

```
include<stdio.h>
#include<conio.h>
#include<math.h>
#include<stdlib.h>
void main()
FILE *f7;
float
DO,PH,BOD,CHLOR,THARD,TSS,TDS,TOALK,NITRATE
,SULPHATE,MPN,G,WQI;
float
DO1,PH1,BOD1,CHLOR1,THARD1,TSS1,TDS1,TOALK1
,NITRATE1,SULPHATE1,MPN1;
float G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,S
I1;
f7=fopen(”f7”,”w”);
//clrscr();
Printf (”PH OF THE RIVER WATER (PH)=\n”);
scanf(”%f”,&PH);
fprintf(f7,”PH=%f\n”,PH);
printf (”TOTAL HARDNESS OF RIVER WATER AS
CaCO3(HARD),mg/I=\n”);
scanf(”%f”,&THARD);
fprintf(f7,”THARD=%f\n”,THARD);
printf(”BOD OF RIVER WATER(BOD),mg/I=\n”);
scanf(”%f”,&BOD);
printf(”TOTAL ALKALINITY OF RIVER
WATER(TOALK),mg/I=\n”);
scanf(”%f”,&TOALK);
fprintf(f7,”TOALK=%f\n”,TOALK);
printf (”DISSOLVED OXYGEN CONCENTRATION IN
RIVER WATER\n”);
printf(”DO),mg/I=\n”);
scanf(“%f”,&DO);
printf(“TOTAL DISSOLVED SOLIDS IN RIVER
WATER(TS),mg/I=\n”);
scanf(“%f”,&TSS);
fprintf(f7,”TS=%f\n”,TSS);
printf(“TOTAL SUSPENDED SOLIDS PRESENT
(TSS),mg/I=\n”);
scanf(“%f”,&TSS);
fprintf(f7,”TSS=%f\n”,TSS);
printf(“CHLORIDE PRESENT IN RIVER
WATER(CHLOR),mg/I=\n”);
scanf(“%f”,&CHLOR);
fprintf(f7,”CHLOR=%f\n”,CHLOR);
printf (“NITRATE PRESENT IN RIVER WATER,mg/
I=\n”);
scanf(“%f”,&NITRATE);
fprintf (f7,”NITRATE=%f\n”,NITRATE);
printf (“SULPHATE PRESENT IN RIVER WATER,mg/
I=\n”);
scanf(“%f”,&SULPHATE);
fprintf(f7,”SULPHATE=%f\n”,SULPHATE);
printf (“ TOTAL MPN PRESENT IN RIVER WATER,mg/
I=\n”);
scanf(“%f”,& MPN);
fprintf(f7,”TCOLIFORM=%\n”,MPN);
 /*UNIT WEIGHTS OF DIFFERENT PARAMETERS*/
PH1=0.13; THARD1=0.07; BOD1=0.13;
TOALK1=0.1;
DO1=0.13; TDS1=0.07;TSS1=0.07;
CHLOR1=0.03;
NITRATE1=0.1;SULPHATE1=0.03; MPN1=0.13;
 /*SCALE RATING FOR PARAMETER PH*/
 If (PH<4.5||PH>=9.5)
G1=0;
else if(PH>=4.5||PH<5)
G1=40;
else if(PH>=5||PH<6)
G1=60;
else if(PH>=6||PH<6.5)
G1=80;
else if(PH>=6.5||PH<=7)
G1=100;
/*SCALE RATING FOR TOTAL HARDNESS,(mg/l)*/
if(THARD<300.0)
G2=100;
else if(THARD=>300||THARD<400)
G2=80;
else if(THARD=>400||THARD<500)
G2=60;
else if(THARD>=500||THARD<=600)
G2=40;
else if(THARD>600)
G2=0;
/* SCALE RATING FOR B.O.D.(5-DAY),(mg/l)*/
if(BOD<1.5)
G3=100;
else if(BOD=>1.5||BOD<3)
```

```
G3=80;
else if(BOD=>3||BOD<6)
G3=60;
else if(BOD=>6||BOD<=12)
G3=40;
else if(BOD>12)
G3=0;
/* SCALE RATING FOR TOTAL
ALKALINITY,(mg/l)*/
if(TOALK<200)
G4=100;
else if(TOALK=>200||TOALK<325)
G4=80;
else if(TOALK=>325||TOALK<450)
G4=60;
else if(TOALK=>450||TOALK<=600)
G4=40;
else if(TOALK>600)
G4=0;
/* SCALE RATING FOR DISSOLVED
OXYGEN,(mg/l)*/
if(DO>7)
G5=100;
else if(DO=>4.4||DO=<7.0)
G5=80;
else if(DO=>4.1||DO=<5.0)
G5=60;
else if(DO=>3.0||DO=<4.0)
G5=40;\
else if(DO<3.0)
G5=0;
\/*SCALE RATING FOR TOTAL DISSOLVED
SOLIDS,(mg/l)*/
if(TDS<=500.0)
G6=100;
else if(TDS>500||TDS<1500)
G6=80;
else if(TDS=>1500||TDS<2100)
G6=60;
else if(TDS=>2100||TDS<=3000)
G6=40;
else if(TDS>3000)
 G6=0;
  /*SCALE RATING FOR TOTAL SUSPENDED
SOLIDS,(mg/l)*/
 if(TSS<30)
 G7=100;
 else if(TSS=>30||TSS<60)
 G7=80;
 else if(TSS=>60||TSS<80)
G7=60;
else if(TSS=>80||TSS<=100)
G7=40;
else if (TSS>100)
G7=0;/* SCALE RATING FOR
CHLORIDES,(mg/l)*/
if(CHLOR<150)
G8=100;
else if(CHLOR=>150||CHLOR<250)
G8=80;
else if(CHLOR=>250||CHLOR<600)
G8=60;
else if(CHLOR=>600||CHLOR<=800)
G8=40;
else if(CHLOR>800)
G8=0;
/*SCALE RATING FOR NITRATE,(mg/l)*/
if(TSS<20.0)
G9=100;
else if(NITRATE=>20||NITRATE<45)
G9=80;
else if(NITRATE=>45||NITRATE<50)
G9=60;
else if(NITRATE=>50||NITRATE<=100)
G9=40;
else if(NITRATE>100)
G9=0;
/*SCALE RATING FOR SULPHATE,(mg/l)*/
if(SULPHATE<150.0)
G10=100;
else if(SULPHATE=>151||SULPHATE<250)
G10=80;
else if(SULPHATE=>250||SULPHATE<400)
G10=60;
else if(SULPHATE=>400||SULPHATE<=1000)
G10=40;
else if (SULPHATE>1000)
G10=0;
/*SCALE RATING FOR TOTAL NUMBER OF COLIFORM,
(MPN/100Ml)*/
if(MPN<=50.0)
G11=100;
else if(MPN>50||MPN<=500)
G11=80;
else if(MPN=>501||MPN<=5000)
G11=60;
else if(MPN=>5001||MPN<=10000)
G11=40;
else if (MPN>10000)
G11=0;
/* CALCULATING WATER QUALITY INDEX(WQL) */
WQI=G1*PH1+G2*THARD1+G3*BOD1+G4*TOALK1+G5*D
O1+G6*TDS1+G7*TSS1+G8*CHLOR1
+G9*NITRATE1+G10*SULPHATE1+G11*MPN1;
printf("______________________________\n");
printf("WATER QUALITY INDEX=%3.2f\n",WQI);
printf("______________________________\n");
fprintf(f7,"WATER QUALITY INDEX=3.2f\
n",WQI);
```

```
/* ASSESSING DEGREE OF POLLUTION */
if(WQI>80)
printf("DEGREE OF POLLUTION :
EXCELLANT-ACCEPTABLE RANGE\n");
else if(WQI>60)
printf("DEGREE OF POLLUTION :
ACCEPTABLE-SLIGHTLY POLLUTED \n");
else if(WQI>40)
printf("DEGREE OF POLLUTION :
SLIGHTLY POLLUTED- POLLUTED\n");
else if(WQI>=0)
printf("DEGREE OF POLLUTION :
POLLUTED - HEAVY POLLUTED RANGE\n");
RANGE\n");
printf("________________________________");
getch();
fclose(f7);
printf("END OF PROGRAM");
INPUT
PH= 8.4; THARD = 76 ; BOD=0.7; TALKA = 280;
DO = 7.4; TDS=122; TSS=90; Cl = 25.3; NO3 = 1.7;
SO4 = 5.59; T-COLIFORM (MPN) = 4
OUTPUT WQI = 74.8
```

Degree of pollution- Acceptable- Slightly Polluted range

B. Computer Program No 2

Program for calculation of water//* quality Index (WQI) and to assess the*/Increase or Decrease in Pollution*/ By Calculating The Sensitivity Index*/Program Written for Calculating Water*/ Quality Index for River*/*

```
#include<stdio.h>
#include<math.h>
FILE *f8;float
DO,PH,BOD,CHLOR,HARD,TSS,TDS,TOALK,NO3,S04,MPN,G,WQI;
float
DO1,PH1,BOD1,CHLOR1,HARD1,TSS1,TDS1,TOALK1,NO31,SO41,MPN1;
float G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,SI,LWQI,WQI1;
f8=fopen("f8","w");
//clrscr();
printf("PH OF THE RIVER WATER(PH)=\n");
scanf("%f",&PH);
printf("TOTAL HARDNESS OF RIVER WATER AS CaCO3(HARD),mg/l=\n");
scanf("%f",&HARD);
fprintf(f8,"HARD=%f\n",HARD);
printf("BOD OF RIVER WATER(BOD),mg/l=n");
scanf("%f",&BOD);
fprintf(f8,"BOD=%f\n",BOD);
printf("TOTAL ALKALINITY OF RIVER WATER (TOALK),mg/l=\n");
scanf("%f",&TOALK);
fprintf(f8,"TOALK=%f\n",TOALK);
printf("DISSOLVED OXYGEN CONCENTRATION IN RIVER WATER\n");
printf("(DO),mg/l=\n");
scanf("%f",&DO);
fprintf(f8,"DO=%f\n",DO);
printf("TOTAL DISSOLVED SOLIDS PRESENT IN RIVER WATER(TDS),mg/l=\n");
scanf("%f",&TDS);
fprintf (f8,"TDS=%f\n",TDS);
print f("TOTAL SUSPENDED SOLIDS PRESENT(TSS),mg/l=\n");
scanf ("%f",&TSS);
fprintf(f8,"TSS=%f\n",TSS);
printf("CHLORIDE PRESENT IN RIVER WATER(CHLOR),mg/l=\n");
scanf("%f",&CHLOR);
fprintf(f8,"CHLOR=%f\n",CHLOR);
printf("NITRATE PRESENT IN RIVER WATER(NO3),mg/l=\n");
scanf("%f",&NO3);
fprintf(f8,"NO3=%f\n",NO3);
printf("SULPHATE PRESENT IN RIVER WATER(SO4),mg/l=\n");
scanf("%f",&SO4);
fprintf(f8,"SO4=%f\n",SO4);
printf("TOTAL COLIFORM/100MLPRESENT INRIVER WATER
(MPN),mg/l=\n");
scanf("%f",&MPN);
fprintf(f8,"CHLOR=%f\n",MPN);
printf("LAST WATER QUALITY INDEX CALCULATED(LWQI)=\n");
scanf("%f",&LWQI);
fprintf(f8,"LWQI=%f\n",LWQI);
/*UNIT WEIGHTS OF DIFFERENT PARAMETERS*/
PH1=0.13; THARD1=0.07; BOD1=0.13;
 TOALK1=0.1;DO1=0.13; TDS1=0.07;
TSS1=0.07; CHLOR1=0.03; NO31=0.1;
SO41=0.03; MPN1=0.13;
/*SCALE RATING FOR PARAMETER PH*/
if(PH<4.5||PH>=9.5)
G1=0;
else if(PH>=4.5||PH<5)
G1=40;
else if(PH>=5||PH<6)
G1=60;
else if(PH>=6||PH<6.5)
G1=80;
else if(PH>=6.5||PH<=7)
G1=100;
```

```
/*SCALE RATING FOR TOTAL HARDNESS,(mg/l)*/
if(THARD<300.0)
G2=100;
else if(THARD=>300||THARD<400)
G2=80;
else if(THARD=>400||THARD<500)
G2=60;
else if(THARD>=500||THARD<=600)
G2=40;
else if(THARD>600)
G2=0;
/*SCALE RATING FOR B.O.D.(5-DAY),(mg/l)*/
if(BOD<1.5)
G3=100;
else if(BOD=>1.5||BOD<3)
G3=80;
else if(BOD=>3||BOD<6)
G3=60;
else if(BOD=>6||BOD<=12)
G3=40;
else if(BOD>12)
G3=0;
/*SCALE RATING FOR TOTAL ALKALINITY,(mg/l)*/
if(TOALK<200)
G4=100;
else if(TOALK=>200||TOALK<325)
G4=80;
else if(TOALK=>325||TOALK<450)
G4=60;
else if(TOALK=>450||TOALK<=600)
G4=40;
else if(TOALK>600)
G4=0;
/*SCALE RATING FOR DISSOLVED OXYGEN,(mg/l)*/
if(DO>7)
G5=100;
else if(DO=>4.4||DO=<7.0)
G5=80;
else if(DO=>4.1||DO=<5.0)
G5=60;
else if(DO=>3.0||DO=<4.0)
G5=40;
else if(DO<3.0)
G5=0;
/*SCALE RATING FOR TOTAL DISSOLVED SOLIDS,(mg/l)*/
if(TDS<=500.0)
G6=100;
else if(TDS>500||TDS<1500)
G6=80;
else if(TDS=>1500||TDS<2100)
G6=60;
else if(TDS=>2100||TDS<=3000)
G6=40;
else if(TDS>3000)
G6=0;
/*SCALE RATING FORE TOTAL SUSPENDED SOLIDS,(mg/l)*/
if(TSS<30)
G7=100;
else if(TSS=>30||TSS<60)
G7=80;
else if(TSS=>60||TSS<80)
G7=60;
else if(TSS=>80||TSS<=100)
G7=40;
else if (TSS>100)
G7=0;
/* SCALE RATING FOR CHLORIDES,(mg/l)*/
if(CHLOR<150)
G8=100;
else if(CHLOR=>150||CHLOR<250)
G8=80;
else if(CHLOR=>250||CHLOR<600)
G8=60;
else if(CHLOR=>600||CHLOR<=800)
G8=40;
else if(CHLOR>800)
G8=0;
/*SCALE RATING FOR NITRATE,(mg/l)*/
if(TSS<20.0)
G9=100;
else if(NITRATE=>20||NITRATE<45)
G9=80;
else if(NITRATE=>45||NITRATE<50)
G9=60;
else if(NITRATE=>50||NITRATE<=100)
G9=40;
else if (NITRATE>100)
G9=0;
/*SCALE RATING FOR SULPHATE,(mg/l)*/
if(SULPHATE<150.0)
G10=100;
else if(SULPHATE=>151||SULPHATE<250)
G10=80;
else if(SULPHATE=>250||SULPHATE<400)
G10=60;
else if(SULPHATE=>400||SULPHATE<=1000)
G10=40;
else if (SULPHATE>1000)
G10=0;
/*SCALE RATING FOR TOTAL NUMBER OF COLIFORM,(MPN/100Ml)*/
if(MPN<=50.0)
G11=100;
else if(MPN>50||MPN<=500)
G11=80;
else if(MPN=>501||MPN<=5000)
```

```
G11=60;
else if(MPN=>5001||MPN<=10000)
G11=40;
else if (MPN>10000)
G11=0;
/*CALCULATING WATER QUALITY INDEX (WQI)*/
WQI=G1*PH1+G2*HARD1+G3*BOD1+G4*TOALK1+G5*DO
1+G6*TDS1+G7*TSS1+G8*CHLOR1
+G9*NO31+G10*SO41+G11*MPN1
printf("-----------------------\n");
printf("WATER QUALITY INDEX=%3.2f\n",WQI);
printf("-----------------------\n");
fprintf(f8,"WATER QUALITY INDEX=%3.2f\
n",WQI);
/*ASSESSING DEGREE OF POLLUTION*/
if(WQI>80)
printf("DEGREE OF POLLUTION:EXCELLENT-
ACCEPTABLE RANGE\n");
else if(WQI>60)
printf("DEGREEOFPOLLUTION:ACCEPTABLE-
SLIGHTLYPOLLUTED RANGE\n");
elseif(WQI>40) printf("DEGREEOFPOLLUTION:
SLIGHTLYPOLLUTED-POLLUTED RANGE\n");else
if(WQI>=0)
printf("DEGREEOFPOLLUTION:POLLUTED-HEAVY
POLLUTED RANGE\n");
printf("--------------------\n");
}/*CALCULATING THE SENSITIVITY INDEX*/
SI=(WQI-LWQI)/WQI;
printf("SENSITIVITY INDEX(SI)=%f\n",SI);
fprintf(f8,"SENSITIVITY INDEX(SI)=%f",SI);
printf("------------------------\n");
if(SI>0)
printf("SI>0:WATER QUALITY IMPROVED\n");
if(SI==0)
printf("SI=0:NO CHANGE IN THE POLLUTION
STATUS\n");
if(SI<0)
printf("SI<0:POLLUTION IS INCREASING\n");
printf("--------------------\n");
getch();
fclose(f8);
```

*printf("**END OF PROGRAM)***

PH= 8.6; THARD = 74; BOD=3.1;TALKA = 240; DO = 7.4; TDS=215; TSS=118; Cl = 21; NO3 = 25.1; SO4 = 17.9; TCOLIFORM = 4

OUTPUT

WQI = 70.2

SENSITIVITY INDEX =0.67

SI<0 = POLLUTION INCREASE.