Water Quality Indices

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Abstract

The quality of water may be assessed using the Water Quality Index (WQI) developed by National Sanitation Foundation, USA in 1970. The index takes into account nine water quality parameters: Dissolved oxygen, Faecal coliform, pH, BOD_5, Temperature difference (1 mile), Total phosphate, Nitrate, Turbidity and Total solids. Water is graded for its quality from the worst to best on a scale of 0 to 100. The quality of water for a given parameter is represented by 'Q' value. Each water quality parameter is assigned a value known as Weighting factor. The value of weighting factor for each parameter ranges from 0 to 1, such that the sum of weighting factors for all the 9 parameters is 1. The water quality index for each parameter is given as the product of Q value and weighting factor. Overall WQI is the sum total of all the 9 water quality indices. The Overall WQI ranges from 0 to 100, and the quality of water is graded into five classes. The WQI though widely used for in the US and developed countries, does not take into account many factors which account for water pollution in Indian rivers and streams. If assessed in terms of WQI, all river waters flowing in the planes would have poor water quality. Besides there are other factors, which account for water pollution in India, such as heavy metals, pesticides and chemicals originating from industrial, agricultural and domestic uses. In order to account for water quality in terms of individual parameters, a unit free index, Water Pollution Index (WPI) is being proposed.

$$WPI = (X - Min) / Range,$$

where, X is the value of the parameter, Min is the minimum acceptable limit, Range is the acceptable range. For dissolved oxygen water quality is defined as

$$WPI (DO) = [(Min - X)/Range] + 1$$

The WPI would take into account not only the upper limits of tolerance but also the lower limits, and may be used for classification of waters for specific purposes. The WPI may be defined as the dilution of water required to make the water acceptable with water having minimum value of the parameter in the acceptable range. The WPI can be used to compare the water quality of different sources.

Introduction

The 2005 Environmental sustainability index (ESI-2005) arrived at by researchers at Yale using intricate mathematical tools has put India at a rank of 101 among 146 countries (Esty et. al., 2005) (Table 1). The dismal performance on India with ascore of 23 out of 100 for environmental systems, vis-à-vis the first ranker, the Finland, with a score of 74 needs to be urgently looked into (Table 2). The most glaring difference between the two countries is with regard to water quality indicator value, -0.96 for India and + 1.61 for Finland, the largest difference among all the parameters assessed.

Table 1. Environmental sustainability index - 2005. Comparative statistics of India and Finland.

	India	Finland
Ranking out of 146 countries	101	1
ESI	45.2	75.1
GDP/capita, USD	2530	23700
Variable coverage	69	75

Table 2. Sustainability scores of India and Finland

	Score out of 100 each	
	India	**Finland**
Environmental systems	23	74
Reducing stresses	50	61
Reducing human vulnerability	46	81
Social and constitutional capacity	51	92
Global stewardship	66	68

Water pollution in India has taken epidemic proportions and the menace poses the biggest challenge to be tackled. Sporadic research on the water front has not yielded perceptible results. Water management requires monitoring water quality, pollution control and judicious management of water resources. In this paper we present a brief treatise of the Water Quality Index (WQI) as given by National Sanitation Foundation (NSF) of America (Brown et. al., 1970). Though WQI is extensively used in most of the countries with slight modifications, its use in India is rare (CCME, 2004; CPCB, 2001; Cude, 2004; Des Moines, 2004). In order to account for variables not included in the WQI, albeit extremely important ones under Indian conditions, we propose an index, Water Pollution Index (WPI), which will assign a number to the water under test as to how many times it has to be diluted with the unpolluted water of minimum limit so as to bring it within the permissible limits for specific use.

The quality of water can be assessed on the basis of several characteristics, each of which beyond specified limits, may render the water unfit for use for specific purpose (Stream Keepers Handbook, 2005). The properties of various hazardous substances have been given by Patnaik, (1999). In order to monitor the water quality level of stream waters, the NSF surveyed 142 scientists and managers engaged in water quality research and management, for 35 short listed water quality factors (BASIN, 2004; Five Creeks, 2004; Path Finder Science, 2005). On the basis of this survey, finally nine factors were selected for water quality assessment. These are:

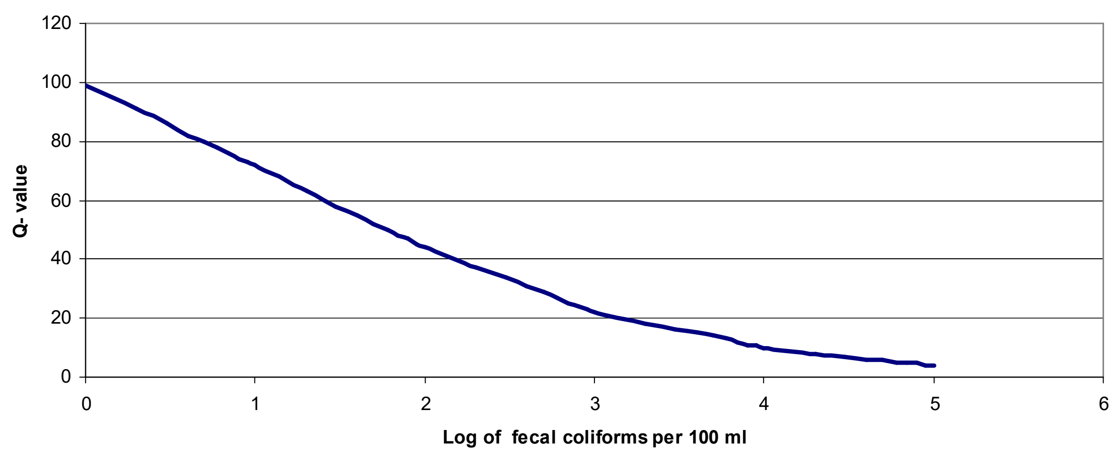
1. Dissolved oxygen (mg/L)
2. Fecal coliform (number/100 ml)
3. pH (standard units)
4. Biochemical oxygen demand – 5 day (mg/L)
5. Temperature change (1 mile, ^{0}C)
6. Total phosphate – P (mg/L)
7. Nitrates (mg/L)
8. Turbidity (NTU)
9. Total solids (mg/L)

Q – Values

Each parameter thus chosen was then scaled from 0 to 100 for given range of values for the parameter to grade water from the worst to the best. The data provided by the scientists were inputted to compute the average values. For each test value, a Q – value was assigned. Standard Q – value curves were drawn for each parameter. In the present communication Q – values were computed from the software available online and graphical representations made there from. Given below are the factors used for WQI:

Fecal coliforms: Fecal coliform bacteria are indicator of water pollution by human and animal excreta. Water contaminated by excreta carry harmful pathogens and are not fit for use. In general total coliforms are about ten times more abundant than fecal coliforms in water. Q- values for FC are given in Fig. 1 and table 3.

Fig. 1. Q- value for fecal coliforms (Q=2 for FC>100000/ 100ml)



Biochemical oxygen demand: Biochemical oxygen demand (BOD-5) measures the amount of oxygen consumed by microorganisms to oxidize organic matter inflowing water sources through death and decay, sewage, sewerage and industrial effluents. A high BOD value may create anaerobic conditions and detrimental to the growth of organisms. Q- values for FC are given in Fig. 2 and table 3.

Dissolved oxygen: Dissolved oxygen (DO) is vital for aquatic life. Percent saturation is defined as the ratio of DO to potential capacity of water to dissolve oxygen at given temperature and pressure. DO at 100 % saturation level is best suited for aquatic organisms. Both under and over saturation affect the growth and survival of organisms in water. Q- values for DO are given in Fig. 3 and table 3.

pH: pH measures the acidic or alkaline nature of water. Most of the aquatic organisms are affected by pH changes and survive best at 6 to 8.5 pH. The pH most suited to water plants and animals is 7.4. Lower or higher pH values decrease biodiversity. Q- values for pH are given in Fig. 4 and table 4.

Fig. 2. Q- value for BOD-5 (Q=2 for BOD>30 mg/L)

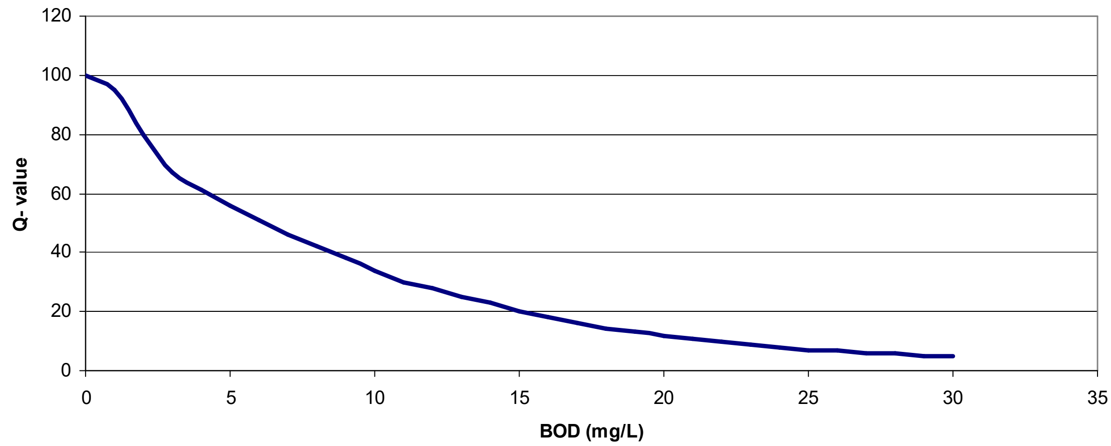


Fig. 3. Q- value for dissolved oxygen (Q=50 for DO>140%)

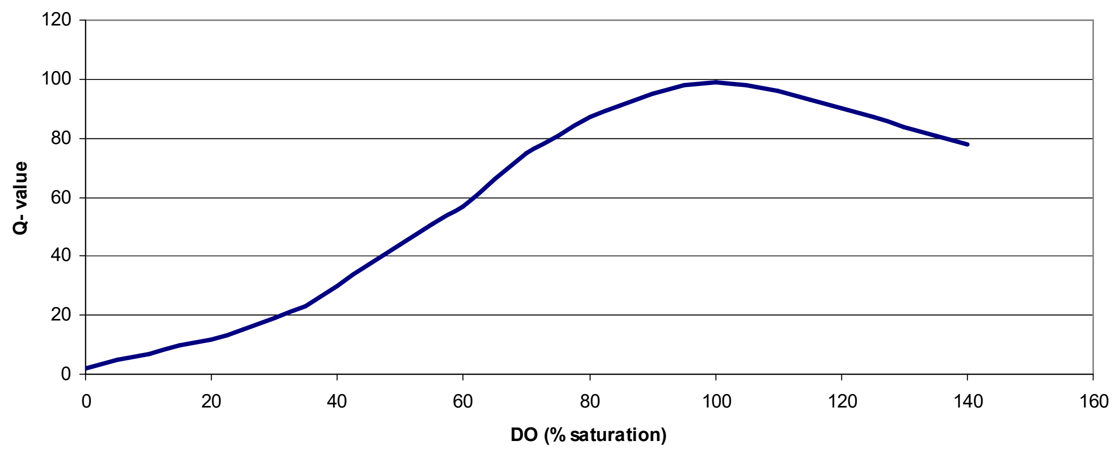
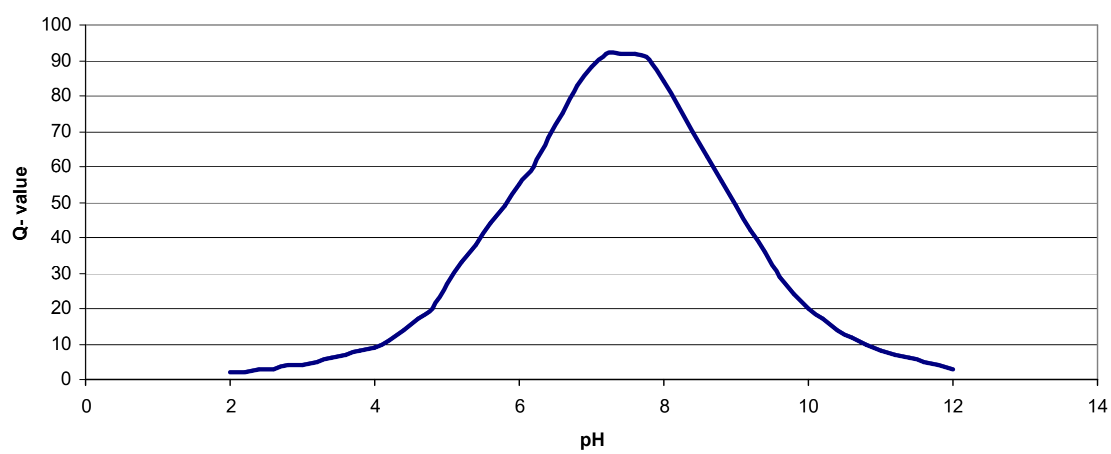
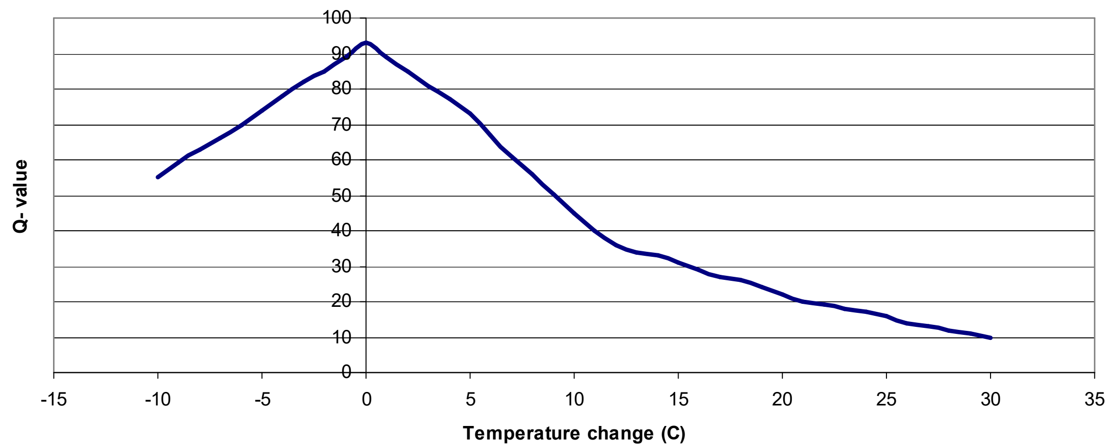


Fig. 4. Q- value for pH (Q=0 for pH<2 and pH>12)



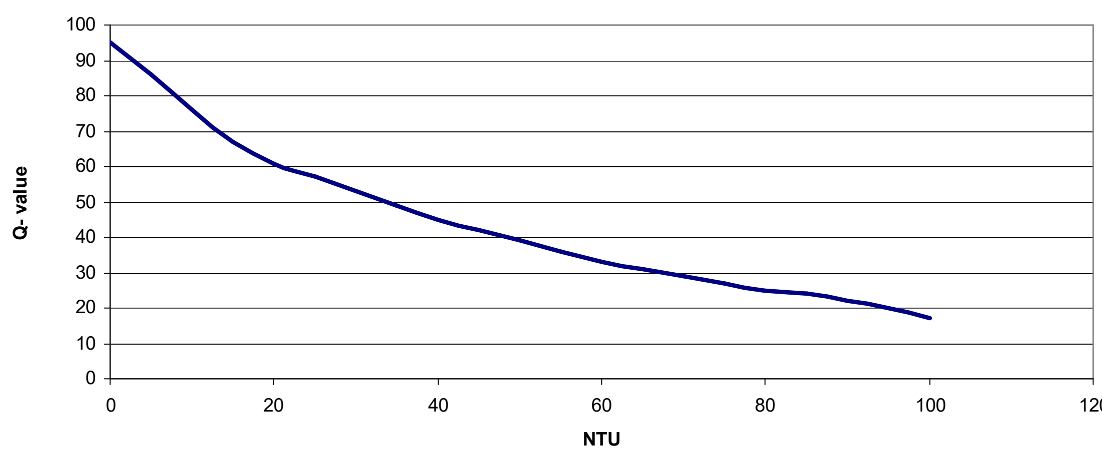
Temperature change: Since most of the organisms are cold blooded, they are quite susceptible to temperature changes. DO content decreases at higher temperatures as the rate of decomposition increases. The metabolic rates also increase at higher temperatures. Hot waters from thermal power plants and industries tend to increase water temperature. Removal of shading trees increases the diurnal variations in water temperature. Temperature change (TC) across points half mile upstream and half mile down stream is used as a factor affecting aquatic life. Q- values for TC are given in Fig. 5 and table 4.

Fig. 5. Q- value for temperature change



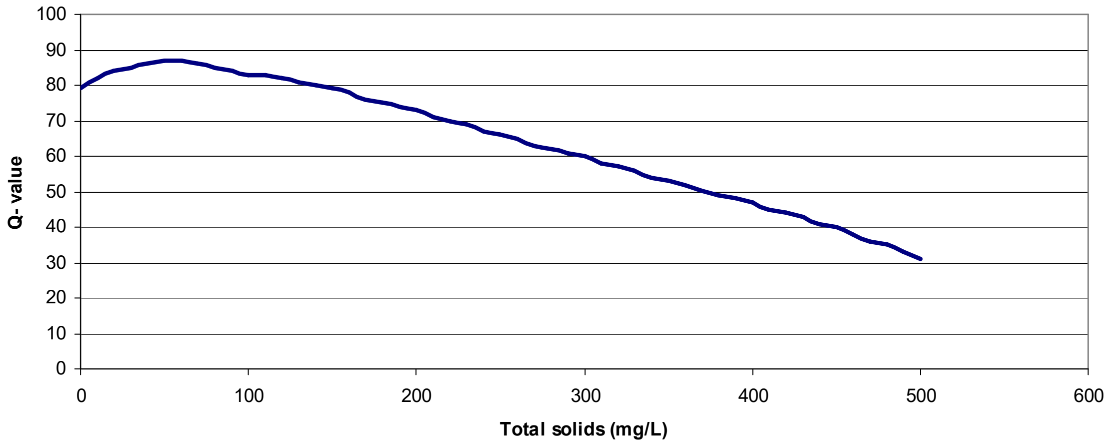
Turbidity: Turbidity measures the murkiness of water. It decreases the penetration of light in water, thus decreasing the growth of algae. Turbidity is caused by sewage disposal, industrial wastes, soil erosion etc. Q- values for turbidity are given in Fig. 6 and table 4.

Fig. 6. Q- value for turbidity (Q=5 for NTU>100)



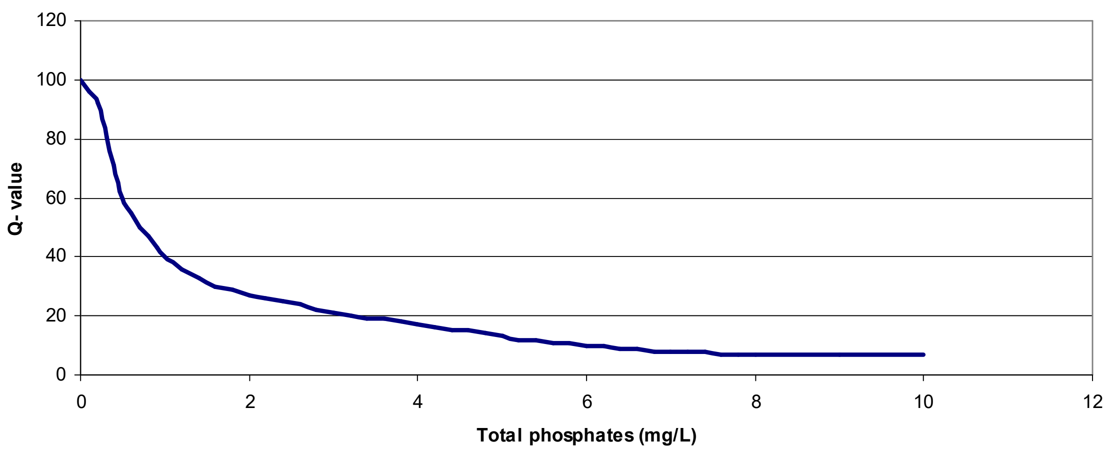
Total solids: Total solids (TS) include suspended solids and dissolved solids. At low concentrations dissolved solids are essential for organisms, but at higher concentrations TS limit the growth of organisms. The sources of TS are ash from thermal power plants, fertilizers, effluents, sewage, sewerage etc. Q- values for TS are given in Fig. 7 and table 5.

Fig. 7. Q- value for total solids (Q=20 for TS>500 mg/L)



Total phosphates: Total phosphates (TP) are the main cause of eutrophication which leads to chocking of streams and other water bodies. Main sources of TP are detergents, fertilizers and sewerage etc. Q- values for TP are given in Fig. 8 and table 5.

Fig. 8. Q- value for total phosphates (Q=2 for TP>10 mg/L)



Nitrates: Besides providing a source of nourishment to plants, nitrates may cause urinary disorders. The main sources of nitrates are fertilizers. Q- values for nitrates are given in Fig. 9 and table 5.

Fig. 9. Q- value for nitrate (Q=1 for nitrates>100 mg/L)

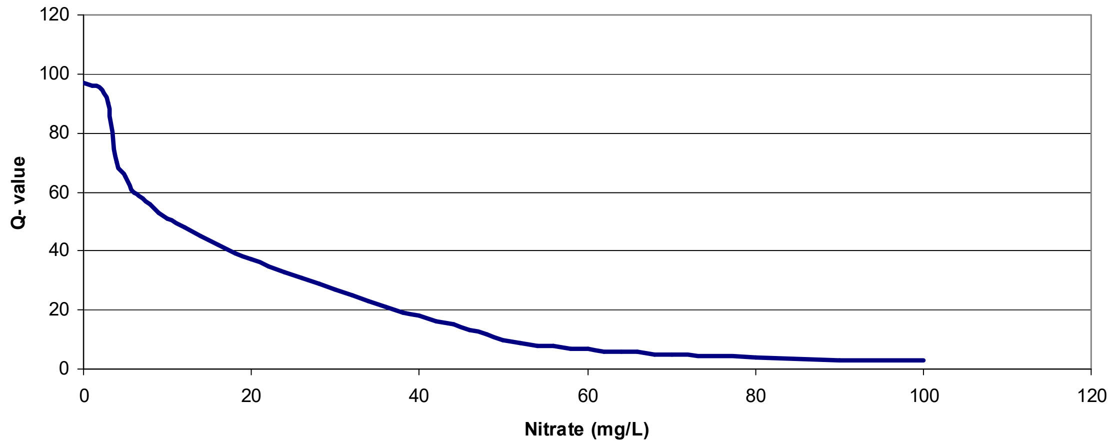


Table 3. Water quality values (Q- values) for Fecal coliform, BOD and DO

Fecal coliforms (per 100 ml)	Log_{10} FC	Q	BOD-5 (mg/L)	Q	Dissolved oxygen (% sat)	Q
1	0	99	0	100	0	2
2	0.30103	91	1	95	5	5
3	0.477121	86	2	80	10	7
4	0.60206	82	3	67	15	10
5	0.69897	80	4	61	20	12
6	0.778151	78	5	56	25	15
7	0.845098	76	6	51	30	19
8	0.90309	74	7	46	35	23
9	0.954243	73	8	42	40	30
10	1	72	9	38	45	37
20	1.30103	63	10	34	50	44
30	1.477121	58	11	30	55	51
40	1.60206	55	12	28	60	57
50	1.69897	52	13	25	65	66
60	1.778151	50	14	23	70	75
70	1.845098	48	15	20	75	81
80	1.90309	47	16	18	80	87
90	1.954243	45	17	16	85	91
100	2	44	18	14	90	95
200	2.30103	37	19	13	95	98
300	2.477121	34	20	12	100	99
400	2.60206	31	21	11	105	98
500	2.69897	29	22	10	110	96
600	2.778151	27	23	9	115	93
700	2.845098	25	24	8	120	90
800	2.90309	24	25	7	125	87
900	2.954243	23	26	7	130	84
1000	3	22	27	6	135	81
2000	3.30103	18	28	6	140	78
3000	3.477121	16	29	5	>140	50
4000	3.60206	15	30	5		
5000	3.69897	14	>30	2		
6000	3.778151	13				
7000	3.845098	12				
8000	3.90309	11				
9000	3.954243	11				
10000	4	10				
20000	4.30103	8				
30000	4.477121	7				
40000	4.60206	6				
50000	4.69897	6				
60000	4.778151	5				
70000	4.845098	5				
80000	4.90309	5				
90000	4.954243	4				
100000	5	4				
>100000		2				

Table 4. Q values for pH, temperature change and turbidity

pH	Q	Temp. change (C)	Q	Turbidity (NTU)	Q
<2	0	-10	55	0	95
2	2	-9	59	5	86
2.2	2	-8	63	10	76
2.4	3	-7	66	15	67
2.6	3	-6	70	20	61
2.8	4	-5	74	25	57
3	4	-4	78	30	53
3.2	5	-3	82	35	49
3.4	6	-2	85	40	45
3.6	7	-1	89	45	42
3.8	8	0	93	50	39
4	9	1	89	55	36
4.2	11	2	85	60	33
4.4	14	3	81	65	31
4.6	17	4	77	70	29
4.8	20	5	73	75	27
5	27	6	67	80	25
5.2	33	7	61	85	24
5.4	38	8	56	90	22
5.6	44	9	50	95	20
5.8	49	10	45	100	17
6	55	11	40	>100	5
6.2	60	12	36		
6.4	68	13	34		
6.6	75	14	33		
6.8	83	15	31		
7	88	16	29		
7.2	92	17	27		
7.4	92	18	26		
7.6	92	19	24		
7.8	90	20	22		
8	84	21	20		
8.2	77	22	19		
8.4	70	23	18		
8.6	63	24	17		
8.8	56	25	16		
9	49	26	14		
9.2	42	27	13		
9.4	36	28	12		
9.6	29	29	11		
9.8	24	30	10		
10	20				
10.2	17				
10.4	14				
10.6	12				
10.8	10				
11	8				

11.2	7
11.4	6
11.6	5
11.8	4
12	3
>12	0

Table 5. Q values for total solids, total phosphate - P and nitrates

Total solids (mg/L)	Q	Total phosphate (mg/L)	Q	Nitrate (mg/L)	Q
0	79	0	100	0	97
10	82	0.1	96	1	96
20	84	0.2	92	2	95
30	85	0.3	81	3	90
40	86	0.4	71	4	70
50	87	0.5	60	5	65
60	87	0.6	55	6	60
70	86	0.7	50	7	58
80	85	0.8	47	8	56
90	84	0.9	43	9	53
100	83	1	40	10	51
110	83	1.2	36	12	48
120	82	1.4	33	14	45
130	81	1.6	30	16	42
140	80	1.8	29	18	39
150	79	2	27	20	37
160	78	2.2	26	22	35
170	76	2.4	25	24	33
180	75	2.6	24	26	31
190	74	2.8	22	28	29
200	73	3	21	30	27
210	71	3.2	20	32	25
220	70	3.4	19	34	23
230	69	3.6	19	36	21
240	67	3.8	18	38	19
250	66	4	17	40	18
260	65	4.2	16	42	16
270	63	4.4	15	44	15
280	62	4.6	15	46	13
290	61	4.8	14	48	12
300	60	5	13	50	10
310	58	5.2	12	52	9
320	57	5.4	12	54	8
330	56	5.6	11	56	8
340	54	5.8	11	58	7
350	53	6	10	60	7
360	52	6.2	10	62	6
370	50	6.4	9	64	6
380	49	6.6	9	66	6
390	48	6.8	8	68	5
400	47	7	8	70	5
410	45	7.2	8	80	4
420	44	7.4	8	90	3
430	43	7.6	7	100	3
440	41	7.8	7	>100	1
450	40	8	7		
460	38	9	7		

470	36	10	7
480	35	>10	2
490	33		
500	31		
>500	20		

Weighting factors

Each of the nine water quality factors is assigned a weighting factor which signifies its importance. Maximum weightage is given to DO, followed by FC. The sum of weighting factors is 1. Table 6 gives the weightings for different water quality factors.

Water Quality Index

WQI is computed for each factor as the product of Q-value and weighting factor.

$$WQI = \text{Q-value} \times \text{Weighting factor}$$

The overall WQI is the weighted average of all Q-values:

$$\text{Overall WQI} = \Sigma(\text{Q-value} \times \text{Weighting factor}) / \Sigma \text{ Weighting factors}$$

If all the 9 factors are considered for computation of WQI, the sum of weighting factors is 1. Less than 9 factors (6 or more) may also be used for WQI. WQI worksheet is given in table 6.

Table 6. WQI worksheet

Factor	Test value	Q- value	Weighting factor (W)	WQI=QxW
DO (% saturation)			0.17	
Fecal coliform nos./100ml			0.16	
pH			0.11	
BOD (mg/L)			0.11	
Temperature change (^{0}C)			0.10	
Total phosphate – P (mg/L)			0.10	
Nitrates (mg/L)			0.10	
Turbidity (NTU)			0.08	
Total solids (mg/L)			0.07	
Overall WQI			Σ WQI =	

Water quality rating

On the basis of WQI, water quality is rated into 5 grades as given in table 7.

Table 7. Water quality rating

WQI		Water quality
>90-100		Excellent
>70-90		Good
>50-70		Medium
>25-50		Bad
0-25		Very bad

Water Pollution Index

Water quality indices with slight modification of the original are used throughout the world (Hallok, 2002; Veerbhadram, 2005). Though suitable for most situations, WQI does not take into account some of the extremely important parameters such as heavy metals and pesticides, most characteristic of Indian rivers and other water resources. Water quality criteria given Central Pollution Control Board, New Delhi, classify waters into 5 groups, A-E (MOSPI, 2003). Though, WQI serves the purpose for most of the cases, for countries like India, where rivers and streams are studded with garbage, heavy metals, pesticides, fluoride, cyanide indusrial organicals etc., especially in the thickly inhabited plains, agricultural and industrial areas. Further, river and stream waters in India are used for drinking purposes as well.

It is therefore ecologically warranted that we have an index which would give a relative number with respect to the minimum accepted limit for specific chemicals. Accordingly we propose an index, Water Pollution Index (WPI) which could be better understood, widely used for all water use purposes and easy to use for water pollution control and management. Guidelines values for some chemicals and pesticides as given by WHO (2004) are given in Tables 8 and 9.

Table 8. Guideline values for chemicals that are of health significance in drinking water (WHO, 2004)

Chemical	Guideline value (mg/L)
Antimony	0.02
Arsenic	0.01
Barium	0.7
Chromium	0.05
Copper	2
Lead	0.01
Manganese	0.4
Molybdenum	0.07
Nickel	0.01
Selenium	0.01
Uranium	0.015
Cadmium	0.003
Mercury	0.001
Boron	0.5
Fluoride	1.5
Cyanide	0.07
Nitrate	50
Nitrite (short term exposure)	3
Nitrite (long term exposure)	0.2

Table 9. Guideline values for some of the pesticides in drinking water (WHO, 2004)

Chemical	Guideline value (μg/L)
Alachlor	20
Aldicarb	10
Aldrin and dialdrin	0.03
Atrazine	2
Carbofuran	7
Chlordane	0.2
2,4 D	30
Endrin	0.6
Lindane	2
Methoxychlor	20
2,4,5 T	9

WPI for parameters for which limits are so defined as not to exceed maximum value: If the limit is defined not to exceed the maximum value, such as fecal coliform , total coliform, BOD, temperature change, total phosphate – P, nitrates, turbidity, total solids, free ammonia, conductivity, sodium adsorption ratio, boron, heavy metals, pesticides etc.

$$WPI = (X - Min)/Range$$

where, X is the test value of the parameter, min is the minimum acceptable limit, and range is the range of acceptable limits for specific use. As for example,

Maximum limit of lindane in drinking water = 2 μg/L
Permissible range of lindane = 0 to 2 μg/L
Let the test value (X) for a water sample = 6 μg/L
WPI = (6 – 0)/(2 – 0) = 3.

This would imply that the sample water is 3 times polluted than the specified limit. Or in other words, 1 L of test water should be diluted with 2 L of water with a water having lindane 0 μg/L for make it suitable for drinking purpose.

If the water is assessed for a number of parameters (n), different values of WPI would be obtained for different factors, maximum of which would be crucial for water quality assessment.

$$WPI\ (max) = Max\ (WPI_1, WPI_2, WPI_3 \ldots WPI_n)$$

Water quality grades are given in Table 10.

Table 10. WPI and water quality

WPI	Water quality
0 to 1	Acceptable for specific purpose
> 1	Water polluted n times. Should be diluted with water of best quality in the acceptable range.
< 0	Water deficient in factor

WPI for parameters for which limits are so defined as not to go below the minimum value: For DO the minimum limit is defined, below which the water is not fit for specific purposes. The WPI for DO value is defined as,

$$WPI\ (DO) = [(Min - X)/Range] + 1$$

For example

Minimum limit of DO in water (say) = 4 mg/L Permissible range of DO = 4 to 8 mg/L Let the test value (X) for a water sample = 2 mg/L WPI = [(4 – 2)/(8 – 4)] + 1 = 1.5

That is, the test water is to be diluted with 0.5 L of water with DO value 8 mg/L to bring it to the minimum permissible level of 4 mg/L.
WPI worksheet is given in Table 11.

Table 11: WPI worksheet.

Parameter	Test value (X)	Minimum acceptable limit (Min)	Maximum acceptable limit (Max)	Range = (Max-Min)	WPI = (X-Max)/Range WPI(DO) =[(Min– X)/Range] +1
		WPI (Max) = Maximum value of WPI =			

The proposed WPI would give a number as to how many times water is to be diluted with the best quality water in the acceptable range so as to bring the water within the permissible limits. WPI is a unitless number and may be used to compare water quality from different water sources and for different parameters, and to rank them accordingly.

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