DEVELOPMENT OF AN OVERALL INDEX OF POLLUTION FOR SURFACE WATER BASED ON A GENERAL CLASSIFICATION SCHEME IN INDIAN CONTEXT

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Abstract. Various National and International Agencies involved in water quality assessment and pollution control have defined water quality criteria for different uses of water considering different indicator parameters. Classification schemes for water quality criteria/standards developed by these agencies differ in addition to terminologies used such as Action level, Guide level etc. in defining the concentration values in these classes. In the present article a general classification scheme viz. Excellent, Acceptable, Slightly Polluted, Polluted and Heavily Polluted water is proposed for surface water quality assessment. The concentration ranges in these classes are defined in Indian scenario considering Indian Standards and CPCB criteria. Standards by the European Community (EC), WHO etc. and the reported facts about the pollution effects of important water quality indicator parameters on the surrounding were also taken into account. The mathematical equations to transform the actual concentration values into pollution indices are formulated and corresponding value function curves are plotted. Based on the individual index values, an 'Overall Index of Pollution' (OIP) is estimated. The application of OIP is demonstrated at a few sampling stations on river Yamuna based on observed water quality data. The general classification scheme along with concentration ranges defined in these classes will be of immense use for determining the surface water quality status with reference to specific individual parameter, and the OIP for assessing the overall water quality status in Indian context.

Keywords: criteria, overall index of pollution, standards, value function curves, water quality

1. Introduction

A major objective of water quality control work is to reduce the incidence of water-related diseases thereby developing water resources of wholesome quality, i.e. water free from visible suspended matter, excessive color, taste and odour, objectionable dissolved matter, aggressive constituents, and bacteria indicative of fecal pollution. The quality of water is defined in terms of its physical, chemical, biological, and bacteriological parameters. Water Quality Criteria are defined as the acceptable levels of concentrations of specific water quality parameters and may vary with the type of use such as drinking, bathing and domestic use, irrigation, recreation and industrial use. The standards/criteria indicate the suitability of water for a specific use e.g. as per the classification scheme of Inland Surface Water by Central Pollution Control Board (CPCB) in India, the criteria for total dissolved

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solids is 500 mg L^{-1} for drinking and 2100 mg L^{-1} for irrigation and industrial cooling. Thus, the criteria are developed for specific individual parameters. However, if this information on water quality parameters measured individually is transformed into a single number (Index) representing the overall quality of water, it will be very useful to the public.

In the present article, the development of Overall Index of Pollution (OIP) considers the important surface water quality indicator parameters viz. pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, total dissolved solids (TDS), total coliform and some of the toxicity indicator parameters viz. Arsenic (As) and Fluoride (F). The classification of water quality is made very general such as Excellent, Acceptable, Slightly Polluted, Polluted and Heavily Polluted. The concentration levels/ranges of the indicator parameters are defined with due consideration to the Indian standards in the proposed classes. Wherever, such criteria were not defined reference was made to European Community Standards, WHO Guidelines etc. (Tables A-1 to A-9 in Appendix).

2. Materials and Methods

2.1. Water quality criteria/standards by international/national agencies

2.1.1. *European Community (EC) Standards*

European Community Standards are developed for three different uses of water viz. drinking, bathing and fish water (Tebbutt, 1992). For drinking water, different indicator parameters such as organic, inorganic, bacteriological and heavy metals in addition to the parameters of aesthetic sense i.e. color, odor are considered, and the standards are expressed as Guide Level and Maximum Admissible Concentration (Table A-I). The Maximum Admissible Concentration (MAC) indicates the strict compliance or the limit beyond which the concentration of a parameter should not exceed. For bathing water, the EC standards indicate Guide Limit (90th percentile values) and Mandatory Limit (95th percentile values) mainly for bacteriological parameters and important toxicity indicator parameters such as cadmium and mercury (Table A-2). Freshwater fish water quality standards by EC emphasize on annual average dissolved concentration of toxic pollutants and heavy metal concentrations in addition to few indicators of organic pollution. These standards are given for two types of fish; salmonid and coarse fish (Table A-3). EC standards are also available for Surface Waters used for Potable abstractions indicating Guide Limit and Mandatory Limit for various water quality parameters after A_1, A_2, A_3 levels of treatment, where, level A_1 indicates simple physical treatment and disinfection; A_2 indicates normal full physical and chemical treatment and disinfection; and A_3 indicates intensive physical and chemical treatment with disinfection (Table A-4).

2.1.2. *World Health Organization (WHO) Guidelines*
WHO Guidelines are indicated in terms of Action Levels for important organic, inorganic and bacteriological parameters; toxicity indicator parameters; and radioactive parameters such as gross alpha and beta activity (Tebbutt, 1992). The term Action Level indicates a level above which the reasons for the presence of a substance should be investigated and appropriate remedial measures be applied (Table A-5).

2.1.3. *Standards by WQIHSR, Tehran*
Institute of Hydrosciences and Water Resources Technology (WQIHSR) in Tehran has developed International Standards for drinking water. These standards indicate Acceptable and Maximum Allowable Concentrations for various water quality indicator parameters (Table A-6).

2.1.4. *Water Quality Criteria by McKee and Wolf*
Criteria by McKee and Wolf (1963) give ranges of promulgated standards for Raw Water Sources of domestic water supply defined as Excellent, Good and Poor where Excellent needs only disinfection, Good requires filtration and disinfection, and Poor requires special/auxillary treatment and disinfection (Table A-7).

2.1.5. *IS-10500 and CPCB Standards*
In India, Desirable Limits for concentrations of various water quality parameters are given in the 'Indian Standard Specification for Drinking Water IS 10500, 1983' (Table A-8). Also, Central Pollution Control Board has developed the standards for Inland Surface Water (CPCB, ADSORBS/3/78-79), considering the classification (A) to (E), wherein, (A) indicates: drinking water without conventional treatment but after disinfection; (B) outdoor bathing; (C) drinking water with conventional treatment and after disinfection; (D) propagation of wild life, fisheries; and (E) irrigation, industrial cooling, and controlled waste disposal (Table A-9).

Thus, it is observed that:

- Different agencies have developed standards for various uses of water.
- All these standards take into account the effect on human health, vegetation, as well as quality of life considerations etc.
- Standards/criteria are also presented for those substances that may occur in water, where data indicate the potential for harm to aquatic life, or to the consumers of the aquatic life.

However, the agencies differ in terms of:

- Definition of terminologies for classification scheme.

- The criteria such as Guide Level, Action Level, Maximum Allowable Concentration and Acceptable Level etc.
- The selection of indicator parameters.

Therefore, it was felt necessary to define a common classification scheme in order to know the water quality status in terms of pollution effects of the parameters under consideration.

2.2. PROPOSED CLASSIFICATION SCHEME

Prati *et al*. (1971) have proposed one such scheme for classification of surface water quality. Based on the similar concept, a classification scheme is proposed in the present work in Indian context, wherein significant indicator parameters as well as the tropical conditions and standards already developed by Indian agencies are referred in detail. Giving due consideration to classification scheme (A to E class of water) by CPCB as detailed in Table A-9 and various other classifications described above, a general classification as Excellent, Acceptable, Slightly Polluted, Polluted and Heavily Polluted water is proposed in this article wherein,

- Excellent means water quality is pristine – Class C_1.
- Acceptable needs only disinfection – Class C_2.
- Slightly Polluted requires filtration and disinfection – Class C_3.
- Polluted requires special/auxillary treatment and disinfection – Class C_4.
- Heavily Polluted water can not be used for any purpose – Class C_5.

2.2.1. *Selection of Indicator Parameters*

The water quality parameters viz. Turbidity, pH, Color, DO, BOD, TDS, Hardness, Cl, SO_4, NO_3, Total Coliform, As and F are considered as the significant indicator parameters of surface water quality in the present study. The concentrations (levels/ranges) of these parameters in the above classes are defined with due consideration of CPCB standards/criteria and IS 10500. For parameters and classes not included in the CPCB standards, reference was made to the standards defined by other agencies. The proposed classification along with ranges of concentrations of these parameters are given in Table I. The basis for selecting the concentration levels for each of the parameters under consideration in the above classes is detailed below.

2.2.2. *Basis for Defining the Concentration Ranges*

Turbidity The Indian Standards for Drinking Water (IS 10500, 1983) specify Maximum Desirable level of 10 NTU for turbidity. This value is considered in the proposed classification scheme for class C_2 (Acceptable water quality). This level is also defined as maximum admissible level in EC standards (Tebbutt, 1982). However, WHO Guidelines (Tebbutt, 1982) and WQIHSR standards (Fintajsl, 1970)

TABLE I
Proposed classification of water quality

Classification	Excellent	Acceptable	Slightly polluted	Polluted	Heavily polluted
	C_1	C_2	C_3	C_4	C_5
Class Index (score)	1	2	4	8	16
Parameters	Concentration limit/ranges				
Turbidity (NTU)	5	10	100	250	>250
pH	6.5–7.5	6.0–6.5 and 7.5–8.0	5.0–6.0 and 8.0–9.0	4.5–5 and 9–9.5	<4.5 and >9.5
Color (Hazen Unit), max	10	150	300	600	1200
DO (%)	88–112	75–125	50–150	20–200	<20 and >200
BOD_5 (20 °C), (mg L^{-1}), max	1.5	3	6	12	24
TDS (mg L^{-1}), max	500	1500	2100	3000	>3000
Hardness $CaCO_3$ (mg L^{-1}), max	75	150	300	500	>500
Cl (mg L^{-1}), max	150	250	600	800	>800
NO_3 (mg L^{-1}), max	20	45	50	100	200
SO_4 (mg L^{-1}), max	150	250	400	1000	>1000
Total coliform (MPN), max	50	500	5000	10000	15000
As (mg L^{-1}), max	0.005	0.01	0.05	0.1	1.3
F (mg L^{-1}), max	1.2	1.5	2.5	6.0	>6.0

Notes: (1) Except for pH and DO, the maximum concentration value indicated is to be included in that class (and not in the next class). (2) In case of DO, upper and lower limits are to be included in that class. (3) In case of pH, lower and upper limit of C_1 are included in C_1. In all other classes (C_2–C_5) lower limit of lower range and upper limit of upper range are included in that class, but upper limit of lower range and lower limit of upper range are excluded from that class.

indicate 5 NTU as Maximum Acceptable Level, which is therefore considered in class C_1 (Excellent water quality). The McKee and Wolf criteria indicates 10–250 NTU as Good water quality, and more than 250 NTU as poor water quality. Hence, accordingly the range was split into 10–100 for class C_3 (Slightly Polluted), 100–250 for C_4 (polluted) and more than 250 as C_5 (heavily polluted) class of water.

pH Central Pollution Control Board (CPCB, ADSORBS/3/78-79), has given pH range 6.5 to 8.5 for classes A, B and D. The Guide limit for EC standards for Surface Waters used for Potable Abstractions is 5.5–9.0. Considering these, pH levels for classes C_1–C_5 defined in the proposed scheme are indicated in Table I.

Color The Desirable Level of 10 Hazen units (maximum) of color in IS Standard for Drinking Water is retained in class C_1. McKee and Wolf allow 20 units of color for Excellent water, with 20–150 for Good, and more than 150 for Poor quality water. Therefore, class C_2 is assigned the limit 150 units. The CPCB standard of 300 units in class B and C water is assigned to class C_3 in the proposed scheme. The polluted water indicating presence of colored substance would be hardly used by the people, and hence the classes C_4 and C_5 are assigned higher concentrations in geometric progression.

DO The maximum concentration of oxygen that can dissolve in water is the function of water temperature, and therefore may vary from place to place and time to time. In India average tropical temperature is 27 °C. The corresponding average DO saturation concentration reported is 8 mg L^{-1} (Metcalf and Eddy, 1972). This represents 100% DO concentration and is applicable in class C_1. However, due to high organic loading, water bodies often become eutrophic which results into high DO concentration during the day time. This is an undesirable situation. Hence classification scheme for DO considers the concentration ranges on lower and higher sides of the average DO level in that class. These ranges in terms of % DO concentration are defined as given in Table I.

BOD The classification for Biochemical Oxygen Demand (BOD) is retained as given by Prati *et al*. (1971). This also conforms with the CPCB standards giving BOD values 2 mg L^{-1} and 3 mg L^{-1}, for class A and B water, respectively. EC freshwater fish water quality standards indicate Guide Level and Maximum Admissible Level of BOD as 3 and 6 mg L^{-1}, respectively, which indicate recreational use. Since, BOD more than 2.5 is indicated as Poor water quality by McKee and Wolf (1963), the classes C_3, C_4, C_5 representing Slightly Polluted, Polluted and Heavily Polluted water are assigned higher concentrations in geometric progression in the proposed classification.

TDS The values for total Dissolved Solids (maximum) 500 mg L^{-1} in class C_1, between 500–1500 in C_2 and 1500–2100 in C_3 in the proposed scheme take into consideration the standards for class A, C and E in CPCB standards. 1500 mg L^{-1} is also the Maximum Admissible Level in EC standards for drinking water. Classes C_4 and C_5 are therefore assigned higher values 3000 and more than 3000 mg L^{-1} to indicate Pollution and Heavy Pollution, respectively.

Hardness Desirable Limit for total hardness in Indian Drinking Water Standards is (maximum) 300 mg L^{-1}, whereas, a value of 500 mg L^{-1} is indicated as Action Level in WHO Guidelines. Accordingly, the ranges for the parameter total hardness were taken as 0–75 mg L^{-1} in C_1, 75–150 mg L^{-1} in C_2 and 150–300 mg L^{-1} in C_3, 300–500 mg L^{-1} in C_4 and more than 500 mg L^{-1} in C_5.

Cl, NO_3 and SO_4 The concentration level for Cl in CPCB standards is 250 mg L^{-1} for class A water. This is also the Action Level in WHO Guidelines. Therefore, class C_1 was assigned a concentration 150 mg L^{-1}, a value less than the Action Level of WHO; and 250 mg L^{-1} was assigned to class C_2. The concentration value 600 mg L^{-1} indicating class C and E water in CPCB classification was assigned to class C_3. The classes C_4 and C_5 were assigned concentrations more than 600 mg L^{-1} (Table I).

For NO_3 the Guide Level of 25 mg L^{-1} and the Maximum Admissible Level of 50 mg L^{-1} are indicated in EC standards for drinking water. However, in CPCB Standards concentration 20 and 50 mg L^{-1} are given for class A and C water, respectively. Therefore classes C_1, C_2, and C_3 in the proposed scheme are assigned concentrations 20, 45 and 50 mg L^{-1} respectively. Levels of nitrate nitrogen at or below 90 mg L^{-1} have no adverse effect on warm water fish (Train, 1979). Therefore, concentration levels of 100 mg L^{-1} and 200 mg L^{-1} are considered for C_4 and C_5 classes of water.

The sulphate concentration in CPCB standards for class A, B and C water is 400 mg L^{-1}, whereas EC drinking water standards are 25 mg L^{-1} Guide Level and 250 mg L^{-1} Maximum Admissible Level. WHO drinking water Guidelines specify a value of 400 mg L^{-1} as Action Level. Therefore, in the proposed scheme, classes C_1 to C_3 are assigned values in this range. The class C_4 is assigned a value of 1000, wherein, 1000 mg L^{-1} is indicated in CPCB standards for class E water. The class C_5 indicating high pollution is implied if the SO_4 concentration is more than 1000 mg L^{-1}.

Total Coliform The total coliform organism count 50, 500 and 5000 MPN/100 mL, (maximum) specified in CPCB classification of Inland Surface Water have been retained in classes C_1, C_2 and C_3, respectively, in the proposed scheme. Water quality criteria by McKee and Wolf (1963) also considers coliform count 50–100 as Excellent, 100–5000 as Good, and more than 5000 as Poor. A count of 10000 (MPN/100 mL) has been indicated as Maximum Admissible Level in EC bathing water standards. This value is assigned to class C_4 (5000–10 000) indicating Polluted water quality making the criteria more stringent. Coliform count more than 10000 obviously indicates heavy pollution and therefore it is considered in class C_5.

As and F Ranges for water quality criteria for toxic elements such as Arsenic and Fluoride have been derived from various standards. Guide Limit defined in EC standards for Surface Water used for Potable Abstractions (Class A_1) for As is 0.01 mg L^{-1}, and Mandatory Limit is 0.05 mg L^{-1}. In CPCB Standards, maximum limit for class A water is 0.05 mg L^{-1}, and for classes B and C it is 0.2 mg L^{-1}. Also, Desirable Limit in Indian Drinking Water Standards is 0.05 mg L^{-1}. Therefore, in the proposed classification, concentration 0.05 mg L^{-1} in Class C_3; 0.01 mg L^{-1} in C_2; and 0.005 mg L^{-1} in class C_1 are assigned. This makes the

proposed classification criteria more stringent for Arsenic. Protection of aquatic life requires As < 0.1 mg L^{-1} (for aquatic vegetation) and less than 1.3 mg L^{-1} to protect fish-food organisms (Train, 1979). Hence, these values are assigned in classes C_4 and C_5.

Indian Standard specification for Drinking Water indicate Desirable Limit for Fluoride as 0.6–1.2 mg L^{-1}. This range is retained in the proposed classification scheme for class C_1. Class C_2 considers maximum level 1.5, where, 1.5 mg L^{-1} is the Mandatory Limit in EC standards for Surface Water used for Potable Abstraction (class A_1), and also the Action level in WHO Guidelines. The range 1.5–3.0 is indicated as Good water quality and concentration more than 3.0 mg L^{-1} is classified as Poor water quality in the classification by McKee and Wolf (1963). Therefore, class C_3 indicating slight pollution considers concentration value 2.5 mg L^{-1}. However, fluoride concentration more than 1.5 mg L^{-1} affects human health such as tooth decay and much higher levels result in bone damage through fluorosis (Tebbutt, 1992). Based on this information, classes C_4 and C_5 are assigned concentration values 6.0 and more than 6.0 mg L^{-1}, respectively.

After assigning the concentration levels/ranges for each of the parameters in the proposed classes, an attempt is made to transform the information on water quality data in discrete terms.

2.3. Development of pollution index (P_i) for individual parameter and an overall index of pollution (OIP)

Different water quality parameters are measured in different units of measurement. Hence, it is necessary to bring them into the commensurate unit so that the integrated index can be obtained and used for decision making. For this purpose, an integer value is assigned to each of the classes C_1, C_2, C_3, C_4 and C_5, in geometric progression i.e. 1, 2, 4, 8 and 16 respectively, where, the number termed as class index indicates the level of pollution in numeric terms. This forms the basis for comparison of water quality from Excellent to Heavily Polluted (Table I). Mathematical expressions are fitted for each of the parameter concentration levels to obtain this numerical value called an index (P_i) indicating the level of pollution for that parameter. These mathematical equations are given in Table II. The value function curves, wherein, the concentration of the parameter is taken on Y-axis and index value on X-axis are plotted for each of the parameter and are shown in Figure 1. These curves give the pollution index (P_i) for individual pollutants. For any particular concentration, the corresponding index can be read directly from these curves. The index value up to 1 indicates Excellent water quality, between 1 and 2 indicates Acceptable, between 2 and 4 indicates Slightly Polluted, between 4 and 8 indicates Polluted and between 8 and 16 indicates Heavily Polluted water.

TABLE II
Mathematical equations for value function curves

Parameters		Mathematical equations
Turbidity	≤5	$x = 1$
	5–10	$x = (y/5)$
	10–500	$x = (y + 43.9)/34.5$
pH	7	$x = 1$
	>7	$x = \exp((y - 7.0)/1.082),\ y > 7$
	<7	$x = \exp((7 - y)/1.082),\ y < 7$
Color	10–150	$x = (y + 130)/140$
	150–1200	$x = y/75$
% DO	<50	$x = \exp(-(y - 98.33)/36.067)$
	50–100	$x = (y - 107.58)/14.667$
	≥100	$x = (y - 79.543)/19.054$
BOD	<2	$x = 1$
	2–30	$x = y/1.5$
TDS	≤500	$x = 1$
	500–1500	$x = \exp((y - 500)/721.5)$
	1500–3000	$x = (y - 1000)/125$
	3000–6000	$x = y/375$
Hardness	≤75	$x = 1$
	75–500	$x = \exp(y + 42.5)/205.58$
	>500	$x = (y + 500)/125$
Cl	≤150	$x = 1$
	150–250	$x = \exp((y/50) - 3)/1.4427)$
	>250	$x = \exp((y/50) + 10.167)/10.82$
NO_3	≤20	$x = 1$
	20–50	$x = \exp((y - 145.16)/76.28)$
	50–200	$x = y/65$
SO_4	≤150	$x = 1$
	150–2000	$x = ((y/50) + 0.375)/2.5121$
Coli	≤50	$x = 1$
	50–5000	$x = (y/50)^{**}0.3010$
	5000–15000	$x = ((y/50) - 50)/16.071$
	>15000	$x = (y/15000) + 16$
As	≤ 0.005	$x = 1$
	0.005–0.01	$x = y/0.005$
	0.01 –0.1	$x = (y + 0.015)/0.0146$
	0.1 –1.3	$x = (y + 1.1)/0.15$
F	0 –1.2	$x = 1$
	1.2 –10	$x = ((y/1.2) - 0.3819)/0.5083$

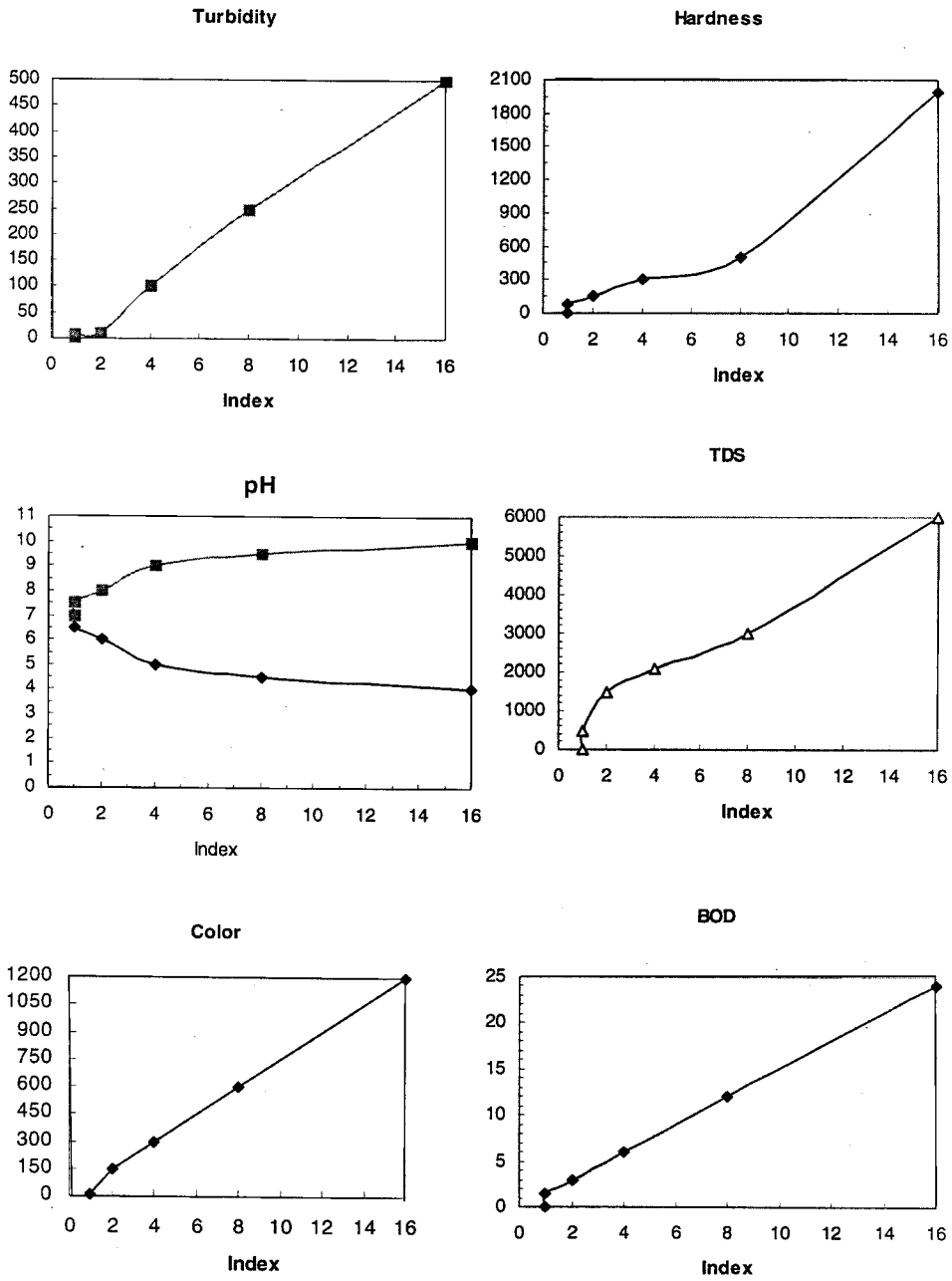

Figure 1. Value function curves for important water quality parameters in the proposed scheme.

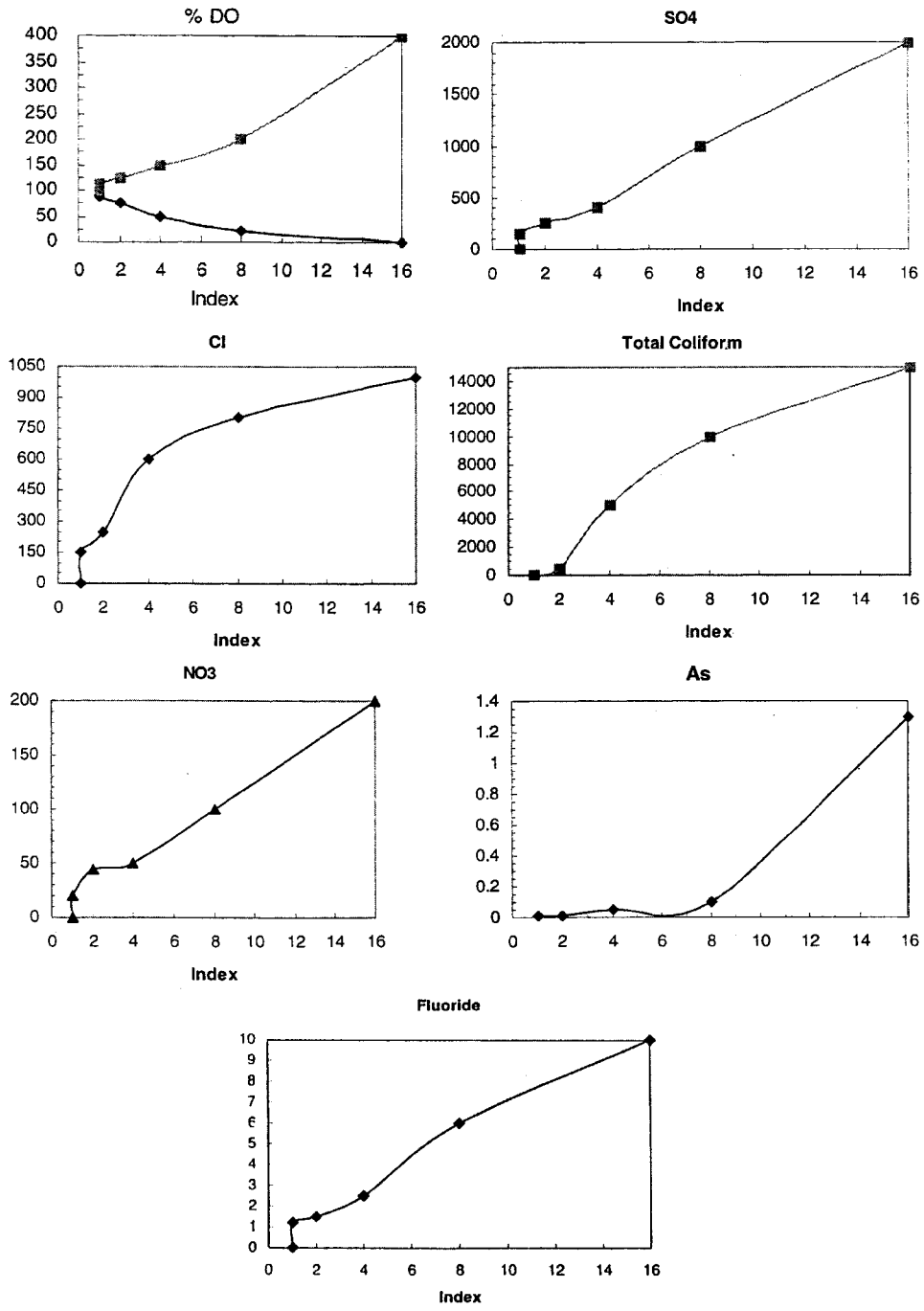

Figure 1. (continued)

Overall Index of Pollution (OIP) is estimated as the average of all the pollution indices (P_i) for individual water quality parameter considered in this study and is given by the mathematical expression

$$\text{OIP} = \frac{\Sigma_i P_i}{n},$$

where P_i = pollution index for ith parameter. $i = 1, 2, \ldots, n$ and n = number of parameters.

The interpretation of OIP values to determine the pollution status is done on similar lines to that for the individual parameter index defined earlier. The OIP is simple to estimate and flexible to the addition or deletion of parameters. However, comparative assessments of water quality at different places or at different times can be made only when the parameters included in the OIP are the same, and accordingly recommendations may be made regarding the specific use of water.

The numerical estimate of OIP corresponds to following classes:

0–1	:	Excellent (Class C_1).
1–2	:	Acceptable (Class C_2).
2–4	:	Slightly polluted (Class C_3).
4–8	:	Polluted (Class C_4).
8–16	:	Heavily polluted (Class C_5).

Here again, the upper limit of the range is to be included in that class. After estimating the OIP, those parameters for which the individual subindices exceed the OIP value be identified. The observed concentrations of these parameters be noted and compared with the concentration levels/ranges given Table I. This would indicate a warning against pollution and necessary remedial measures may be taken. In case of Polluted and Heavily Polluted classes, more stringent measures for abatement of pollution are necessary to avoid any severe effects on human health, vegetation, aquatic life etc.

3. Application of OIP to Water Quality Assessment in River Yamuna

The proposed scheme of water quality classification and the methodology presented for estimation of OIP was applied to assess the water quality status at a few sampling stations on the Yamuna River. The various sampling stations from Sonipat to Allahabad on the Yamuna River are shown in Figure 2 (CPCB Report, 1999–2000). The observed water quality data in the month of June for three consecutive years 1995–1997 at six stations viz. Hathnikund (HK), Kalanaur (KN), Palla (Pl), Nazimuddin Bridge (NB), Mazawali (MZ) and Etawah (ET) were considered for estimation of OIP. The data are given in Table III. Pollution indices for each of the water quality parameter measured at these stations were estimated using value

function curves for each parameter or using the mathematical expression for that curve (Table IV). The OIP was calculated by taking the average of all the pollution indices for individual water quality parameters. Figure 3a depicts the estimated OIP at these stations in the month of June for three consecutive years 1995–1997, and Figure 3b location-wise.

At Hatnikund, the overall water quality was in the range Excellent to Acceptable for all the three years. At Kalanaur, it was slightly polluted in 1996, but Excellent in 1995 and 1997. At Palla, water quality was always Excellent. At Nizamuddin Bridge (at the center of river), water quality status was indicated as Polluted and Heavily polluted. This is obvious because number of drains meet river Yamuna upstream of this point in the stretch under consideration. At sampling point Mazawali, water quality status was always slightly polluted and at station Etawah there was improvement in water quality from Slightly Polluted to Acceptable from the year 1995 to 1997. Thus, based on the estimated values of OIPs, the sampling stations where pollution control measures are required can be identified. The detailed about the specific parameters responsible for pollution can be obtained by referring to the concentration ranges defined in Table I and the level of treatment required to make the water suitable for designed use at that location can be decided.

4. Conclusion

A general scheme for classification of surface water quality is proposed for India. Important indicator parameters of water quality considered in the present study were pH, Turbidity, Color, DO, BOD, Cl, TDS, Hardness, SO_4, NO_3, As, F and Total Coliform. The concentration ranges for these classes were defined by referring to the National/International Agencies Standards and other reported scientific information on pollution effects of these parameters. Mathematical equations formulated for all the parameters under consideration and the corresponding value function curves transformed the actual concentration values into individual pollution indices. The OIP estimated based on the individual parameter indices represents the overall quality of water.

As a case study, the OIP values estimated at a few sampling stations on the Yamuna River, are useful to ascertain the suitability of water for designated best use at a particular location and to determine the level of treatment required for the individual parameter by referring to the concentration ranges defined in the proposed classification scheme.

Thus, the Overall Index of Pollution is definitely very useful to the public for assessment of surface water quality status and can be used as a powerful tool in formulating the pollution control strategies in terms of treatment required at different levels.

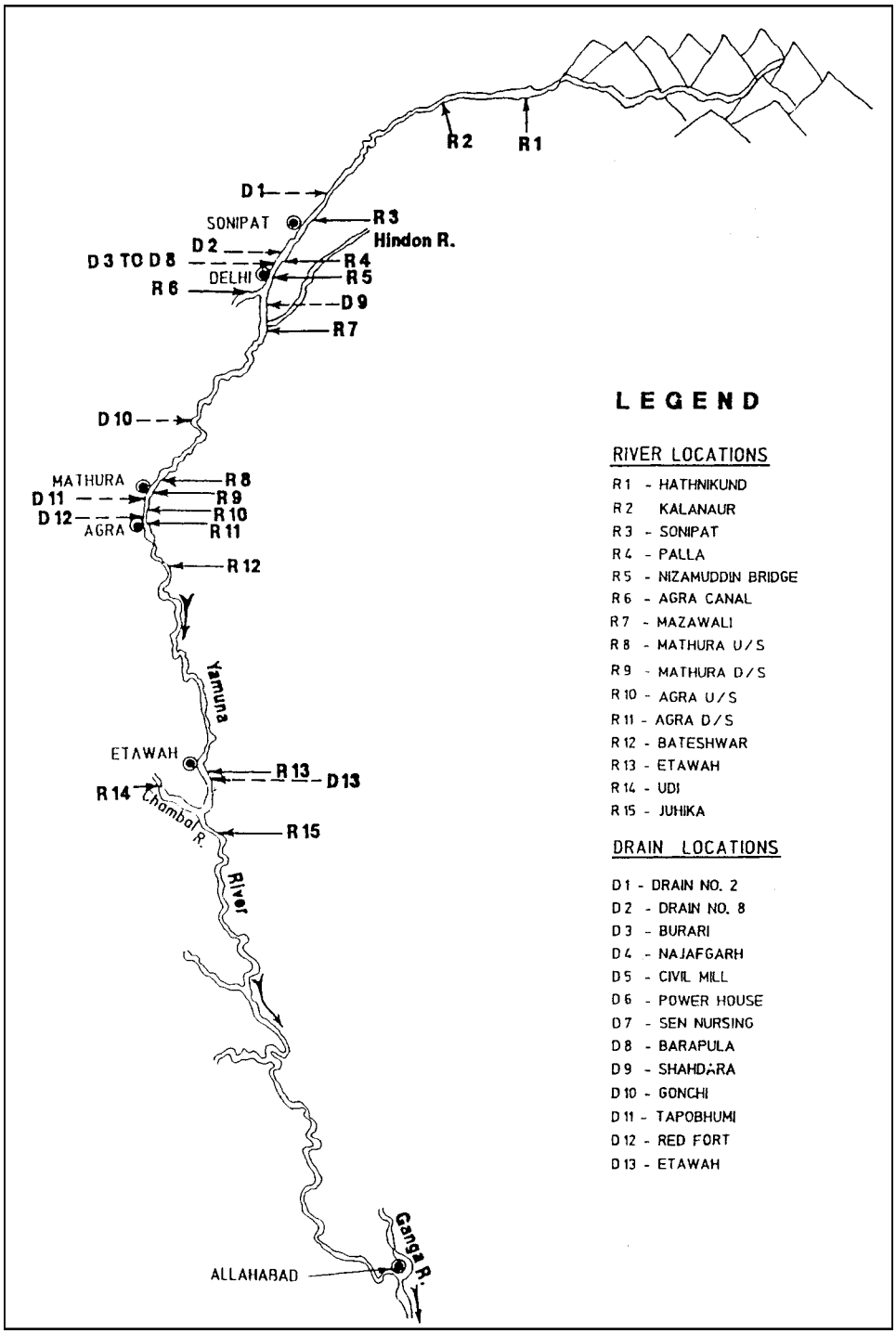

Figure 2. Location map of sampling stations on Yamuna River.

TABLE III
Water quality in Yamuna River

Parameters	Stations					
	HK	KN	PL	NB	MZ	ET
June 1995						
pH	7.87	8.07	8.5	7.61	7.93	8.5
Turbidity	1	1	1	6	3	5
Hardness	91	136	110	116	284	408
TDS	124	160	180	274	750	1188
BOD	1	1	1	7	8	12
DO	7.6	7.1	6.5	ND	ND	4.9
Cl	12	8	10	35	101	322
NO_3	NT	0.009	0.04	6.43	15.24	4.72
SO_4	18	24	15	46	69	98
Total coliform	452	1512	620	872000	30000	29000
June 1996						
pH	8.22	6.61	8.07	7.13	8.06	8.69
Turbidity	5	9	6	5	10	16
Hardness	116	182	96	180	214	254
TDS	ND	ND	ND	ND	ND	ND
BOD	1	203	2	9	8	6
DO	9.5	7.1	9.7	0	8	8.1
Cl	9	186	10	100	96	188
NO_3	NT	NT	NT	14.7	9.18	NT
SO_4	42	73	36	72	50	87
Total coliform	220	104000	2700	396000	86000	2900
June 1997						
pH	8.22	8.16	8.02	7.46	7.72	8.65
Turbidity	ND	ND	ND	ND	ND	ND
Hardness	144	86	150	216	400	270
TDS	212	148	219	555	836	828
BOD	1	1	2	9	7	3
DO	11.4	9.6	7.6	3.6	6.85	7.9
Cl	14	15	30	28	35	213
NO_3	0.002	NT	0.001	5.26	5.68	0.03
SO_4	45	25	40	72	64	75
Total coliform	3400	3800	2000	534000	151000	2500

Note: ND – Not done, NT - Not traceable

TABLE IV

Individual parameter indices at various sampling stations on river Yamuna

Parameters	Stations					
	HK	KN	PL	NB	MZ	ET
June 1995						
pH	2.23	2.69	4.00	1.76	2.36	4.00
Turbidity	1.14	1.14	1.14	1.29	1.20	1.26
Hardness	0.50	0.87	0.66	0.71	2.08	3.09
TDS	0.59	0.62	0.64	0.73	1.41	2.59
BOD	0.67	0.67	0.67	4.67	5.33	8.00
DO	1.01	1.21	1.52			2.74
Cl	0.15	0.14	0.14	0.20	0.51	4.64
NO_3		0.34	0.34	0.46	0.69	0.42
SO_4	0.29	0.34	0.27	0.52	0.70	0.93
Total coliform	1.94	2.79	2.13	74.13	18.00	17.93
OIP (June 1995)	0.79	1.05	1.15	9.38	3.58	4.59
June 1996						
pH	3.09	0.70	2.69	1.13	2.66	4.77
Turbidity	1.26	1.38	1.29	1.26	1.41	1.52
Hardness	0.71	1.25	0.54	1.23	1.51	1.83
TDS						
BOD	0.67		1.33	6.00	5.33	4.00
DO	1.50	1.21	1.58		1.00	1.06
Cl	0.14	1.65	0.14	0.50	0.47	1.69
NO_3				0.67	0.52	
SO_4	0.48	0.73	0.44	0.72	0.55	0.84
Total coliform	1.56	22.93	3.32	42.40	21.73	3.39
OIP (June 1996)	1.17	3.69	1.43	6.73	4.27	2.27
June 1997						
pH	3.09	2.92	2.57	1.53	1.95	4.59
Turbidity						
Hardness	0.94	0.46	0.98	1.52	3.02	1.96
TDS	0.67	0.61	0.68	1.08	1.59	1.58
BOD	0.67	0.67	1.33	6.00	4.67	2.00
DO	2.41	1.54	1.01	4.43	1.33	0.90
Cl	0.15	0.15	0.19	0.18	0.20	2.39
NO_3	0.34		0.34	0.43	0.44	0.34
SO_4	0.51	0.35	0.47	0.72	0.66	0.75
Total coliform	3.56	3.68	3.04	51.60	26.07	3.25
OIP (June 1997)	1.48	1.16	1.11	7.49	4.41	1.88

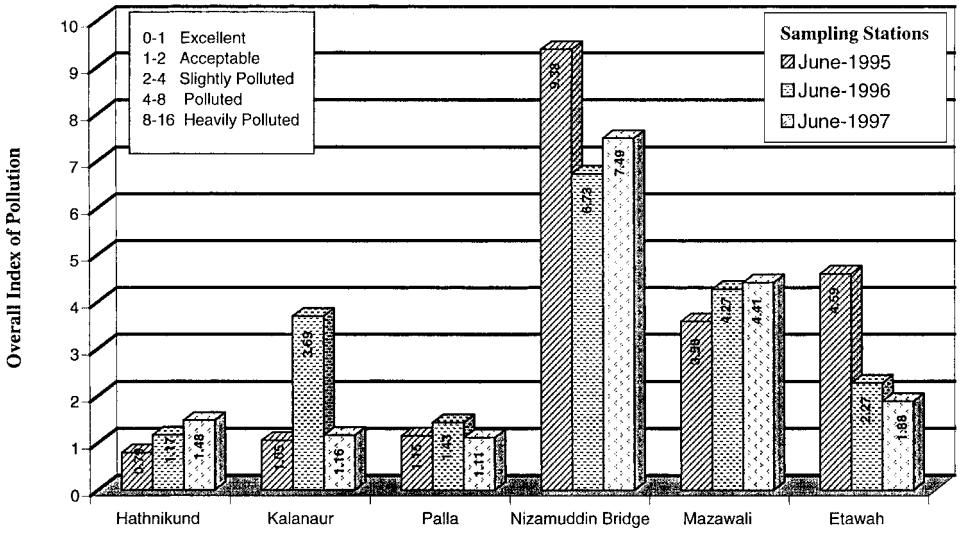

Figure 3a. Overall Index of Pollution for River Yamuna (Year-wise).

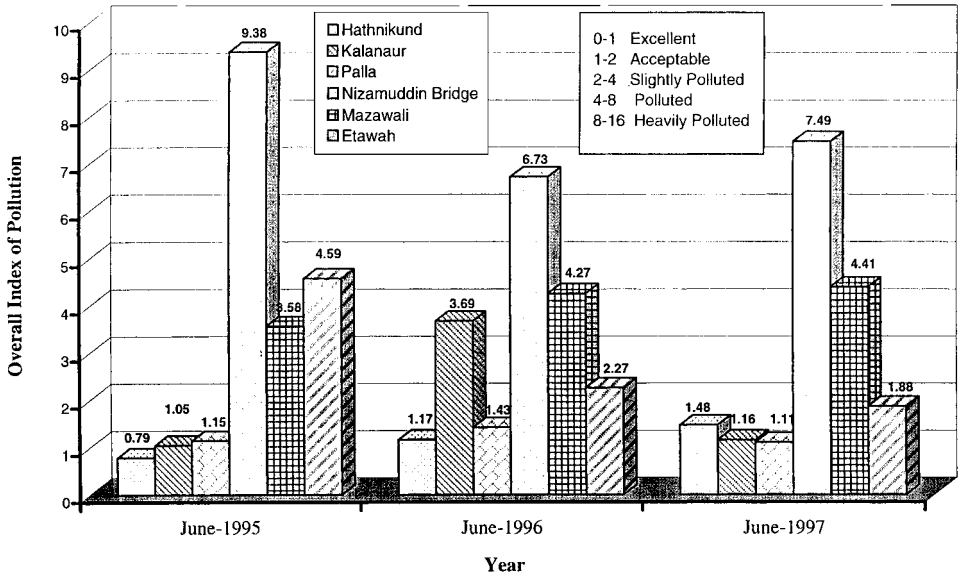

Figure 3b. Overall Index of Pollution for River Yamuna (Location-wise).

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Appendix

TABLE A-1
EC drinking water standards[a]

Parameter	Expressed as	Guide level	Maximum admissible concentration
Colour	mg L^{-1} Pt/Co scale	1	20
Turbidity	mg L^{-1} $S_{ii}O_2$ scale	1	10
Odour	Diluation number	0	2 (12 °C) 3 (25 °C)
Temperature	°C	12	25
pH	Unit	6.5–8.5	
Conductivity	μS cm (20 °C)	400	
Chloride	mg L^{-1} as Cl	25	
Sulphate	mg L^{-1} as SO_4	25	250
Calcium	mg L^{-1} as Ca	100	
Magnesium	mg L^{-1} as Mg	30	50
Sodium	mg L^{-1} as Na	20	175
Total dissolved solids	mg L^{-1}		1500
Nitrate	mg L^{-1} as NO_3	25	50
Ammonia	mg L^{-1} as NH_4	0.05	0.5
Phenols	μg L^{-1} as C_6H_5OH		0.5
Boron	μg L^{-1} as B	1000	
Iron	μg L^{-1} as Fe	50	200
Manganese	μg L^{-1} as Mn	20	50
Phosphorus	μg L^{-1} as P_2O_5	400	5000
Fluoride	μg L^{-1} as F		1500 (12 °C) 700 (25 °C)
Arsenic	μg L^{-1} as As		50
Cadmium	μg L^{-1} as Cd		5
Cyanide	μg L^{-1} as CN		50
Mercury	μg L^{-1} as Hg		1
Lead	μg L^{-1} as Pb		50
Pesticides (total)	μg L^{-1}		0.5
PAH	μg L^{-1}		0.2
Total coliforms	MPN/100 mL		<1
Faecal coliforms	MPN/100 mL		<1
Total colonies 37 °C	per mL	10	
Total colonies 22 °C	per mL	100	

[a] Directive 80/778/EEC.

TABLE A-2
EC bathing water standards[a]

Parameter (mg L^{-1}, except where noted)	Guide limit 90th percentile	Mandatory limit 95th percentile
Cadmium	0.0025	0.0025
Mercury	0.0003	0.0003
Dissolved oxygen	80–120% saturation	
Faecal coil MPN/100 mL	100	2000
Total coli MPN/100 mL	500	10000
Salmonella MPN/L		0
Faecal strep MPN/100 mL	100	
Entero viruses MPN/10L		0

[a] Directive 76/110/EEC.

TABLE A-3
EC freshwater fish water quality standards[a]

Parameter (mg L^{-1}, except where noted)	Annual average dissolved concentration	
	Salmonid fish	Coarse fish
Arsenic	0.05	0.05
Cadmium	0.005	0.005
Chromium	0.005–0.05	0.15–0.25
Copper	0.001–0.028	0.001–0.028
Lead	0.004–0.02	0.05–0.25
Mercury	0.001	0.001
Nickel	0.05–0.2	0.05–0.2
Zinc	0.01–0.125	0.075–0.5
Phosphate	65	131
Ammonia (total)	0.031	0.16
Ammonia (free)	0.004	0.004
Nitrite	0.003	0.003
BOD	3	6
Residual chlorine	0.0068	0.0068
pH (units)	6–9	6–9
Temperature °C	21.5	28
Suspended solids	25	25

[a] Directive 78/659/EEC.

TABLE A-4
EC standards for surface waters used for potable abstractions[a]

Parameter (mg L^{-1}, except where noted)	Treatment type					
	A_1		A_2		A_3	
	Guide Limit	Mandatory Limit	Guide Limit	Mandatory Limit	Guide Limit	Mandatory Limit
pH units	6.5–8.5		5.5–9.0		5.5–9.0	
Colour units	10	20	50	100	50	200
Suspended solids	25					
Temperature (°C)	22	25	22	25	22	25
Conductivity (μS cm^{-1})	1000		1000		1000	
Odour	3		10		20	
Nitrate (as NO_3)	25	50		50		50
Fluoride	0.7–1.0	1.5	0.7–1.7		0.7–1.7	
Iron (soluble)	0.1	0.3	1.0	2.0	1.0	
Manganese	0.05		0.1		1.0	
Copper	0.02	0.05	0.05	1.0		
Zinc	0.5	3.0	1.0	5.0	1.0	50
Boron	1.0		1.0		1.0	
Arsenic	0.01	0.05		0.05	0.05	0.1
Cadmium	0.001	0.005	0.001	0.005	0.001	0.005
Chromium (total)	0.05	0.05		0.05		
Lead		0.05		0.05		0.05
Selenium		0.01		0.01		0.01
Mercury	0.0005	0.001	0.0005	0.001	0.0005	0.001
Barium		0.1		1.0		1.0
Cyanide		0.05		0.05		0.05
Sulphate	150	250	150	250	150	250
Chloride	200		200		200	
MBAS	0.2		0.2		0.5	
Phosphate (as P_2O_5)	0.4		0.7		0.7	
Phenol		0.001	0.001	0.005	0.01	0.1
Hydrocarbons (ether soluble)		0.05		0.2	0.5	1.0
PAH		0.0002		0.0002		0.001
Pesticides		0.001		0.0025		0.005
COD					30	
BOD (with ATU)	<3		<5		<7	
DO percent saturation	>70		>50		>30	
Nitrogen (kjeldahl)	1		2		3	
Ammonia (as NH_4)	0.05		1	1.5	2	4
Total coliforms/100 mL	50		5000		50000	
Faecal coliforms/100 mL	20		2000		20000	
Faecal streptococci/100 mL	20		1000		10000	
Salmonella	absent in 5L		Absent in 1L			

[a] Directive 76/464/EEC.

TABLE A-5
Some examples of WHO Guidelines for drinking water quality[a]

Characteristic	Action level	
Arsenic	0.05	mg L^{-1}
Cadmium	0.005	mg L^{-1}
Chromium	0.05	mg L^{-1}
Cyanide	0.1	mg L^{-1}
Fluoride	1.5	mg L^{-1}
Lead	0.05	mg L^{-1}
Mercury	0.001	mg L^{-1}
Nickel	0.1	mg L^{-1}
Nitrate and nitrite nitrogen	10	mg L^{-1}
Nitrite nitrogen	1.0	mg L^{-1}
Selenium	0.01	mg L^{-1}
Chloride	250	mg L^{-1}
Sulphate	400	mg L^{-1}
Hardness as $CaCO_3$	500	mg L^{-1}
Total dissolved solids	1000	mg L^{-1}
Aluminium	0.2	mg L^{-1}
Copper	1.0	mg L^{-1}
Iron	0.3	mg L^{-1}
Manganese	0.1	mg L^{-1}
Sodium	200	mg L^{-1}
Zinc	5.0	mg L^{-1}
Chlorophenols	0.1	μg L^{-1}
Chloroform	30	μg L^{-1}
DDT	1.0	μg L^{-1}
Heptachlor	30	μg L^{-1}
Lindane	3.0	μg L^{-1}
Monochlorobenzene	3.0	μg L^{-1}
1,4-Dichlorobenzene	0.1	μg L^{-1}
2,4-D	100	μg L^{-1}
Gross alpha activity	0.1	Bq L^{-1}
Gross beta activity	1.0	Bq L^{-1}
Colour	15	TCU
Turbidity	5	NTU
Taste	Not objectionable to 90% of consumers	
pH	6.5 to 8.5	
Coliforms	Absent in 100mL	

[a] Guidelines for Drinking Water Quality, WHO, Geneva, 1984.

TABLE A-6
Drinking water quality standards by WQIHSR

Parameter		Acceptable	Maximum allowable concentration
Color		5 units	50 units
Turbidity		5 units	25 units
pH		7.0–8.5	$9.2 < pH < 6.5$
Cl	mg L^{-1}	200	600
SO_4	mg L^{-1}	200	400
Cd	mg L^{-1}	75	200
Mg	mg L^{-1}	50	150
TDS	mg L^{-1}	500	1500
Fe	mg L^{-1}	0.3	1.0
Mn	mg L^{-1}	0.1	0.5
Phenol	mg L^{-1}		0.002
As	mg L^{-1}	0.05	
Cd	mg L^{-1}	0.01	
Cr	mg L^{-1}	0.05	
Pb	mg L^{-1}	0.05	

TABLE A-7
Ranges of promulgated standards for raw water sources of water supply[a]

Constituent	Excellent	Good	Poor
BOD (Monthly avg.)	0.75–1.5	1.5–2.5	>2.5
Max, day	1.0–3.0	3.0–4.0	>4.0
Coli./100 mL (Monthly avg.)	50–100	50–5000	>5000
Max, day	<5% over 100	<20% over 5000	<5% over 20000
DO mg L^{-1}	4.0–7.5	4.0–6.5	4.0
% saturation	75% or better	60% or better	—
pH avg.	6.0–8.5	5.0–9.0	3.8–10.5
Cl max mg L^{-1}	$\leq$50	50–250	>250
F mg L^{-1}	<1.5	1.5–3.0	>3.0
Phenol mg L^{-1}	None	0.005	>0.005
Color units	0–20	20–150	>150
Turbidity units	0–10	10–250	>250

[a] McKee and Wolf, 1963.
Excellent: Needs disinfection; Good: Filtration and disinfection; Poor: Special auxillary treatment and disinfection.

TABLE A-8
Indian standard specification for drinking water[a]

Substance or characteristics	Requirement/ desirable limit
Colour, Hazen units, max	10
Odour	Unobjectionable
Taste	Agreeable
Turbidity NTU, max	10
pH value	6.5 to 8.5
Total Hardness (as $CaCO_3$) mg L^{-1} max	300
Calcium (as Ca) mg L^{-1}, max	75
Magnesium (as Mg) mg L^{-1}, max	30
Copper (as Cu) mg L^{-1}, max	0.05
Iron (as Fe), mg L^{-1}, max	0.3
Manganese (as Mn), mg L^{-1}, max	0.1
Chloride (as Cl), mg L^{-1}, max	250
Sulphate (as SO_4) mg L^{-1}, max	150
Nitrate (as NO_3), mg L^{-1}, max	45
Fluoride (as F), mg L^{-1}, max	0.6–1.2

[a] (IS-10500-1983).

TABLE A-9
Classification of inland surface water (CPCB Standards)

Characteristics	A	B	C	D	E
Dissolved oxygen, mg L^{-1}, min	6	5	4	4	–
Biochemical oxygen demand, mg L^{-1}, max	2	3	3	–	–
Total coliform organisms MPN/100mL, max	50	500	5000	–	–
Total dissolved solids, mg L^{-1}, max	500	–	1500	–	2100
Chloride (as Cl) mg L^{-1}, max	250	–	600	–	600
Colour, Hazen units, max	10	300	300	–	–
Sodium absorption ratio, max	–	–	–	–	26
Boron (as B), mg L^{-1}, max	–	–	–	–	2
Sulphate (as SO_4), mg L^{-1}, max	400	–	400	–	1000
Nitrates (as NO_3), mg L^{-1}, max	20	–	50	–	–
Free ammonia (as N) mg L^{-1}, max	–	–	–	1.2	–
Conductivity at 25 °C millimhos cm^{-1}, max	–	–	–	1.0	2.25
pH value	6.5–8.5	6.5–8.5	6.5–8.5	6.5–8.5	6.0–8.5
Arsenic (as As), mg L^{-1}, max	0.05	0.2	0.2	–	–
Iron (as Fe), mg L^{-1}, max	0.3	–	50	–	–
Fluorides (as F), mg L^{-1}, max	1.5	1.5	1.5	–	–
Lead (as Pb), mg L^{-1}, max	0.1	–	0.1	–	–
Copper (as Cu), mg L^{-1}, max	1.5	–	1.5	–	–
Zinc (as Zn), mg L^{-1}, max	15	–	15	–	–

[a] If the coliform count is found to be more than the prescribed tolerance limits, the criteria for colifoms shall be satisfied if not more than 20% of samples show more than the tolerance limits specified, and not more than 5% of samples show values more than 4 times the tolerance limits. Further, the faecal coliform should not be more than 20% of the coliform.
A: Drinking water (without conventional treatment but after design).
B: Outdoor bathing (Swimming pool-bathing ghat).
C: Drinking water with conventional treatment and after design.
D: Propagation wild life, fisheries (recreation and aesthetic).
E: Irrigation, industrial cooling and controlled waste disposal.
Note: For arsenic, iron, fluorides, lead, copper and zinc source – Indian Standard: Tolerance limits for inland surface waters subject to pollution, IS: 2296–1982.

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