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Development of an Overall Water Quality Index (OWQI) for Surface Water in Indian Context

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ABSTRACT

A number of water quality indices based on classification criteria, sub-indices and aggregation function have been developed by the researchers for categorizing the water quality for different uses. In the present study, a general Overall Water Quality Index (OWQI) is developed to classify the surface water into five categories, viz. excellent, good, fair, poor and polluted. For this purpose, the concentration ranges have been defined on the basis of the Indian Standards (IS) and Central Pollution Control Board (CPCB) standards also taking into account other International standards of World Health Organization (WHO) and European Commission (EC). Sixteen parameters are selected based on social and environmental impact and weights are assigned on their relative importance to impact the quality of water. The proposed index improves understanding of water quality issues by integrating complex data and generates a score which describes the status of water quality. The proposed index will be very useful for the water management authorities to maintain good health of surface water resources.

Key words: OWQI, water quality, standards, sub-indices, Sagar Lake.

INTRODUCTION

The quality of water is defined in physical, chemical, biological forms in each category and the water quality parameters are selected on the basis of their intended use. A number of sites for the water quality monitoring create voluminous information and results in complexity to categorize the quality of water for various purposes. Such classifications are generally used for comparison of quality of water on individual parameter basis as per the national and international standards. Even after comparison, it is extremely difficult to arrive at any conclusion due to a number of parameter values in different ranges. In order to overcome such difficulties an Overall Water Quality Index (OWQI) is developed in this paper based on sixteen parameters that are generally used for drinking purpose under the surface water category. These parameters include turbidity, colour, total dissolved solids (TDS), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), secchi depth, hardness, chloride, fluoride, nitrate, total phosphate, iron, sulphate, arsenic and total coliform.

In general, the major objective of water quality assessment is to determine the fulfillment of defined objectives; to describe water quality at regional, national or international scales, and also to investigate trends in time[1] so that it can be classified within the respective regulatory standards[2] for various intended purposes such as potable water, agricultural, recreational and industrial water uses[3]. A number of water quality indices have been developed by various researchers but many of them have some kind of flaws. Bharti and Katyal (2011)[4] reviewed a number of water quality indices for surface water vulnerability assessment. A comparison of various water quality indices was made by Abbasi (1999)[5] and an overview of various types of sub-indices, aggregation functions and flaws is presented in Table 1.

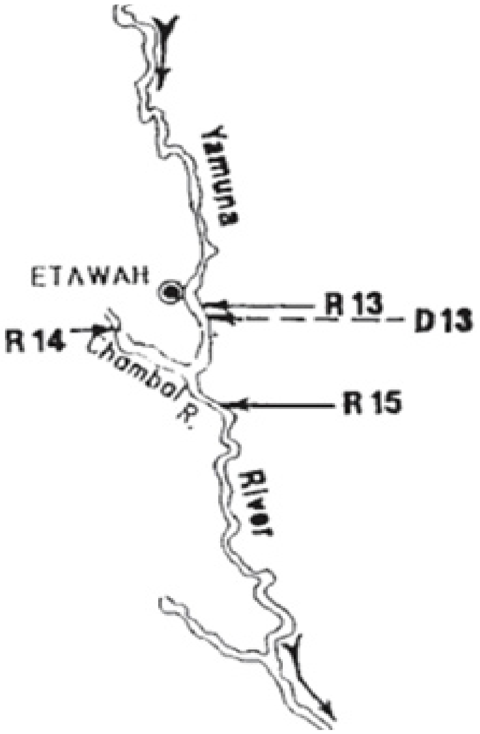

Fig. 1: Location map of sampling stations on Yamuna River, India (Sargaonkar and Deshpande, 2003)[3]

Sargaonkar & Deshpande (2003)[3] and Boyacioglu (2007)[1] have developed two water quality indices in the exponential form and in linear form, respectively during the last decade but the coliform index developed by Boyacioglu (2007)[1] gives erroneous value of index in the parameter range of 5000 to 50000, while in case of Sargaonkar & Deshpande (2003)[3], some eclipsing problem occurs in the indices of DO, hardness, nitrate and coliform.

Keeping in view, the flaws in the above indices, an Overall Water Quality Index (OWQI) is developed by considering sixteen water quality parameters which covers physical, chemical and biological aspects of water. The concentration ranges, for this purpose, have been defined in Indian Standards (IS) and Central Pollution Control Board (CPCB) standards also taking into account International standards of World Health Organization (WHO) and European Commission (EC). This OWQI helps in understanding the quality of water by integrating the complex voluminous data and generates a score to describe the status of water quality. Such indices will prove very helpful for environmentalists, decision makers and field engineers in maintaining good health of surface water resources.

METHODOLOGY

The general methodology for the development of a water quality index can be

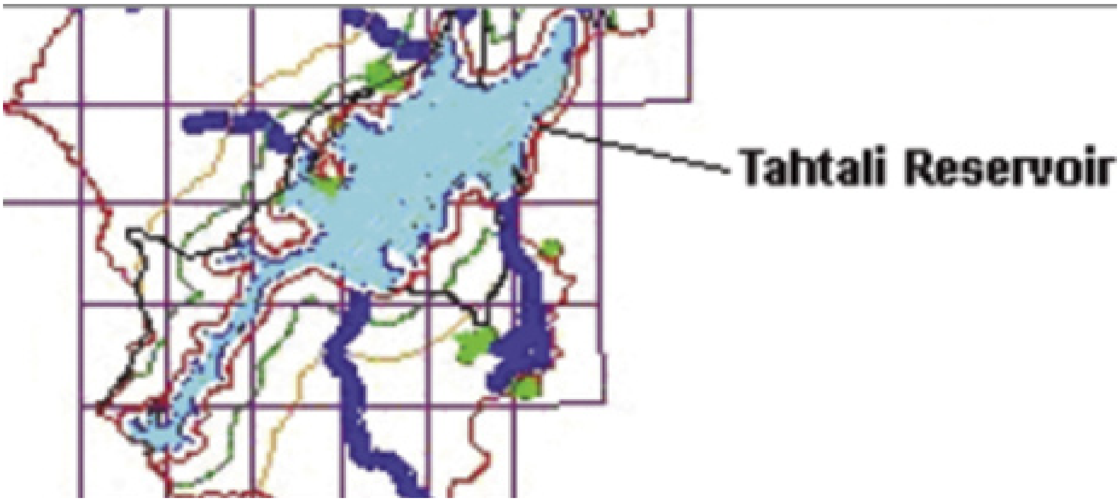

Fig. 2: Location map of Tahtali Reservoir, Turkey (Boyacioglu, 2007)[1]

Table. 1: Comparison of various water quality indices (Abbasi, 1999)[5]

S. N.	Index	Sub-Indices	Aggregation Function	Flaws
1	Horton (1965)[6]	Segmented linear (step functions)	Weighted sum multiplied by 2 Dischotomous term	Eclipsing region
2	Brown et al. (1970)[7]	Implicit non-linear	Weighted sum	Eclipsing region
3	Landwehr (1976)[8]	Implicit non-linear	Weighted product	Non-linear
4	Parti et al. (1971)[9]	Segmented non-linear	Weighted sum (arithmetic mean)	Eclipsing region
5	Mc Duffie & Haney (1973)[10]	Linear	Weighted sum	Eclipsing region
6	Dinius (1972)[11]	Non-linear	Weighted sum	Eclipsing region
7	Dee et al. (1973)[12]	Implicit non-linear	Weighted sum	Eclipsing region
8	O'Connor's (1972)[13]	Implicit non-linear	Weighted sum	Eclipsing region
9	Deininger & Landwehr (1971)[14]	Implicit non-linear	Weighted sum & geometric mean	Eclipsing region & non-linear
10	Walski & Parker (1974)[15]	Non-linear	Weighted product Geometric mean	Non-linear
11	Stoner (1978)[16]	Non-linear	Weighted sum	
12	Nemerow & Sumitomo (1970)[17]	Segmented linear	Root mean square of max. & arithmetic mean	- ve value
13	Smith (1987)[18]	Multiple types	Minimum operator	- ve value
14	Viet & Bhargava (1998)[19]	Multiple types	Weighted product	- ve value

Table. 2: Proposed water quality classification criteria

S.N.	Parameters	Unit			Classes		
			Excellent	Good	Fair	Poor	Heavily Polluted
Index Score			95-100	75-94	50-74	25-49	0-24
1	Turbidity	NTU	5	10	25	250	>250
2	Colour	Hazen Unit	10	15	50	175	>175
3	Total Dissolved Solids	mg/L	500	1000	1500	3000	>3000
4	pH	-	6.5-8.5	6.0 - 6.4 & 8.6 - 9.0	5.5 - 5.9 & 9.1 - 9.5	< 5.5 & > 9.5	< 5.5 & > 9.5
5	DO	mg/L	8	6	4	2	<2
6	BOD	mg/L	2	3	5	7	>7
7	Secchi Depth	m	>=10	8.5	5	2.5	<0.85
8	Total Hardness	mg/L	< 300	400	500	600	>600
9	Chloride	mg/L	200	250	600	800	>800
10	Fluoride	mg/L	0.7-1.5	1.6	1.7	2	>2
11	Nitrate	mg/L	10	20	50	100	>100
12	Total Phosphate	mg/L	0.02	0.16	0.4	0.65	>0.65
13	Iron	mg/L	0.1	0.3	0.5	1	>1
14	Sulphate	mg/L	25	150	250	400	1000
15	Arsenic	mg/L	0.005	0.01	0.05	0.1	0.2
16	Total Coliform	MPN	50	500	5000	50000	>50000

Table. 3: Development of sub-indices function for various parameters

S. N.	Parameter	Range of Parameter	Sub-Index Function
1	Turbidity	0 - 5	Y=100
		6 - 10	Y=-4*X+115
		11 - 25	Y=-1.667*X+91.67
		26 - 250	Y=-0.111*X+52.78
		> 250	Y=-0.1*X+50
2	Colour	0 - 10	Y=100
		11 - 15	Y=-4*X+135
		16 - 50	Y=-0.7143*X+85.71
		> 50	Y=-0.2*X+60
3	TDS	0 - 500	Y=100
		501 - 1000	Y=-0.2*X+195
		1001 - 1500	Y=-0.0278*X+91.67
		1501 - 3000	Y=-0.0167*X+75
		> 3000	Y=-0.0083*X+50
4	pH	6.5 - 8.5	Y=100
		6.0 - 6.4 & 8.6 - 9.0	Y=50
		5.5 - 5.9 & 9.1 - 9.5	Y=25
		< 5.5 & > 9.0	Y=0
5	DO	8 and above	Y=100
		6 - 7.9	Y=10*X+15
		0 - 5.9	Y=12.5*X
6	BOD	< 2	Y=100
		2 - 2.9	Y=-20*X+135
		3 - 7	Y=-12.5*X+112.5
		> 7	Y=-5*X+60
7	Secchi Depth	10 and above	Y=100
		< 10	Y=100*LOG(0.90*X+1)
8	Total Hardness	100 - 300	Y=100
		301 - 400	Y=-0.2*X+155
		> 400	Y=-0.25*X+175
9	Chloride	200 and below	Y=100
		201 - 250	Y=-0.4*X+175
		251 - 600	Y=-0.0714*X+92.86
		> 800	Y=-0.125*X+125
10	Fluoride	0.7 - 1.2	Y=100
		1.6 - 2.0	Y=-260.8*LN(X)+205.38
		< 0.7 & > 2.0	Y=0
11	Nitrate	10 and below	Y=-0.5*X+100
		11 - 20	Y=-2*X+115
		21 - 50	Y=-0.8333*X+91.67
		51-100	Y=-0.5*X+75
		> 100	Y=-0.25*X+50
12	Total Phosphate	0.020 and below	Y=-250*X+100
		0.021 - 0.160	Y=-142.857*X+97.86
		0.161 - 0.40	Y=-104.1667*X+91.67
		0.40 - 0.65	Y=-100*X+90

		> 0.65	Y=-250*X+187.5
13	Iron	0.10 and below	Y=-50*X+100
		0.11 - 0.30	Y=-100*X+105
		0.31 - 0.50	Y=-125*X+112.5
		0.50 - 1.0	Y=-50*X+75
		> 1.0	Y=-25*X+50
14	Sulphate	0 - 25	Y=100
		26 -150	Y=-0.16*X+99
		151 - 250	Y=-0.25*X+112.5
		251 - 400	Y=-0.1667*X+91.67
		401 - 1000	Y=-0.0156*X+31.25
15	Arsenic	0 - 0.005	Y=100
		> 0.005 - 0.01	Y=-4000*X+115
		> 0.01 - 0.05	Y=-625*X+81.25
		> 0.05 - 0.1	Y=-500*X+75
		> 0.1 - 0.2	Y=-20.833*X+27.08
16	Total Coliform	0 - 50	Y=-0.1*X+100
		51 - 500	Y=-0.0444*X+97.22
		501 - 5000	Y=-0.0056*X+77.78
		5001 - 50000	Y=-0.0006*X+52.78
		> 50000	Y=-0.0005*X+50

summarized in the following four steps:

- Parameter Selection - Selection of suitable/ concerned water quality parameter.
- Development of Sub-indices Function - Transformation of concentration of water quality parameters into mathematical equations.
- Assignment of Weights - Deciding suitable weights of various selected water quality parameters.
- Aggregation of Sub-indices to Construct an Overall Index – Construction of an overall water quality index (OWQI).

Table 4: Assignment of significance weight to the water quality parameter

Sl. No.	Parameter	Weight Factor
1	Turbidity	1
2	Colour	2
3	Total Dissolved Solids	3
4	pH	1
5	DO	4
6	BOD	2
7	Secchi Depth	3
8	Total Hardness	1
9	Chloride	1
10	Fluoride	3
11	Nitrate	3
12	Total Phosphate	2
13	Iron	3
14	Sulphate	2
15	Arsenic	4
16	Fecal Coliform	4
	Total weight	39

Selection of Water Quality Parameters

In India, Indian Standards (IS 10500: 1991) and Central Pollution Control Board (CPCB) standards govern the quality of water for various uses. Based on Indian and other standards, total sixteen parameters, viz. turbidity, colour, TDS, pH, DO, BOD, secchi depth, total hardness, chloride, fluoride, nitrate, total phosphate, iron, sulphate, arsenic and total coliform are considered significant to affect the surface water quality. For all these parameters, a class classification criterion has been devised to categorize the quality of water into five classes. These classes include excellent, good, fair, poor and heavily polluted. The proposed water quality classification criteria along with class and index score are given in Table 2.

Development of Sub-indices Function

Sub-indices functions are basically the equations that transform the concentration ranges into the index score through mathematical equations. These scores are then further converted to a common scale based on their relative importance to impact the quality of water. These sub-indices function are developed based on the water quality standards and their concentrations to meet in particular range. For this purpose, mathematical expressions were fitted for each parameter to obtain the sub-index equations as given in Table 3. In this index, the corresponding variation between the range of parameter and index is kept uniform to provide more accurate value of indices.

Assignment of Parameter Weights

Selection of parameter weight is one of the most important tasks. Therefore, due emphasis should be given to decide the weight of each parameter. The parameter which greatly impacts the quality of water shall be given higher weight and vice-versa. These weights have been decided based on the judgment of the authors and the experience gained from the literature. The weight factors of all the sixteen parameters range from 1 to 4 and are presented in Table 4.

Aggregation of sub-indices - Overall Water Quality Index (OWQI)

In order to gauge the influence of each individual parameter on a common single scale, the

Table. 5: OWQI and corresponding class and status of water quality

Class	OWQI Value	Status of Water
Heavily Polluted	0 - 24	Unsuitable for All Purposes
Poor	25 - 49	Special Treatment (Special Treatment)
Fair	50 - 74	Needs Treatment (Filtration & Disinfection)
Good	75 - 94	Acceptable
Excellent	95 - 100	Pristine Quality

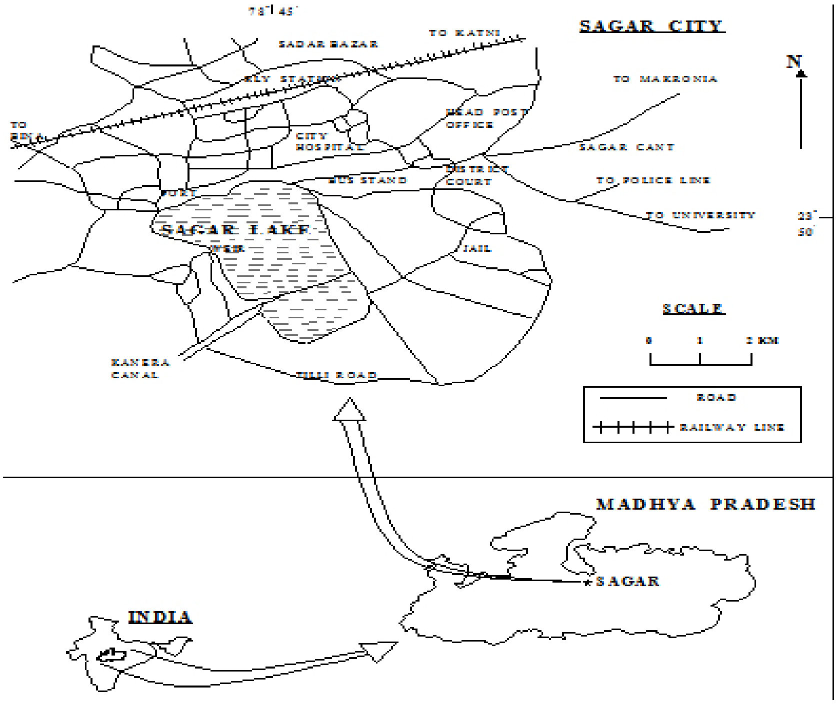

Fig. 3: Location map of Sagar Lake, India (Singh et al., 2009)[20]

score generated by each parameter was averaged-out. The following weighted average aggregation function is used for this purpose.

$$OWQI = \sum_{i=1}^{n} w_i . Y_i \quad ...(1)$$

where,
wi = weight of the ith water quality parameter
Yi = sub-index value of the ith parameter

Based on the status of water quality, the index value range from 0 to 100 and is classified into five categories: heavily polluted (0-24), poor (25-49), fair (50-74), good (75-94) and excellent (95-100). The status of water corresponding to different OWQI values is presented in Table 5. If the index goes down, then it indicates that some of the water quality parameters are being affected due to any particular reason and suitable measures are needed to further improve the quality of water. Thus this index may be used as a guiding rule in management of quality of surface water resources.

Table 6: Observed water quality and corresponding indices at Etawah on the Yamuna River (June, 1997)

Parameter	Value	Indices
pH	8.65	50
Turbidity (NTU)	ND	100
Hardness (mg/L)	270	100
TDS (mg/L)	828	29
BOD5 (mg/L)	3	100
DO (mg/L)	7.9	94
Cl (mg/L)	213	90
NO3 (mg/L)	0.03	100
SO4 (mg/L)	75	87
Total Coliform (MPN/100ml)	2500	64
OWQI	79	

Table. 7: Observed water quality and corresponding indices for the Tahtali Reservoir

Parameter	Value	Indices
Arsenic (mg/L)	0.0058	92
Fluoride (mg/L)	0.792	100
Nitrate-N (mg/L)	5.84	97
DO (mg/L)	9.62	100
BOD5 (mg/L)	4.16	61
Total Phosphorous as PO4 (mg/L)	0.098	84
pH	8.18	100
Total Coliform (CFU/100ml)	170	90
OWQI	92	

RESULTS AND DISCUSSION

The proposed OWQI is used as an application for the estimation of the index of water quality of sampling sites at Etawah on Yamuna River and Sagar Lake in India and Tahtali Reservoir in Turkey. The data of these sampling locations is taken from the published literature[1,3,20] in which the study area are well described as shown in Figures 1 to 3. An MS Excel 2007 based computer programme is developed for computation of the water quality indices both individual parameter-wise and an overall index. This programme also suggests the quality class and status of water based on the OWQI.

Applications of OWQI for assessment of water quality of surface water bodies

The OWQI was computed for Etawah sampling location on the Yamuna River, Tahtali Reservoir and Sagar Lake. Yamuna River and Sagar Lake falls in the northern and central part of India, respectively while Tahtali Reservoir falls in City of Izmir in the western part of Turkey (Figures 1 to 3). The water quality indices are first estimated parameter-wise and then OWQI is computed for each location (Table 6 to 8).

Table. 8: Observed water quality and corresponding indices for the Sagar Lake

Parameter	Value	Indices
Secchi Depth (m)	0.23	8
pH	6.6	100
DO (mg/L)	4.37	55
Hardness (mg/L)	178.08	100
Chloride (mg/L)	63.34	100
Nitrate (mg/L)	9.76	95
Phosphate (mg/L)	0.44	46
Iron (mg/L)	1.71	7
BOD5 (mg/L)	11.4	3
TDS (mg/L)	378	100
OWQI	54	

It is observed from Table 6 that the OWQI is 79 for the Etawah location on Yamuna River which indicates that the water falls in Class "Good" and the quality of water is "Acceptable". Similar is the case for the Tahtali Reservoir where OWQI is 92 (Table 6) and the quality is relatively better. In case of Sagar Lake, it is seen from Table 7 that the OWQI is 54 and the corresponding quality class is "Fair" and this water needs treatment (filtration and disinfection) before any use.

CONCLUSIONS

In this paper an Overall Water Quality Index (OWQI) is developed to provide a simple tool for assessment of quality of surface water resources for drinking water supply. The OWQI is developed based on National and International standards by considering sixteen parameters covering physical, chemical and biological aspects of water. The application of OWQI is demonstrated for three different sampling locations and status of water is described on the basis of computed index. This OWQI provides a simpler means for the water quality assessment and is very useful of decision makers, planners and field engineers for maintaining good health of surface water resources. The proposed index can also be used as a decision support tool for the water quality management.

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REFERENCES

1. Boyacioglu, H., Development of a water quality index based on a European classification scheme. *Water SA*, **33**(1): 101-106 (2007).
2. Khan, A. A., Paterson, R. & Khan, H. Modification and Application of the CCME WQI for the Communication of Drinking Water Quality Data in Newfoundland and Labrador. In: 38th Central Symposium on Water Quality Research, Canadian Association on Water Quality, Burlington, Canada (2003).
3. Sargaonkar, A. &, Deshpande, V. Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environmental Monitoring and Assessment*, **89**: 43-67 (2003).
4. Bharti, N. & Katyal, D. Water quality indices used for surface water vulnerability assessment. *International Journal of Environmental Sciences*, **2**(1): 154-173 (2011).
5. Abbasi, S. A. Water quality indices, A state-of-the art. *Journal of the Institution of Public Health Engineers*, **1**: 13-24 (1999).
6. Horton, R. K. An index number system for rating water quality. *Journal of Water Pollution Control Administration* **37**(3): 300 (1965).
7. Brown, R. M., McClelland, N. I., Deininger, R. A. & Tozer, R. G. A Water Quality Index: Do We Dare?" *Water Sewage Works*, **117**(10): 339-343 (1970).
8. Landwehr, J. M. A statistical view of a class of water quality indices. *Water Resources Research*, **15**(2): 460-468 (1976).
9. Parti, L., Pavanello, R. & Pesarin, F. Assessment of surface water quality by single index of pollution. *Water Research*, **5**: 741-751 (1971).
10. Mc Duffie, B. & Haney, J. T. A proposed river pollution index. American Chemical Society, Division of Water, Air and Waste Chemistry, New York, NY (1973).
11. Dinius, S. H. Social accounting system for evaluating water. *Water Resources Research*, **8**(5), 1159-1177 (1972).
12. Dee, N., Baker, J., Drobny, N., Duke, K. M., Whitman, I. & Fahringer, D. An environmental evaluation system for water resource planning. *Water Resources Research*, **9**(3), 523–535 (1973).
13. O'Cornor, F. M. The application of multi-attribute scaling procedures to the development of indices of water quality. Ph.D. Dissertation , University of Michigan (1972).
14. Deininger, R. & Landwehr., J. M. A water quality index for public water supplies. School

of Public Health, Univ. of Michigan, Ann Arbor (1971).

15. Walski, T. M. & Parker, F. L. Consumers water quality index. Journal of Environmental Engineering Division, *ASCE*, 593-611 (1974).
16. Stoner, J. D. Water quality indices for specific water use. U.S. Geological Survey, Reston, Y.A. *Circular*, 140-770 (1978).
17. Nemerow, N. L., Sumitomo, H. Benefits of water quality enhancement. Syracuse, University, Syracuse, N.Y., Report No. 16110 DAJ (1970).
18. Smith, D. G. Water quality indexes for use in New Zealand's rivers and streams. Water Quality Centre Publication No. 12, Water Quality Centre, Ministry of Works and Development, Hamilton, New Zealand (1987).
19. Viet, N. T. & Bhargava, D. S. Water quality and management Saigon river in Hochi Minch city, Vietnam. *Indian Journal of Environmental Health*, **31**: 321 (1998).
20. Singh, S., Kumar, B., Thakural, L. N. & Galkate, R. V. A comprehensive study on water balance, sedimentation and physico-chemical characteristics of Sagar Lake in India. *Environment Monitoring and Assessment*, **148** (1-4), 265-276 (2009).