Development of Water Quality Indices for Designated Best Uses of Surface Water Body

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Abstract: Use specific Water Quality Indices for Municipal and Industrial ($WQI_{M\&I}$), Ecological (WQI_E) and Irrigational (WQI_I) have been developed and applied on the Satluj river water quality monitoring data. All the water quality parameters against which prescribed limits exist have been selected for inclusion in the indexing. Relative importance assigned to the General Parameters through expert opinion analysis by Pair-wise comparison technique and Sub-index (SI_{gp}) was calculated through aggregated weighted root sum function. In case of heavy metals and pesticides, flexibility of using open ended lists of parameters had been introduced and maximum operator sub-indices were used. Transformation curves for each of the selected parameters were developed while using the water quality criteria and standards as the basis. In case of heavy metals and pesticide parameters, the transformation curves were developed for concentration ratios. Geometric mean of these sub-indices had been taken to obtain the final index.

Keywords: Specific Water Quality Index, Maximum Operator, Transformation Equations, Pair-Wise Comparison, River Satluj

I. INTRODUCTION

Rivers due to their role in carrying off the municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution [1]. For effective water pollution control and water resources management, interpretation of a large number of water quality data is required. Results, available in the form of a huge and complex data matrix on a large number of physico-chemical parameters, are often difficult to interpret and draw meaningful conclusions [2]. Traditional approaches to assess river water quality are based on the comparison of monitored parameter values with the existing local standard values. In many cases, use of this methodology allows proper identification of contamination sources, and it may be essential for checking legal compliances. However, this methodology does not provide global vision on the spatial and temporal trends in the overall water quality in a watershed [3].

Water quality indices (WQIs) are intended to provide simple and easy to understand information for the managers and decision makers on the water quality and possible uses of a given water body. These provide a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality [4]. WQI reflects the composite influence of significant physical, chemical and biological water quality parameters. A single WQI value makes the information more easily and rapidly understood than a long list of numerical values for a large number of parameters.

Development and use of WQIs for monitoring the water quality of streams and rivers and lakes [5]-[8] has become a routine for many environmental agencies throughout the world. Use of WQI was initially proposed by Horton [9]. Since then, many methods for the calculation of WQIs have been developed. In general, they all consider similar physical and chemical parameters, but differ in the way the parameter values are integrated and interpreted.

In India, all the important rivers are monitored and vast monitoring data has been accumulated in the process over the years. But, the data has remained underutilized in the river water quality management for reasons of limited ability to communicate the data to the people, who really matter, in the language they understand. Quite a few workers have tried to use the WQIs available for the communication of the water quality monitoring data but with limited success [10]-[15]. Review of these attempts has indicated that purposeful communication of the water quality data by the existing WQIs is not possible at least because of the following reasons:

- Use of indicators rather than attributes of quality as parameters in the WQIs
- Not considering the parameters (like heavy metals, pesticides and other toxic pollutants) that may often matter in many of the cases in India
- Lack of rating curves for the parameters being monitored under river water quality monitoring programs
- Lack of openness to allow the flexibility of inclusion or exclusion of parameters

- Existing WQIs focusing mostly on general water quality and not use specific

In view of this, a study has been instituted to develop use specific WQIs for ecological (WQI$_E$), irrigational (WQI$_I$) and municipal & industrial (WQI$_{M\&I}$) water qualities. The WQIs developed are supposed to depend on the water quality criteria and standards and have the openness and flexibility required for objective and purposeful reporting of the water quality of all the rivers across the country. Further, efforts have been made to make the WQIs calculations computer (excel worksheet) friendly.

II. MATERIALS AND METHODS

A. Development of use specific water quality indices

The proposed water quality indices are decreasing scale index (the index numbers decrease with the increasing degree of pollution). WQIs calculations involved selection of parameters, assignment of weights to the selected parameters, transformation of the monitored parameter values into common environmental scale units (CESU) through use of Parameter Rating Curves/Equations (PRC/E), and aggregation of the parameter values into the final index score.

A.1 Selection of parameters and assignment of weights

Water quality is a composite and complicated term. It is expressed in terms of a large number of and a wide variety of (sometimes eclipsing) variables. There can be differences in opinion regarding the small set of parameters that mostly describe the water quality. Practicability, technological and economical constraints often restrict monitoring of the water quality in terms of the desired set of indicators.

Conventionally expert opinion has been the basis for the selection of parameters for WQI. But, this approach is fraught with both uncertainty and subjectivity. Recent trend has been to depend on the water quality criteria and standards. Non-existence of any standard or criterion for a specific parameter/variable is considered to indicate its least importance in describing the water quality. On the basis of the water quality standards and criteria and the literature on water quality, separate sets of parameters/variables have been screened for municipal and industrial use, ecological use and irrigational use. Selection of the general parameters and assignment of relative importance to the parameters was done through the expert opinion analysis by pair-wise comparison method.

A.2 Parameter rating curves/equations

Different parameters occurring in different ranges, expressed in different units and having different sensitivities are not compatible for the direct aggregation. Values of the parameters, prior to the aggregation, should be converted into compatible, common scale or single scale units (often referred to as Common Environmental Scale Units, CESU). In the present study, a common environmental scale unit with 0-1 range had been considered. For facilitating the conversion of the monitored parameter values into the CESU values, parameter specific rating curves or transformation equations were developed. These curves/equations divided on the scale of 0 to 1 into five sections: the worst quality (0-0.08), poor quality (0.08-0.30), moderate quality (0.30-0.70), good quality (0.70-0.92) and the excellent quality (0.92-1.00).

Water quality standards and criteria of several official bodies [16]-[29], the Indian effluent standards and the literature available on water quality were used as the bases in the development of the parameter rating curves/transformation equations.

The total possible range of monitored values, which a parameter can take, were first sectionalized and related with the five sections of the parameter rating curves/transformation equations. Rating curves for the parameters were then obtained through plotting the parameter values in CESU against the corresponding range of monitored values of the parameter. Transformation equations were obtained through transforming the plotted curves into equations through curve fitting. Statistical testing, such as, chi-square test and regression coefficient, have been used in the final selection of the transformation equations for the parameters.

For toxic metals, and for pesticides and other toxic organic compounds a slightly different approach was followed for the development of rating curves or transformation equations. The metal or pesticide and other toxic organic compound concentration was first converted into a concentration ratio scale by dividing the actual value with the water quality standard prescribed for that specific heavy metal or pesticide and toxic organic compound. The resultant concentration ratio scale was then divided into 5 sections to correspond with the five sections of the CESU range for obtaining the rating curves or transformation equations.

A.3 Aggregation of parameters

For each of the three groups of selected parameters, sub-indices were developed on 0-1 scale, sub-index for general parameters (SI_{gp}), sub-index for heavy metals (SI_{hm}) and sub-index for pesticide and other toxic organic compound (SI_{ptoc}). Geometric mean of all the three sub-indices has been taken as the overall WQI. For obtaining the WQI on 0-100 scale, the geometric mean value was multiplied by 100.

B. Study area and water quality monitoring program of river Satluj

The river Satluj is one of the five great rivers of undivided Punjab. It originates in Tibetan Plateau, flows through the Himalayan Range in Indian state of Himachal Pradesh, and enters the plains of Punjab near Nangal. Most of the river water is diverted for irrigation, municipal and industrial uses at the Nangal head-works and very little of the river water flows in the river beyond Nangal. Beyond Nangal the river flows across the Punjab plains for about 238 km and then joins the river Beas at the Harike wetland system (internationally recognized Ramsar wetland site). In this 238 km stretch of the river, the Himachal Pradesh hills bordering the Punjab state and the agricultural plains and urban settlements of a major part of the Punjab state constitute the catchments of the river Satluj. Watershed area of the river in this stretch is about 10,880 km2 (between 31° 45' N 74° 57' E and 30° 45' N 76° 50' E). Downstream to the confluence point with the river Beas, at the Harike head-works, the river water is again mostly diverted for irrigation, municipal and industrial uses.

Agricultural drainage and storm-water are the major contributors of both water and pollution loads to the river mainly through five tributaries Swan river, Sirsa river, Siswan river, Budha Nala and East-Bein river. In addition to this, urban settlements (Nangal, Ropar, Phillaur, Ludhiana, Phagwara, Jallandhar, Nawashahar and Hoshiarpur and others) and multitude of industries (textile processing, metal surface finishing, leather processing, distilleries, fertilizer, chemical, etc. industries) also contribute water and pollution to the river.

Satluj river water quality monitoring program was instituted in July 1996 by National River Conservation Directorate (NRCD), Ministry of Environment and Forests, Government of India, New Delhi, through Thapar University. The Satluj river has been monitored at 8 stations within the 238 km stretch (**Fig-1 and Table-1**). In the present study of development and application of three WQIs, data from these eight monitoring stations located on the main river, have been considered.
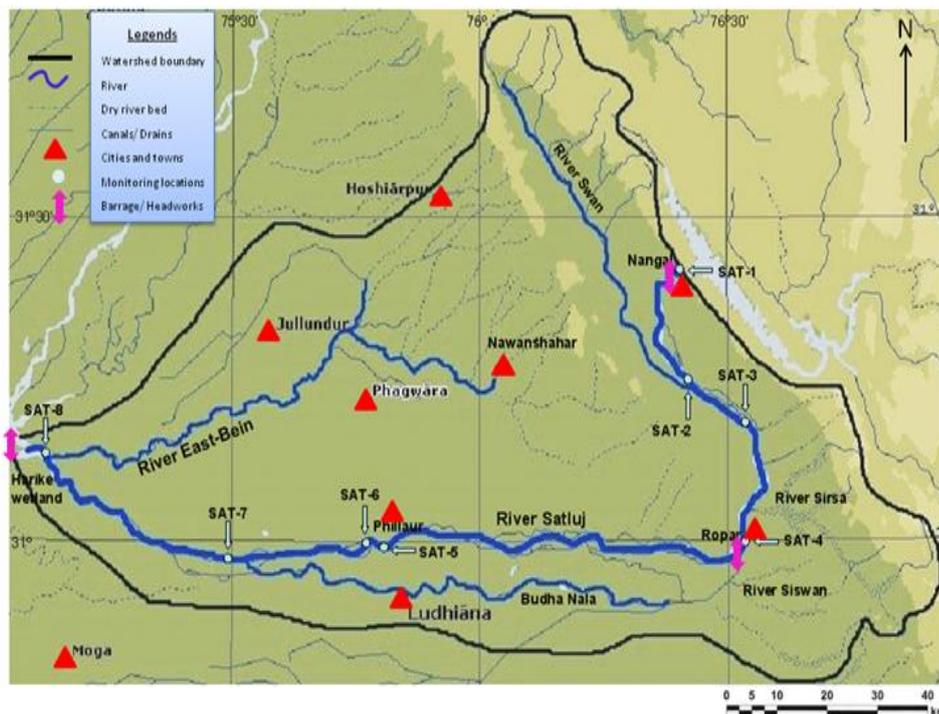

Fig-1. Map of river Satluj watershed showing monitoring stations

Table 1: Description of monitoring stations at river Satluj

Station	Sampling Scheme	Station Specification
SAT – 01 (Nangal)	By Boat from the middle of the reservoir	Reservoir upstream to Nangal Dam, No domestic/industrial activity, Crematoria,Washing, Bathing & Boating, Lift Irrigation, Headworks for take-off Nangal Hydel Canal and Anandpur Sahib Hydel Canal
SAT – 02 (Anandpur Sahib)	By Bridge from the middle	20 km from Nangal Dam, NFL and PACL are located on the upstream side
SAT – 03 (Bunga Sahib)	By Bridge from the middle	37 km from Nangal Dam, Downstream to the river Swan a seasonal rivulet, Commercial fishing
SAT – 04 (Ropar Head Works)	By Boat from the middle of the reservoir	59 km from Nangal Dam, Headworks for take-off Sirhind Canal and Bist Doab Canal, Wastewater discharge of thermal power plant, Recreational activities, boating, water games
SAT – 05 (Phillaur u/s)	From the left bank	135 km from Nangal Dam, Upstream to Phillaur drain, Sand extraction from river bed, Downstream to industrial discharges from Ropar, Agricultural runoff
SAT – 06 (Phillaur d/s)	By Bridge from the middle	136 km from Nangal Dam, Downstream of Phillaur drain and upstream to Budha Nala, Agricultural runoff
SAT – 07 (Sangowal village)	By Bridge from the middle	171 km from Nangal Dam, Downstream to Budha Nala and upstream to the tributary East-Bein
SAT – 08 (Yusufpur)	By Bridge from the Left, Middle and Right	218 km from Nangal Dam, Downstream to the tributary East Bein, Sand extraction

III. RESULTS AND DISCUSSION

A. *Parameter selection and assignment of weights*

The lists of probable parameters for specific to three designated uses (ecological, irrigational and municipal & industrial uses) were categorized into three groups: General parameters; Heavy metals (open ended list of parameters); and pesticides and other toxic organic compounds (open ended list of parameters).

Final selection of general water quality parameters for inclusion in the WQIs and relative weights assigned to them are given in **Table-2**. Selection of the general parameters and assignment of relative importance to the parameters was done through the expert opinion analysis. The other two groups of parameters were not subjected to the expert opinion analysis. The expert opinion analysis was carried out using a pair-wise analysis technique [30]. Each of the panelists was asked to make pair-wise comparison of the selected list of parameters and rate the first parameter of the pair against the second by one of the following five options: Much more important (+2), More important (+1), Equally important (0), Less important (-1), Least important (-2). Ratings of each of the experts were analyzed to get the individual expert's relative weights for the parameters. Sum of weights assigned to all the selected parameters was taken as a unity. Through combining the relative weights assigned by all the experts for individual parameters and taking arithmetic mean, final relative weights for the individual parameters were obtained.

Table 2: Groups of Water Quality Parameters and their Assigned Weights

Ecological WQI		Irrigational WQI		Municipal and Industrial WQI	
Parameter	Weight	Parameter	Weight	Parameter	Weight
BOD_5	0.172	Sodium Absorption Ratio	0.149	Fecal Coliform	0.231
DO% Saturation	0.166	TDS	0.130	Chloride	0.155
pH	0.130	Conductivity	0.123	Nitrate-N	0.145
COD/BOD_5 ratio	0.128	BOD_5	0.119	pH	0.142
TSS	0.108	Chloride	0.116	TDS	0.136
Total-N	0.106	Fecal Coliform	0.099	Ammonical-N	0.103
Total-P	0.103	COD/BOD_5 ratio	0.099	Conductivity	0.088
Ammonical-N	0.088	Total-N	0.092		
		pH	0.073		
Σw	1.000	Σw	1.000	Σw	1.000

Table 3: Summary of Transformation Equations for the determination of Ecological use WQI rating values

Parameters	Concentration Range	Transformation Equation
DO % saturation	0-100	$y = 0.002x^2 + 0.768x - 0.640$
	100-130	$y = -0.01x^2 + 1.3x + 70$
pH	2.7 – 5.5	$y = 41.05\ln(x) - 39.74$
	5.5 – 7.5	$y = -27.81x^2 + 396.3x - 1307.7$
	7.5 – 9.5	$y = -22.33x^2 + 346.3x - 1242.8$
	9.5 – 12.0	$y = -11.252x + 137.19$
Suspended Solids (mg/L)	0 – 250	$y = 96.012e^{-0.0102x}$
Ammonical-N (mg/L)	0 – 0.1	$y = 97.13e^{-3.29x}$
	0.1 – 5.0	$y = -15.9\ln(x) + 32.31$
Total-N (mg/L)	0 – 2.5	$y = 2x^2 - 17x + 100$
	2.5 – 30	$y = -25.1\ln(x) + 91.42$
Total-P (mg/L)	0-0.1	$y = 97.66e^{-3.35x}$
	0.1-5.0	$y = -15.9\ln(x) + 32.31$
BOD_5 (mg/L)	0-30	$y = 0.111x^2 - 6.449x + 101.4$
COD/BOD_5 Ratio	0-250	$y = 100.4e^{-0.01x}$
Heavy metal/ Pesticides conc. ratio	0 - 16	$y = 101.9e^{-0.15x}$

Table 4: Summary of Transformation Equations for the determination of Irrigational use WQI rating values

Parameters	Concentration Range	Transformation Equation
pH	2.7 – 4.0	$y = 76.35\ln(x) - 75.86$
	4.0 – 7.5	$y = -3.852x^2 + 64.61x - 167.18$
	7.5 – 11.2	$y = -2.649x^2 + 30.33x + 22.268$
	11.2 – 12.0	$y = 21.66x^2 - 540.1x + 3362$
Conductivity (μS/cm)	0 – 6000	$y = 2E\text{-}06x^2 - 0.030x + 105.8$
TDS (mg/L)	0 – 3500	$y = 4E\text{-}06x^2 - 0.043x + 106.8$
Total-N (mg/L)	0 – 100	$y = 96.57e^{-0.02x}$
BOD_5 (mg/L)	5-100	$y = -28.6\ln(x) + 135.4$
COD/BOD_5 Ratio	40-750	$y = -29.9\ln(x) + 202.9$
Sodium Absorption Ratio	0 – 40	$y = 0.032x^2 - 3.557x + 98.80$
Chloride (mg/L)	0-900	$y = -2E\text{-}05x^2 - 0.080x + 100.3$
Fecal Coliform (mpn/100ml)	0 – 1000	$y = -4.7772\ln(x) + 103$
	1000-1000000	$y = -8.9341\ln(x) + 132$
Heavy metal conc. ratio	0 - 16	$y = 101.9e^{-0.15x}$

Table 5: Summary of Transformation Equations for the determination of Municipal & Industrial use WQI rating values

Parameters	Concentration Range	Transformation Equation
pH	2.7 – 5.0	$y = 6.889x^2 - 40.00x + 57.79$
	5.0 – 7.5	$y = -10.66x^2 + 161.9x - 513.8$
	7.5 – 9.5	$y = -22.33x^2 + 346.3x - 1242.8$
	9.5 – 12.0	$y = 2.666x^2 - 69.33x + 448$
Conductivity (μS/cm)	0 – 4500	$y = 8E-07x^2 - 0.025x + 104.1$
TDS (mg/L)	50 – 3000	$y = 6E-06x^2 - 0.046x + 96.90$
Ammonical-N (mg/L)	0 – 2	$y = -7x^2 - 1x + 100$
	2 – 40	$y = -20.5\ln(x) + 84.61$
Nitrate-N (mg/L)	0 – 23	$y = 0.161x^2 - 7.953x + 104.5$
Chloride (mg/L)	0-1200	$y = 7E-05x^2 - 0.157x + 99.60$
Fecal Coliform (mpn/100ml)	0 – 1000	$y = 80.702e^{-0.001x}$
	1000-100000	$y = -4.7772\ln(x) + 63$
Heavy metal/ Pesticides conc. ratio	0 - 16	$y = 101.9e^{-0.15x}$

B. Construction of transformation equations

Concentration ranges expected for all the potential general water quality parameters and Parameter Transformation Equations (PTE) are given in **Table-3** for WQI$_E$, **Table-4** for WQI$_I$ and **Table-5** for WQI$_{M\&I}$. Though water quality criteria and standards were used as the bases, some degree of subjectivity was forced into the development of parameter rating curves/transformation equations specially for dividing the range of parameters' values into 5 sections. Differences in the criteria and standards prescribed among different nations and organizations have also made this subjectivity inevitable. Sectionization of the 0-1 CESU into five sections (for relating with the actually measured values) has also been quite arbitrary, but done using the standard normal distribution curve as the basis.

C. Aggregation of parameters

Sub-index for general parameters (SI$_{gp}$) was calculated by weighted root sum function. Parameter CESU values were multiplied with their respective relative weights and summed up. Square root of this sum was taken as the sub-index SI$_{gp}$ (**Table-6**).

Table 6: Sub-index calculation for the general parameters

Water quality parameter (i)	Monitored value of the parameter (P$_{i.Mon.}$)	Parameter value in CESU (P$_{CESU}$)	Relative weight assigned to the parameter (W)	$P_{CESU} \times W$
1.	P$_{1.Mon.}$	P$_{1.CESU}$	W$_1$	$P_{1.CESU} \times W_1$
2.	P$_{2.Mon.}$	P$_{2.CESU}$	W$_2$	$P_{2.CESU} \times W_2$
…	…	…		…
I	P$_{i.Mon.}$	P$_{i.CESU}$	W$_i$	$P_{i.CESU} \times W_i$
…	…	…		…
N	P$_{n.Mon.}$	P$_{n.CESU}$	W$_n$	$P_{n.CESU} \times W_n$
			$\sum W = 1$	$SI_{gp} = \sqrt{\sum P_{CESU} \times W}$

In case of the other two groups of parameters (heavy metals and pesticides and other toxic organic compounds), maximum operator concept [31] was used for identifying the metal parameter and the pesticide/other toxic organic compound parameter to be considered in the sub-indices calculations. Measured values of these parameters were first converted into concentration to standard ratios (ri) (Eq.1). Then the parameter that has the maximum ri value within the group of parameters is considered further (Eq.2 and Eq.3), and transformed into common environmental scale units (r$_{CESU}$) using the rating curve/transformation equation for the metals and pesticides. The obtained r$_{CESU}$ value was considered as the sub-index value for the group of the parameters.

$$r_i = \frac{C_i}{S_i} \qquad \text{---- (Eq.1)}$$

Where

r_i = concentration ratio of ith substance,

C_i = substance with concentration (mg/L) and

S_i = prescribed standard value of the ith substance

$$MaximumOperator(SI_{hm}) = r_{CESU} = \max\{r_1, r_2, ..., r_n\} \quad \text{----- (Eq.2)}$$

$$MaximumOperator(SI_{ptoc}) = r_{CESU} = \max\{r_1, r_2, ..., r_n\} \quad \text{----- (Eq.3)}$$

Geometric mean of all the three sub-indices has been taken as the overall WQI. For obtaining the WQI on 0-100 scale, the geometric mean value was multiplied by 100 (Eq.4).

$$WQI_E = 100 \times (SI_{gp}.SI_{hm}.SI_{ptoc})^{\frac{1}{3}} \qquad \text{----- (Eq.4)}$$

D. Evaluation of the river Satluj water quality by application of use specific WQIs

The Satluj river water quality monitoring data obtained at the 8 monitoring stations along the main river for the period April 2010 to March 2011 have been analyzed for the WQI_E, WQI_I and $WQI_{M\&I}$. During this period only general parameters were monitored monthly. Data on heavy metals and pesticides and other toxic organic compounds parameters were not available. In that case the sub-indices for these groups were not considered in calculating the WQIs.

Seasonal variations in the calculated WQI_E, WQI_I and $WQI_{M\&I}$ are given in **Table 7**, and shown in **Fig-2, 3** and **4** respectively. While observing the WQI_E scores, water quality at all the 8 stations has been found moderate to good with mean WQI_E score ranging from 52.57-89.64, however, mean WQI_E scores at all the eight stations has been observed to be low in summer. This effect might be due to low flow in the river. Mean WQI_E scores were on higher side in the upper and middle stretch (from SAT-1 to SAT-6) of the river in winter and in lower stretch (SAT-7 and SAT-8) in monsoon. Similarly mean WQI_I scores revealed the water quality always ranging from good to excellent (84.26-98.49). In this case also low scores were observed in summer and higher scores were mostly in monsoon. In case of $WQI_{M\&I}$, the mean scores were in the range of moderate to good quality (79.13-96.02). Water quality only at SAT-1 was excellent.

When looked from the view of spatial variability, the water quality was the lowest by most of the time at SAT-7 and SAT-8. This has been along the expected lines and could be due to the Budha Nala and East-Bein discharges into the river upstream to SAT-7 and SAT-8 respectively. Spatial trends of different WQIs along the river over the period are shown in **Fig-5**.

On the basis of the WQIs, the Satluj river stretch can be divided into two sections: the river stretch upstream to SAT-6, and the river stretch downstream to SAT-6. The upstream stretch of the river carried relatively better quality water. The mean values of WQI score were in the range of good water quality with lower standard deviations. The downstream stretch of the river experienced steep decline in water quality upto SAT-7 and water quality slightly recovered beyond SAT-7. This stretch experiences rapidly increasing flow of water. Municipal and industrial wastewater, including the treated effluent from the STPs of Phillaur and Ludhiana, in the form of Phillaur drain and Budha Nala is discharged into the river in this stretch. Water quality in this stretch of the river appears heavily depends on the effectiveness of sewage diversion and treatment by the STPs of both Phillaur and Ludhiana cities. The river water quality is apparently not much influenced by the discharges of the East-Bein, which carried municipal and industrial wastewater of Phagwara and Jalandhar cities into the river upstream to SAT-8. This could be because of the fact that the effluent of the East-Bein, though discharged into the river upstream to SAT-8, might not have properly mixed with the river water. The river water quality showed no significant temporal trends. Instead, the river water quality is randomly varying.

Table 7: Patterns in seasonal variations in WQIs

| Station	Summer		Monsoon		Winter		Annual			
	Mean	SD	Mean	SD	Mean	SD	Min	Max	Mean	SD
WQI$_E$										
SAT-1	84.71	3.20	86.29	2.60	87.38	1.11	81.56	89.64	86.12	2.50
SAT-2	81.68	4.63	85.47	0.43	83.39	3.09	75.00	87.92	83.51	3.33
SAT-3	84.56	4.30	86.41	2.30	87.42	1.46	78.79	89.29	86.13	2.93
SAT-4	81.04	4.71	83.35	1.52	85.78	1.41	74.93	86.52	83.39	3.37
SAT-5	77.91	7.73	79.32	2.00	82.49	1.65	67.80	86.52	79.91	4.71
SAT-6	74.35	5.62	78.01	4.71	78.75	3.48	69.97	83.56	77.04	4.69
SAT-7	63.62	8.05	70.21	5.83	62.98	4.83	52.57	78.65	65.60	6.71
SAT-8	66.38	4.83	69.56	5.15	63.77	4.44	59.14	76.83	66.57	5.01
WQI$_I$										
SAT-1	97.90	0.41	96.52	1.51	98.00	0.49	95.17	98.49	97.47	1.11
SAT-2	96.20	1.43	97.41	0.30	96.94	0.94	94.16	97.83	96.85	1.05
SAT-3	97.26	1.06	97.66	0.48	97.93	0.28	95.81	98.34	97.62	0.69
SAT-4	96.38	1.32	96.87	0.75	97.50	0.05	94.42	97.61	96.91	0.93
SAT-5	95.45	2.05	96.32	0.99	96.40	0.20	92.42	97.02	96.06	1.27
SAT-6	93.15	1.67	95.76	1.20	94.11	2.00	91.10	96.60	94.34	1.87
SAT-7	88.71	3.14	92.66	1.90	89.73	2.82	84.26	95.07	90.37	2.98
SAT-8	89.61	2.89	93.35	0.77	90.48	3.26	85.46	95.28	91.14	2.85
WQI$_{M\&I}$										
SAT-1	93.47	1.92	92.56	3.68	93.21	2.31	87.08	96.02	93.08	2.51
SAT-2	89.37	3.35	90.74	1.98	90.34	3.44	85.82	93.95	90.15	2.78
SAT-3	91.53	2.24	90.53	2.94	93.14	1.16	87.88	94.60	91.73	2.32
SAT-4	90.92	1.95	88.66	2.46	89.97	1.80	86.53	93.48	89.85	2.12
SAT-5	89.97	1.11	89.14	3.11	87.67	0.87	85.20	91.76	88.93	2.05
SAT-6	84.51	0.60	86.44	0.94	85.95	1.09	83.89	87.25	85.63	1.18
SAT-7	81.63	2.12	85.35	0.97	84.01	2.92	79.18	88.16	83.66	2.53
SAT-8	82.78	1.77	85.53	0.48	84.73	4.15	81.13	90.83	84.35	2.66
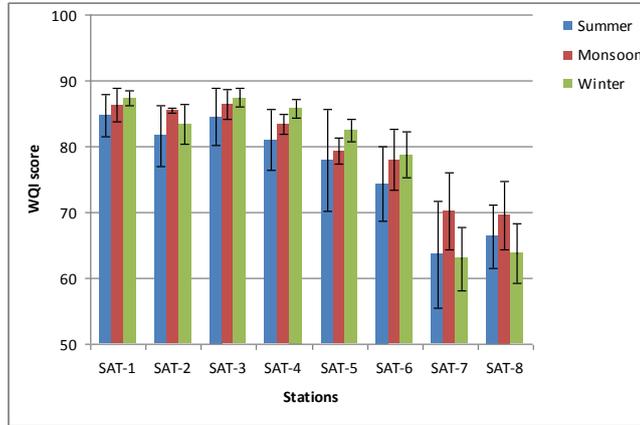
Fig-2: Comparison in WQI$_E$ score with respect to seasons at different stations of river Satluj
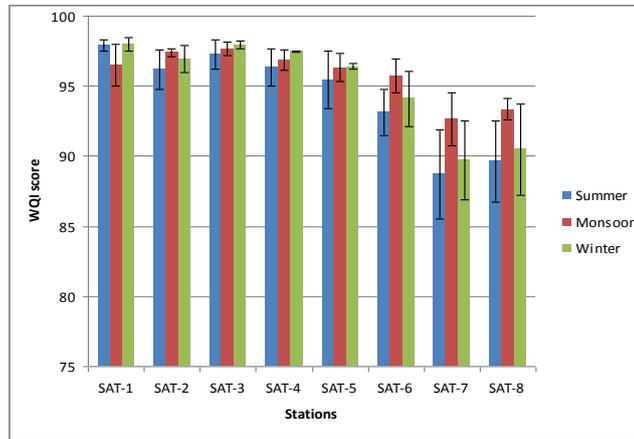

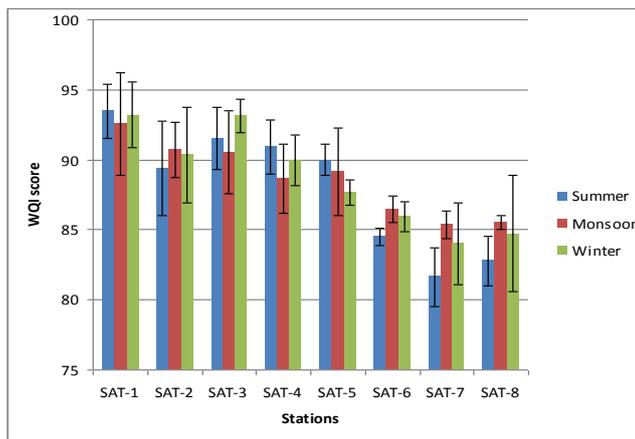**Fig-3: Comparison in WQI$_I$ score with respect to seasons at different stations of river Satluj**

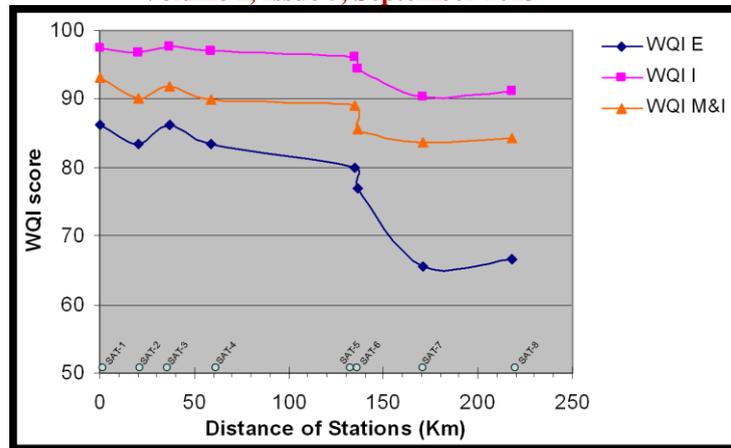**Fig-4: Comparison in WQI$_{M\&I}$ score with respect to seasons at different stations of river Satluj**

Fig-5: Spatial variations in WQI$_E$, WQI$_I$ and WQI$_{M\&I}$ score

IV. CONCLUSION

Water quality indices specific to the ecological (WQIE), irrigational (WQII) and municipal and industrial (WQIM&I) use of water has been developed keeping in mind the water quality management of surface water resources for their best designated uses. All the parameters for which prescribed water quality criteria and standards exist have been selected for inclusion in the WQI. Developed WQIs are open to allow the flexibility of inclusion or exclusion of any parameter. Application of the WQIs to the monitoring data available has indicated the importance of including the heavy metal parameters in the WQI. When heavy metals were not considered the water quality of the river Satluj was found to be good, while the actual water quality was not that high. Lack of data on pesticides did not allow assessment of importance of incorporating pesticides and other toxic organic compounds parameters in the WQI. The WQIs, together with the SIhm and SIptoc, will be of immense help in deciding the strategies and programs for the river water quality management, specially, through source control of pollution.

Water of river Satluj diverted at many places for irrigational and municipal uses and the river is also feeding Ropar wetland and Harike wetland systems (both are Ramsar sites). The developed WQIs were applied on the Satluj river water quality data (from eight monitoring stations) for monthly monitoring data for the period 2010-11 (data only on general parameters was used). During the period, the river water quality was found to be moderate to good quality. On the basis of the spatial trend in WQIs, the Satluj river stretch is divisible into two sections: the river stretch upstream to SAT-6 with relatively better and slowly deteriorating water quality (WQIE >70), and the river stretch downstream to SAT-6 with rapidly declining water quality (WQIE <70). The WQIs scores estimated will also be useful to ascertain suitability of the water for the conservation of status of the river Satluj.

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REFERENCES

[1] Singh, K.P.; Malik, A.; Sinha, S. (2005) Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical technique: a case study. Analytical Chemical Acta, 538 (1-2), 355-374.

[2] Koklu, R.; Sengorur, B.; Topal, B. (2010) Water quality assessment using multivariate statistical methods – A case study: Melen river system (Turkey). Water Resources Management, 24, 959-978.

[3] Debels, P.; Figueroa, R.; Urrutia, R.; Barra, R.; Niell, X. (2005) Evaluation of water quality in the Chillan river (central Chile) using physicochemical parameters and a modified water quality index. Environmental Monitoring and Assessment, 110 (1-3), 301-322.

[4] Bordalo, A.A.; Nilsumranchit, W.; Chalermwat, K. (2001) Water quality and uses of the Bangpakong River (Eastern Thailand). Water Research, 35 (15), 3635-3642.

[5] Palupi, K.; Sumengen, S.; Inswiasri, S.; Agustina, L.; Nunik, S.A.; Sunarya, W.; Quraisyn, A. (1995) River water quality study in the vicinity of Jakarta. Water Science and Technology, 31 (9), 17-25.

[6] Hallock, D. (2002) A Water Quality Index for Ecology's Stream Monitoring Program. A Department of Ecology Report. http://www.ecy.wa.gov/biblio/0203052.html. Accessed 7 February 2012.

[7] Khan, F.; Husain, T.; Lumb, A. (2003) Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada. Environmental Monitoring and Assessment, 88 (1-3), 221-248.

[8] Hanh, P.T.M.; Sthiannopkao, S.; Ba, D.T.; Kim, K.W. (2011) Development of water quality indexes to identify pollutants in Vietnam's surface water. Journal of Environ. Eng. ASCE, 137 (4), 273-283.

[9] Horton, R.K. (1965) An Index Number System for Rating Water Quality. J. Water Pollution Control Fed., 37(3), 300-306.

[10] Sinha, S.K. (1995) Potability of some rural pond's water at Muzzaffarpur (Bihar) – a note on water quality index. Pollution Research, 14, 135-140.

[11] Dhamija, S.K.; Jain, Y. (1995) Studies on water quality index of a lentic water body of Jabalpur, MP. Pollution Research, 14, 341-346.

[12] Sargaonkar, A.; Deshpande, V. (2003) Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. Environmental Monitoring and Assessment, 89 (1), 43-67.

[13] Samantray, P.; Mishra, B.K.; Panda, C.R.; Rout, S.P. (2009) Assessment of water quality index in Mahanadi and Atharabanki rivers and Taldanda Canal in Paradip area, India. J. Hum. Ecol., 26(3), 153-161.

[14] Kumar, A.; Dua, A. (2009) Water quality index for assessment of water quality of river Ravi at Madhopur, India. Global Journal of Environmental Sciences, 8(1), 49-57.

[15] Jindal, R.; Sharma, C. (2011) Studies on water quality of Satluj river around Ludhiana with reference to physic-chemical parameters. Environmental Monitoring and Assessment, 174, 417-425.

[16] Environment (Protection) Rules (1986) General standards for discharge of environmental pollutants Part A: Effluents. Pollution Control Law Series: PCLS/02/2010, Central Pollution Control Board, New Delhi, India.

[17] IS 10500: 1991, Edition 2.2 (2003-09) Indian Standard, Drinking Water – Specification (First Revision), Bureau of Indian Standards, New Delhi, India.

[18] Central Pollution Control Board, Surface Water Quality Criteria. http://www.wbphed.gov.in/Static_pages/guidelinevalues.html. Accessed 11 September 2011.

[19] WHO (World Health Organization) (2008) Guidelines for Drinking Water Quality, Incorporating the First and Second Addenda, Volume 1 (Recommendations), 3rd Edition, Geneva.

[20] Ayers, R.S.; Westcot, D.W. (1994) Water quality for agriculture, FAO irrigation and drainage paper. Food and Agriculture Organization, Rome.

[21] Parameters of Water Quality, Interpretation and Standards (2001) Environmental Protection Agency, Ireland. http://www.epa.ie/downloads/advice/water/quality/name,26970,en.html. Accessed 20 December 2011.

[22] Ministry of Natural Resources and Environment (MONRE) (2008) National technical regulation on surface water quality, QCVN 08: 2008/BTNMT, Hanoi, Vietnam.

[23] Ministry of Science and Technology (MOST) (2005) Industrial waste water discharge standards, TCVN 5945: 2005, 2nd Ed., Hanoi, Vietnam.

[24] South African Water Quality Guidelines, Volume-1: Domestic Use. 2nd Ed., 1996. Department of Water Affairs and Forestry, Pretoria, South Africa.

[25] South African Water Quality Guidelines, Volume-2: Recreational Use. 2nd Ed., 1996. Department of Water Affairs and Forestry, Pretoria, South Africa.

[26] South African Water Quality Guidelines, Volume-4: Agricultural Use: Irrigation. 2nd Ed., 1996. Department of Water Affairs and Forestry, Pretoria, South Africa.

[27] South African Water Quality Guidelines, Volume-7: Aquatic Ecosystems. 2nd Ed., 1996. Department of Water Affairs and Forestry, Pretoria, South Africa.

[28] CCME (1999) Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment, Environment Canada, Hull, Quebec.

[29] USEPA (1999) National Recommended Water Quality Criteria – Correction. Office of Water 4304, United States Environmental Protection Agency.

[30] Reddy, A.S. (2003) Environmental management systems for pulp and paper mills. Ph.D. Thesis, Punjabi University, Patiala (Punjab), India.

[31] Liou, S.M.; Lo, S.L.; Wang, S.H. (2004) A generalized water quality index for Taiwan. Environmental Monitoring and Assessment, 96 (1-3), 35-52.