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Seasonal Monitoring using Harmonic Analysis of Water Quality in Lower Yamuna Basin

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Abstract:

Regular monitoring of water quality helps in identification of nature and extent of pollution and its control. It also helps in prioritisation of pollution control activities, formulation of standards, assessment of adequacy and effectiveness of various pollution control programs. The existing network of water quality monitoring at selected stations in the lower Yamuna basin with periodic variations analysed using harmonic analysis is presented in this paper. Measurement of water quality at selected sites in a basin has to be done in an equally rational manner that puts more emphasis on anthropogenic inputs nowadays. The status of water quality is assessed both inside as well as outside the basin at outlet points of tributaries on main Yamuna river especially from the point of confluence of Chambal till its confluence with Ganga. In order to obtain overall status of water quality, composite index of water quality has been derived using MS-EXCEL based on data from Central Pollution Control Board. It was found that pH and temperature; biological oxygen demand (BOD) and chemical oxygen demand (COD); and faecal and total coliforms (TC and FC) - are important component of water quality monitoring in the region.

Keywords: Composite water quality index, periodicity, site of monitoring, upstream-downstream pollutant flow, water quality trend.

1. Introduction:

In recent years, as a result of increased awareness towards the impact of human activities on environment, water quality investigations have also been conducted at some sites to assess mainly those factors, which can be potentially controlled, including the costs associated with implementing controls and achieving specific goals or standards. In this context, some guidelines have been formulated on strategies for planning, operating and evaluating water quality network in terms of where, what and when to sample or measure. A review of existing studies shows that if a general framework for design of an effective water quality network, taking into consideration not only data collection but also its analysis, monitoring and economic aspect, can significantly reduce logistics and operating constraints (Steele, 1985).

Besides the traditional statistical analysis of hydrological data using mainly correlation and regression, and probability concepts particularly in surface stream flow data network and to some extent in water quality network result, another technique employing harmonic method has proved to be helpful in analysing seasonal behaviour of natural phenomena like rainfall, runoff, temperature, *etc.* Ever since the successful reproduction of observed precipitation curve in Wisconsin, U.S.A. (Horn, and Bryson, 1960) through adding all six harmonic terms, the method was found to be useful in determining regional concentration / variation of seasonal components. Convergence of amplitude and phase angles of various harmonic terms at different places can significantly reduce the need for frequency of data collection at some of the sites. Resultant coefficients obtained from harmonic analysis have been used to analyse upstream-downstream shifts in stream temperature for the Yampa river basin in Colorado and Wyoming (Steele, Baner, Wentz, and Warner, 1979). He also attempted regionalization of the harmonic mean temperature in Pakistan. Even for water quality measurements, harmonic analysis helps in regionalization. It is because of certain spatial characteristics of pollutants, *e.g.* isopleths drawn for dissolved oxygen per unit concentration in a stream reach of the Mississippi river showed a lower regional concentration in the months of July and August (Larson, 1976 cited in Rodda). In India, too, use of harmonic series was successfully demonstrated in reproducing monthly precipitation series and in determination of optimum time of annual maxima on harmonic dial (Ahlawat and Thakur, 1999).

The 1990s has seen the launch of a new initiative by the WHO to provide timely, and if possible real-time, quality-controlled data at about 1000 stations worldwide to strengthen the global programme of water resource assessment. The World Hydrological Cycle Observing System (WHYCOS) uses satellite communications to link strategically selected new and existing stations reporting water levels, discharges, water quality and meteorological variables (Jones, 1997).

Use of GIS coupled with DEM (Digital Elevation Model) – DEDNM software developed in the case of one of the tributary of St. Lawrence river in Canada, proved to be useful in assessing the vulnerability of stream reaches to pollution. It can simulate overland flow to compute the distance of travelled by contaminants from their point of application to receiving surface waters (Cluis, Martz and Quentin, 1996).

In the light of enormous studies on water quality, a comprehensive analysis of water quality monitoring has been presented in the present paper for lower Yamuna basin.

2. Material and Methods:

2.1 Study Area:

The lower Yamuna basin, being a transitional area of climate and geology with most of its coverage in central India, is selected for the present study. Geographically, lower Yamuna basin includes the area from confluence point with Chambal including all right and left bank tributaries, downstream of Agra-Etawah ridge till its confluence with Ganga at Allahabad. Delineation of the region's boundary is done in accordance with the relief and drainage features shown on toposheets. It is in the regions like this, an assessment of hydrological and water quality data network of Central Water Commission (CWC) and Central Pollution Control Board (CPCB) becomes important because the crucial question here is what to measure, where to measure and when to measure in the case of low amount of runoff and rainfall with deteriorating water quality status in its numerous seasonal tributaries (Fig. 1). Moreover, its major portion is dominated by ravinous tract falling mainly in the southern tributaries of the Yamuna river, *viz*. Chambal, Sind, Betwa and Ken.

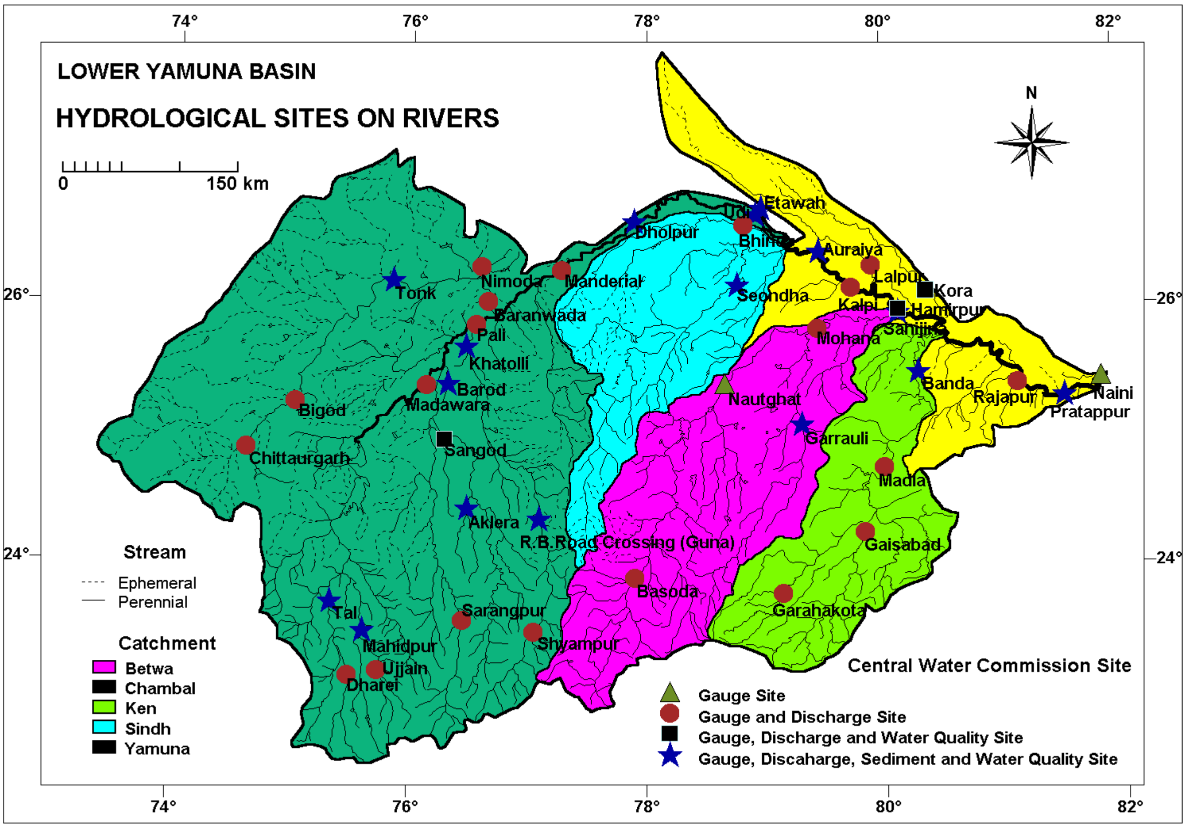


Figure 1: Catchment-wise network of hydrological-cum-water quality monitoring sites
(Source: Author using ILWIS based on drainage data from SOI Toposheets, Site data from CWC)

2.2 Data and Methodology:

The analysis is based on data collected from secondary sources. Long-term annual data for water quality monitoring stations was obtained from Central Pollution Control Board Report (2000) on Water Quality Statistics of River Yamuna. Year-wise monthly data of various water quality parameters was used for major CPCB stations on river Yamuna and its main tributaries. Further, primary data regarding the nature and functioning of data stations, maintenance, communication and publication of data, and the economic or other managerial problems, was also gathered from regional Centre of CPCB at Bhopal. Water samples were also obtained at some of the selected sites.

Assessment of water quality data network is made with the help of simple central tendency measures by analysing comparative values at limited stations. Coefficient of variation for both annual and seasonal values is used to compare situation at different sites. For periodicity of pollutants, harmonic series was used that can be expressed mathematically as the algebraic sum of a Fourier series of sine curves (Conard and Pollak, 1950):

$$Y = a_o + a_1 \sin x \cos\phi_1 + a_2 \sin 2x \cos\phi_2 + \dots\ a_6 \sin 6x \cos\phi_6 + a_1 \cos x \sin\phi_1 + a_2 \cos 2x \sin\phi_2 + \dots\ a_6 \cos 6x \sin\phi_6$$

… Eq. (1)

or, $$Y = a_0 + \sum_{n=1}^{6} p_n \cos nx + q_n \sin nx$$

.. Eq. (2)

Thus, equation (2) is a general term for Fourier series where, p_n and q_n are known as Fourier coefficients. From these, phase angle (p_k) and amplitude (a_k) were determined in MS-EXCEL using the relation of their substituted values as:

$$p_k/q_k = \tan\phi_k$$
$$\Rightarrow \phi_k = \tan^{-1}(p_k/q_k)$$

…Eq. (3)

and, $a_k = p_k/\sin\phi_k$, also $a_k = p_k/\cos\phi_k$

$$\therefore \quad a_k = \sqrt{p_k^2 + q_k^2}$$ … Eq. (4)

Further, the percentage contribution of the K^{th} harmonic to the total variance representing monthly fluctuations is calculated in order to determine the number of significant terms as:

$$V_k = (a_k^2/2S_m^2) \times 100\%$$ . .. Eq. (5)

$$S_m^2(\text{var}) = \frac{\sum (m_\tau - \overline{m}_x)^2}{N}$$

where,

m_τ = mean monthly values,

$\overline{m}_x$ = mean annual values

In order to determine relative importance of various parameters involved in water quality monitoring, a correlation matrix was obtained based on observed values. Further, Composite index of water quality for knowing the trend at particular time and at particular station has been calculated by Harkin's Method discussed in Central Board for the Prevention and Control Water Pollution Manual (1987):

$$z_{ij} = \frac{R_{ij} - R_{ic}}{Si}$$ … Eq. (6)

where,

R_{ij} is the rank of the j^{th} observation of i^{th} water quality parameter

R_{ic} is the rank of the 'control' value (*i.e.* standard for the i^{th} water quality parameter,

Si is the standard deviation of the ranks for the i^{th} variable.

3. Results and Discussions:

3.1 Water Quality Status of Lower Yamuna

A comparative picture of river water quality monitored by CPCB in its different stretches reveals that lower Yamuna stretch is the diluted section with respect to most of parameters as per Ministry of Environment and Forest Report (2004). Within this main lower Yamuna diluted stretch, spatial variation exists among its different tributary stretches. Bio-mapping of Yamuna river basin by CPCB in 1999 have categorized the usage of water in different class according to scheme adopted by CPCB earlier during its first phase of implementation. These uses were identified for major riverine systems of the country and in lower Yamuna 6 stretches were found to be heavily polluted (CPCB 2001).

An analysis of maximum, minimum and mean concentration of these parameters in 2001 provided a brief objective status of water quality at 5 impact stations in lower Yamuna stretch, *viz.* Etawah and Juhika (before and after the confluence of Yamuna with Chambal respectively); Udi on Chambal and Hamirpur on Betwa (just before their confluence with Yamuna). Parameterwise results described in detail in CPCB report are summarized as follows:

Organic Parameters: Dissolved Oxygen (DO) level at all stations was found to be very low ranging from 5 to 13 mg/l. Biological Oxygen Demand (BOD) level was above the desirable limit of 5 mg/l many a times with the maximum level at Etawah. After dilution with Chambal waters, the level at Allahabad becomes normal. Chemical Oxygen Demand (COD) shows almost similar spatial trend like that of BOD but its level was high at Juhika also.

Bacteriological Parameters: Faecal Coliform (FC) colonies are present in large number throughout lower Yamuna tract. The average value was more than 5000 to about 40,0000 in 2001 against the maximum acceptable limit of 2000 colonies/100ml of water. There exists 100% violation of the total Coliforms (TC) norms on lower Yamuna stations.

Mineralogical Parameters: Electrical Conductivity (EC) of lower Yamuna water is, however, well within the limits. Average alkalinity level is about 150 mg/l in the region and variation is little at Hamirpur and Allahabad. It shows good maintenance of pH level in lower Yamuna tract. Records were missing at other stations. Calcium level is higher than that of magnesium at the observed stations on Betwa in Lower Yamuna basin. But, all stations do not have continuous record of their levels.

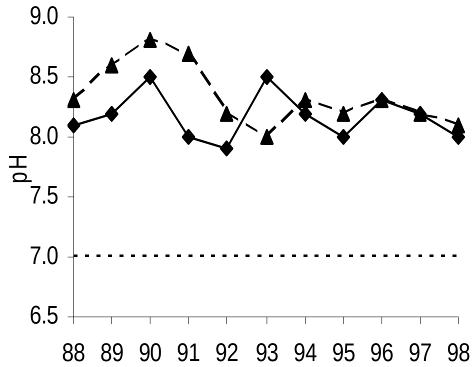
Following two sites were surveyed in detail in terms of their physical parameters and CPCB results were confirmed by mere sight of blackish water at these sites due to commercial and industrial wastewater here in addition to domestic waste:

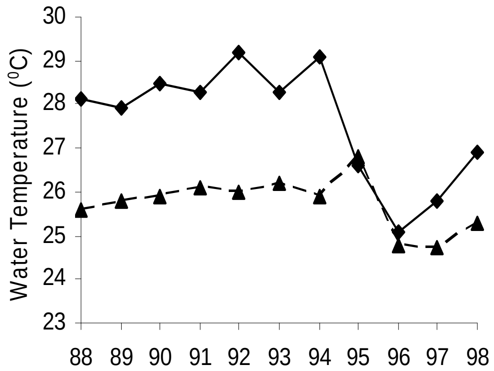
1. Khan river near Indore before confluence with Kshipra;
2. Betwa at Mandideep town near Bhopal;

Other places in the basin showed green colour in most of the stretches of the rivers. The Ken river, among the cleaner stretches identified by CPCB also, really possesses good aesthetic sense. A light to medium grey colour, especially around *Kshipra* river at Ujjain is a characteristic of water that has undergone some decomposition. However, at Ujjain, near *Kshipra* river, the special care is taken by authorities to control odour for devotees' bath during *'Kumbh'* festival. The dark grey colour of drains/tributaries joining *Khan* river in areas around industrial units of Indore is indicative of septic condition having undergone extensive decomposition under anaerobic conditions. The blackening of water observed at places lying in outskirts of Indore and Mandideep in Betwa catchment suggests the formation of various sulfides. Average pH value in lower Yamuna stretch is within the normal range most of the time with slightly alkaline tendency. It gradually shows a spatial decline after confluence with southern tributaries. Temperature varies from season to season and also with geographic location. In higher plateau regions, average temperature measured from Bhopal upper lake was 25.3^{0}C and in plains it was 23.3 ^{0}C at Hamirpur.

3.2 Water Quality Trend

Average annual trend and temporal variability in water quality analysed at two impact stations in lower Yamuna for a decade (1988-1998) further ascertained the dilution impact of water as a result of confluence of Yamuna with Chambal (Fig. 2 and Table 1).





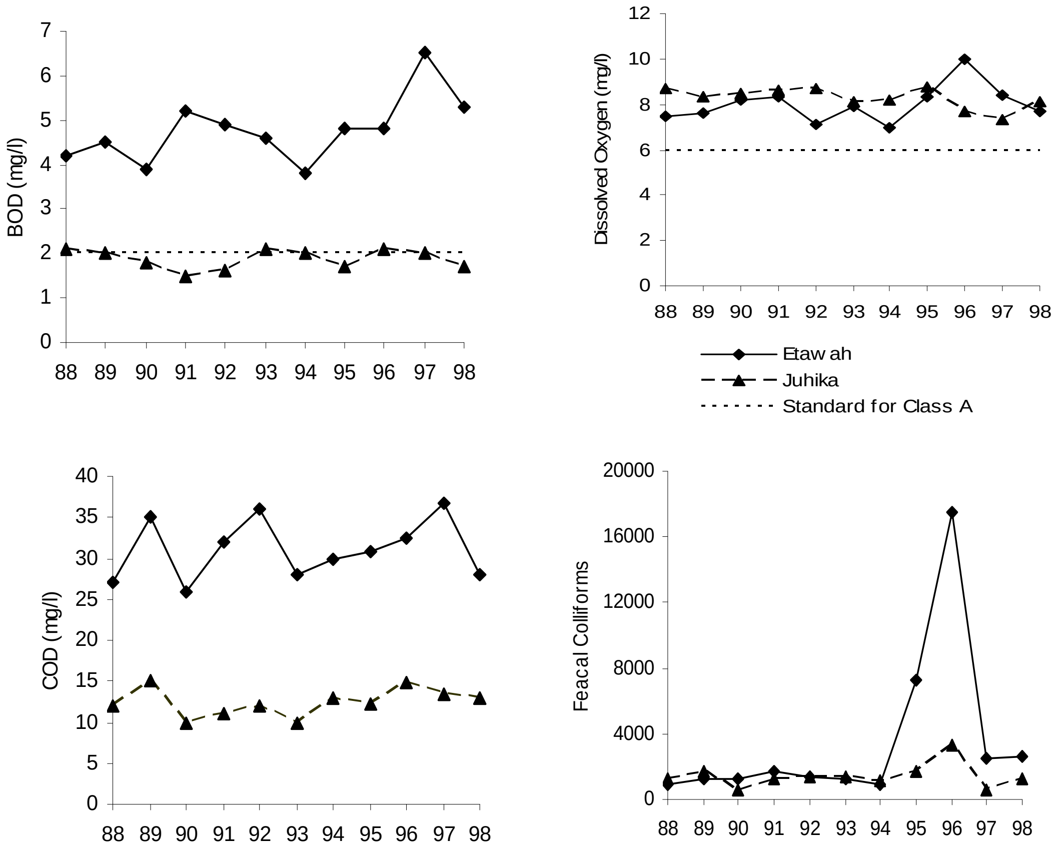


Figure 2: Mean annual value (1988-1998) of pollutants at Etawah and Juhika
(Source: Plotted in MS-EXCEL based on data from Government of India, CPCB (2000) Water Quality Status of Yamuna River, Series: ADSORBS/32/1999-2000)

Table 1: Decadal mean value (1988-1998) of pollutants and their coefficient of variation at Etawah and Juhika

Parameter	Etawah		Juhika	
	Average	C_V (%)	Average	C_V (%)
pH	8.17	2.34	8.34	2.91
DO	8.00	9.76	8.27	5.33
BOD	4.77	14.95	1.87	11.18
FC	3,512.91	135.01	1,407.82	49.18
TC*	56,592.75	112.46	5,879.50	34.46
TKN	0.93	85.47	0.48	37.63
COD	31.07	11.31	12.40	12.85
WT	27.62	4.62	25.74	2.27
AMM	0.28	122.72	0.15	35.00

* 4 year data (1994-98) Computed from data source: Government of India, CPCB (2000) Water Quality Status of Yamuna River, Series: ADSORBS/32/1999-2000.

It is clear from Fig. 2 that almost all parameters throughout the 10-year period have maintained higher levels at Etawah. There has been declining trend in pH value and average temperature at both the stations. For rest of the water quality parameters, a dynamic equilibrium is obtained with respect to average pollutant concentration with occasional rise in 1996.

Mean values for all the parameters were higher at Etawah except for pH and DO. However, temporal variability analysed in terms of coefficient of variation was highest for bacteriological parameters at both the stations. Therefore, a regular monitoring for longer period of time is required for these parameters. Although variability in other organic parameters, like total Kjahadel nitrogen (TKN) and free ammonia (AMN), is high but their concentration is low (Table 1). Hence, a quarterly monitoring would be sufficient at these stations.

3.2.1 Water Quality Trend in Betwa River Catchment

River Betwa, the *Vetrawati* of *Puranas*, reflected crystal clear blue waters in Vindhyachal. It has been referred in the *Puranas* that the water of Betwa river heals *Kushtha Rog* (Leprosy). It is believed that *Bhagwan Ram* took holy bath in *Vetrawati* on his way to the Dandkaranya jungle. Even today on many religious occasions the people of the town, city and villages adjoining to river Betwa come to take holy bath in the river Betwa. With time, water quality of Betwa river, too, has deteriorated especially in upper Betwa industrial region. Changing status of water quality with respect to both maximum and minimum levels in a year was analysed in detail for a 3-year period (1998-2001) at three stations in Betwa catchment - lower and upper lake stations at Bhopal in upper reaches and Hamirpur in lowermost reaches (Table 2).

Table 2: Maximum and minimum value (1999-2001) of pollutants at lower and upper lake, Bhopal (Upper Betwa Sub-Catchment) and at Hamirpur (Lower Betwa)

Parameter	Upper Lake		Lower Lake		Hamirpur	
	Max	Min	Max	Min	Max	Min
Dissolved Oxygen mg/ml)	8.83	6.53	11.4	7.47	9.63	6.23
BOD (mg/l)	5.47	2.63	10.93	3.47	4.40	1.77
COD (mg/l)	54.7	27.1	98.97	38.1	17.80	6.40
Nitrites-Nitrates	0.63	0.12	0.973	0.2	--	--
TKN	2.42	1.66	3.229	2.21	22.35	7.15
Temp (^{0}C)	34	20.3	30.17	20	30.67	16.17
pH	8.77	7.27	9.2	7.23	8.60	7.40
Turbidity (JTU/NTU)	59.3	18	70	28	27.33	8.67
Total Dissolved Solids (mg/l)	270	154	412	201	189.33	94.20
Faecal Coliforms (mpn/100ml)	--	--	60	60	700.00	700.00
Total Coliforms (mpn/100ml)	2,400	2,133	2,400	2,400	326,433.33	2,266.67
Conductivity (u mho/cm)	358	247	487	353	491.00	160.33
Total alkalinity (mg/l)	96.3	33	112.3	48	147.33	63.67
Sulphates (mg/l)	19	8.18	23.71	8.34	74.13	6.43
Calcium (as $CaCO_3$ mg/l)	114	48.7	166	72.7	98.00	44.00
Magnesium (as $CaCO_3$ mg/l)	58.7	23.3	76.67	34	47.33	8.00
Hardness (as $CaCO_3$ mg/l)	165	90	212	115	116.33	71.33
Chlorides (mg/l)	40	15.7	49	22.3	22.67	9.33
Sodium (mg/l)	--	--	--	--	22.00	7.33

Source: Compiled from Government of India, CPCB. Annual Water Quality Status of India, 1998-2001

In case of lower lake (outlet point), a declining trend was observed both in maximum and minimum values in regard of most of the parameters except chlorides and hardness, whereas at intake point in upper lake there has been an overall increasing trend. It means as a result of stringent water quality control measures and their regular monitoring in all months, water quality within lake is showing positive trend in recent years. It was also observed during two successive field visits to lake in 1999 and 2004. Local boat people consulted in this regard also informed about ban on engine-powered boats for tourists. As a result of these bans, pH and turbidity level measured in these two years also showed improvements. At Hamirpur, even 5-year data (1997-2001) showed no definite trend with respect to most of water quality parameters. The water of Betwa river in lower reaches is less hard as compared to lake water in plateau region. But for other parameters it has significantly higher levels especially in case of coliforms and high pH, where violation was of the order of 33%, respectively during the period covered. Due to these spatio-temporal variations in water quality, there is a need for more central monitoring stations on Betwa river and its tributaries as it serves as a lifeline of people in its catchment. Highly polluted upper Betwa stretch near Mandideep can affect water quality in lower reaches as well. An analysis of month-wise changes in water quality can provide insight into the need for inclusion of parameters at seasonal monitoring stations.

3.3 Seasonal Variation in Water Quality of Lower Yamuna Stretch

A comparative picture of nine parameters for 48 months (April 1995-March 1999) at three stations – Juhika, Udi and Etawah was useful to draw inferences about seasonal monitoring requirements (Table 3). A comparison of the data representing the winter, pre-monsoon, monsoon, and post-monsoon period with the annual ones based on monthly data reveals significant variations (Table 5). Seasonal variation in the case of pH, DO, BOD and COD reveals that the lowest concentrations are found during monsoon months followed by post-monsoon and winter months. On the contrary, total coliforms count and water temperatures are higher during monsoon months as compared to other seasons. It means bacteriological pollution increases during rainy season due to more favourable conditions of growth and rest of the pollutants get dilution effect of rain. The spatial variation in seasonal pattern regarding all parameters except temperature and dissolved oxygen is more akin to observed values at both the stations on main lower Yamuna - Juhika and Etawah. At Udi on Chambal river just before its confluence, a high concentration of pollutants occurs especially during pre-monsoon months. Rainfall in winter season is highly variable. The coefficient of variation of mean annual values depicts maximum variation in case of total coliforms followed by COD. Coefficient of variation (C_V) for pH is lowest, which means for relatively stable values of pH monitoring in all months can be avoided at places. Quarterly monitoring is important for all parameters and monthly monitoring is essential for bacteriological parameters in the basin.

Table 3: Variability of mean (1995-99) water quality parameters during different seasons

Station	Parameter mean	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual Mean	Annual C_V (%)
Juhika	pH	8.13	8.28	8.19	8.07	8.18	1.87
	WT	17.26	28.69	29.33	24.21	25.24	20.55
	DO	8.43	8.09	6.63	8.69	7.91	13.05
	BOD	2.08	2.26	1.28	1.44	1.83	39.18
	COD	15.17	15.48	11.83	11.88	13.89	29.96
	TC	4,175	6,247	12,138	6,644	7,268	89.42
Udi	pH	8.10	8.44	7.99	7.89	8.15	3.05
	WT	18.28	29.89	30.44	25.36	26.37	19.59
	DO	10.37	8.79	7.07	9.05	8.80	17.27
	BOD	7.42	6.16	1.68	3.38	4.89	50.73
	COD	36.58	39.69	17.33	16.63	29.48	40.57
	TC	29,058	13,731	17,237	9,300	17,701	121.78
Etawah	pH	8.17	8.29	8.17	8.16	8.21	1.92
	WT	17.90	29.51	30.71	25.84	26.29	19.92
	DO	9.46	9.22	7.79	8.61	8.82	10.27
	BOD	1.19	1.66	1.43	1.25	1.42	23.98
	COD	10.50	11.94	11.25	8.38	10.81	29.03
	TC	1,163	1,536	11,026	1,469	3,804	159.31

Computed from data source: Government of India, CPCB (2000) Water Quality Status of Yamuna River, Series: ADSORBS/32/1999-2000.

3.4 Periodicity of Selected Water Quality Parameters

The mean monthly values of 4 years (95-99) at all the three water quality monitoring stations were considered to describe seasonal characteristics objectively using equations (1) to (5) of harmonic analysis . Firstly, an average curve was drawn for each of the seven parameters. From the mean Fourier coefficients computed in MS-EXCEL, a cyclic trend was clearly visible in each parameter value from which amplitude and phase angles were obtained (Table 4).

Table 4: Amplitude, Phase Angle and Explained Variance of Different Harmonics of Mean Values (1995-98)

Har-monic	Etawah			Udi			Juhika		
	a_k (mm)		Variation ϕ_k (%)	a_k (mm)		Variation ϕ_k (%)	a_k (mm)		Variation ϕ_k (%)
(a) Water Temperature									
1	6.7937		84.10	6.7377		85.08	6.8081		86.14
2	2.7345		13.63	2.5501		12.19	2.3039		9.86
3	0.7205		0.95	0.4411		0.36	0.4958		0.46
4	0.2565		0.12	0.6220		0.73	1.0743		2.14
5	0.6961		0.88	0.6473		0.79	0.8547		1.36
6	0.2979		0.16	0.4785		0.43	0.0979		0.02
			99.84			**99.57**			**99.98**
(b) pH									
1	0.1319		35.12	0.3131		79.28	0.1458		45.19
2	0.0730		10.74	0.0886		6.36	0.0420		3.74
3	0.0360		2.62	0.0990		7.92	0.0633		8.50
4	0.0668		9.01	0.0504		2.06	0.0589		7.37
5	0.1180		28.08	0.0679		3.73	0.1115		26.42
6	0.0598		7.21	0.0202		0.33	0.0454		4.38
			92.79			**99.67**			**95.62**
(c) DO									
1	0.9554		55.66	1.8379		73.16	0.7962		29.75
2	0.2499		3.81	0.3367		2.46	0.6264		18.42
3	0.2484		3.76	0.3891		3.28	0.3447		5.58
4	0.7639		35.58	0.7025		10.69	0.8945		37.55
5	0.0951		0.55	0.6187		8.29	0.3402		5.43
6	0.0729		0.32	0.2213		1.06	0.1867		1.64
			99.68			**98.94**			**98.36**
(d) BOD									
1	0.3229		45.17	3.1862		82.49	0.7552		55.28
2	0.1864		15.05	0.7043		4.03	0.4005		15.55
3	0.1312		7.46	1.0814		9.50	0.1618		2.54
4	0.1368		8.10	0.2856		0.66	0.3153		9.63
5	0.1851		14.85	0.6371		3.30	0.2854		7.89
6	0.1040		4.68	0.0313		0.01	0.2167		4.55
			95.32			**99.99**			**95.45**
(e) COD									
1	2.8398		40.91	15.3571		82.46	2.3006		15.29
2	1.1910		7.20	2.1003		1.54	1.0471		3.17
3	0.7132		2.58	2.9407		3.02	2.1630		13.51
4	1.5662		12.45	2.8562		2.85	2.3670		16.18
5	0.6249		1.98	4.2728		6.38	1.1308		3.69
6	1.8542		17.44	2.3125		1.87	2.8875		24.08
			82.56			**98.13**			**75.92**
(f) TC									
1	4685.20		29.88	11146.54		13.37	4081.18		19.72
2	4325.34		25.47	14955.61		24.07	3605.39		15.39
3	4038.95		22.20	16575.15		29.56	5394.30		34.45
4	2767.19		10.42	7519.16		6.08	2987.81		10.57
5	2736.19		10.19	15111.51		24.57	4069.74		19.61
6	821.88		0.92	3298.96		1.17	330.21		0.13
			99.08			**98.83**			**99.87**

Source: Computed using Fourier Series Analysis in MS-EXCEL from various data tables of Government of India, CPCB (2000) Water Quality Status of Yamuna Rive, Series: ADSORBS/32/1999-2000.

Convergence of the resulting series can be seen by comparing ratios of amplitudes of successive harmonic terms to the amplitude of first terms. It is quite interesting to note here that these results are unlike rainfall (Ahlawat, 1999) where both - amplitude ratio and contribution of cumulative percentage to successive higher harmonic terms show little effect after the third term. The fact that observed water quality curve has more than two or three maxims emphasise upon seasonal character. It is clear from the tables that spatial range of variation explained by different harmonics is different for each harmonic term and parameter. The sine curve of the first harmonic, having one maximum and one minimum, describes the tendency towards an annual variation in the observed curve for almost all water quality parameters especially at Udi station on Chambal. But, it explains little proportion of seasonal variation except water temperature where it contributes about 85%. Amplitude of successive harmonic terms also show little variation at the stations located in close vicinity of same temperature zone.

The second harmonic, which consists of sine curve with two maxims and two minims, describes the semi-annual tendency of the observed curve in case of temperature and BOD. But, in the present case, the amplitude of second observed maxim being much smaller than the first one, the second harmonic term explains only 15% of the total variation on an average at two stations. Similarly, the third harmonic, which consists of sine curve with three maxims and three minims, shows threefold variation in case of total coliforms. Fourth harmonic is important for COD and DO which means a tri-monthly monitoring is more suited for these as compared to quarterly pattern. Even fifth harmonic is important for BOD and pH after first and second. A bi-monthly monitoring can be adopted for these important parameters if resources don't permit monthly monitoring. Concentration of total coliforms is quite variable, reflecting higher and differential character of bacteriological pollution in the basin and it definitely needs monitoring on monthly basis.

As the curve cannot be completely described by the one or two harmonics alone, therefore, complete description of observed curve for each parameter requires the solution of complex Equation (2) obtained from the above analysis by substituting values of Fourier coefficients. From this harmonic analysis, residual seasonal trend can be obtained. When annual mean is added to the total sum of all six harmonics, the observed water quality values are reproduced to a high degree of accuracy except COD. The stochastic character still remains as stationary harmonic series explains only 75-80% of the total variation even after adding all terms. The greatest deviation noted between the observed curve and the reconstructed monthly means was found to be 0.4. Thus, periodicity of phenomena is helpful in determining the time of maximum for the significant harmonic terms and the frequency of monitoring at data stations. Number of parameters is another crucial aspect here to determine the computations involved in large data set.

3.5 Composite Water Quality Index

3.5.1 Important Components of Water Quality Monitoring

As many water parameters are involved to judge the best use of water, therefore, cost and time constraints make it difficult to monitor all of these in different smaller stretches. The relationship of parameters within and with the other downstream stations can be modelled to a certain extent. A correlation matrix of the most important parameters presents a good relative picture of pH, related inversely with organic and bacteriological parameters. BOD and COD, as expected, have a very positive correlation (Table 5). Therefore, only four different parameters are considered to determine overall status of water quality.

Table 5: Correlation among important water quality parameters at three stations

	pH	**WT**	**DO**	**BOD**	**COD**	**TC**
pH	1.0000					
WT	-0.1536	1.0000				
DO	-0.0699	0.9964	1.0000			
BOD	-0.9489	0.4576	0.3812	1.0000		
COD	-0.9619	0.4179	0.3399	0.9990	1.0000	
TC	-0.9821	0.3369	0.2565	0.9913	0.9962	1.0000

Computed from data source: Government of India, CPCB (2000) Water Quality Status of Yamuna River, Series: ADSORBS/32/1999-2000.

3.5.2 Water Quality Index

In order to obtain combined picture of the status of water quality, a composite water quality index based on Harkin's rank deviation method (Eq.6) was calculated for the same stations using 48 months data related to four most important parameters. Their respective ranks considered in descending order of magnitude of values during the period April 1995-March 1999 clearly bring out that the standard values for class A have not reached even once in case of pH and total coliforms. The relative rank of standard DO and BOD is also high leaving few values above them (Table 6).

Table 6: Composite water quality index at Juhika and Udi (April 1995-Mar1999)

			Juhika						Udi		
Year	**Months**	**RpH**	**RDO**	**RBOD**	**RTC**	**WQI**	**RpH**	**RDO**	**RBOD**	**RTC**	**WQI**
		49.0	46.0	17.5	49.0	0	49.0	45.0	32.5	49.0	0
1995	Apr	25.5	6.0	17.5	29.0	12.51	27.0	36.5	5.5	5.0	15.88
	May	2.5	5.0	17.5	8.0	27.09	23.0	24.5	8.0	11.0	15.47
	Jun	33.0	21.0	17.5	9.0	12.17	11.0	49.0	3.5	6.0	20.44
	Jul	10.5	32.0	37.5	1.0	21.75	40.0	29.5	43.0	2.0	12.96
	Aug	14.0	19.5	17.5	6.0	18.52	33.0	31.0	32.5	21.0	6.06
	Sep	24.0	47.5	17.5	41.5	3.35	22.0	43.5	32.5	33.0	4.84
	Oct	45.0	2.0	17.5	33.5	10.74	38.0	21.0	20.0	36.0	5.03
	Nov	15.5	27.5	49.0	39.0	13.17	44.0	33.0	26.0	13.5	7.22
	Dec	30.0	35.5	37.5	22.5	7.97	27.0	36.5	20.0	9.5	11.16
1996	Jan	17.0	7.0	37.5	45.5	14.75	9.0	19.0	20.0	34.5	12.97
	Feb	6.0	19.5	37.5	3.5	24.88	12.0	7.0	32.5	1.0	25.08
	Mar	10.5	42.0	17.5	14.0	13.36	1.5	4.0	12.5	4.0	31.23
	Apr	1.0	8.0	1.0	12.0	26.60	10.0	17.5	12.5	17.5	18.03
	May	15.5	27.5	7.5	48.0	7.74	3.0	11.0	8.0	43.5	19.20
	Jun	27.0	37.5	26.0	33.5	4.31	7.0	23.0	16.0	28.0	14.55
	Jul	13.0	33.5	17.5	18.0	11.84	35.0	21.0	26.0	38.0	4.59
	Aug	38.5	49.0	37.5	10.0	10.26	32.0	34.0	26.0	24.0	5.29
	Sep	18.0	37.5	25.0	30.0	7.15	20.5	46.0	36.0	34.5	5.08
	Oct	40.0	17.0	37.5	17.0	11.76	36.0	43.5	43.0	9.5	9.04
	Nov	5.0	22.5	17.5	19.0	16.62	42.0	3.0	10.0	43.5	11.58
	Dec	7.5	13.5	17.5	41.5	13.90	24.0	1.0	8.0	40.5	15.92
1997	Jan	42.0	18.0	17.5	45.5	4.14	25.0	2.0	2.0	25.5	19.26
	Feb	9.0	31.0	2.0	41.5	10.56	1.5	24.5	1.0	23.0	21.42
	Mar	2.5	9.5	37.5	36.0	20.18	5.0	32.0	20.0	20.0	15.22
	Apr	4.0	43.0	7.5	28.0	12.70	4.0	8.0	20.0	13.5	23.60
	May	22.0	39.5	7.5	16.0	9.68	16.0	35.0	12.5	25.5	10.54
	Jun	19.5	41.0	37.5	31.0	8.20	8.0	26.5	26.0	29.0	12.09
	Jul	7.5	24.0	37.5	11.0	20.12	37.0	42.0	26.0	15.0	6.63
	Aug	43.0	35.5	37.5	45.5	2.99	43.0	39.0	43.0	16.0	6.25
	Sep	37.0	25.5	37.5	25.5	7.69	39.0	26.5	43.0	27.0	5.09
	Oct	44.0	30.0	7.5	27.0	4.31	45.0	16.0	15.0	8.0	13.98
	Nov	35.5	45.0	37.5	25.5	5.82	27.0	47.0	26.0	19.0	7.02
	Dec	30.0	22.5	37.5	41.5	6.97	30.0	38.0	17.0	46.5	3.25
1998	Jan	30.0	15.0	7.5	45.5	7.09	34.0	13.0	5.5	43.5	9.93
	Feb	12.0	25.5	37.5	13.0	17.35	30.0	29.5	12.5	3.0	15.33

	Mar	30.0	33.5	3.5	5.0	13.12	30.0	48.0	3.5	7.0	14.69
	Apr	25.5	9.5	37.5	37.5	12.10	20.5	10.0	43.0	43.5	10.69
	May	30.0	39.5	37.5	33.5	5.37	13.0	14.0	43.0	46.5	11.65
	Jun	41.0	13.5	37.5	22.5	11.15	41.0	28.0	32.5	31.5	3.23
	Jul	19.5	44.0	37.5	15.0	12.18	15.0	40.0	43.0	22.0	9.92
	Aug	22.0	47.5	37.5	24.0	8.87	17.5	41.0	43.0	30.0	7.26
	Sep	34.0	29.0	37.5	20.0	8.86	19.0	21.0	43.0	37.0	8.49
	Oct	22.0	4.0	37.5	2.0	25.27	17.5	5.0	43.0	17.5	18.12
	Nov	35.5	16.0	37.5	33.5	8.70	14.0	17.5	43.0	39.0	10.75
	Dec	47.0	11.0	17.5	37.5	6.67	48.0	15.0	43.0	31.5	6.47
1999	Jan	46.0	3.0	3.5	3.5	20.35	46.0	6.0	32.5	40.5	7.85
	Feb	48.0	12.0	17.5	7.0	14.32	47.0	12.0	43.0	12.0	12.62
	Mar	38.5	1.0	7.5	21.0	14.86	6.0	9.0	26.0	48.0	15.63

Computations from data source: Government of India, CPCB (2000) Water Quality Status of Yamuna River, Series: ADSORBS/32/1999-2000.

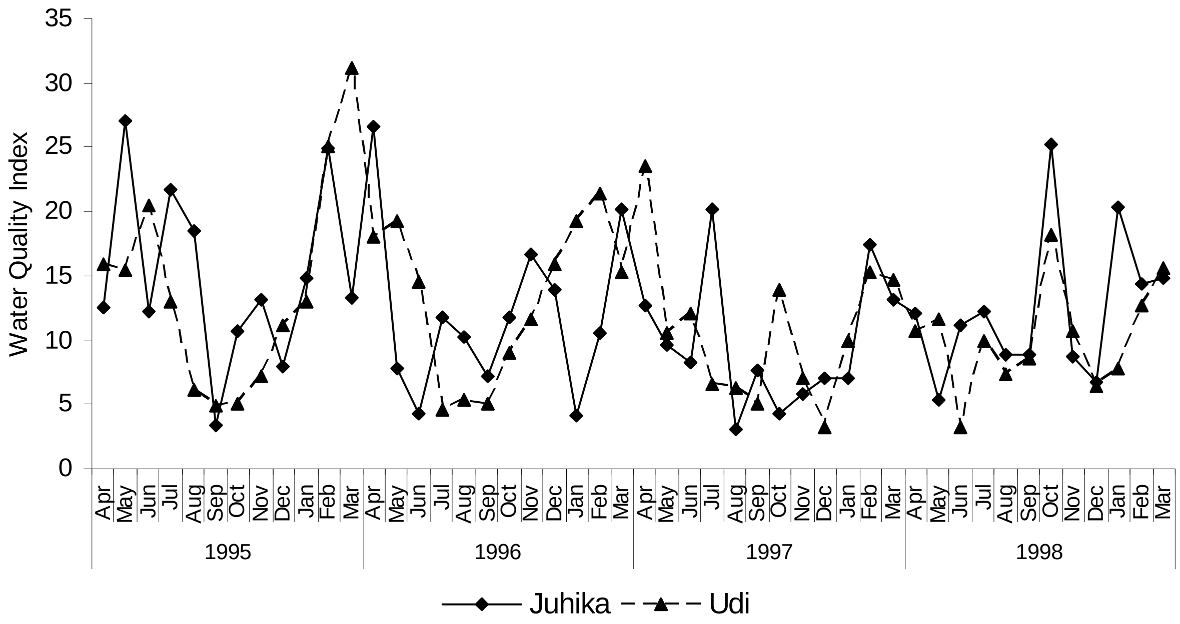


Figure 3. Monthly Water Quality Index at Juhika and Udi (April'95-March'98)
(Source: Plotted in MS-EXCEL from computed data Table 6)

It is clear from above Table 6 and Figure 3 that water quality index based on composite ranked standard deviations from standard of A class for these four parameters - pH, DO, BOD and TC showed lower values during monsoon months as a result of increased flow in river and dilution of pollutants thereafter. Even in these months the composite index was much higher than standard (0). The average value of water quality index based on four-year data (1995-99) was 10.12 at Juhika and 11.81 at Udi. There was no such clear-cut year-wise reduction in deviation.

4. Conclusion:

Industrialized areas around Mandideep in Raisen district, industries at Indore, and religious waste at Ujjain especially during 'Kumbh' require strict and urgent monitoring on daily basis. Detailed analysis of water quality parameters at two impact stations on main lower Yamuna and one station each on Chambal and Betwa provided good upstream and downstream relationship regarding concentration of pollutants. Out of several water quality variables, three components - pH and temperature; biological oxygen demand (BOD) and chemical oxygen demand (COD); and faecal and total colliforms (TC and FC) were found to explain more than 65% of total variation among water quality indicators. Therefore, data should be collected and analysed in detail, at least, for these components at other stations. Water quality index for both the stations shows an overall declining trend interspersed with peaks and lows during pre-monsoon and monsoon season respectively. The index shows convergence in the two series towards the end, which means a narrowing down of gap between water quality of Chambal and lower Yamuna after its confluence. Thus, impact of Yamuna Action Plan is still not significant. However, in case of upper lake at Bhopal, pollution monitoring programme was found to have some impact on reduction of concentration of pollutants - a fact visible during field visits to lake as well. Seasonal variations in water quality like rainfall are very important to determine frequency of monitoring. Clear harmonic trend was visible in seasonal variations of water quality for different parameters. At present, the cost and time constraints limit the extension of water quality network to few places only. In those cases, only seasonal monitoring can be done for pH, micro pollutants, COD and water temperature as suggested by harmonic analysis.

With the availability of advanced facilities in water quality labs, it is now possible to analyse the results quickly. Quality control on sampling is another important aspect for evaluation of optimum design consideration. Use of statistical software is common nowadays for analysing complex water quality parameters. A more rigorous statistical analysis of the variables of water quality reflecting spatial variation in pollutants and use of water quality index in river classification was demonstrated in the study conducted in Langat river basin of Malaysia. (Juahir *et al.* 2011). The scope of seasonal monitoring study presented in this paper is further ascertained by Okeke and Adinna, 2013 while analysing seasonal concentration of pollutants in Ontamiri river of Nigeria.

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References:

1) Ahlawat, R. And B. Thakur (1999): An Optimum Assessment of Rainfall Data in the Catchments of Betwa and Ken Rivers: The Southern Yamuna System (Bundelkhand Region). *Annals of the Nat. Asso. of Geog. of India*, XIX (1 & 2): 72-104.
2) Ahlawat, R. (2007): Hydrological Data Network Analysis for Water Resource Planning in Lower Yamuna Basin: A Case Study of Betwa River Catchment. Unpublished Ph.D. Thesis, Department of Geography, University of Delhi, India.
3) Central Board for the Prevention and Control of Water Pollution (1987): Manual for Statistical Analyses and Interpretation of Water Quality Data, MINARAS/2/86-87 Series.
4) Central Pollution Control Board (2000): Water Quality Status of Yamuna River, ADSORBS/32/1999-2000 Series.
5) Central Pollution Control Board (2001): Rationalization and Optimization of Water Quality Monitoring Network, MINARAS/15/2001-02 Series.
6) Conrad, V. and Pollak, L.W. (1950): Methods in Climatology. Harvard University Press, Cambridge.
7) Correspondent (1998): M.P. River Heavily Polluted: Panel, The Hindustan Times, May 31.
8) Central Board for the Prevention and Control Water Pollution (1987): Manual for Statistical Analyses and Interpretation of Water Quality Data, MINARAS/2.
9) Cluis, D., Martz, L. and Quentin, E. (1996): Coupling GIS & DEM to Classify the Hortonian Pathways of Non-Point Sources to the Hydrographic Network. In: Kover, K. and Nachtnebel, H.P. (Eds.). Application of GIS in Hydrology and Water Resource Management. Proceedings of the Vienna HydroGIS96 Conference. IAHS Pub. 235: 37-44.
10) Dwivedi, V.K. and Bhar, A.K. (2003): Problems of Water Balance and Trend in the Water Level of Upper Bhopal Lake, M.P., India. In: Rao, B. V., Reddy, K.R., Sarada, C. and Raju, K. (Eds.). Proceedings of the International Conference on Hydrology and Watershed Management. Vol. I & II. Hyderabad: BSP Pub. 237-243.
11) Government of India, Ministry of Environment and Forests. Annual Report 2003-04.
12) Harmancioglu, N.B., Ozkul, S.D. and Alpaslan, M.N. (1998): Water Quality Monitoring and Network Design. In: Harmancioglu, N.B., Singh, V.P. and Alpaslan, M.N. (Eds.). Environmental Data Management. Kluwer Academic Pub., Dordrecht, The Netherlands. 61-100.

13) Horn, L.H. and Bryson, R.A. (1960): Harmonic Analysis of the Annual March of Precipitation over the United States. *Annals of the Asso. Of Amer. Geog.*, 50(2): 157-171.
14) Jones J.A.A., 1997. Global Hydrology: Processes, Resources and Environmental Management. Addison Wesley Longman Ltd., Harlow, Essex.
15) Kazmi, A.A. and Muttamara, S. (1998): Water Quality Modelling of the Yamuna River. Proceedings of the First International Specialised Conference on Water Quality and its Management. Central Board of Irrigation and Power, India. 120-128.
16) Larson, (1976): cited in J.C. Rodda (ed.) Facets of Hydrology*,* Vol. II. John Wiley and Sons, New York.
17) Linsely, R.K. *et al.* (1992): Water Resource Engineering. Tata McGraw Hill, 4th Edition, Delhi.
18) Pinter, J. and Somlyody, L. (1986): Optimization of Regional Water Quality Monitoring Strategies. In: Moss, M.E. (Ed.) Integrated Design of Hydrological Networks, IAHS Pub. 158: 259-268.
19) Steele, T.D. (1985): Strategies for Water Quality Monitoring. In: Rodda, J. C. (Ed.) Facets of Hydrology, Vol. II, New York: John Wiley & Sons. 311-44.
20) Steele, T.D., Baner, D.P., Wentz, D.A. and Warner, J.W. (1979): The Yampa river basin, Colorado, and Wyoming - A Preview to Expanded Coal-Resource Development and Its Impacts on Regional Water Resources. US Geological Survey - Water Resources Investigations.
21) Vice, R.B. and Swenson, H.A. (1965): A Network Design for Water Quality. Symposium on Design of Hydrological Networks. WMO & IASH Pub. 67: 325-340.
22) Juahir, H. Et al. (2011): Spatial Water Quality Assessment of Langat River Basin (Malaysia) using Environmetric Techniques. *Environ. Monit. Assess*. 173:625–641. (open access at Springerlink.com, doi: 10.1007/s10661-010-1411-x)
23) Okeke P.N. and Adinna E.N. (2013): Water Quality Study of Ontamiri River in Owerri, Nigeria. *Uni Jourl. of Environ. Res. and Tech*. 3 (6): 641-649 (www.environmentaljournal.org)