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Research article

SEASONAL VARIATION AND ASSESSMENT OF WQI OF RAW WATER QUALITY IN WATER TREATMENT PLANTS AT DELHI, INDIA

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ABSTRACT: In the present study seasonal variation of physicochemical parameters of three types of raw water sources for the WTPs in Delhi has been studied. The sources of raw water for producing potable water in Delhi are Yamuna River, Ganga water from Uttar Pradesh, water from Bhakra through Haryana, Ranney wells and tube wells. Raw water samples for one year study (2011-2012) were collected from WTPs located at Wazirabad, Haiderpur and Bhagirathi in Delhi fortnightly. The samples were subjected to physicochemical analysis like pH, TDS, EC, Total Alkalinity, Total hardness, Ca hardness, Mg hardness, nitrate, chloride, sulphate, fluoride, sodium and potassium for various seasons; summer, monsoon, autumn, winter and spring. The results showed that most of the parameters exceeded the norms in winter season as compared to other seasons. Water Quality Index (WQI) was also calculated for all three sampling locations in different seasons. The results revealed that the water quality was excellent in monsoon and very poor in winter. The water is safe to use only after boiling and filtering or by Reverse Osmosis treatment for drinking purpose by the individuals.
Key words: WQI, raw water, WTP, seasonal variation, physicochemical parameters

INTRODUCTION

Delhi is situated along a perennial source of water, the river Yamuna, having its origin from Yamunotri glacier with a length of 1370 km and basin area of 366,220 Km^2, finally merging with river Ganga at Triveni Sangam, Allahabad, Uttar Pradesh. The river divides the city into East Delhi known as Trans Yamuna Area, and New Delhi. The National Capital Territory of Delhi (NCTD) has an area of 1483 km^2 and comprises of three constituents MCD (1297.29 km), NDMC (42.74 km^2) and DCB (42.97 km^2) respectively (Figure 1). The Delhi Jal Board (DJB), constituted under the Delhi Water Board Act, 1998, is responsible for the supply and distribution of potable water in the area under the jurisdiction of the Municipal Corporation of Delhi. The sources of raw water (Figure 2) for producing potable water in Delhi are Yamuna River, Ganga water from Uttar Pradesh, water from Bhakra through Haryana, Ranney wells and tube wells. The DJB has nine water treatment plants (WTPs) as can be seen in Figure 2. Six plants are functional with a combined capacity of production of 690 million gallons daily (MGD) of potable water. Table 1 presents the capacity of six operational WTPs indicating source of raw water [1]. Apart from this, there are four process waste water recycling plants (total capacity 45 MGD) which produces potable water from waste water of WTP [2]. Delhi's share of Yamuna River's total water is 4.6 % and it is the direct raw water source for Wazirabad I,II & III WTP and Chandrawal I & II WTP. Haiderpur I & II WTP and Nangloi WTP get their raw water from Bhakra storage of the Ravi and Beas Rivers. The upper Ganga canal supplies around 450 ft^3/sec of water to Delhi out of which 200 ft^3/sec is supplied to the Bhagirathi plant and 250 ft^3/sec goes to Sonia Vihar plant. Quality criteria for raw water generally follow drinking-water criteria and even strive to attain them, particularly when raw water is abstracted directly to drinking-water treatment works without prior storage as with WTPs in Delhi. Present study is carried out to study the seasonal variation in water quality parameters of raw water supplied to WTPs in Delhi. In addition seasonal WQI is also evaluated to assess the water quality relative to its desirable state (as defined by water quality objectives).

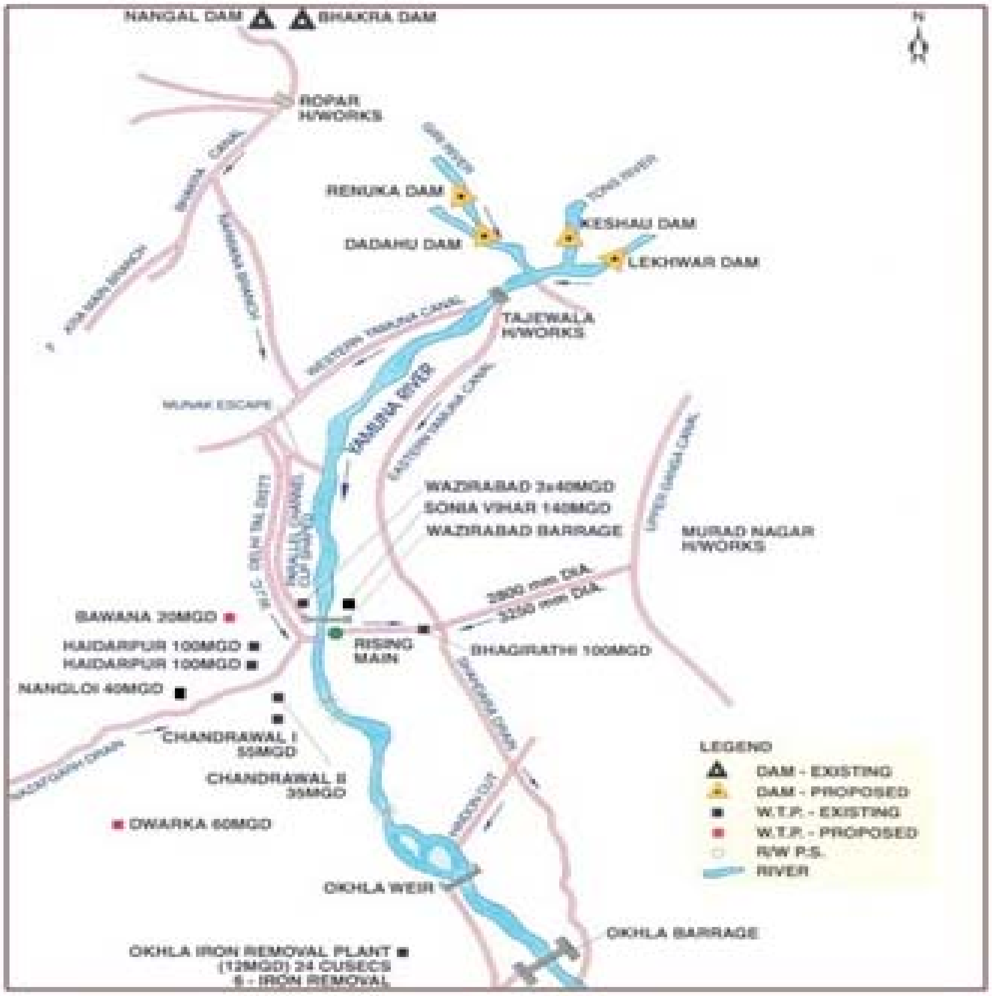

Fig-1: WTP's in Delhi and raw water sources

MATERIAL AND METHODS

Sampling Locations

Samples of water were collected from six WTPs in Delhi namely Nangloi, Haiderpur, Wazirabad, Sonia Vihar, Bhagirathi and Chandrawal fortnightly (October 2011 to September 2012). As indicated in Table 1, there are three raw water sources for the six WTPs of Delhi, therefore raw water from Haiderpur, Wazirabad and Bhagirathi only are collected for analysis.

Collection of samples

Water samples were collected in 2-litres plastic cans sealed by screw cap and labeled properly. The samples were collected in different seasons like autumn (October-November), winter (December-January), spring (February-March), summer (April, May, June) and Monsoon (July, August, September). Preservations of samples were done as per the Standard Methods for the Examination of Water and Wastewater [3]. Sample from each location was collected twice in a month i.e., four to six times in a season at 15 days interval to determine the average value of the results, which were compared with drinking water standards [4].

Analysis of samples

The samples were analyzed following the methods given in APHA manual. Measurements of temperature and pH were made with pH electrode. EC was determined using digital EC Meter. Total dissolved solid (TDS) was determined by filtering a known volume of water and then drying it at 180^{o}C. Alkalinity was determined by titration with 0.02 N sulphuric acid. Total, calcium and magnesium hardness were determined by EDTA titration method. Sodium and Potassium were determined using Flame Photometer. Nitrate and fluoride were determined by ISE electrode. Chloride was determined by argentometric titration method. Sulphate was determined by turbidimetric method [5].

Water Quality Index

The concept of indices to represent gradation in water quality was first proposed by Horton [6,7] It indicates the quality by an index number, which represents the overall quality of water for any intended use. It is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water [8,9,10] But the uses of water are manifold and quality of water required for each use varies tremendously. The main purpose of WQI is to turn complex water quality data into information that is understandable and usable by the public. It gives the public a general idea of the possible problem with water in a particular region.

The calculation of WQI was made using a weighted arithmetic index method given below [11] in the following steps.

Calculation of sub index of quality rating (*qn*)

Let there be n water quality parameters where the quality rating or sub index (*qn*) corresponding to the nth parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. The value of *qn* is calculated using the following expression.

$qn = 100[(Vn - Vio) / (Sn - Vio)]$ (1)

Where

qn = quality rating for the nth water quality parameter.

Vn = estimated value of the nth parameter at a given sampling station.

Sn = standard permissible value of nth parameter

Vio = ideal value of *n*th parameter in pure water.

All the ideal values (*Vio*) are taken as zero for drinking water except for pH=7.0 and dissolved oxygen=14.6mg/L.

Calculation of unit weight (*Wn*) Calculation of unit weight (*Wn*) for various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$Wn = K/Sn$

Where

Wn = unit weight for nth parameters

Sn = standard value for nth parameters

K = constant for proportionality and is calculated by using the equation as follows:

$K = [1 / (\Sigma 1/ Sn=1,2,..n)]$

Where Sn is the standard value for nth parameters

Calculation of WQI

WQI is calculated from the following equation

$WQI = \Sigma qnWn / \Sigma Wn$

Based on WQI, quality of water can be assessed using the water quality index scale [12] (Table 2)

Table 1: WTP's in Delhi and raw water sources

S.No.	Name of WTP	Raw water source	Capacity (MGD)
1	Chandrawal I & II	River Yamuna	90
2	Wazirabad I, II & III	River Yamuna	120
3	Haiderpur I & II	Bhakra storage/Yamuna	200
4	Nangloi	Bhakra storage	40
5	Bhagirathi	Upper Ganga Canal	100
6	Sonia Vihar	Upper Ganga Canal	140
		Total	690

Table 2: Water Quality Index (WQI) scale

Water Quality	WQI
Excellent	0-25
Good	26-50
Poor	51-75
Very poor	76-100
Unsuitable	Above 100

Table 3: Water quality rating (q_n) of different parameters of raw water at different stations

	pH	TDS	EC	TA	TH	Chloride	Sulphate	Nitrate	Calcium	Magnesium	Fluoride	Sodium
Summer												
HR	34	32.2	91.5	66.67	32	6.4	22.66	0.98	87.56	96.66	19	7.5
WR	28	43.9	130.5	75	34.11	13.6	28	1.33	97.77	96.66	30	20
BR	37.33	23.9	66.89	55.28	25	3.2	14.66	0.8	69.77	76.66	20	5.5
Monsoon												
HR	30	26.03	76.24	62.78	30.33	4.4	19.33	1.77	88.89	80	10	4.5
WR	29.33	34.63	102.11	7.56	36.72	8.8	26	2.57	89.77	143.33	15	9
BR	35.33	22.3	62.14	56.94	24.22	3.2	13.33	1	64.89	80	11	4.5
Autumn												
HR	56	34.25	92	89.17	45.16	4	22	1.51	110.66	176.66	44	6
WR	56	77.65	223.75	131.25	68	27.2	46	1.84	122	373.33	60	38
BR	53.33	28	70.91	74.17	34.83	10	16	0.91	85.33	136.66	48	4.5
Winter												
HR	40	35.15	98.66	77.92	43.83	5.6	25.33	1.48	112.66	156.66	62	6
WR	44	114.7	333.5	140.83	81	58.4	60.66	3.31	170	383.33	69	51
BR	52	28.55	70	65.42	31.83	4	14	0.88	76.66	126.66	44	3.5
Spring												
HR	36	36	131.03	94.58	45.33	4	24	1.33	108.66	180	29	4
WR	30.66	95.1	245.25	118.75	63.5	34.8	86	2.73	133.33	303.33	43	40
BR	37.33	27.85	71.32	62.08	27	3.2	16	0.93	70.66	93.33	30	6.5

Table 4: Sub-index (q_{nWn}) values of different parameters of raw water at different stations

	pH	TDS	EC	TA	TH	Chloride	Sulphate	Nitrate	Calcium	Magnesium	Fluoride	Sodium
Summer												
HR	4.0001	0.0644	0.3047	0.5553	0.1065	0.0256	0.1511	0.0218	1.1671	3.2217	19	0.0309
WR	3.2942	0.0878	0.4345	0.6247	0.1135	0.0544	0.1868	0.0296	1.3032	3.2217	30	0.0824
BR	4.3918	0.0478	0.2227	0.4604	0.0832	0.0128	0.0978	0.0178	0.9300	2.5551	20	0.0226
Monsoon												
HR	3.5295	0.0520	0.2538	0.5229	1.0099	0.0176	0.1289	0.0393	1.1849	2.6664	10	0.0185
WR	3.4506	0.0692	0.3400	0.0629	0.1222	0.0352	0.1734	0.0571	1.1966	4.7772	15	0.0371
BR	4.1565	0.0446	0.2069	0.4743	0.0806	0.0128	0.0889	0.0222	0.8649	2.6664	11	0.0185
Autumn												
HR	6.5884	0.0685	0.3063	0.7427	0.1503	0.0160	0.1467	0.0336	1.4750	5.8881	44	0.247
WR	6.5884	0.1553	0.7450	1.0933	0.2264	0.1088	0.3068	0.0409	1.6262	12.4431	60	0.1565
BR	6.2742	0.056	0.2361	0.6178	0.1159	0.0400	0.1067	0.0202	1.1374	4.5549	48	0.0185
Winter												
HR	4.706	0.0703	0.3285	0.6490	0.1459	0.0224	0.1690	0.0329	1.5017	5.2215	62	0.0247
WR	5.1766	0.2293	1.1105	1.1731	0.2697	0.2336	0.4046	0.0735	2.2661	12.7764	69	0.2100
BR	6.1178	0.0571	0.2331	0.5449	0.1059	0.0160	0.0934	0.0196	1.0218	4.2216	44	0.0144
Spring												
HR	4.2354	0.072	0.4363	0.7878	0.1509	0.0160	0.1601	0.0296	1.4484	5.9994	29	0.0165
WR	3.6071	0.1902	0.8166	0.9891	0.2114	0.1392	0.5736	0.0607	1.7772	10.1100	43	0.1647
BR	4.3918	0.0557	0.2375	0.5171	0.0899	0.0128	0.1067	0.0207	0.9418	3.1107	30	0.0268

Table 5: Drinking water standards by recommending agencies and unit weights

S. No.	Parameters	std (Sn)	Recommending Agency	unit weights (Wn)
1	pH	8.5	ICMR	0.096894118
2	TDS	500	WHO	0.0016472
3	EC	300	ICMR/BIS	0.002745333
4	T.Alkalinity	120	ICMR	0.006863333
5	T. Hardness	300	ICMR	0.002745333
6	Chlorides	250	ICMR	0.0032944
7	sulphate	150	ICMR/BIS	0.005490667
8	Nitrate	45	ICMR/BIS	0.018302222
9	Calcium	75	ICMR/BIS	0.010981333
10	Magnesium	30	ICMR/BIS	0.027453333
11	Fluoride	1	ICMR/BIS	0.8236
12	Sodium	200	ICMR/BIS	0.004118
				Sum=1.004135273
	k=0.8236			

RESULTS AND DISCUSSION

In the discussion, the water quality parameters have been compared with the drinking water standards prescribed by the Bureau of Indian Standards [13].

Assessment of Water Quality Parameters

pH

pH is a numerical expression that indicates the degree to which water is acidic or alkaline. It causes chemical reactions such as solubility and metal toxicity depending on its concentrations. It did not vary significantly in the seasons i.e., the results were uniform throughout this study, with minor seasonal differences (Figure 2a). The changes in pH may occur due to agricultural and domestic waste. All values lied within the tolerance limit. The lower pH value tends to make water corrosive and higher pH provides taste complaint and negative impact on skin and eyes [14].

TDS

Total Dissolved Solids (TDS) mainly consists of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter [15] High TDS in winter at all sampling locations could be because of domestic effluent discharges and surface run-off from the cultivated fields which might have increased the concentration of ions. Low TDS in monsoon at all sampling locations could be because of dilution effect by rainwater (figure 2b). TDS exceeded the tolerance limit only at Wazirabad (573mg/L) in winter, rest lied within the permissible limits. Dissolution of calcite and other minerals might be contributing TDS at different locations [16]. Beyond the limit, palatability decreases and causes gastro intestinal irritation [17] during cooking forms scales in the cooking vessels [18]

EC

Electrical conductivity (EC) measures the amount of ions in a solution. It is an indirect measure of the total dissolved solids content of water [14] Conductivity was above acceptable limit (300mg/L) in Wazirabad in all seasons and was highest in Winter (1000mg/L) (figure 2c). This might be due to the presence of inorganic dissolved solids such as chloride, sulfate, sodium, magnesium, calcium and iron cations [14] Lowest conductivity was recorded in Bhagirathi (186mg/L) during monsoon season, which might be because of dilution effect by rainwater. Excess values lead to scaling in boilers, corrosion and quality degradation of the product [19]

Alkalinity

Alkalinity is a measure of the ability of water to neutralize acids. It is due to presence of bicarbonates, carbonates and hydroxide of calcium, magnesium, sodium, potassium and salts of weak acids and strong bases as borates, silicates, phosphates, etc [15]. Seasonal changes influenced the concentrations at different locations (figure 2d) with alkalinity being highest at Wazirabad in winter season (169 mg/L). Increase in alkalinity during winters may be due to industrial discharge, as well as low rainfall, high evaporation etc. Lower alkalinity in monsoon is due to dilution [20] Large amount of alkalinity imparts a bitter taste, harmful for irrigation as it damages soil and hence reduces crop yields [2].

Total hardness

Water that require considerable amount of soap to produce foam or lather and generate scale in hot-water pipes, heaters, boilers, and others are called hard water. It reflects the nature of the geological formations with which it has been contact. The principal hardness causing cations are calcium, magnesium, strontium, ferrous iron, and manganous ions associated with bicarbonate, sulphate, chloride, nitrate and silicate respectively. Among them calcium and magnesium cause by far the greatest portion of the hardness occurring in natural waters [8]. TH values at all locations and in all seasons were within the acceptable limit (300mg/L) with highest (243mg/L) at Wazirabad in winter season (Fig 2e).

Ca hardness

Ca hardness exceeded the acceptable limit in autumn, winter and spring season at Haiderpur and Wazirabad (fig 2f). Highest value (128mg/L) was recorded at Wazirabad in winter while lowest value (52mg/L) was recorded at Bhagirathi in summer. Similar results were also observed for magnesium hardness (Fig 2g).

Sulphate

Seasonal variations in sulphate at different locations are shown in figure 2h.The lowest value (20 mg/L) was found at Bhagirathi in monsoon and the highest (129mg/L) at Wazirabad in spring showing the influence of seasons on concentration. At all locations concentrations are within the limit (200mg/L).

Chloride

Chloride is a widely distributed element in all types of rock in one or the other form. Presence of chloride in water indicates presence of organic wastes particularly of animal origin [21] Increase in chloride concentration on discharge of municipal and industrial waste has been reported [17]. Seasonal variations showed higher chloride concentration in autumn, winter and spring while lowest in summer and monsoon (figure 2i). The highest value (146mg/L) was observed at Wazirabad in winter and the lowest (8 mg/L) at Bhagirathi in monsoon, summer and spring. High concentrations of chlorides are troublesome for irrigation, harmful to aquatic life [22], corrode concrete used for construction purposes [17] and make water unfit for drinking or livestock watering [23].

Fluoride

Fluoride is universally present in almost every water, earth crust, many minerals, rocks etc. (Shah, Shilpkar and Acharya 2008). Seasonal variation indicated higher concentrations in winter (0.69mg/L) and lower in monsoon (0.1mg/L) (figure 2j). All the values were very low compared to acceptable limit (1mg/L). At decreasing levels, dental caries becomes a serious problem and at increasing levels, dental fluorosis becomes a problem [8].

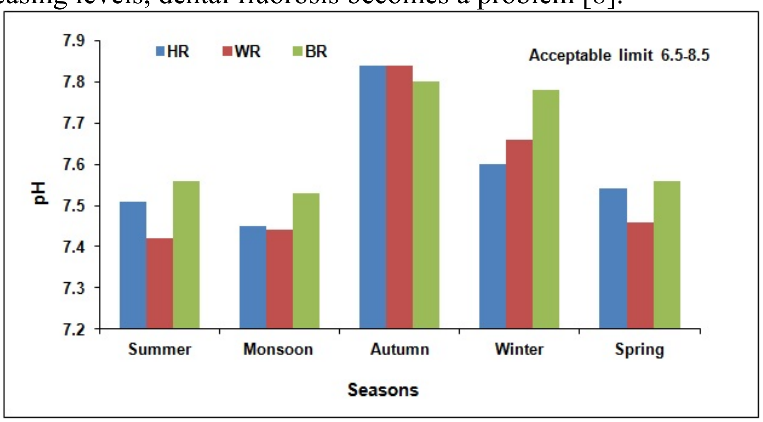

Fig-2a: Seasonal variation in pH at different locations

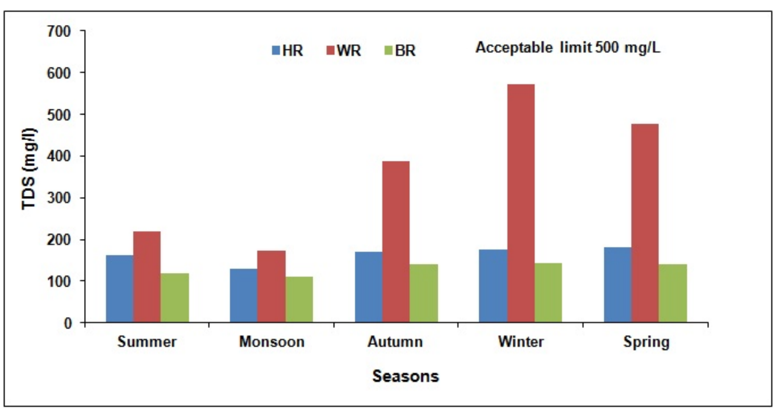

Fig-2b: Seasonal variation in TDS at different locations

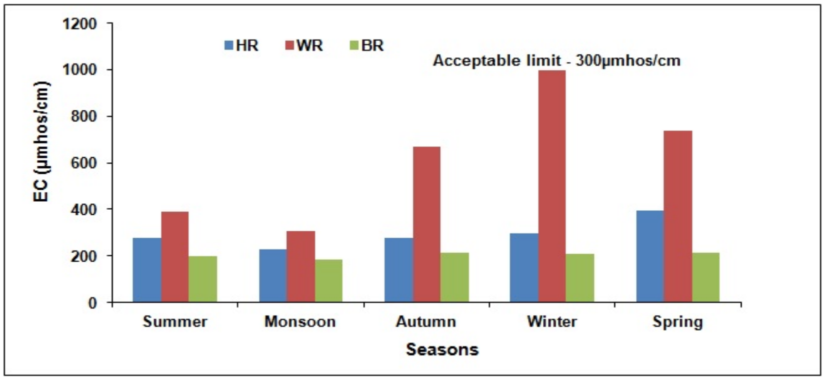

Fig-2c: Seasonal variation in EC at different locations

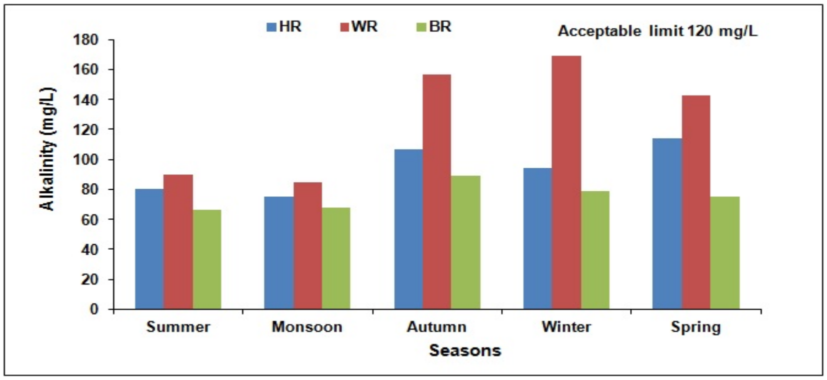

Fig-2d: Seasonal variation in Alkalinity at different locations

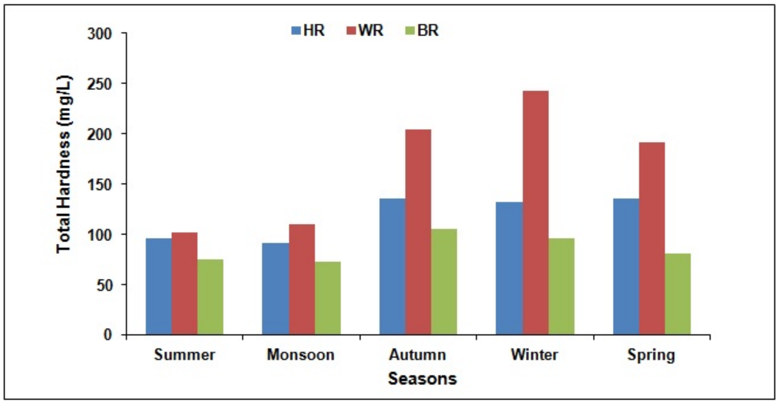

Fig-2e: Seasonal variation in TH at different locations

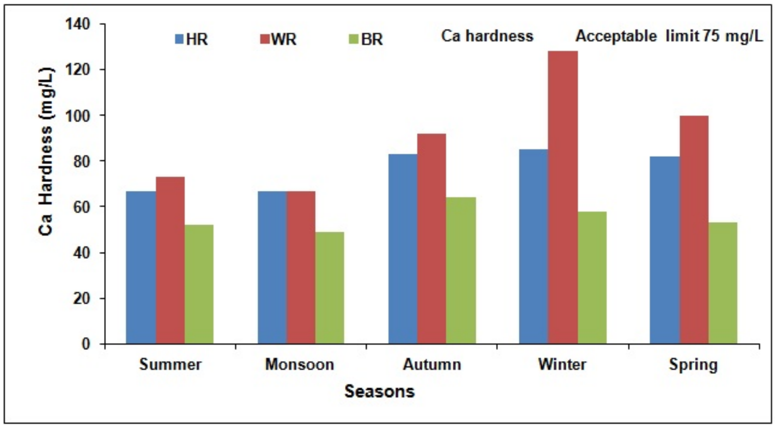

Fig-2f: Seasonal variation in Ca hardness at different locations

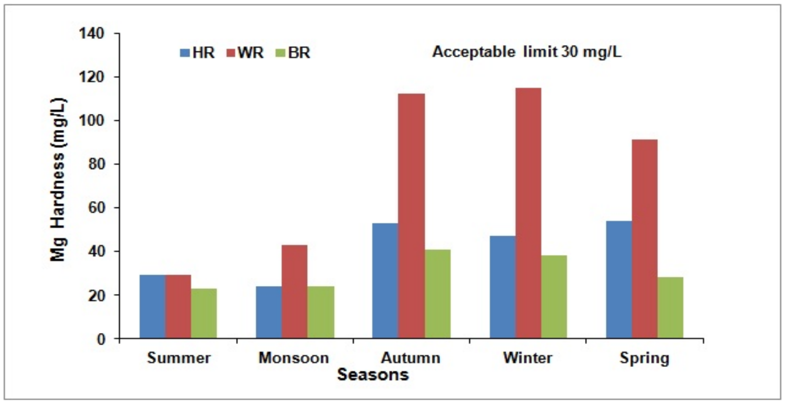

Fig-2g: Seasonal variation in Mg hardness at different locations

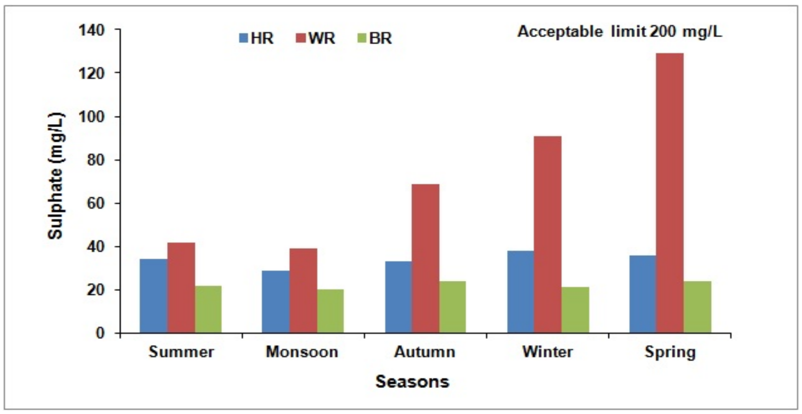

Fig-2h: Seasonal variation in sulphate at different locations

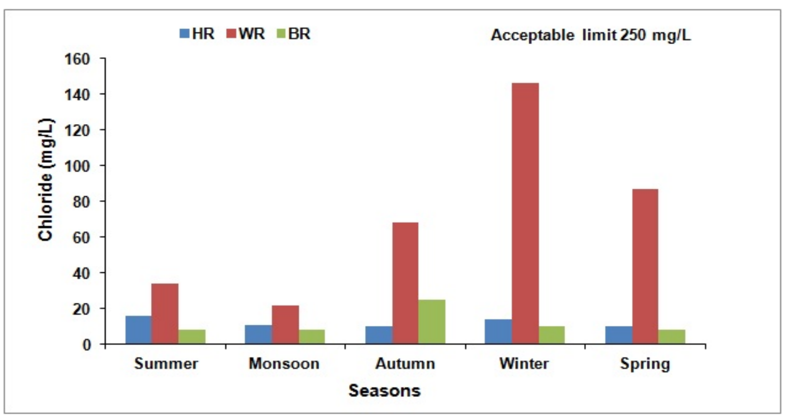

Fig-2i: Seasonal variation in chloride at different locations

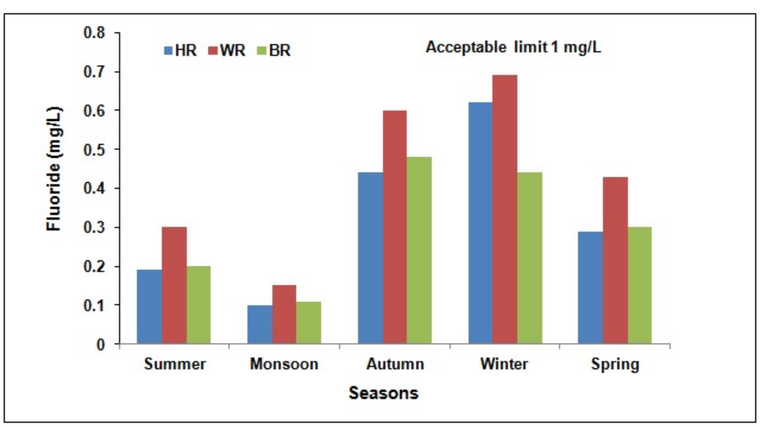

Fig-2j: Seasonal variation in fluoride at different locations

Sodium

Sodium salts are highly soluble in water and impart softness in contrast to hardness [17]. Sodium concentrations varied seasonally at each location (Figure 2k). Highest sodium concentration (102mg/L) was found at Wazirabad in winter while lowest (7mg/L) was recorded at Bhagirathi in winter. Sodium is mostly excreted in urine. All values are within the limit (200mg/L). Higher concentration can cause cardiovascular diseases and toxemia associated with pregnancy in women [12]

Potassium

Presence of potassium ion in the natural waters is very important since it is an essential nutrient element. Potassium varied seasonally at different locations (Figure 2l). The lowest (3mg/L) concentration was found at Bhagirathi in monsoon and the highest (15mg/L) was found at Wazirabad in spring.

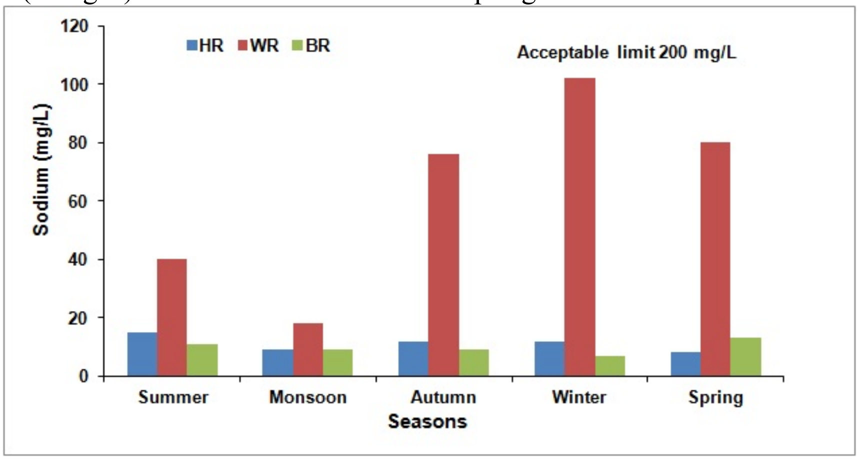

Fig-2k: Seasonal variation in sodium at different locations

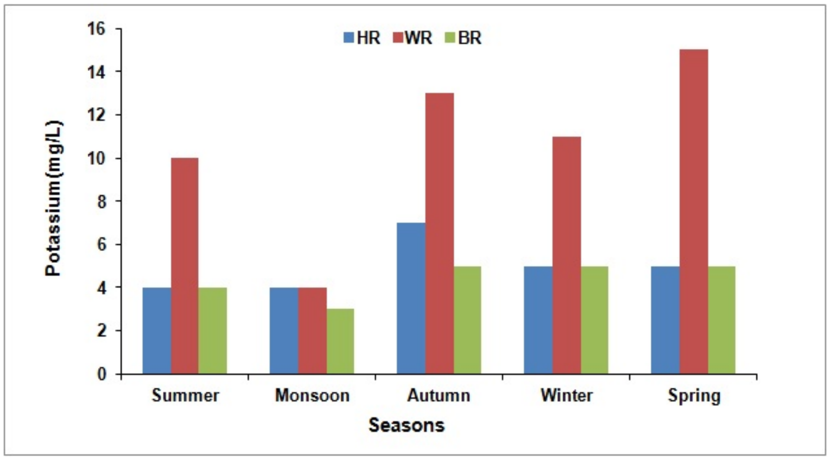

Fig-2l: Seasonal variation in potassium at different locations

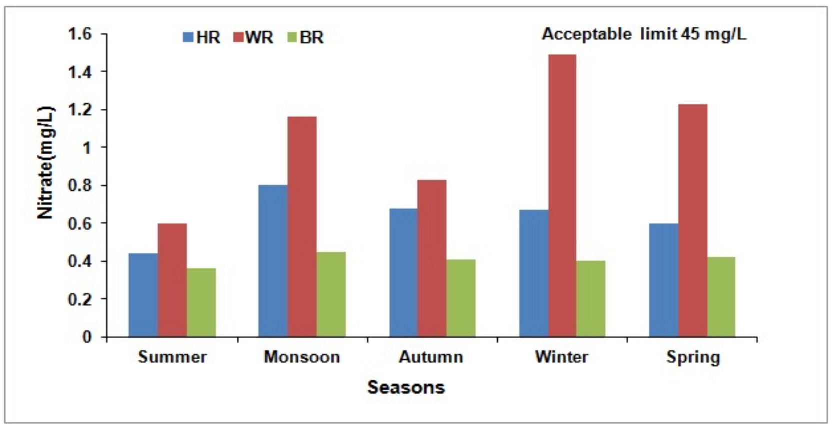

Fig-2m: Seasonal variation in nitrate at different locations

Nitrate

Seasonal variations in nitrate concentrations are shown if figure 2m. Nitrate concentrations were within the acceptable limit at all locations and was highest at Wazirabad in winter (1.49mg/L) and lowest (0.36mg/L) at Bhagirathi in summer. Nitrate was higher in winter because of decreased microbial and bacterial activity that reduces the nitrogen conversion into nitrate and nitrite [5] Lower concentrations of nitrate in surface waters during the summer may be caused by lower nitrate concentrations in ground water discharging to streams and uptake by plants (Figure 2m).

Assessment of raw waters quality based on WQI

Many researchers have considered different water quality parameters for the assessment of water quality index [24] In this study those parameters for which standards are available like pH, TDS, EC, nitrate, fluoride, chloride, sulphate, alkalinity, total hardness, Ca hardness, Mg hardness and sodium were considered for the assessment of WQI in summer, monsoon, autumn, winter and spring season. In the present study the application of WQI gives us a comparative evolution of water quality at different sampling stations during different seasons. WQI evaluated for the 3 sampling locations in different seasons are given in Table 6. The minimum (18.44) and maximum (92.54) values indicate the range of water quality at different locations in different seasons. In winter, the quality at sampling locations was poor as compared to other seasons. In monsoon, the range occurred under good to excellent category. The dilution properties due to rain might be the reasons for improved water quality in monsoon. It was observed that even at the same monitoring location the quality of water varied from season to season. At location HR, the water quality is excellent in monsoon and poor in autumn and winter. At WR, it is good in monsoon and summer, poor in spring and becomes degraded (very poor) in autumn and winter. Similarly water quality at BR was excellent in monsoon, good in summer and spring while degraded (poor) in autumn and winter. Very low standard deviation in monsoon shows that fluctuation in water quality index at different locations is lesser than other seasons.

Table 6: Water Quality Index (WQI) of different locations in Different seasons at Delhi

Sampling locations	Seasons									
	Summer		Monsoon		Autumn		Winter		Spring	
	WQI	Status	WQI	Status	WQI	Status	WQI	Status	WQI	Status
HR	28.53	Good	18.44	Excellent	59.20	Poor	74.56	Poor	42.18	Good
WR	39.27	Good	25.21	Good	83.15	Very poor	92.54	Very poor	61.39	Poor
BR	28.72	Good	19.56	Excellent	60.93	Poor	56.21	poor	39.34	Good
Minimum	28.53		18.44		59.20		56.21		39.34	
Maximum	39.27		25.21		83.15		92.54		61.39	
SD	6.15		3.63		13.36		18.17		11.96	

CONCLUSION

The analysis of water from 3 different raw water sources showed that most of the parameters exceeded the norms in winter season as compared to other seasons. This might be due to industrial discharge, low rainfall, and high evaporation and so on in winters. Most of the parameters were under the acceptable limit. There was seasonal variation among the 3 sampling locations and even at the same monitoring location the quality of water varied from season to season. The Water Quality Indices are among the most effective ways to communicate the information on water Quality trends to the general public or to the policy makers and water quality management. Water quality index showed excellent water quality in monsoon and very poor in winter because most of the parameters were within the norms in monsoon compared to other seasons. Its evaluation will not only be helpful to understand the seasonal quality of water but also has advantages for government agencies and institutions where regular water quality data is required.

Based on the results and analysis of water samples, it is recommended to use water only after boiling and filtering or by Reverse Osmosis treatment for drinking purpose by the individuals. However, for other domestic purposes, water can be used if the WQI shows status of water quality either good or excellent.

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