Original Research Article   https://doi.org/10.20546/ijcmas.2017.612.184

Seasonal Variations in Physico-Chemical Properties of Yamuna Water and its Suitability for Irrigation

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A B S T R A C T

K e y w o r d s Bicarbonates, Boron, Nitrate, Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC). **Article Info** *Accepted:* 12 October 2017 *Available Online:* 10 December 2017	Indian urbanisation at fast pace has led to increased wastewater discharge into river Yamuna which is intensively used for irrigation in urban, peri-urban and rural areas. In this backdrop, water quality of Yamuna was assessed at six sites along a stretch from Mathura, Agra and Etawah during winters, summers, rainy and post-rainy seasons. The pH of Yamuna water (7.01-7.84) did not register conspicuous variations in different seasons and sites. Other physico-chemical parameters were maximum during summers (EC: 2.6 - 3 dS/m, bicarbonate: 4.2 - 5.2 meq l^{-1}, chloride: 7.0-8.6 meq l^{-1}, sodium adsorption ratio (SAR): 5.1 - 8.28 and boron: 1.2 - 2.0 mg l^{-1}). Nitrate was maximum (5.6 - 6.8 mgl^{-1}) during rainy season. Residual sodium carbonate (RSC) remained negative in all seasons and sites. Since, several physico-chemical parameters varied within slight to moderate restrictive use range, therefore, Yamuna water can be used for irrigation with certain recommended precautions.

Introduction

Water quality, a global concern, critically interlinks to sustainable agriculture, animal and human health and environmental quality worldwide including Indian subcontinent (Kumar *et al.,* 2017). Indian rivers are getting polluted and contaminated on receiving the huge quantity of untreated wastewater being drained from urban and industrial sources (CPCB, 2012). Total wastewater generation from urban areas in India is above 38,000 MLD, out of which only 35% is treated (CPCB, 2010). Major Indian cities also extract freshwater from rivers for domestic and industrial usage, therefore, quality of river water stands critical from human and animal health as well as ecological point of view. Yamuna, a major tributary of river Ganges, originates from Yamunotri glacier (38^0 59' N 78^0 27' E) in the lower Himalayas at an elevation of about 6387m amsl. Yamuna has a catchment area of over 366,220 Km^2 and total length of about 1376 Km (CPCB, 2012). Yamuna traverses seven states (Uttarakhand, Himachal Pradesh, Haryana, Delhi, Rajasthan, Uttar Pradesh and Madhya Pradesh) but its water is severely polluted in Delhi and Uttar Pradesh segments (Sharma *et*

al., 2017). To abate the contamination and pollution of Yamuna, Government of India launched a mega project called Yamuna Action Plan in 1993 (CPCB, 2006), however, restoration of the ecological fitness of Yamuna water to the required water quality standards is yet a big concern. Farmers especially poor and marginal one lift Yamuna water and irrigate crops which can be detrimental to crop quality, soil, human and animal health and environmental quality (Hasan *et al.,* 2017).

In this backdrop, a study covering about 410 Km stretch of Yamuna River was conducted during 2016 at six sites in three districts of Uttar Pradesh state (Mathura, Agra and Etawah) which is dominantly beset with sandy loam soils, semi-arid climate and annual rainfall of about 550-750 mm. The already concluded studies on Yamuna water quality indicate that fitness of Yamuna water for irrigation of agricultural crops near Delhi is highly variable and unpredictable with respect to location within metropolitan limits and time (Sharma *et al.,* 2017). Therefore, this study which involves a much large and less studied stretch of 410 Km (Mathura to Etawah) was carried out to assess suitability of Yamuna water for irrigation to agricultural crops during winter, summer, rainy and post-rainy seasons. This paper discusses the physico-chemical properties of Yamuna water vis-à-vis designate irrigation water quality guidelines to indicate its fitness for agricultural crops for advisory to the farmers.

Materials and Methods

Sampling site

A total of six sampling sites were selected along 410 Km stretch of Yamuna River in three districts of Uttar Pradesh i.e., Mathura, Agra and Etawah (Figure 1). Two sites in each district (one 5 Km upstream and another

5 Km downstream of first and last municipal drain, respectively) were sampled during each season i.e., winter, summer, rainy and post-rainy seasons.

Analysis of physico-chemical parameters

Physico-chemical parameters viz., pH, electrical conductivity (EC), ions concentration (boron, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^- CO_3^{2-}, Cl-and NO_3^{2-}) were estimated in Yamuna water, collected in pre-sterilised HDPE plastic bottles of 100 ml, following standard methods and procedures as per the APHA (2005). At every sampling site, three samples were collected i.e., from mid (D/2) of the river width (D) and one each at either side of river at D/4 transact from about one foot depth. These samples were composited and subjected to physico-chemical analysis. The physico-chemical parameters so determined were compared with the standard irrigation water quality guidelines given by Ayers and Westcot (1994) which has been presented in Table 1. Sodium toxicity hazard was assessed through determining SAR and RSC using following standard equations (1& 2) furnished by Richards (1954) and Eaton (1950), respectively.

$$*SAR = Na^+/ [(Ca^{2+} + Mg^{2+})/2]^{1/2} \ (1)$$

$$**RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$
(2) (* and ** = all concentrations are in meq l^{-1})

Results and Discussion

pH and EC

The pH of Yamuna water did not register any conspicuous variations at different sites and seasons (range: 7.01 to 7.84), however, it was most alkaline in summers (7.53 to 7.84), near neutral in rainy season (7.01 to 7.21) and moderate in post-rainy season (7.21 to 7.38) and winters (7.06 to 7.4) (Figure 2). The

irrigation quality guidelines suggest that at this pH range, water can safely be used for all the crops and soil types. Earlier studies of Sharma *et al.,* (2017) also well corroborate with these findings on river water pH.EC of Yamuna water at different sites followed the order: summers (2.6 to 3 dS/m)>post rainy season (1.84 to 2.45 dS/m)>winters (1.67 to 2.34 dS/m)>rainy season (1.15 to 1.50 dS/m) (Figure 3). Higher EC during summer may be a cumulative effect of more solubility of ions at higher temperature, higher domestic wastewater discharge on account of more consumption of water, higher evaporation rate from surface of water bodies and lower flow rate of river. The lowest EC of Yamuna water during rainy season can be ascribed to high surface runoff and resultant dilution of dissolved ions that directly determine EC. It can be concluded that EC of Yamuna water at various sampling sites during different seasons was found to lie in slight to moderate range of restrictive use as per the irrigation water quality guidelines. These findings on EC of river water are supported by Islam *et al.,* (2015) and Edopkayi *et al.,* (2015). As such, care may be taken to not apply Yamuna water in excessive quantity on regular basis in agricultural crops since it may involve endanger of accumulation of salts in the crop root zone and build of adverse osmotic potential. Nevertheless, on sandy loam soils of study area Yamuna water can be used at moderate to optimum application levels with or without dilution and leaching of salts, which is also in accordance with Dastane (1969).

Bicarbonate and chloride

Bicarbonates become a concern at high pH (7.4 to 9.3), high ion concentration (>3 meq l^{-1}) and under drip or sprinkler methods of irrigation in view of deposition of lime on roots that causes iron induced chlorosis (Zuo

et al., 2007). Data depict that bicarbonate concentration in Yamuna water i.e., summer (4.2 to 5.2meq l^{-1})>post-rainy season (2.2 to 3.8 meq l^{-1})> winter (2.1 to 2.9 meq l^{-1})> rainy season (1.0 to 2.0 meq l^{-1}) was found to be in slight to moderate restrictive range of water use for agricultural crops (Figure 4). Chloride concentration in Yamuna water followed an order i.e., summer (7.0 to 8.6 meq l^{-1})> post-rainy season (5.0 to 6.0 meq l^{-1})>winter (4.3 to 5.0 meq l^{-1})> rainy season (1.5 to 2 meq l^{-1}) (Figure 5). These results on bicarbonate and chloride in river water also corroborate with findings of Singh and Nath (2015). As such, except rainy season chloride concentration in Yamuna water was found to be fit for slight to moderate restrictive use for irrigation of agricultural crops in the zones of various sampling sites.

SAR and RSC

SAR, an indicator of mitigation of Na$^+$ hazard due to presence of Ca^{2+} and Mg^{2+} ions, was found to vary seasonally in order of summer (5.1to8.3)>post-rainy season (4.7 to 7.4)> winter (2.7 to 4.7)> rainy season (2.6 to 4.3), (Table 2). This shows that Yamuna water is safe from sodium toxicity hazard point of view as per the standard irrigation water quality guidelines. However, the values of SAR for Yamuna water are much higher than reported for other rivers by Thitame and Pondhe (2010), Maharana *et al.,* (2015) and Hasan *et al.,* (2017), which indicate huge flux of untreated domestic wastewater drained in Yamuna. Both, EC and SAR of irrigation water antagonistically affects water infiltration rate in soil. Therefore, EC and SAR of Yamuna water at different sites were correlated (Table 3), and it was found that from water infiltration hazard point of view Yamuna water can be used without any restrictions at all sites in different seasons except at S$_6$site during post-rainy season.

Table.1 Standard irrigation water quality guidelines (Ayers and Westcot, 1994)

Parameter		Degree of Restriction on Use for irrigation		
		None	Slight to moderate	Severe
pH		Normal 6.5 to 8.4		
Electrical conductivity (EC, dS/m)		< 0.7	0.7 – 3.0	> 3.0
SAR		< 3	3. – 9	>9
SAR = 0-3	EC =	>0.7	0.7-0.2	<0.2
= 3-6		>1.2	1.2-0.3	<0.3
= 6-12		>1.9	1.9-0.5	<0.5
= 12-20		>2.9	2.9-1.3	<1.3
= 20-40		>5	5-2.9	<2.9
RSC		< 0	0-2.5	>2.5
Bicarbonate (meq l^{-1})		< 1.5	1.5 – 8.5	> 8.5
Boron (B, mg l^{-1})		< 0.7	0.7 – 3.0	> 3.0
Nitrate-N (mg l^{-1})		< 5.0	5.0 – 30	>30
Chloride (meq l^{-1})		< 4	4. – 10	>10

Table.2 Sodium adsorption ratio (SAR) of Yamuna water at different sampling sites in different seasons

Sampling sites	SAR			
	Winter	Summer	Rainy season	Post-rainy season
S_1	2.7	5.1	2.6	4.7
S_2	3.6	5.4	3.1	5.8
S_3	3.3	5.8	3.1	5.8
S_4	3.6	6.8	3.6	6.4
S_5	4.7	7.2	4.1	7.4
S_6	4.5	8.3	4.3	7.3

Table.3 Correlation of SAR and EC of Yamuna water at different sites for different seasons to

assess degree of restriction for use in irrigation owing to infiltration hazard

Sampling sites	SAR	EC	Degree of restriction for use in irrigation
Winter			
S_1	2.7	2.05	None
S_2	3.6	2.15	
S_3	3.3	2.07	
S_4	3.6	2.34	
S_5	4.7	1.86	
S_6	4.5	1.67	
Summer			
S_1	5.1	3	None
S_2	5.4	2.8	
S_3	5.8	3	
S_4	6.8	2.8	
S_5	7.2	2.6	
S_6	8.3	2.6	
Rainy season			
S_1	2.6	1.27	None
S_2	3.1	1.15	
S_3	3.1	1.50	
S_4	3.6	1.45	
S_5	4.1	1.30	
S_6	4.3	1.28	
Post-rainy season			
S_1	4.7	2.03	None
S_2	5.8	2.26	
S_3	5.8	1.99	
S_4	6.4	2.45	
S_5	7.4	1.91	
S_6	7.3	1.84	Slight to moderate

**Table.4** Residual sodium carbonate (RSC, meq l^{-1}) of Yamuna water at different sampling sites in different seasons

Sampling sites	RSC (meq l^{-1})			
	Winter	Summer	Rainy season	Post-rainy season
S_1	-1.5	-4.0	-0.4	-2.2
S_2	-1.4	-3.8	-0.4	-2.0
S_3	-1.0	-3.4	-1.9	-2.8
S_4	-1.1	-1.1	-2.8	-1.4
S_5	-0.8	-0.9	-1.8	-0.9
S_6	-0.8	-0.3	-1.5	-2.4

Fig.1 Schematic representation of six sampling sites along Yamuna river, stretch from
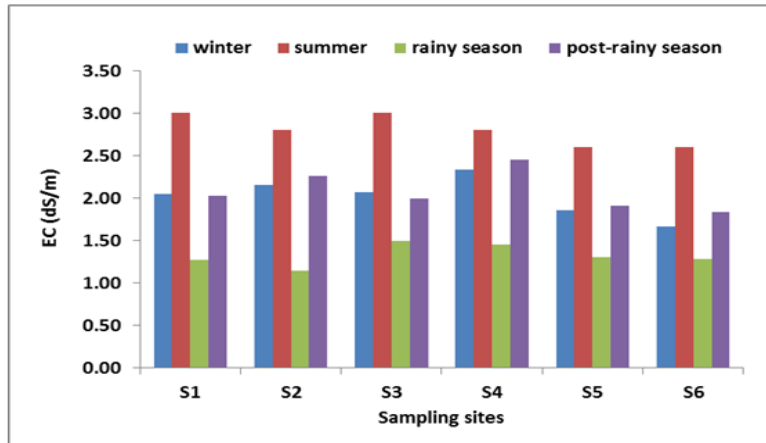
Mathura to Etawah
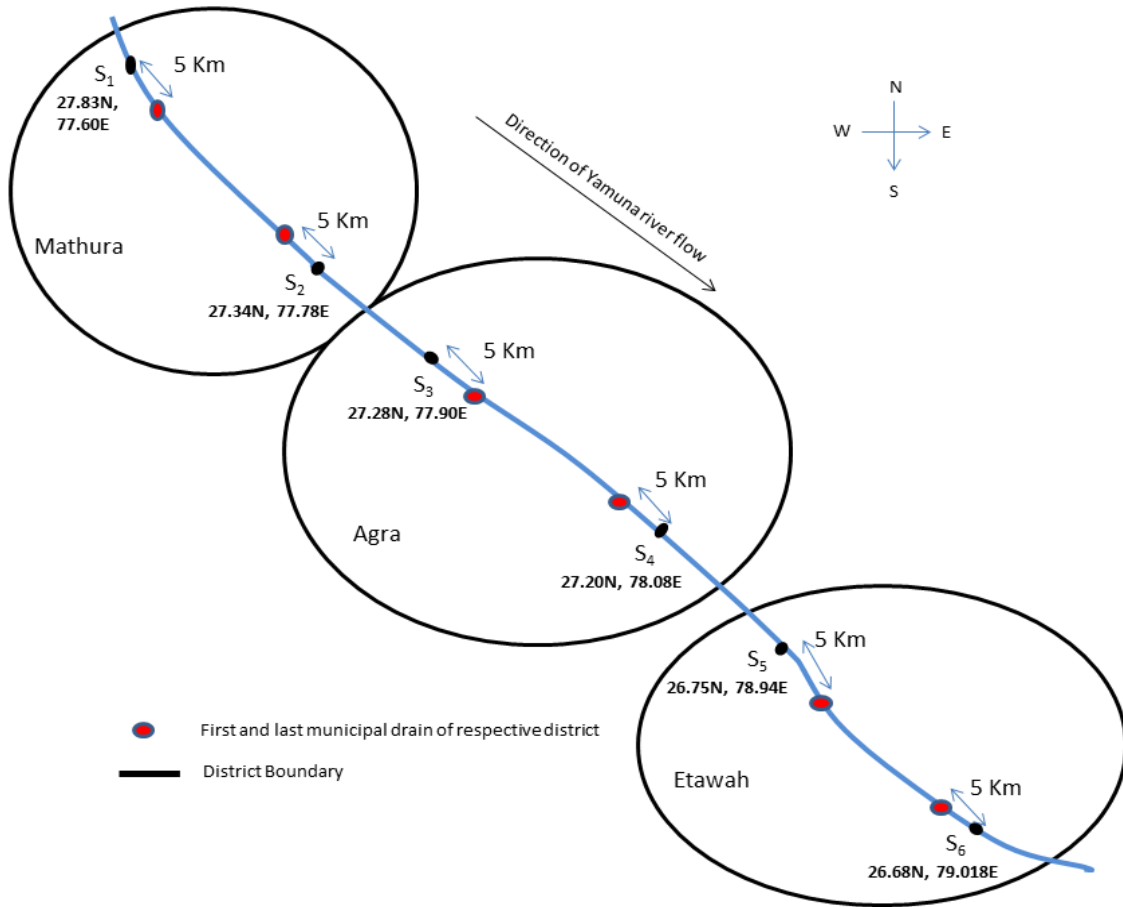
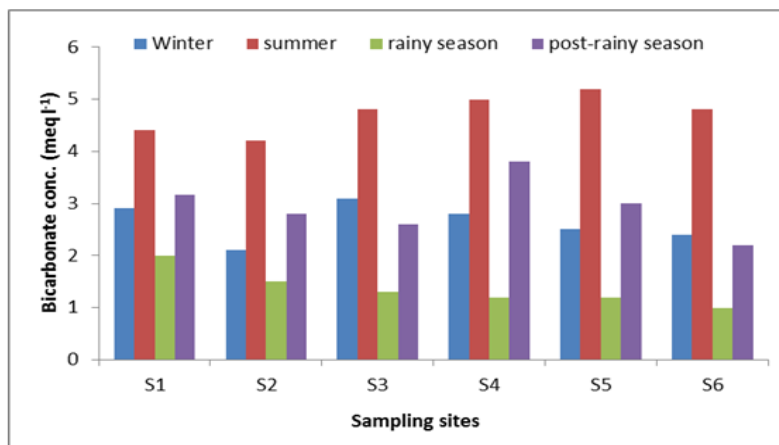**Fig.2** Seasonal variations in the pH of Yamuna water at different sampling sites
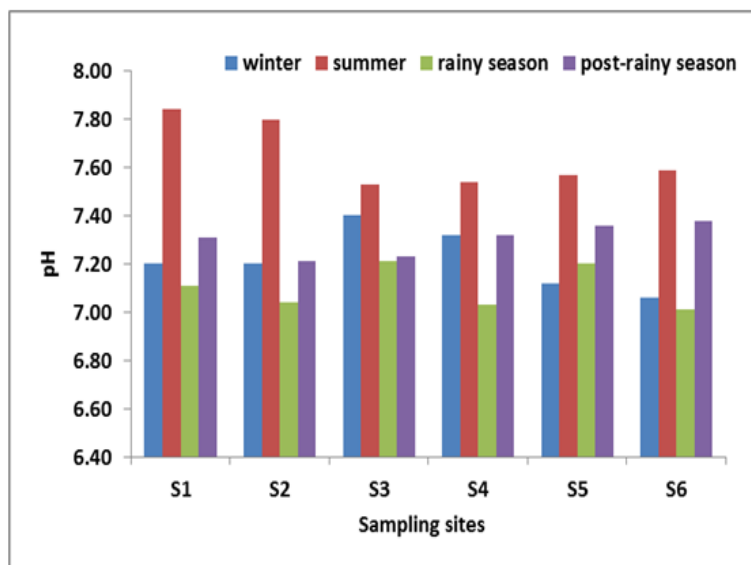
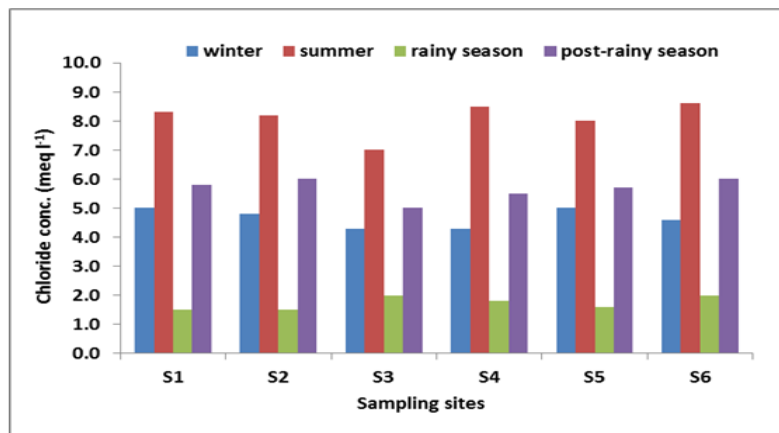**Fig.3** Seasonal variations in electrical conductivity (EC, dS/m) of Yamuna water at different

sampling sites

Fig.4 Seasonal variations in bicarbonate concentration (meq l^{-1}) of Yamuna water at different sampling sites

Fig.5 Seasonal variations in chloride concentration (meq l^{-1}) of Yamuna water at different sampling sites

Fig.6 Seasonal variations in boron concentration (mg l^{-1}) of Yamuna water

at different sampling sites

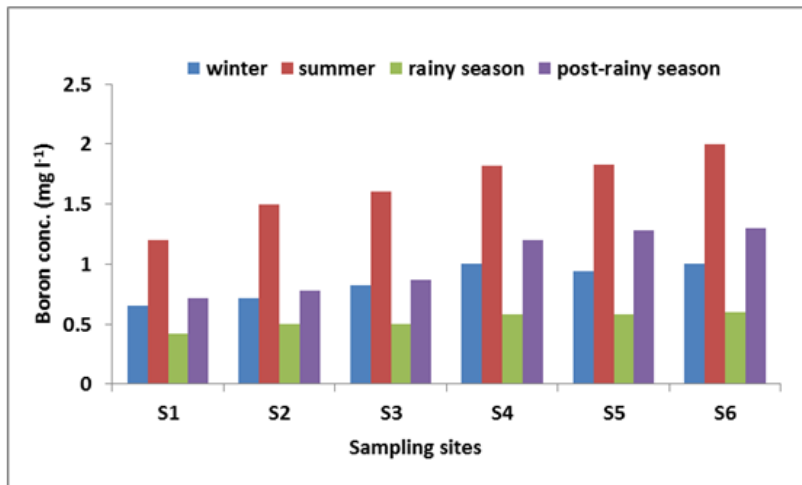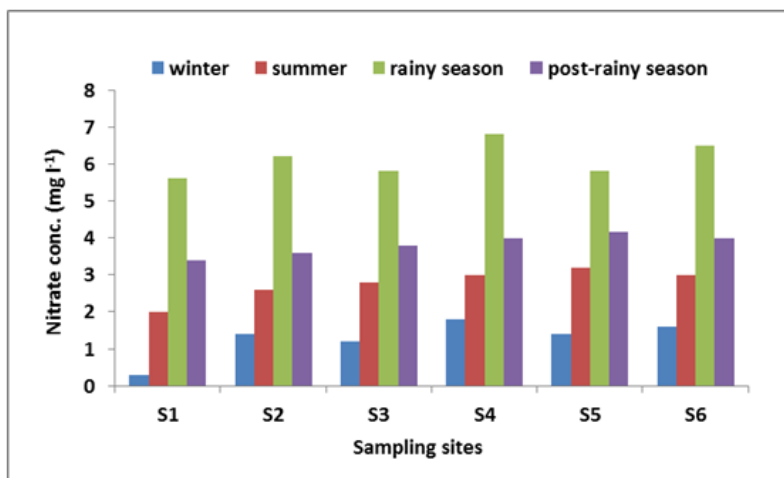**Fig.7** Seasonal variations in nitrate concentration (mg l^{-1}) of Yamuna water
at different sampling sites

Since sodium hazard increases with increase in concentration of bicarbonate ions due to precipitation of Ca^{2+} and Mg^{2+} as carbonates, therefore, RSC becomes highly important in determining quality of irrigation water.

However, RSC of Yamuna water at various sampling sites in all seasons was negative and good for use in agriculture (Table 4).These results are also in conformity with the findings on RSC of river water by Haritash *et al.,* (2016).

Boron

Boron, an essential element for crop plants becomes toxic above critical levels (Wimmer, 2013). Boron in river water can be contributed via cyclic seasalt, geothermal water, water-rock interaction i.e., chemical weathering and anthropogenic inputs (Liu *et al.,* 2012). Boron in Yamuna water can involve action of last two sources i.e., chemical weathering and anthropogenic inputs. The concentration of boron in Yamuna water followed seasonal variations in order of summer (1.2 to 2.0 mgl^{-1})> post-rainy season

(0.72 to 1.3 mgl^{-1})> winter (0.65 to 1.0 mgl^{-1})>rainy season (0.42 to 0.6 mgl^{-1}), (Figure 6). Boron concentration in Yamuna water falls under category of slight to moderate restrictive use. These results are also in conformity with findings of many authors working on water quality of Yamuna or other rivers in Indian subcontinent (Hassan *et al.,* 2017).

Nitrate

Nitrate (NO$_3^{2-}$) concentrations showed seasonal variations in order of rainy season (5.6 to 6.8 mgl^{-1})> post-rainy season (3.4to 4.17 mgl^{-1})> summer (2.0 to 3.2 mgl^{-1})> winter (0.3 to 1.8 mgl^{-1}) (Figure 7). These values corresponds to nitrate-N (10 mg l^{-1} nitrate-N = 45 mg l^{-1} nitrate) as: rainy season (1.23 to 1.49mgl^{-1})> post-rainy season (0.748 to 0.92 mgl^{-1})> summer (0.44 to 0.70 mgl^{-1})> winter (0.07 to 0.39 mgl^{-1}). In fact, higher concentration of nitrate in river water during rainy and post-rainy season over summers links to high runoff input from agricultural fields. As per the standard irrigation water quality guidelines, with existing nitrate-N level in Yamuna water, it can be used without any restrictions. Similar results on nitrate concentrations have also been reported by Sharma *et al.,* (2017).

The results of this study showed that most of the physico-chemical parameters assessed for Yamuna water confirm to slight to moderate range of restrictive use for irrigation to agricultural crops. As such, a safer side practice i.e., desired dilution and judicious use of polluted/contaminated river water should be followed in long-term use of Yamuna water for irrigation of agricultural crops in the studied stretch for avoiding the adverse influences on human, animal and soil health as well as on environmental quality.

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