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Monitoring of Hazardous Inorganic Pollutants and Heavy Metals in Potable Water at the Source of Supply and Consumers end of a Tropical Urban Municipality

Shah A. B. and Singh R. P.*

Department of Environmental Science, Babasaheb Bhimrao Ambedkar (Central) University, Lucknow-226025, India

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ABSTRACT: River water is not only an indispensable source for irrigation but also plays a vital role for drinking water supply for most of the urban municipalities. Water from rivers is pumped at specific sites and after treatment at municipal water treatment plants supplied as domestic potable water supply. The present study was undertaken to assess the suitability of Gomti river water at Gaughat being used as the source of water supply for Lucknow city and to evaluate post-treatment potable water quality at the consumer end by monitoring the levels of inorganic pollutants (nitrate, nitrite, ammonium and phosphate) and heavy metals. Municipal water supply at Gaughat showed marked variations in the levels of pH (7.13-8.63) and electrical conductivity (375.66-571.67µS/cm). The amount of nitrate, nitrite, ammonium and phosphate was observed 26.25, 0.082, 6.9 and 1.82 mg/l respectively at Gaughat. Also, the levels of heavy metals in the municipal water source at Gaughat varied significantly for Fe (0.33-1.65 mg/l), Cu (0.077-0.108 mg/l), Cd (0.03-0.052 mg/l), Pb (0.68-0.96 mg/l) and Cr (0.036-0.065 mg/l). Water at the user end was also contaminated as the concentration of analysed inorganic pollutants and heavy metals were correspondingly higher than observed at the source. While comparing potable water at the user end of Lucknow municipality with the BIS (Drinking Water Specifications) and WHO standards for drinking water, the concentration of all studied heavy metals and other inorganic contaminants were much above the permissible levels, thus posing a serious threat to the public health.

Key words: Drinking water, Gomti river, Heavy metals,Nnitrate, Nitrite, Public health

INTRODUCTION

Pure and safe drinking water is an essential and basic need to sustain life and maintenance of human health (Urashima, 2008; Mudiam *et al.*, 2012; Wang and Yu, 2014). River water is often used for domestic needs and also supplied as potable water by municipal corporations. Contamination of drinking water sources and supplies with hazardous chemicals like nitrate, nitrite, ammonium and heavy metals has become an increasing concern in developing countries, including India (Khan *et al.,* 2014). Increased rate of diseases outbreaks both in developed and developing regions have long been recognized due to poor potable water supplies to public (WHO, 2009) and in addition, poor water quality and scarcity can stifle a nation's economy, negatively impact the environment and fuel conflicts (Rai, 2010; Pham *et al*., 2011).

The elevated levels of nitrogenous inorganic pollutants (nitrate, nitrite, ammonium) and inorganic phosphates in river water due to runoff from agricultural fields, discharge of municipal/industrial sewage etc. lead to many health hazards (Kumari *et al.,* 2013). Nitrate-N levels in drinking water of 10mg/l or greater have been linked to methaemoglobinaemia or blue baby syndrome in infants and gastric carcinomas (Tank and Chandel, 2010) and non-Hodgkin's lymphoma in humans (Rao and Puttana, 2000; Rawat and Singh, 2009). Nitrite in human body may lead to the formation of carcinogenic nitrosamine upon reaction with secondary amines, thus posing the risk of stomach, liver and esophageal cancer (Kim Shapiro *et al.,* 2006) and high concentration of ammonium in body can lead to convulsion, coma and even death (Rawat *et al.,* 2012).

Heavy metals released by human activities into the environment beyond toxic limits are progressively finding their fate into water bodies thereby making the water unfit for drinking and also their bioaccumulation in food chains threaten the life of animals and human beings (Zhang *et al.,* 2009; Ishaq and Khan, 2013; Nazeer *et al.,* 2014). Characteristically, heavy metals are carcinogenic and neurotoxic in nature, however, their toxicity and targeted organs

*Corresponding author E-mail: cceseditor@gmail.com

vary from metal to metal and also depend upon the level of intake, strength of body immune system and duration of exposure (Dieter *et al.*, 2005; Khan *et al.*, 2014). Consumption of water contaminated with heavy metals may lead to their chronic accumulation in the kidneys, liver, bones etc. resulting in disruption of various metabolic activities (Bakirdere *et al.*, 2013).

The provisions of clean drinking water and its normalized supply play an important role for decreased mortality and improved economic progress in developing countries (Koc, 2010). Regular monitoring of drinking water at the source of supply and at consumer end is of prime importance for generating the database on overall feature and chemical characteristics of water that can help minimize the health hazards to a large extent (Cieszynska *et al.*, 2012; Faridi *et al.*, 2012). Being a developing country, India is not having advanced treatment processes and provisions at municipal water treatment plants for the removal of hazardous inorganic pollutants like heavy metals and reactive nitrogen species from potable water prior to public supply.

Although some of the monitoring studies on drinking water of Lucknow city have evaluated variable concentration of various inorganic contaminants (Mishra and Mishra, 2008; Lohani *et al.*, 2008; Mudiam *et al.*, 2012). However, monitoring of multi metals (Fe, Cu, Cd, Cr and Pb) and reactive nitrogen species (nitrate, nitrite, and ammonium) and phosphate in drinking water before and after municipal treatment has not been investigated in different seasons. Therefore, the present study is aimed at monitoring the water quality of river Gomti at Gaughat being used as the source of drinking water supply for Lucknow Municipal Corporation and to evaluate the status of post-treatment drinking water quality at the user end during pre-monsoon, monsoon and post monsoon periods in a semi-arid, tropical city of India.

MATERIALS & METHODS

Lucknow, the capital of Uttar Pradesh (26^{o}5/N latitude, 80^{o}56/E longitude, 128 m above the sea level), is spread over an area of 310 km^2 in the central plain of the Indian subcontinent, supporting a population of 36.50 lakh. It has a distinct tropical climate with a marked monsoonal effect. The year is divided into three distinct seasons *i.e*., summer (March to June), rainy (July to October) and winter (November to February). The temperature ranges from a minimum of 5^{0}C in winter to a maximum of 47^0 C in summer. The mean average relative humidity is 60% with a rainfall of 1006.8 mm. Gomti river, a tributary of Ganga River, originates from Fulhar lake near Pilibhit flowing through the Lucknow city meandering for about 12 Km, is a major freshwater ecosystem in India. Lucknow Jal Sansthan, an Organisation of Govt. of UP, has been entrusted to provide safe and potable drinking water to the city dwellers. Sampling station at Gaughat of river Gomti which is the source of raw municipal water supply for Lucknow city along with seven residential sampling sites which are the locations of municipal water supply for various residential areas of Lucknow were chosen for the monitoring of drinking. Residential areas included Aminabad, Indira Nagar, Aishbagh, Nishatganj, Telibagh, Hazratganj and Charbagh and these sites in the results and discussion are designated as site1, site2, site3, site4, site5, site6 and site7 respectively. Water samples from Gaughat and other residential areas were collected during August 2012-July 2013. Water samples were collected in triplicates in polypropylene sampling bottles that were acid soaked overnight and rinsed with tap water and then with distilled water. Collected samples were transported and stored in the dark at 4ºC for further analysis (APHA 2005). One bottle from each station was acidified in the laboratory before storage for heavy metal analysis. pH, electrical conductivity (EC), nitrate, nitrite, ammonium and phosphate were monitored monthly, while as for heavy metals seasonal variations during the pre-monsoon, monsoon and post-monsoon was conducted both at the Gaughat and residential areas. Basic parameters such as pH and EC were measured on spot using potable digital pH and EC meters. Nitrate, nitrite, ammonium and phosphate were measured in triplicate by using standard methods for examination of water and wastewater (APHA, 2005). Heavy metals viz. Fe, Cu, Cd, Pb and Cr were determined after acid digestion of samples with an acid mixture (9 parts nitric acid: 4 parts perchloric acid) at about 100º C. Blanks were also run simultaneously and analyzed to correct for possible external contributions of the metals. Analytical data quality of metals was ensured through repeated analysis (n=3) of EPA quality control in samples. Metal concentration was determined by atomic absorption spectrophotometer (AAS 240 FS, Varian). Statistical analysis of data by one way ANOVA followed by Duncan Multiple Range Tests was performed to determine the significance of differences among the mean values using (SPSS Version 20). Results of testing were considered significant if the calculated P-values were dá0.05. Relationships between physicochemical parameters and metal concentration in drinking water at the user end were studied by using Pearson Linear Correlation method.

RESULTS & DISCUSSION

Safe water supply is recognized as the highest priority task in environmental protection throughout the globe (Adewuyi *et al*., 2014). The declaration of access to pure and safe drinking water as "human birth right" could actually mean "death right" if the water quality of potable sources is not regularly monitored to check their suitability and purity for human consumption (Mebrahtu and Zerabruk, 2011). In the present study, the mean values of pH of water at

Gaughat varied between 7.13 in September and 8.63 in February (Table 1). These values indicated that pH of drinking water source was slightly alkaline in nature. Significant differences were observed for the pH values of water samples at Gaughat during all months (pd≤0.05). At the consumer end, pH values at different studied sites showed variations from 6.9 at site 1 to 8.66 at Site 6 during May (Fig.1). Statistically significant differences were observed for monthly pH values in drinking water at consumer end sites (pd≤0.05), except in the month of September. While comparing the pH of drinking water with drinking water quality standards, it was observed to be slightly above than prescribed by BIS (2003) at sites 3, 6 and 7. It has been reported pH of water systems plays a significant role in metal solubility (Jonnalagadda and Mhere, 2001). Various factors that govern pH fluctuations in water include temperature changes, dissolution of atmospheric CO_2, organic matter decomposition in water, dilution of alkaline substances and metabolic activities of phytoplanktons and other aquatic life (Fawzy *et al.*, 2012). In the current study, the slight alkaline nature of drinking water of Lucknow city is in accordance with the previous reports of Mullai *et al., (*2013) while evaluating pH of Uppanar river of Tamilnadu.

The electrical conductivity measurements in water depict the temporal variations in total dissolved solids and major ions present in it. During the present study, it was found that source of drinking water i.e., Gaughat showed highest EC (571.67µs/cm) in May and lowest value for EC (375.66 µs/cm) was recorded in August (Table1). Monthly variations in EC of water samples at Gaughat were significant (pd—0.05). At the user end, EC values of drinking water ranged from374.66 µs/cm in July to 475 µs/cmin May at site 7 and 5 respectively (Fig.2). Maximam EC during the summer months reported in the current study may be due to low and lenient flow of water in Gomti river and high temperature during this period leads to the increased salt content in water due to evaporation of water (Bellos and Swadis, 2005). Further increased EC shows the presence of free ions and other chemical substances such as nitrates, chlorides, phosphates in water. For EC of drinking water, WHO guidelines (2011) has prescribed maximum permissible limit of 400 mS/m. At the consumer end, significant differences were observed between all sites for EC in all studied months (pd—0.05).

Nitrate content in water is typically reported as either nitrate-nitrogen (NO_3-N) or nitrate (NO_3^-). Nitrate-N being the most common form of nitrogen present in natural waters is the end product of aerobic decomposition of organic matter (Rai, 2010; Agca *et al.,* 2014). For primary drinking water, USEPA has set a standard of 10 mg/l for nitrogen when reported in nitrate-N form and 45 mg/l when reported in nitrate form. In the present study, the water at Gaughat showed highest NO_3^{--} (26.25 mg/l) in May and lowest NO_3^- (13.45 mg/l) was reported in August (Table 1). While comparing the monthly concentrations of nitrate both at Gaughat water and at user end of all sites, significant differences were observed (pd—0.05). Nitrate concentration in public water supply at the consumer end showed maximum value (40.86 mg/l) at site 7 in September and minimum value (11.17 mg/l) was analysed at site 1 in April (Fig.3). Since nitrate concentration in water samples reported at Gaughat was within the permissible limit 45 mg/l. However, for its use as potable water supply to the Lucknow, it is recommended that nitrate concentration in water at the consumer end should not exceed 10mg/l. Further if water supply has a nitrate level approaching 3-5 mg/l, it is recommended that it should not be used for mixing baby foods or for drinking water for new born infants. Rawat and Singh (2009) have reported as much as 44.83 mg/l of nitrate in the surface waters of Lucknow, which may be due to discharge of municipal and industrial wastes, excessive application of nitrogenous fertilizers, manures and irrigation with untreated water. Dar *et al*., (2010) reported nitrate concentration in summer in 85% of the wells exceeding WHO permissible limits in Kashmir (India). In the extensive agricultural areas of north east Australia, Thorburn *et al*., (2003) concluded that 14-21% of the wells were extensively contaminated with nitrate.

In the present study, monthly variations in nitrite (NO_2^-) concentration analysed from Gaughat water and consumer end of Lucknow are depicted in Table 1 and Fig.4 respectively. Nitrite levels analysed in water at Gaughat and at various residential sites showed significant differences (pd—0.05). At Gaughat, maximum nitrite (0.082 mg/l) was observed in May and minimum nitrite (0.026 mg/l) in July. Correspondingly, at the user end higher nitrite levels were reported than at the source. Highest nitrite (0.1 mg/l) at site 5 and lowest (0.02 mg/l) at site 2 was analysed in September and February respectively. Nitrite levels reported in this study were slightly below the permissible limits prescribed by BIS (2003) at various sites, except at site 5 which showed nitrite concentration in water above permissible levels. Enhanced nitrite production in water may be due to oxidation of ammonium and reduction of nitrate by bacteria (Rawat *et al.,* 2012; Mullai *et al.*, 2013). Ammonium nitrogen (NH_4-N) in water samples at studied sites was found to vary between 2.67 mg/l and 6.9 mg/l at Gaughat (Table 1) and at the user end ammonium levels varied from 1.14 mg/l at site 3 to 5.16 mg/l at site 7 during April and August, respectively (Fig. 5). Ammonium in water has been seldom reported to be present in water at 1 mg/l unless ammonium fertilizers or other ammonia sources such as wastewater gets added to the water sources or supplies. During the current study, NH_4-N contents were much higher than maximum permissible limit for drinking water of 0.5 mg/l NH_4-N recommended by BIS (2003). The results depict higher ammonium levels in water than previously reported by Rawat and Singh (2009) in surface and groundwater sources of Lucknow city. Excretion of ammonium by the phytoplanktonic organisms may be the reason for higher ammonium levels in water and also their death or decomposition in water storage tanks can lead to increased levels of ammonium and nitrite in the water supply (Damotharan *et al.*, 2010).

Domestic wastewaters containing detergents, municipal and industrial effluents and agricultural runoff are the main anthropogenic sources for elevated phosphate levels in surface water. In most of the natural surface waters, phosphorus ranges from 0.005 to 0.02 mg/l (WHO, 2011). For phosphates WHO has not established any specific guideline value for drinking water. In the present study variations in phosphate levels of drinking water are depicted in Table 1 for Gaughat and Fig.6 for residential sites. Significant differences were observed for the monthly variations in phosphate contents in drinking water both at source and consumer end (pd—0.05). At Gaughat maximum phosphate (1.82 mg/l) in October and minimum (0.6 mg/l) in March was observed. From the residential sites, highest phosphate content (2.14 mg/l) at site4 in August and lowest (0.44 mg/l) phosphate at site6 in January was reported. The high concentration of phosphates are probably due to chemical weathering of rocks, release of soil minerals and also discharge of sewage into aquatic systems (Singh *et al*., 2005). Since phosphates are used at potable water treatment plants, this may be the reason for elevated phosphate contents in drinking water at the residential sites.

Heavy metals can enter drinking water by corrosion of distribution pipes as well as from industrial and natural geo-genic sources (Singh *et al.*, 2005; Haloi and Sarma, 2012). In the present study, seasonal variations in the average values of heavy metal contents recorded in water at Gaughat during the course of study period are shown in Table 2. It was observed that in municipal water supply most of the metals recorded were above the permissible limits prescribed by BIS (2003) for Drinking Water Specifications. Metal contents recorded at Gaughat were in the order of Fe>Pb>Cu>Cr>Cd. Except for Pb (pe—0.05), one way anova showed significant differences between and among the groups of metals (Fe, Cu, Cd and Cr) recorded in water at Gaughat during all the three seasons (pd—0.05). At Gaughat maximum metal concentration for Fe (1.65 mg/l), Cu (0.108 mg/l) and Cr (0.065 mg/l) were reported in monsoon season, while as maximum Cd (0.052 mg/l) was seen in pre-monsoon and Pb (0.96 mg/l) was observed to be maximum in post-monsoon season. Minimum concentration for Fe (0.33 mg/l) was recorded in premonsoon, Cu (0.077 mg/l) in post-monsoon, Cd (0.03 mg/l) in monsoon, Pb (0.68 mg/l) in monsoon and Cr (0.036 mg/l) in postmonsoon season at Gaughat. The variable metal contents reported in water at Gaughat during the present study depict discharge of wastewater and runoff from the catchment area into river system. Further, seasonal fluctuations in the metal contents may be due to the rain dilution effects. The leaching of metals from the soil minerals and organic matter due to rainfall may influence the concentration of heavy metals in river bodies (Singh *et al.*, 2005; Lohani *et al.*, 2008). Nevertheless, the presence of these metals in the water column used for public supply leads to various types of toxicity, like renal failure is related to the contamination of drinking water with Cd and Pb; liver cirrhosis to the contamination with Fe, Cu and Mo; hair loss to the contamination with Cr and Ni; and chronic anemia to the contamination with Cd and Cu (Jarup, 2003; Johri *et al.*, 2010; Mandour, 2012).

Seasonal fluctuations in the levels of heavy metals (Fe, Cu, Cd, Pb and Cr) studied at seven residential sites of urban Lucknow are depicted in Table 3. At the user end metal levels reported in the water supply exhibited same trend as detected at Gaughat i.e. Fe>Pb>Cu>Cr>Cd. However, the concentrations of these metals at user end were correspondingly higher than the background levels.

At the consumer end, the heavy metals studied showed significant differences in all seasons at all sites (pdá0.05). According to the results, Fe content in the drinking water at consumer end varied from 0.15 mg/l to 5.32 mg/l. Highest Fe content (5.32 mg/l) was recorded at site5 during the monsoon period, followed by Fe (5.24 mg/l) at site7 and Fe (4.75 mg/l) at site6 and lowest Fe concentration (0.15 mg/l) was reported at site 2 during the post monsoon period which may due to the use iron in coatings of pipes used to transport drinking water, overtime corrosion/deterioration of these iron coatings can lead to excessive iron into water supplies (Mandour, 2012). Iron has been reported to

Table 2. Seasonal variations in metal content (mg/l) in Gaughat water of Gomti river used as raw potable water supply for Lucknow city (n=3± S D)

	Fe	Cu	Cd	Pb	Cr
Pre M	0.336±0.016[c]	0.088±0.206[a]	**0.052±0.004[a]**	0.74±0.18[a]	0.057±0.003[b]
M	**1.65±0.13**[b]	**0.108±0.005[a]**	0.03±0.006[a]	0.68±0.16[a]	**0.065±0.005[a]**
Po M	1.128±0.007[a]	0.077±0.022[b]	0.045±0.005[b]	**0.96±0.061[a]**	0.036±0.004[c]
BIS 2003	**0.3**	**0.05**	**0.01**	**0.05**	**0.05**

(Different letters signify the statistical differences among physico-chemical parameters ($p < 0.05$)

cause liver cirrhosis when present in drinking water. In the present study, iron values exceeded the permissible limits prescribed by BIS (2003) and WHO (2011) for drinking water. Our results on Fe levels in drinking water are much higher than reported by Iqbal *et al.*, (2013) in drinking water of Pakhtunkhwa, Pakistan.

Copper concentration in drinking water varies due to fluctuations in pH and hardness of the water supply (Xu *et al*., 2006). Levels of Cu in drinking water at studied sites varied from (0.036 mg/l) to (0.37 mg/l). During the monsoon period highest Cu concentration (0.37 mg/l) was observed at site5, followed by (0.21 mg/l) at site3 during the premonsoon period. Lowest Cu concentration (0.036 mg/l) was observed at site2 during the postmonsoon period. Our result on Cu levels was much lower than U.S. EPA's Drinking Water Equivalent levels (1.3 mg/l) and WHO guideline value (2.0 mg/l). However, Cu levels were above the prescribed permissible levels of BIS (2003). Xu *et al*., 2006 reports excessive levels of Cu concentrations in drinking water of Shanghai China, Chile (1.2 mg/l) and United States (4.8 mg/l). Copper in drinking water supplies largely comes due to leaching from piping and plumbing fixtures. Addition of Cu into waterways is due to natural weathering of rocks and soil/sediments and also anthropogenic sources such as industrial effluents and sewage treatment plant effluents largely contribute to elevated copper levels in water courses (Lokhande *et al*., 2011). Although copper serves as a nutritional requirement for body, exposure to excessive levels of copper can result in number of adverse health effects, most commonly gastrointestinal distress (Alam *et al.*, 2012). Copper can bind with certain enzymes thereby interfering with their protection of cells from free radical damage (Uriu-Adams and Keen, 2005).

In the present study, Cd was also reported from the drinking water supplies of residential sites of urban Lucknow. Among the reported metals, Cd content in drinking water was found to be least. However, the Cd levels were just above the prescribed limits for drinking water (BIS, 2003). Cd content during the present study showed significant variations at all sites during different seasons (Pdá0.05). Highest Cd content (0.046 mg/l) was observed during the postmonsoon period at site3. The lowest Cd (0.006 mg/l) was recorded at site4 during the premonsoon period. Reports of the present study on Cd content in water are much below than recorded by Khan *et al*., (2014), but higher than reported by Mishra and Mishra (2008) in Gomti river. The presence of Cd in drinking water supplies has been correlated with the plumbing of pipelines. Cadmium exposure to humans can lead to both short term (diarrhea, vomiting and destruction of mucous membrane) as well as long term (itai-itai disease, bone and kidney damage) effects (Muhammad *et al.*, 2011; Bakirdere *et al.*, 2013). Chromium levels recorded in the current study were slightly above the prescribed standards of BIS. Maximum Cr (0.051 mg/l) was observed at site6 during the monsoon period, while as minimum Cr concentration (0.013 mg/l) was recorded at site4 during the postmonsoon period. Site6 was followed by site7 for the second highest observed Cr (0.047 mg/l) during the monsoon and (0.046mg/l) in the premonsoon period. The present levels of Cr detected in drinking water are less than 0.1 mg/l Cr reported earlier by Lohani *et al.*, (2008) while assessing heavy metal contamination in river Gomti of Lucknow. One of the major sources of Cr in aquatic environments is paint manufacturing industries. Also chromium compounds are used as pigments, mordents and dyes in the textiles and in leather industries as a tanning agent (Lokhande *et al.*, 2011). Cr exposure in drinking water has been reported to cause stomach cancer, alongside anemia and damage to the gastrointestinal tract, lymph nodes, and liver (Beaumont *et al.*, 2008; Adewuyi *et al.*, 2014)

Lead is one of the nonessential and toxic metals to human health. Discharge of Pb into surface water is mainly through paints, solders, pipes, building materials etc. (De, 2002). In the present study, Pb reported in drinking water from seven residential sites of Lucknow city varied between (0.15 – 0.58 mg/l). Maximum Pb concentration was observed at site 6 (0.58 mg/l) followed by site7 (0.57 mg/l) both during postmonsoon period and at site5 (0.46 mg/l) during the premonsoon period. Minimum Pb concentration (0.15 mg/l) was observed at sites1, 2 and 4 during the post monsoon periods. The Pb levels detected in water supplied to Lucknow city does not fall within the safe limits of Lead in water prescribed by BIS (2003). In this study, Pb content in drinking water was higher than reported by Bakirdere *et al*., (2013) in tap and bottled water samples. Further, Parameswari and Mudgal, (2013) found the highest Pb contents in ground water samples in South India. Since Pb pollution in fresh surface water sources is also due to dry and wet deposition of atmospheric fallouts and highest in those water bodies adjacent to highway roads, this may be the probable reason for greater Pb concentration in water supplies from rivers such as Gomti.

Correlation matrix between physicochemical parameters and heavy metals in the drinking water of residential sites of Lucknow was performed using Pearson correlation analysis (Table 4). Nitrate showed significant correlation with pH and conductivity at (pdá0.01) and with phosphate (pdá0.05). Nitrite exhibited significant positive correlation with nitrate and ammonium (pdá0.01). Phosphate also was significantly correlated with EC (pd"0.01). Among the studied heavy metals, Fe showed positive correlation with nitrite (pdá0.05). Cadmium was correlated with Cu (pdá0.05). However, Pb showed significant positive correlation with both ammonium and Cd (pdá0.01).

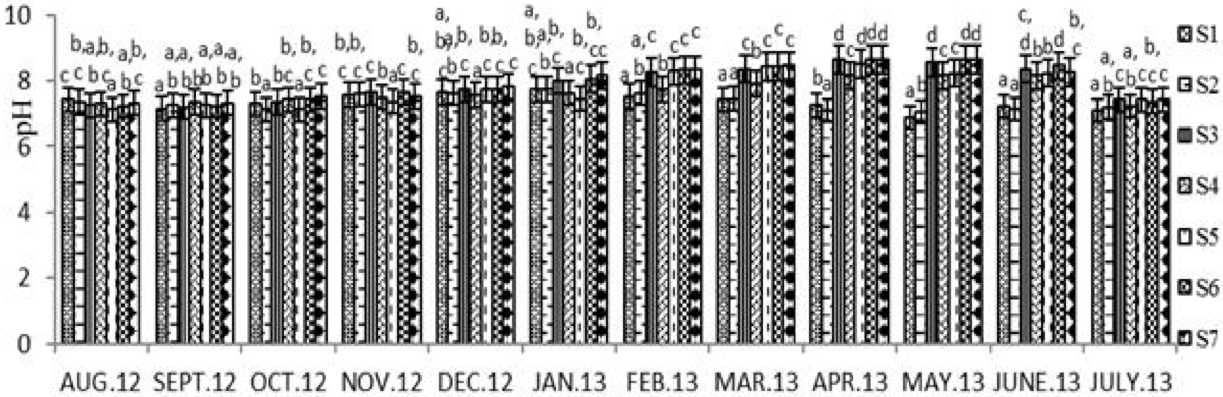
Table 3. Seasonal variation in concentration of heavy metal content (mg/l) in potable water at user end in Lucknow City (n=3± S D)

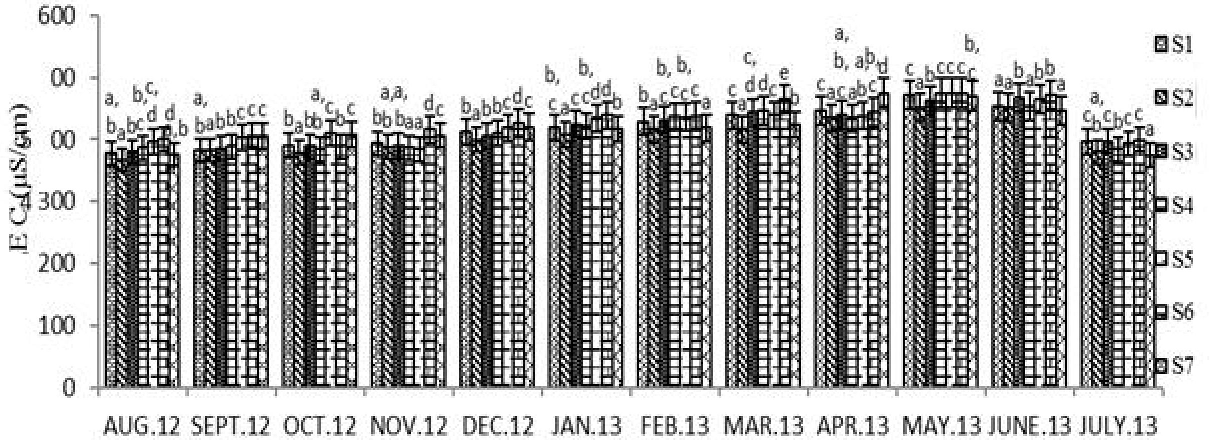
	Fe			Cu			Cd			Pb			Cr		
	Pre M	M	Po M	Pre M	M	Po M	Pre M	M	Po M	Pre M	M	Po M	Pre M	M	PoM
S1	0.506± 0.02^{a}	3.37± 0.04^{a}	0.16± 0.01^{a}	0.046± 0.01^{a}	0.04± 0.01^{a}	0.044± 0.01^{a}	0.012± $0.001^{a,b}$	0.007± 0.004^{a}	0.0098± 0.001^{a}	0.21± 0.02^{a}	0.255± $0.05^{a,b}$	0.152± 0.04^{a}	0.0207± 0.0002^{a}	0.0206± 0.0003^{a}	0.0155± 0.004^{a}
S2	0.518± 0.09^{a}	3.38± 0.13^{a}	0.15± 0.01^{a}	0.05± 0.02^{a}	0.06± 0.03^{a}	0.036± 0.01^{a}	0.01± $0.00^{a,b}$	0.008± 0.003^{a}	0.0083± 0.001^{a}	0.21± 0.08^{a}	0.29± 0.04^{b}	0.15± $0.04^{a,b}$	0.023± $0.005^{a,b}$	0.0206± 0.0002^{a}	0.015± 0.001^{a}
S3	1.18± 0.06^{b}	4.16± 0.06^{b}	0.28± 0.05^{b}	0.21± 0.08^{c}	0.2± 0.01^{b}	0.067± $0.04^{a,b}$	0.04± 0.009^{d}	0.033± 0.009^{c}	**0.046± 0.019^{b}**	0.52± $0.03^{c,d}$	0.304± 0.014^{b}	0.23± 0.01^{b}	0.026± 0.0005^{b}	0.0308± 0.001^{b}	0.026± 0.0005^{b}
S4	2.09± 0.05^{c}	4.61± 0.08^{c}	0.34± 0.05^{b}	0.11± $0.008^{a,b}$	0.29± $0.11^{b,c}$	0.102± 0.01^{b}	0.006± 0.002^{a}	0.007± 0.001^{a}	0.0073± 0.001^{a}	0.406± 0.006^{b}	0.18± 0.02^{a}	0.15± $0.03^{a,b}$	0.02± 0.0008^{a}	0.018± 0.002^{a}	0.013± 0.005^{a}
S5	2.64± 0.09^{d}	**5.32± 0.11^{c}**	2.18± 0.05c	0.21± 0.01^{c}	**0.37± 0.05^{c}**	0.223± 0.02^{c}	0.018± $0.002^{b,c}$	0.018± 0.001^{b}	0.012± 0.003^{a}	0.46± $0.02^{b,c}$	0.45± 0.03^{c}	0.35± 0.04^{c}	0.046± 0.0008^{c}	0.043± 0.004^{c}	0.033± 0.002^{c}
S6	3.16± 0.05^{e}	4.75± 0.08^{d}	2.36± 0.05^{d}	0.12± 0.02^{b}	0.26± $0.05^{b,c}$	0.098± 0.01^{b}	0.022± 0.005^{c}	0.015± $0.002^{a,b}$	0.019± 0.009^{a}	**0.58± 0.02^{d}**	0.57± 0.05^{d}	0.54± 0.05^{d}	0.05± 0.001^{c}	**0.051± 0.008^{c}**	0.03± $0.00^{b,c}$
S7	3.52± 0.08^{f}	5.24± 0.07^{d}	2.43± 0.08^{d}	0.127± 0.02^{b}	0.26± $0.06^{b,c}$	0.097± 0.02^{b}	0.014± $0.003^{a,b}$	0.018± 0.004^{b}	0.014± 0.002^{a}	0.49± 0.01^{c}	0.56± 0.06^{d}	0.57± 0.03^{d}	0.046± 0.002^{c}	0.047± 0.006^{c}	0.0358± 0.005^{c}
BIS		**0.3**			**0.05**			**0.01**			**0.05**			**0.05**	

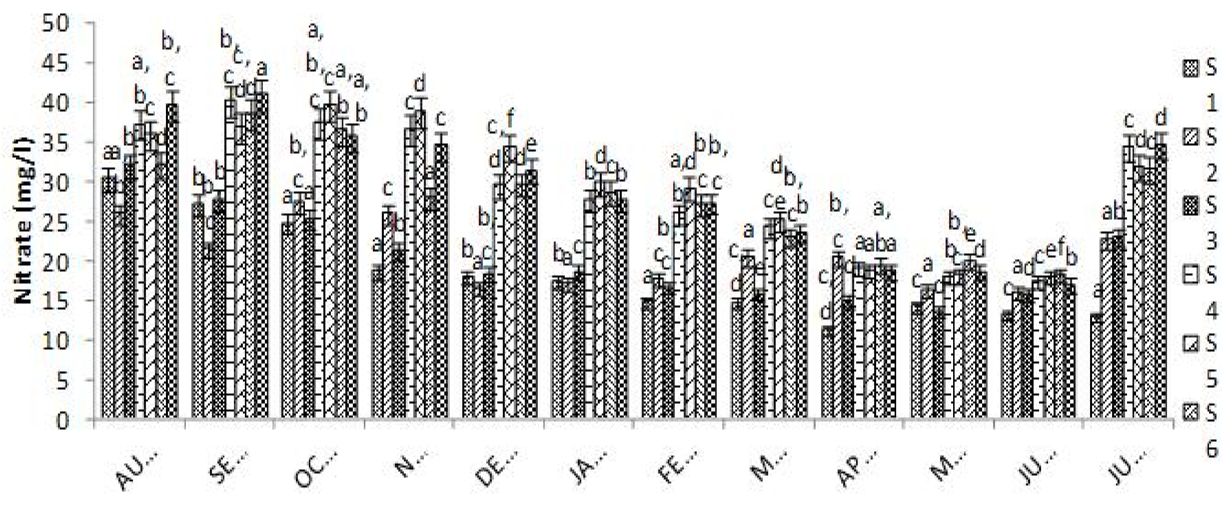
(Different letters signify the statistical differences among physico-chemical parameters ($p < 0.05$). S1= Aminabad, S2=Indira Nagar, S3=Aishbagh, S4=Nishatganj, S5=Telibagh, S6=Hazratganj and S7=Charbagh. Pre M= Premonsoon; M=Monsoon and Po M =Postmonsoon (Values represent Pearson correlation coefficient, significant at **0.01 and *0.05 level).

Table 4 Correlation coefficient (r) between physicochemical parameters and heavy metals of potable water at the user end of Lucknow municipality

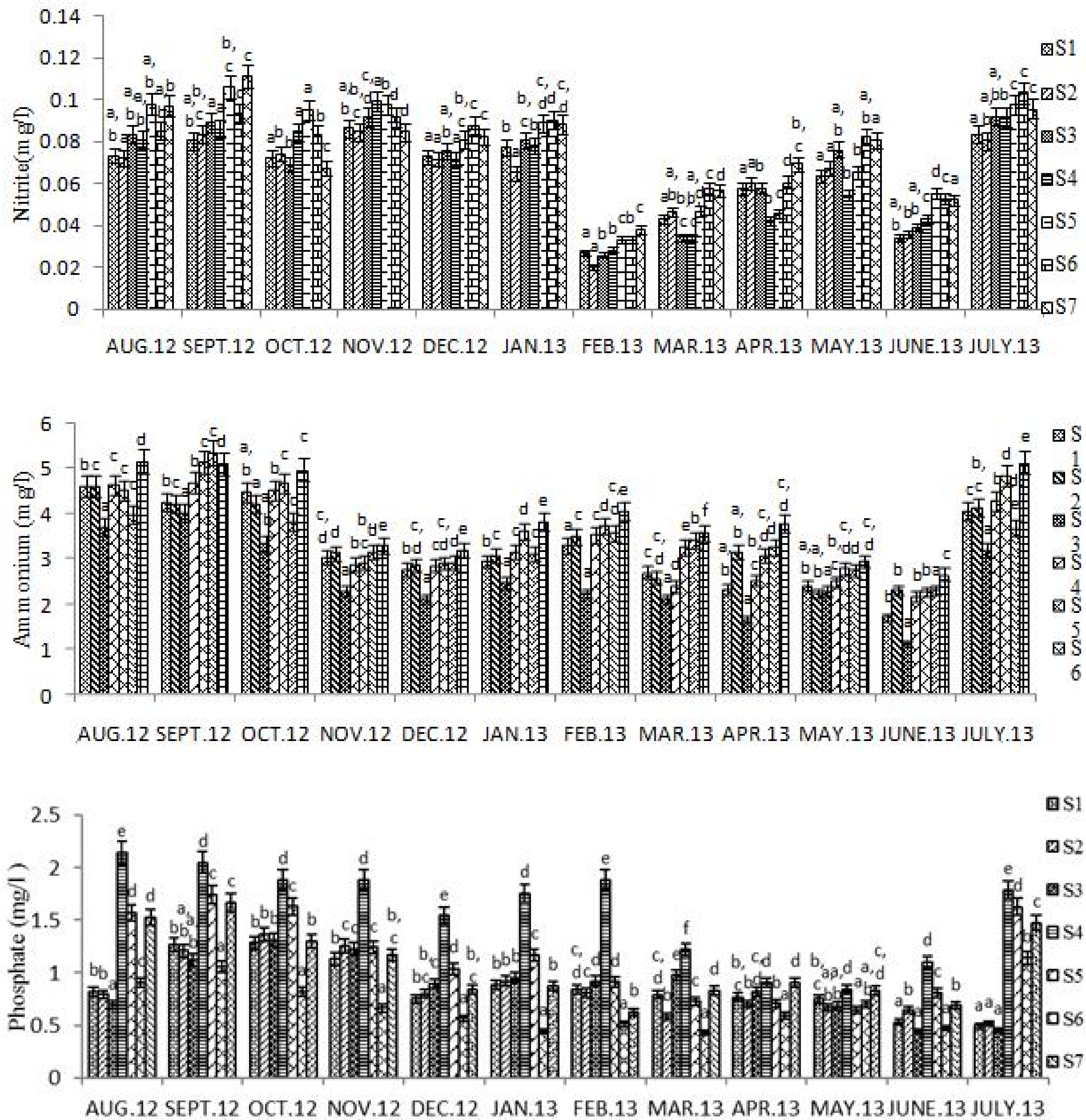
	pH	E. C	Nitrate	Nitrite	Ammonium	Phosphate	Fe	Cu	Cd	Pb	Cr
pH	1	.621**	-.581**	-0.327	-0.334	-.500*	0.131	-0.122	0.199	0.255	0.178
E.C		1	-.586**	-0.289	-0.12	-.589**	-0.141	-0.283	0.156	0.237	-0.112
Nitrate			1	.805**	.420*	.501*	0.268	-0.158	-0.222	-0.111	-0.043
Nitrite				1	.618**	0.399	.446*	-0.241	-0.151	0.234	0.23
Ammonium					1	.412*	-0.014	0.081	0.139	.589**	0.36
Phosphate						1	0.133	0.282	-0.156	-0.1	-0.024
Fe							1	0.157	-0.235	0.162	0.34
Cu								1	.456*	0.377	.499*
Cd									1	.592**	.452*
Pb										1	.760**
Cr											1







(Fig. 1 to 6) Monthly variations in pH (Fig.1), EC (Fig.2), Nitrate (Fig.3), Nitrite (Fig.4), Ammonium (Fig.5) and Phosphate (Fig.6) of drinking water at user end of urban Lucknow (Different letters signify the statistical differences among physico-chemical parameters ($p < 0.05$). S1= Aminabad, S2=Indira Nagar, S3=Aishbagh, S4=Nishatganj, S5=Telibagh, S6=Hazratganj and S7=Charbagh



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Highest correlation among metals wasobserved for Cr with Cu and Pb (pd”0.01) and with Cd at (pd”0.05). Significant positive correlation between various parameters reveals the close association between the parameters and also their influence on one another. It is also hypothesized that metals showing significant positive correlation among each other signify that they may be leached out from the same sources and their mobility in the environment may be the same (Haloi and Sarma, 2012; Mansouri *et al.*, 2012; Agca *et al.*, 2014).

CONCLUSIONS

Monitoring of specific inorganic contaminants and heavy metals in this study instead of plethora of parameters can be handy in reflecting the actual water quality supplied by the municipal corporation. Though water is treated at municipal treatment plants, post-treatment concentrations can be compared to the standard prescribed limits, which indicate whether the treated water can be reused for public supply. The present study reveals that the presence of inorganic pollutants and heavy metals in municipal water supplies of urban Lucknow is a major cause of concern for the public health. It was observed that among the studied sites Hazratganj and Charbagh were most polluted as water samples from these sites contained maximum metals contents. Further, the alkaline nature of this potable water can increase the metal toxicity at the consumer end. From the present study, it is concluded that the existing water treatment procedures do not comply with the specific drinking water standards. Therefore, the potable water supplied by the municipal cooperation should be treated prior to supply, for optimal removal of hazardous pollutants, so that public health is protected.

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