Asian Journal of Water, Environment and Pollution, Vol. 13, No. 3 (2016), pp. 45–54.
DOI 10.3233/AJW-160026

Evaluation of Suitability of River Water for Multipurposes by Assessing Various Indices

Mahfuz S. Sultana*, S. Rana, T. Imam, M. Aktaruzzaman and S. Yoshida[1]

Department of Environmental Sciences, Jahangirnagar University, Dhaka, Bangladesh
[1]National Institute of Radiological Sciences, Chiba, Japan
✉ mahfuzasharifa@yahoo.com

Received December 2, 2015; revised and accepted June 21, 2016

Abstract: The present research has evaluated the suitability of river water near industrial area of Dhaka for multi uses by calculating various indices. A considerable variation in the content of physicochemical and toxic elements in the studied river water suggests input of pollution from different sources. Further, excess concentration of Fe, Al and K compared to WHO standard was observed in Turag, Pb, Fe, Al, Cr and K in Buriganga, Cd, Fe, K, Al and Cr in Shitalakhya, Fe, Al and K in Bongshi and As in Dhaleswari river water. Moreover, all the river water is found to be safe for irrigation with respect to pH, TDS, SAR and MR. However, the metal pollution indices PF, PD, PLI and irrigation indices Na% and KI indicates that Buriganga river water is no longer suitable for the use of any purposes. But water of Turag, Shitalakhya and Bangshi River still can be used by controlling the source of pollution through proper treatment of waste or by preventing any further discharge of waste into the river. On the other hand Dhaleswari river water can be used for all purposes. Moreover, from the toxicity distribution pattern, it is seen that Buriganga > Shitalakhya > Bangshi > Turag > Dhaleswari. Therefore, proper management plan is necessary to protect this invaluable resource for multi use.

Key words: Irrigation, sodium adsorption ratio (SAR), Kellys index (KI), pollution indices (PF, PD, PLI).

Introduction

Surface water is the most important resource throughout the world, specially in a country like Bangladesh, where a majority of the population depends on it directly or indirectly. River water is highly susceptible to contamination from various sources of pollution. Different chemicals and trace metals have created such a pervasive surface water problem, affecting both moving water and still water, which need to be given special attention (Wang et al., 2008). Usually, river basins generally constitute areas with a high population density owing to favourable living conditions such as the availability of fertile lands, water for irrigation, industrial and drinking purposes and efficient means of transportation (Vega et al., 1998). Further, river plays a role in assimilating or carrying off industrial and municipal waste water, manure discharges and runoff from agricultural fields, road ways and streets which are responsible for river pollution (Stroomberg et al., 1995). During winter, the river water along with waste water is excessively pumped for irrigation. So contamination occurs by toxic elements from water to food chain through soil and field crops.

However, in Bangladesh major industrial hotspots are located close or in the major cities and are preferably sited adjacent to rivers or water bodies that facilitates disposal of effluents. Since our country is networked with small or big rivers, the pollution load from different sites has been added up and finally destroyed the fresh water aquatic ecosystem. The main rivers flowing around Dhaka are Buriganga, Turag, Dhaleswari,

*Corresponding Author

Shitalakhya and Bangshi. It is found that around 49% industries of Bangladesh including tannery, textile and dying, chemical, plastic metallurgy, resin, fertilizer etc. are located in greater Dhaka and surrounded by these rivers (Faisal et al., 2004). These rivers are being polluted with wastewater of thousands of industrial units, sewerage wastes and from agricultural practices which contain huge volume of toxic substances including heavy metals such as Cr, Cu, Pb, Ni, Mn, As, Cd, Fe, Hg and organic contaminants (Mahfuza et al., 2012, 2009; Moniruzzaman et al., 2009; Mohiuddin et al., 2010). Higher concentration of these toxic substances in the ecosystem lead to an excessive accumulation causing toxic to plant, living organisms and environment as a whole. The water of various sites of Buriganga and Turag has been significantly polluted and posed a serious threat to public health by creating incidents of water-borne and skin diseases (Ahmed et al., 2011; Tajuddin et al., 2012). Therefore, as a result of insensible human action and failure by the authorities to enforce rules and regulation to save the rivers, the rivers surrounding Dhaka are saturated with various toxic substances. On the other hand, with increasing industries and population in Dhaka, demand for clean water increases which put added pressure on the government to utilize the river water for multiuses.

Although many researches have been carried out to know the water quality of few rivers in Dhaka (Ahmed et al., 2011; Alam et al., 2011; Ali et al., 2008; Mahfuza et al., 2012, 2009; Moniruzzaman et al., 2009; Mohiuddin et al., 2010), the study on the suitability of river water around Dhaka for multipurpose has been rarely reported. Therefore, it is essential to take a comprehensive research to assess the various indices of essential and toxic elements of various rivers surrounding Dhaka in order to know the suitability of river water for different uses such as irrigation/fishing for agricultural production or drinking/recreation water for domestic purposes or raw water use for industrial purposes.

Materials and Methods

Samples were collected from the five rivers—Turag (RW 1-3), Dhaleshwary (RW 4), Buriganga (RW 5, 6), Shitalakhya (RW 7-10) and Bangshi (RW 11-14)—which exposed of different degrees of environmental pollution around Dhaka, the capital city of Bangladesh

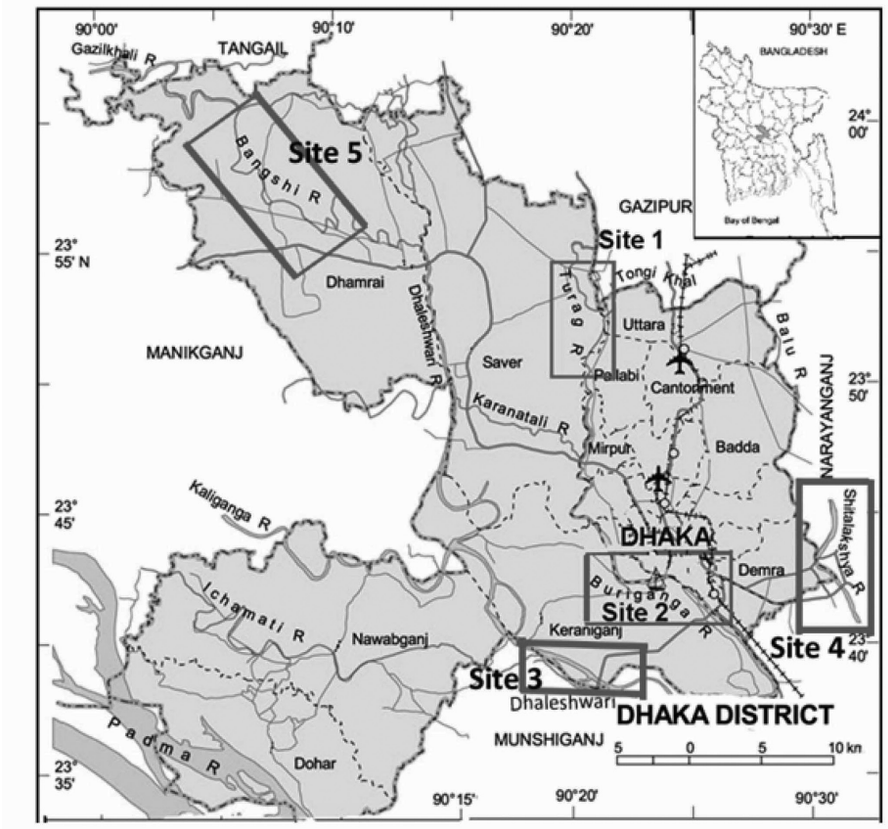

Figure 1: Map of the studied rivers.

(Figure 1). Buriganga is the most polluted river in Bangladesh which receives pollution load from the clusters of Hazaribug tannery industries and also from Naraynganj knitwear industries, sewerage wastes and urban pollution. The sampling sites of Shitalakhya river were selected near Kachpur Bridge at Dhaka-Chittagong highway because this area is situated between Narayangong Pourasava textile cluster and Rupgonj textile cluster. Besides a number of polluting industries of Adamje EPZ discharge their waste into river in this area and also one of the polluted river in Dhaka. Followed by Turag river, Turag Khal and Dhaleshary water also receives pollution load from numerous industries such as textile and dyeing, metal processing, battery manufacturing, pharmaceuticals and Pb-Zn melting etc. and also from domestic raw sewage of Gazipur area and preferred as polluted river. Bongsi river water is polluted by the hundreds of industries in DEPZ area. Further, this river waters were extensively used in the surrounding areas for irrigation to produce various agricultural products and causes environmental risk for the surrounding inhabitants. The map of the sampling sites is shown in Figure 1.

River water was collected from the fourteen stations along the five rivers (Sites 1, 2, 3, 4 and 5) for the analysis of physicochemical properties and toxic and major elements. River water samples were filtered by using disposable syringe filter unit and 0.45 µm Cellulose Acetate hyprophilic membrane filter. The physicochemical properties pH, EC, DO, salinity and TDS were analyzed in the laboratory of the department of Environmental Sciences, Jahangirnagar University, Dhaka, Bangladesh using standard methods (APHA, 2005). Further, the trace and major elements (Cu, Zn, Pb, Cr, Cd, As, V, Co, and Fe, Al, K, Na, Ca, Mg) in water samples were measured by ICP-MS (Aligent 7500, Yokogawa) and ICP-OES (VISTA-Pro, Seiko) after diluting the solution to a suitable concentration in the laboratory of the National Institute of Radiological Sciences, Chiba, Japan. The standard solutions were prepared from SPEX Multi Element Plasma standards (XSTC-1 and 355) supplied by SPEX industries, Inc. (Meutuchen, NJ, USA) and used to get calibration curves. The elements In, Rh and Bi were chosen as the internal standards in this analysis. The analytical procedures are same as Yoshida et al. (1998).

Data Analysis

Irrigation Water Quality Indices

In order to assess the suitability of studied river water for irrigation, some water quality indices like Sodium Adsorption Ratio (SAR), sodium percentage (Na%), the Kellys Index (KI) and magnesium ratio (MR) were considered and calculated following standard equation in Table 1.

Table 1: Common indices for irrigation water quality evaluation

Sl no	*Water quality indices*	*Sources*
1	$SAR = Na^{+}/\sqrt{((Ca^{2+} + Mg^{2+})/2)}$	Richard, 1954
2	$Na\% = ((Na^{+} + K^{+}) \times 100)/(Na^{+} + K^{+} + Ca^{2+} + Mg^{2+})$	Wilcox, 1948
3	$KI = Na^{+}/(Ca^{+} + Mg^{2+})$	Kelly, 1963
4	$MR = (Mg^{2+} \times 100)/(Ca^{2+} + Mg^{2+})$	Paliwal, 1972

Metal Pollution Load Indices

Pollution Factor (PF) and Degree of Pollution (PD)

The pollution factor (PF) and the degree of pollution (PD) are used to determine the pollution status of river water. The pollution factor is calculated according to the following equation.

$$PF = \text{Measured concentration/Permissible limit}$$

where WHO standard (2011) is used for permissible limit. PF values for describing the pollution level are shown in Table 2.

Table 2: Pollution factor and level of pollution factor (Hakson, 1980)

Pollution factor	*Level of pollution factor*
$PF_i < 1$	Low contamination factor indicating low contamination
$1 \leq PF_i < 3$	Moderate contamination
$1 \leq PF_i < 3$	Moderate contamination
$1 \leq PF_i < 3$	Moderate contamination

The degree of pollution (PD) is defined as the sum of all pollution factors. The degree of pollution (PD) is calculated according to the following equation.

$$PD = \Sigma_{i}^{n} PFi$$

PD values for describing the degree of pollution are shown in Table 3.

Pollution Load Index (PLI)

The PLI proposed by Tomlinson et al. (1980) provides some understanding to the public of the area about the quantity of a component in the environment. The PLI of a single site is the *n*th root of *n* number of multiplied

Table 3: Degree of pollution (PD) class and level of degree of pollution

Degree of pollution (PD) class	*Level of degree of pollution*
PD < 8	Low degree of contamination
8 ≤ PD < 16	Moderate degree
16 ≤ PD < 32	Considerable degree
32 ≤ PD	Very high degree

together Pollution factor (PF) values. The PF is the ratio obtained by dividing the concentration of each metal in the water by the baseline value.

$$PLI = (PF_1 \times PF_2 \times PF_3 \times \cdots \times PF_n)^{1/n}$$

Site indices can be treated in exactly the same way to give a zone or area index. Therefore, PLI for a zone is the *n*th root of *n* number of multiplied together PF values. A PLI value of zero indicates perfection, a value of one indicates the presence of only baseline levels of pollutants, and values above one would indicate progressive deterioration of the site and estuarine quality (Tomlinson et al., 1980).

Results and Discussion

Characterization of the Physicochemical Properties of the River Water

The physicochemical parameters such as pH, EC, TDS, salinity and DO of the irrigation water of the studied rivers varies 6.99-9.50, 194-2780 µS/cm, 93-1375 mg/L, 0.1-1.29% and 0.1-2.93 mg/L respectively. The pH for irrigation water are within the permissible limit (WHO, 2011) in all the studied river water except Bongshi. Moreover, EC of all the river exceeds the standard value except Dhaleshary whereas TDS value crosses only for the water of Shitalakhya. It is also interesting that the similar trend in the physicochemical properties (TDS and EC) of the river water was observed in all the studied rivers (Figure 2). Further, DO value shows toxic level in all the river water. Therefore, toxic level of these properties in the river water is harmful to aquatic life and surrounding ecosystem. To control this type of pollution in river environment proper treatment of industrial waste is necessary before discharge into the river.

Characterization of the Trace and Major Elements in the River Water

The concentration of trace and major elements obtained in the studied river water are presented in Figures 3a, 3b, 3c and 3d.

The concentration of Cu, Zn, As, Pb, Sr, K and Ca are found in all the studied river water within the range of 2.32 to 29.00 ppb, 2-112 ppb, 1.92-16.1 ppb, 4.68-0.96 ppb, 31.67-244 ppb, 0.90-25.53 ppm and 6.27-41.16 ppm respectively. Of them, the concentration of Cu, Zn, As, Sr and Ca are within the drinking water standard of WHO (2011) in all the studied river except K. The

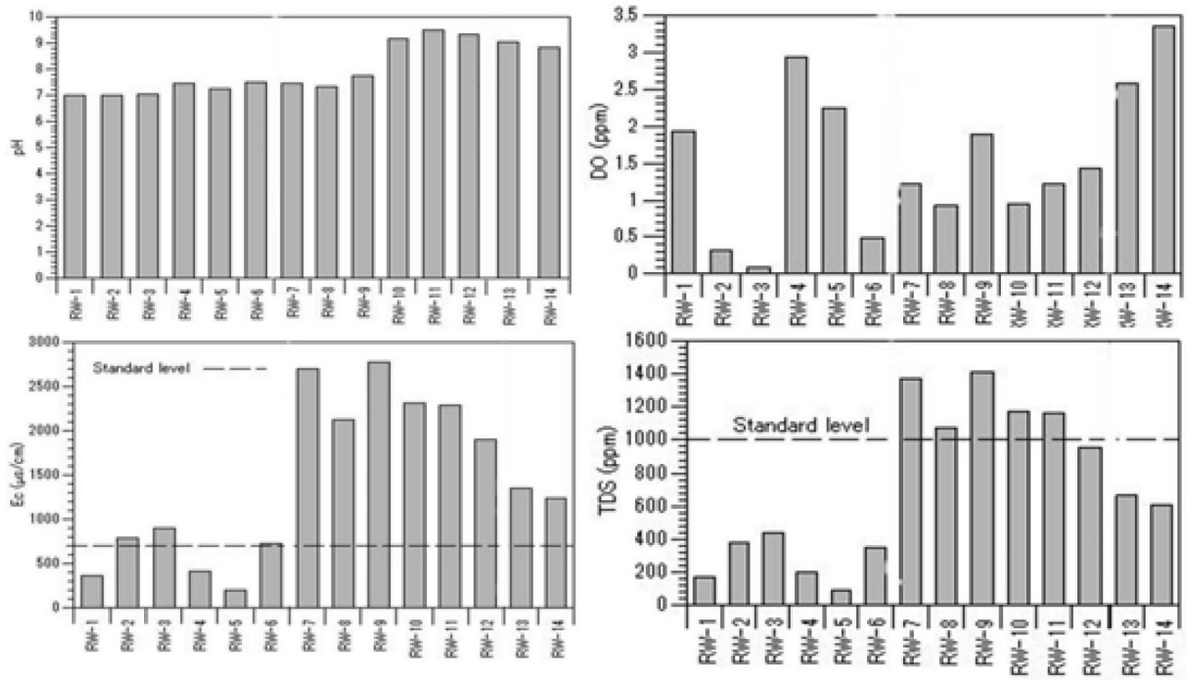

Figure 2: The variation of pH, DO, TDS and EC in the studied river water.

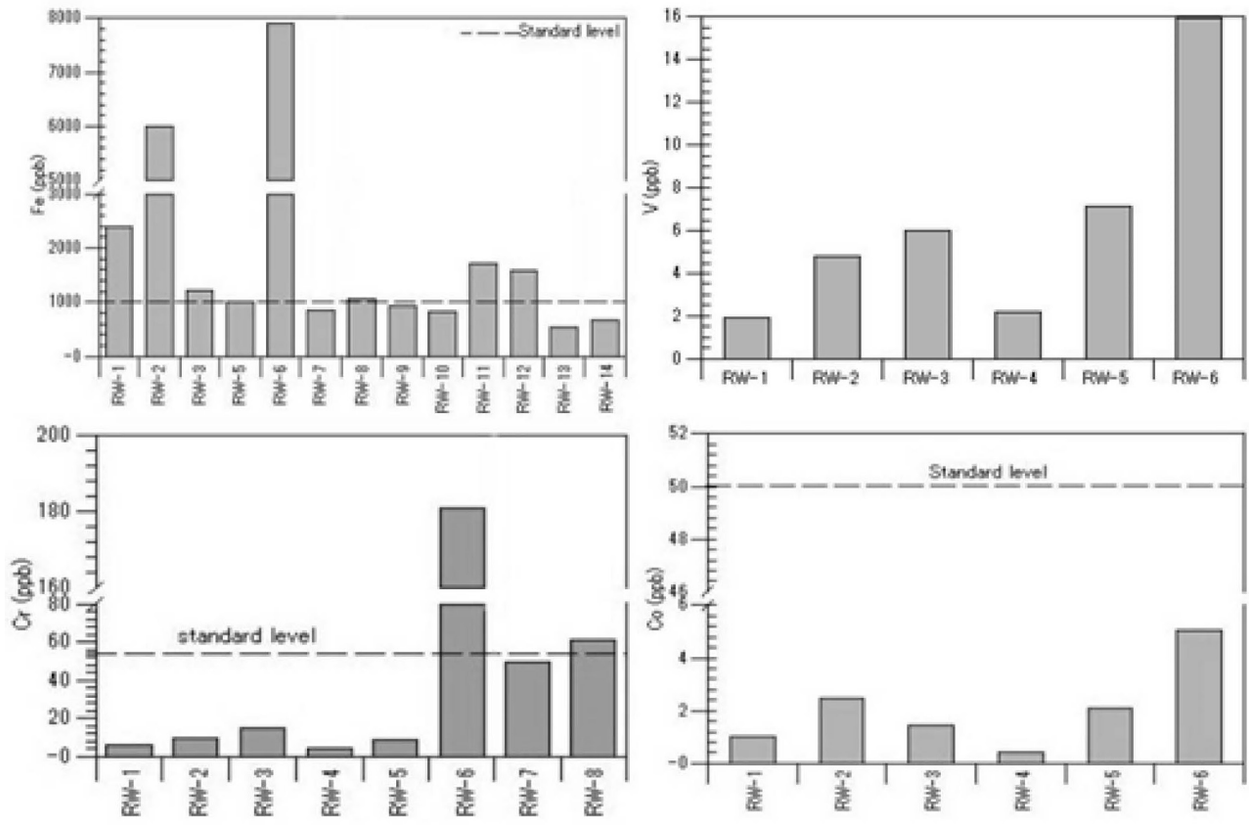

Figure 3a: Variation of toxic elements (Fe, V, Cr and Co) in the water of the studied rivers.

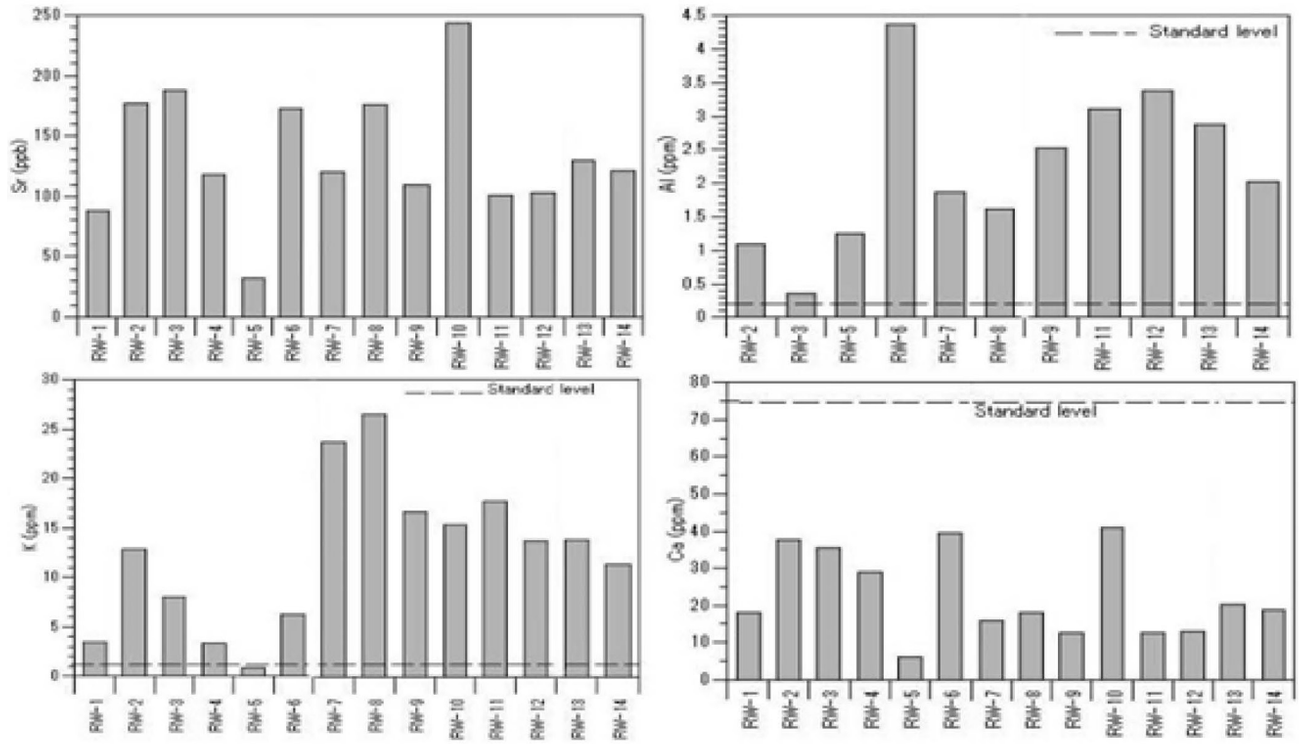

Figure 3b: Variation of toxic elements (Sr, Al, K and Ca) in the water of the studied river.

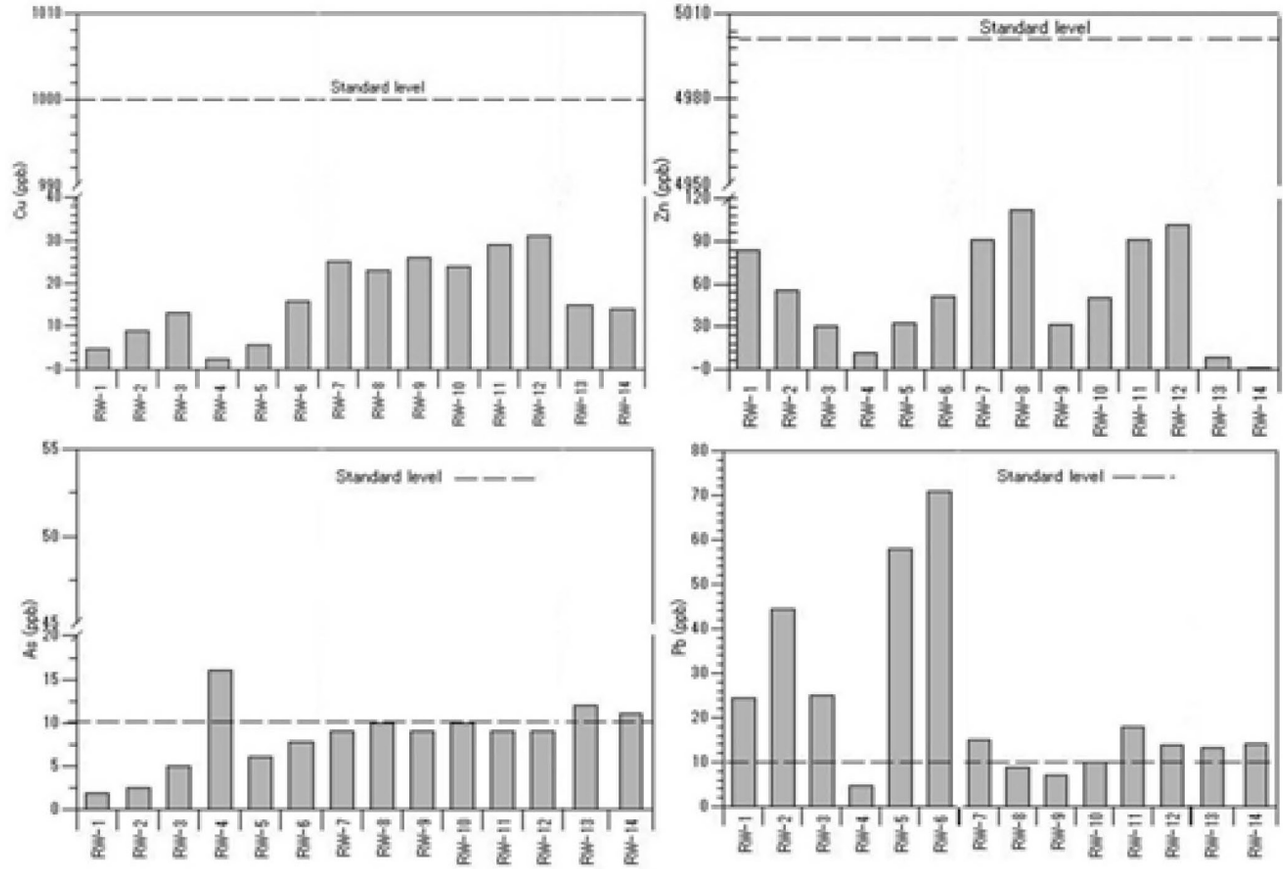

Figure 3c: Variation of toxic elements (Cu, Zn, As and Pb) in the water of the studied river.

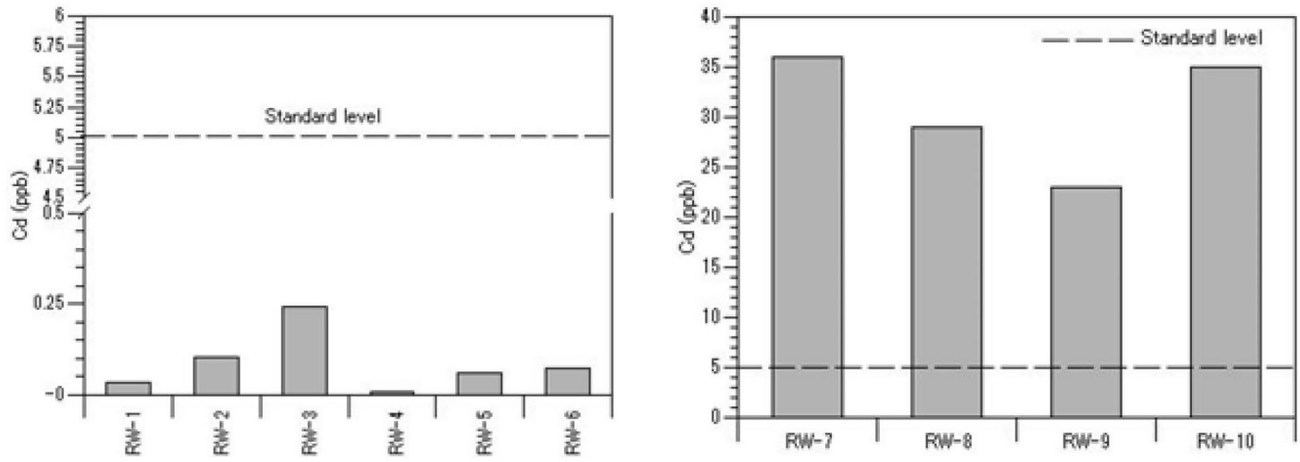

Figure 3d: Variation of Cd in the water of the studied river.

concentration of As is observed within the drinking water standard in all the river water except Dhaleshary. Further, the concentration of Fe and Al are found in all the river water except Dhaleshary with the range 546-7.90 and 0.36-4.37 ppm respectively. Moreover, the average concentration of Fe and Al cross the drinking water standard in all the river water which may be originated from the surface runoff or leaching of highly enriched Fe and Al containing soil of the studied areas. The concentration of V and Co are found in all the river water except Shitalakhya and Bongshi with the range 1.92-15.94 and 0.43-5.05 ppb respectively. Further, the concentration of Cr and Cd are found in all the river water except Bongshi with the range 4.46-180.07 and

0.007-36 ppb respectively. The average concentration of Cr crosses in the Buriganga river water whereas average concentration of Cd crosses in the Shitalakhya river water. In addition, the concentration of Pb crosses in all the river water except Dhaleshary. The above findings indicate that a large amount of toxic substances is released in to the Turag, Buriganga, Bangshi and Shitalakhya river from the surrounding industries which altered them unsuitable for irrigation and other purposes.

Assessment of the River Water Quality

Irrigation Water Quality

The results of the various irrigation water quality indices of the studied rivers are given in Table 4. The variation of the water pH of the studied rivers was observed to be in the moderate to normal range for irrigation. This implied that the water of the studied river is suitable for irrigation purpose. Salinity of river water that is used for irrigation is determined by EC, which is used as a surrogate measure of TDS concentration in water (Sundaray et al., 2009). According to the classifications of irrigation water based on EC and TDS, the Shitalakha and Bongshi river water are unsuitable for irrigation for high salinity. Comparing with WHO standard, EC of the river Shitalakha and Bongshi exceeded the tolerance limit for irrigation. The higher the EC the less quantity of water is available to plants and damage the crops (Khodapanah et al., 2009).

Further, the suitability of river water for irrigation was verified by calculating the sodium adsorption ratio (SAR), the sodium percentage (Na%), the Kellys Index (KI) and magnesium ratio (MR). The SAR value of all the river water was classified as normal level so showed excellent for irrigation use. The magnesium ratio (MR) of the studied river varied from 28 to 36%. However, sodium toxicity (Na%) of the Turag and Buriganga river water shows unsuitable for irrigation. The studied river water was further classified for irrigation suitability based on Kellys Index (KI). Usually, water with KI value <1 is suitable for irrigation whereas >1 is unsuitable for irrigation. It is seen that all the river water except Dhaleshary showed KI value >1, therefore unsuitable for irrigation.

Metal Pollution Load Indices

The pollution factor (PF) and pollution level of toxic metals in the studied river water are given in Table 5. Wide variation of toxicity levels was observed within the toxic metals as well as studied rivers. Out of eight toxic elements (Cd, Cr, Fe, Cu, Zn, Pb, As and Al) the pollution factor was found highest in Fe (26) and lowest in Cu (0.004) in the studied river water. Further, high pollution level was found for Fe, Al and Pb in the Turag river water, Fe, Cr, Pb and Al in the Buriganga river water, Fe, Cd and Al in Shitalakha river water and Fe and Al in Bongshi river water. Therefore, all the river water except Dhalashwary contain harmful level of toxic

Table 4: Water quality classes of the studied river water for irrigation use

Parameter	*Rate of hazard*	*Water class*	*River name*
pH	6.5-8.4	Suitable	Turag, Buriganga, Dhaleshary
	5.1-6.4 and 8.5-9.5	Moderate	Shitalakha, Bongshi
	0-5 and >9.5	Severe	
EC	250-750	Good	
	750-2250	Permissible	Turag, Buriganga, Dhaleshary
	>2250	Unsuitable	Shitalakha, Bongshi
TDS	<450	Good	Turag, Buriganga, Dhaleshary
	450-2000	Permissible	Shitalakha, Bongshi
	>2000	Unsuitable	
Na%	<40	Good	
	40-60	Permissible	
	60-80	Cautious	Turag, Buriganga
	>80	Unsuitable	
SAR	<10	Excellent	All river water
	18-26	Cautious	
	>26	Unsuitable	

Table 5: Pollution factor and pollution level of the studied river water

Element	*Turag*		*Buriganga*		*Dhalashwary*		*Shitalakhya*		*Bongshi*	
	PF value	*Pollution level*	*PF value*	*Pollution level*	*PF value*	*Pollution level*	*PF value*	*Pollution level*	*PF value*	*Pollution level*
Fe	19.96	Very high	26.35	Very high	-	-	3.5	Causing concern	5.71	Very high
Cr	0.3	Low	3.62	Causing concern	0.09	Low	1.22	Moderate	-	-
Cu	0.007	Low	0.008	low	0.0004	Low	0.01	Low	0.015	Low
Zn	0.03	Low	0.02	Low	0.004	Low	0.02	Low	0.034	Low
As	0.5	Low	0.8	Low	1.6	Moderate	1	Moderate	1.2	Moderate
Cd	0.08	Low	0.02	Low	0.002	Low	12	Very High	-	
Pb	4.4	Causing concern	7.1	Causing concern	0.5	Low	1.5	Moderate	1.8	Moderate
Al	5.5	Causing concern	21.87	Very high	-	-	12.61	Very High	17	Very high

elements which can not be used for drinking, irrigation, fishing and industrial purposes. However, Dhalashwary river water can be used for all purposes.

Moreover, the degree of pollution (PD) are used to determine the pollution status of river and PLI proposed by Tomlinson et al. (1980) provide some understanding to the public of the area about the quantity of a component in the environment. The degree of pollution (PD) and pollution load index (PLI) of the studied rivers are presented in Figures 4 and 5. The degree of pollution reveal that Buriganga river water has very high degree of pollution level; Turag, Shitalakhya and Bangshi rivers have considerable degree of pollution level and Dhalashwary river water has low degree of pollution level. Therefore, Buriganga river water is no longer suitable for fishes and other aquatic organisms or for the use of any other purposes. But rivers of Turag, Shitalakhya and Bangshi rivers still can be managed by controlling the source of pollution through proper treatment of waste or by preventing any further discharge of waste into the river. The PLI value of the various rivers showed the following trend Buriganga > Shitalakhya > Bangshi > Turag > Dhalashwary. So it is high time to protect the rivers from further pollution to save the river water which is one of the most important natural resource of our country.

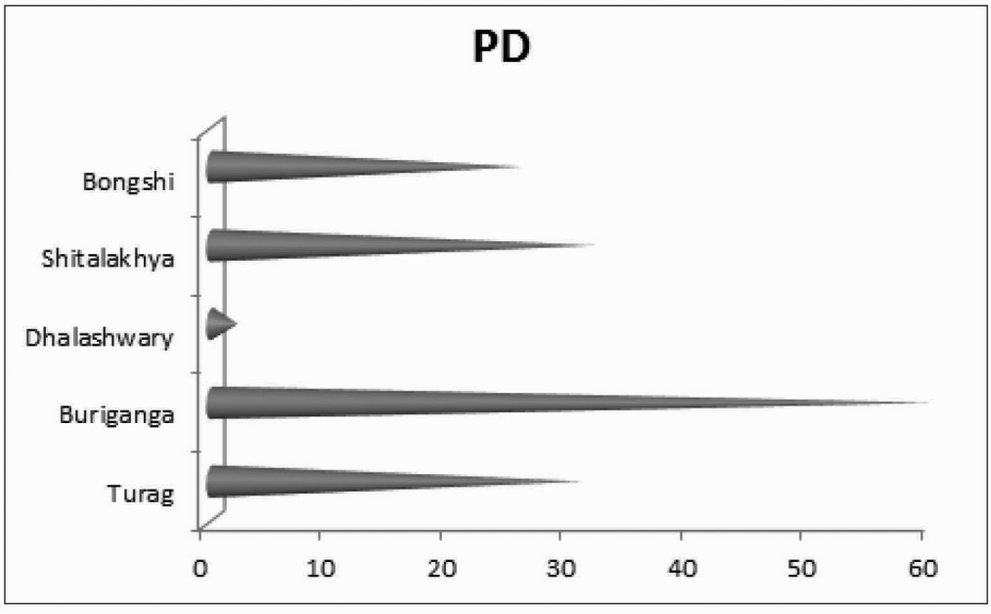

Figure 4: Degree of pollution (PD) of the studied rivers.

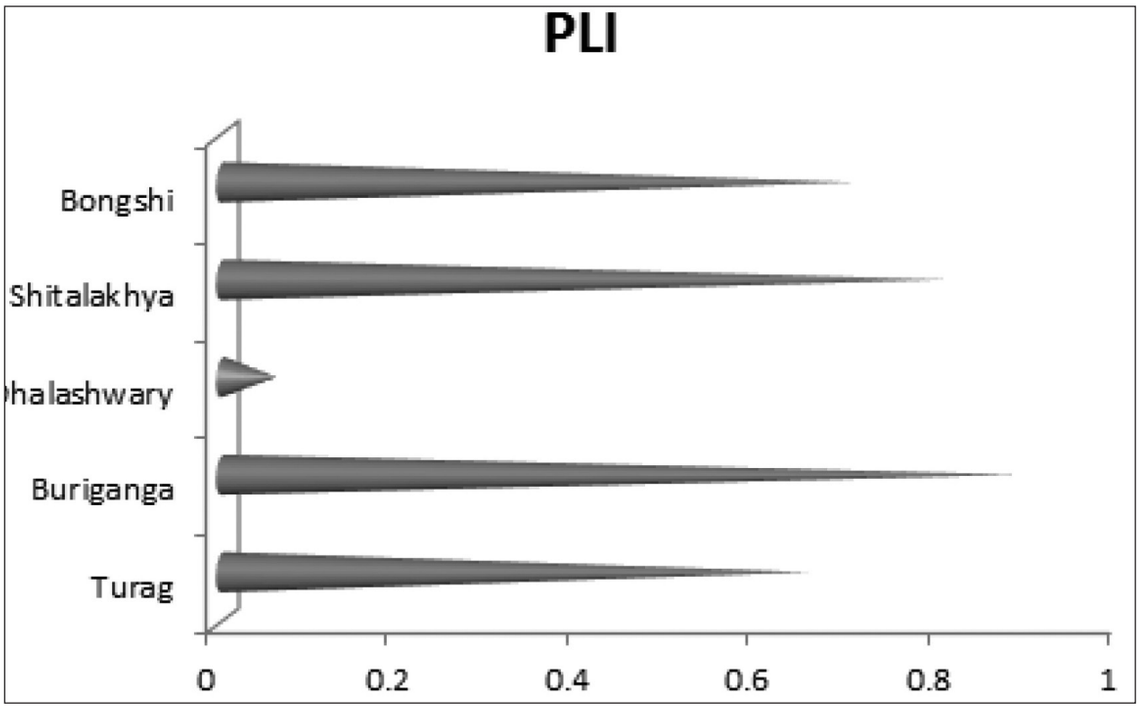

Figure 5: Pollution load index (PLI) of the studied rivers.

Conclusion

Water indices of the rivers (Turag, Dhaleswari, Buriganga, Shitalakhya and Bangshi) were investigated in order to know the suitability of river water for multi uses such as irrigation, industrial and domestic purposes as the river is a major source of water in this area. In general, physicochemical properties such as pH, EC, DO, salinity and TDS cross the WHO standard in the river water of Buriganga and Shitalakhya than other studied rivers. Further, the concentration of Cr, Fe, Pb, Al and K exceeded WHO standard in Buriganga river water, Cd, Fe, K, Al, Pb and Cr in Shitalakhya river water, Fe, Al, K and Pb in Turagh and Bangshi river water and As in Dhaleshwari river water. Moreover, all the river water is found to be safe for irrigation with respect to pH, TDS, MR and SAR. However, the metal pollution indices PF, PD and irrigation water quality indices Na% and KI indicate that Buriganga river water is no longer suitable for the use of any purpose. But water of Turag, Shitalakhya and Bangshi rivers still can be managed by controlling the source of pollution through proper treatment of waste or by preventing any further discharge of waste into the river. On the other hand Dhaleswari river water can be used for all purposes. Moreover, from the toxicity distribution pattern and PLI value of the various rivers showed the following trend Buriganga > Shitalakhya > Bangshi > Turag > Dhalashwary. Therefore, a large amount of toxic substances which released in to the Turag, Buriganga, Bangshi and Shitalakhya rivers from the surrounding industries altered them unsuitable for irrigation and other purposes. As the studied rivers are the most utilized rivers in greater Dhaka, so it is necessary to protect these rivers by enforcing the environmental policy of water resource management for multiuse.

Acknowledgement

The authors are highly grateful to the Japan Society for Promotion of Science (JSPS) for their kind support (Short-Term Invitation Fellowship) to conduct this research work at National Institute of Radiological Sciences, NIRS, Chiba, Japan. Authors are also grateful to the Ministry of Science and Technology of Bangladesh for providing assistance to this research. Further, we are thankful to Md Rafiqul Islam, the technical officer of the Department of Environmental Sciences for his cooperation during sample analysis in the laboratory of Environmental Sciences, Jahangirnagar University, Dhaka, Bangladesh.

References

Ahmed, M.K., Das, M., Islam, M.M., Akter, M.S. and S. Islam (2011). Physico-Chemical Properties of Tannery and Textile Effluents and Surface Water of River Buriganga and Karnatoli, Bangladesh. World Applied Sciences Journal, **12(2):** 152-159.

Alam, A.M.S., Islam, M.A., Rahman, M.A., Alam, M.N., Siddique, M. and M.A. Matin (2003). Comparative study of the toxic metals and nonmetal status in the major river systems of Bangladesh. Dhaka Univ. J. Sci., **51(2):** 201-208.

Ali, M.N. and K. Alam (2008). Ecological Health Risk of Buriganga River, Dhaka, Bangladesh. Hydro Nepal, **3:** 25-28.

APHA (2005). Standard Methods for the Examination of Water and Wastewater. 22nd edition. ISBN #978-087553-0130.

Faisal, I., Shammin, R. and J. Junaid (2004). Industrial Pollution in Bangladesh. World Bank Report.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control a sedimentological approaches. Water Research, **14:** 975-1001.

Kelley, W.P. (1963). Use of saline irrigation water. Soil Science, **95:** 355-391.

Khodapanah, L., Sulaiman, W.N.A. and N. Khodapanah (2009). Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran. European Journal of Scientific Research, **36(4):** 543-553.

Sultana, Mahfuza S., Kulsum, U., Shakila, A. and M.S. Islam (2012). Toxic Metal Contamination on the River near Industrial Area of Dhaka, U. Journal of Environmental Research and Technology, **2(2):** 56-64.

Sultana, Mahfuza S., Islam, M.S., Saha, R. and A.M.A. Mansur (2009). Impact of the effluent of textile dyeing industries on the surface water quality inside D.N.D. embankment, Narayanganj. Bangladesh J. Sci. Ind. Res., **44(1):** 65-80.

Moniruzzaman, M., Elahi, S.F. and M.A.A. Jahangir (2009). Study on Temporal Variation of Physico-chemical Parameters of Buriganga River Water through GIS (Geographical Information System) Technology. Bangladesh J. Sci. Ind. Res., **44(3):** 327-334.

Mohiuddin, K.M., Zakir, H.M., Otomo, K., Sharmin, S. and N. Shikazono (2010). Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. Int. J. Environ. Sci. Tech., **7(1):** 17-28.

Paliwal, K.V. (1972). Irrigation with saline water. I.A.R.I. Monogram no. 2 (New series), New Delhi.

Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Hand Book, No. 60.

Stroomberg, G.J., Freriks, I.L., Smedes, F. and W.P. Cofmo (1995). Quality Assurance in Environmental Monitoring. P. Quevauviller (ed.). VCH, Weinheim.

Sundaray, S.K., Nayak, B.B. and D. Bhatta (2009). Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India—A case study. Environmental Monitoring and Assessment, **155:** 227-243.

Tajuddin, S.M., Yasuda, M., Yustiawati, Syawal S.M., Sato, T., Tanaka, S. and M. Kurasaki (2012). Comparative Assessment. IJEP, **2(4):** 8-13.

Vega, M.R., Barrado, E. and L. Deban (1998). Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Wat. Res., **32(12):** 3581-3592.

Wang, S., Cao, Z., Lan, D., Zheng, Z. and G. Li (2008). Concentration distribution and assessment of several heavy metals in sediments of west-four Pearl River Estuary. Environ Geol., **55:** 963-975.

WHO (2011). Guidelines for drinking water quality 1: Recommendations. WHO, Geneva.

Wilcox, L.V. (1948). The quality of water for irrigation use. US Department of Agriculture, Technical Bulletin, Washington, DC.

Yoshida, S., Muramatsu, Y., Tagami. K. and S. Uchida (1998). Concentration of Lanthanide elements, Th and U in 77 Japanese surface soil. Environ. Int., **24:** 275-286.