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Spatial Variation of Rainwater Quality Parameters at Khulna City of Bangladesh

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Abstract In the present study, rainwater samples were collected from the Khulna city of Bangladesh during pre-monsoon season (March-May) and monsoon season (June-October) with standard rainwater collection instruments in the year 2017 to 2019 to evaluate their physical and chemical quality parameters properties. The following water quality parameters were determined: pH, EC, TDS, DO, alkalinity, acidity, hardness, Ca^{2+}, Mg^{2+}, $SO4^{2-}$, NO_3^{2-}, Cl^- and heavy metals. This study revealed that rain water quality was within the permissible drinking water standards limits prescribed by Environment Conservation Rule (ECR, 1997) of Bangladesh. Metal ions (As, Cd, Cr, Pd and Hg) were found in below the detection limit (BDL) of AAS for these collected rainwater samples. Rainwater quality during monsoon season was better than that of pre-monsoon season in Khulna city due to particle of dusts in the air. Atmospheric suspended particulate matter (SPM) including PM10 might be contributed some parameters; EC TSD, Ca^{2+}, Mg^{2+}, $SO4^{2-}$, NO_3^2 and pH may be slightly changed due to present gaseous components (CO_2, SO_2 and NO_2). If rainwater is properly harvested that will be a safe, cost effective and alternative to provide an access to safe drinking water in the saline coastal region of Khulna area.

Keywords: *rainwater, salinity, heavy metals, water quality, physicochemical properties*

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1. Introduction

Khulna coastal area is one of the most vulnerable areas in Bangladesh in terms of access to safe drinking water, mostly because of salinity problem [1]. In coastal regions groundwater quality patterns are complex, because of the input from different water sources including precipitation, seawater, ascending deep groundwater and anthropogenic sources [2]. Problems in coastal areas are typically connected to contamination of fresh water resources by saline water and include well field salinization, crop damage, and surface water quality deterioration [3]. Salinity becomes a major problem in south-western coastal region of Bangladesh, where irrigation water quality is affected by high levels of salinity which is a source of irrigation salinity and it mainly results from rises in the groundwater table due to excessive irrigation and the lack of adequate drainage for leaching and removal of salts [4,5]. Most crop lands in the coastal areas of Bangladesh remain fallow in the dry season because surface water resources are saline and unsuitable for irrigation, while groundwater is not intensively utilized because of the fear of seawater intrusion into aquifers [6]. Seawater intrusion is a major threat in the coastal aquifers of Bangladesh, especially in southwestern region [7,8,9]. The over dependence on groundwater for drinking, agricultural and industrial sector and different climatic and natural phenomenon causes coastal groundwater contamination [10].

Microbial pathogens, arsenic (As) in groundwater and salinity are main issues surrounding water quality in Bangladesh. For decades, the widespread contamination of groundwater by As in Bangladesh has been recognized as a severe problem [11,12]. Although it is naturally occurring, Arsenic contamination is a continuing public health issue in Bangladesh, potentially affecting millions of people [13,14]. Chronic exposure to high levels of arsenic is associated with a multitude of health issues including cancers, cardiovascular disease and skin lesions [15]. Salinity has been recognized as a significant water problem in coastal Bangladesh for some time, as a result of both man-made and natural causes [16,17]. On the coast, most of the groundwater used for water supply is pumped from the top 150 m, but much of it is saline [18]. The health effects of dietary salt intakes are understood and well-documented. However, studies on health effects of drinking saline water are scarce demonstrated significant risk of pre/eclampsia and gestational

hypertension in women in the Dacope Upazila of Bangladesh; rates were higher in coastal residents compared to non-coastal areas [19,20]. It also showed that women consuming tube well drinking water were at higher health risks than those who used pond water or rainwater.

Rainfall in Bangladesh is not consistent temporally or spatially; 80 % of the rainfall occurs during June–September [14,21]. This seasonal nature of water supply affects the choices people make in selecting drinking sources and the quality of those sources. The long dry season results in local water scarcity and degraded water quality, and necessitates the use of multiple drinking water sources to meet basic personal needs. Khulna city is humid during summer and pleasant in winter. Khulna has an annual average temperature of 26.3 °C (79.3 °F), with monthly average temperatures from 12.4 °C (54.3 °F) in January to 34.3 °C (93.7 °F) in May. Its annual average rainfall is 1,809.4 millimetres (71.24 in), and about 87 percent falls between May and October [22].

Safe drinking water is a fundamental need of every human being despite of any socioeconomic status. It is impossible to stop arsenic and salinity problem in Khulna area. Ground water, surface water or supplied water by Khulna Water Supply and Sewerage Authority (KWASA) has exceeded acceptable limit in some parameters especially arsenic and iron. Rainwater is alternative source of drinking water [23]. Harvesting of rainwater can play significant role in agricultural purposes. About half of Singapore's land area is used as catchments for rainwater collection. The new building or complex requires discharging no more than 1% rainwater to sewerage in Germany. Local governments are very active in promoting rain water harvesting by way of subsidies in Japan. Madhya Pradesh local government of India offers rebate of 6 % on property tax to encourage the public for implementing rainwater harvesting systems. Rainwater harvesting materials are tax-free in USA [24,25,26]. Due to cost effectiveness, rainwater harvesting (RWH) systems are practicing already in some rural parts of Bangladesh but very few in urban areas [27]. With the preeminent of our knowledge no studies has been reported yet in assessment of physicochemical quality parameters of rainwater of Khulna city. So the present study aims to investigate the physicochemical properties of rainwater of Khulna city and assess the rainfall water whether it is acidic or not. It is also intended to delineate its utility for proper understanding and future management perspective of rainwater harvesting.

2. Material and Method

2.1. Study Area and Sampling Time

Khulna is Bangladesh's third-largest city, after Dhaka and Chittagong in Bangladesh. It covers an area of 59.57 square kilometres (23.00 sq mi); Khulna is north of the Bay of Bengal. It is part of the Ganges Delta, the world's largest river delta. The Sundarban, the world's largest mangrove forest, is in the southern part of the delta. Khulna is considered the gateway to the Sundarbans and home of the Bengal tiger [28]. The samples were collected from Daulatpur area near Khulna University of Engineering and Technology (KUET) in Khulna city (Latitude: 22° 53' 15.00" N Longitude: 89° 31' 0.12" E.), from the year 2017 to 2019 by the proper sampling process. Samples were collected two times (Pre-monsoon and monsoon season) in each year. Pre-monsoon season lasts from March through May month and monsoon season lasts from June through October month. Each sampling started at the time of the onset of each rainfall incident.

2.2. Sample Collection

In this study, for the analysis of physicochemical properties, samples were collected from sampling area's city dwellers houses. Rainwater samples were collected manually in an open space from a height of 10 ± 2 meters above ground level, in clean acid-washed polyethylene bottles through glass funnels. The sampling bottles were labeled with a distinctive identification number. (Table 1) for each sample, and stored at 4°C prior to analysis. Five liters plastic bottles were used for collecting samples for physicochemical analysis. Prior to collection, the plastic bottles were cleaned by detergent solution and followed by it was treated with 5% nitric acid overnight. These bottles were finally washed with de-ionized water and dried in the air. During sampling the sample bottles were firmly screwed. The pH, electrical conductivity EC) and total dissolved solids (TDS) were measured at the site during sample collection. Then samples were reserved in ice bag tied well. Then, it was carried to the laboratory and stored in the refrigerator for analysis.

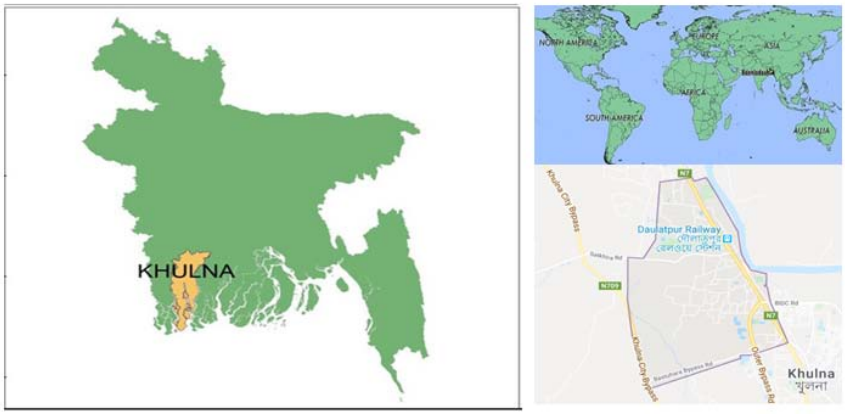

Figure 1. Sampling location for rain water

Table 1. Sample Identification Number

Sample Identification no	Sampling Time
K-1701	Pre-monsoon season, 2017
K-1702	Monsoon season, 2017
K-1801	Pre-monsoon season, 2018
K-1802	Monsoon season, 2017
K-1901	Pre-monsoon season, 2019
K-1902	Monsoon season, 2019

2.3. Sample Analysis

pH, Temperature and Electrical Conductivity (EC) were measured at the sampling spot and the other parameter TDS, DO, heavy metals and anions of the samples were analyzed at the Institute of National Analytical Research and Service (INARS) of Bangladesh Council of Scientific and Industrial Research (BCSIR) by standard methods [29]. The temperature of water was recorded with the help of a thermometer calibrated from Cali-lab, India. pH, EC and DO were measured by portable multi parameter meter (Senion^{TM}156, HACH, USA). TDS was determined gravimetrically by following standard methods [30,31]. A certain amount of samples were filtered by using Whatman 44 filter paper followed by drying at 180°C in a calibrated oven for measuring TDS. Acidity and carbon dioxide was determined by NaOH titration method.

Analysis of metals such as Arsenic (As), Iron (Fe), Magnesium (Mg), Calcium (Ca), Lead (Pb), Mercury (Hg), Zinc (Zn) and Cadmium (Cd) were measured by Atomic Absorption Spectrometry. 100 mL sample was digested in 5 mL HNO_3 on a hot plate in fume hood [32]. The sample was gently boiled to the lowest possible volume until digestion completed as shown by a light color, lucid solution. After complete digestion, cool sample was transferred to 100 mL volumetric flask and diluted up to the mark. The sample was then filtered and analyzed by Atomic Absorption Spectrometer (Model: AA240FS, Varian, Australia) for metals content following the techniques described previously. In case of high concentration, the sample was diluted by using de-ionized water [33].

Anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-}) were measured using Ion Chromatograph (SIC10AVP, Shimadzu, Japan) following the procedure reported earlier. Samples were filtered through 0.22 micron filter to avoid dust particles. 1.3 mM Sodium carbonate (Na_2CO_3) and 1.7 mM Sodium bi-carbonate ($NaHCO_3$) mixer was used as a mobile phase to separate ions in an ionic chromatographic column (HIC 10A super).

2.4. Calibration Standards Used for Sample Analysis

Zero solution (5% $NaSO_2$ solution), buffer solutions (pH=4.0, pH=7.0), 1000 µS/cm of NaCl solution were used to calibrate portable multi parameter meter for determining Dissolved Oxygen, pH & conductivity, respectively.1000 mg/L stock metals and anions standard (Scharlau, Spain) solutions were used to make calibration standards. The stock standards were diluted to certain concentration of calibration standards required to measure different metals by AAS.

3. Result and Discussion

Table 2. Physicochemical Parameters of Rainwater

Sample ID	pH	DO (mg/L)	EC (µS/cm)	TDS (mg/L)
K-1701	6.50	4.86	53.7	26.4
K-1702	6.79	5.88	31.8	15.1
K-1801	6.44	4.55	58.5	27.5
K-1802	6.58	5.77	37.3	17.3
K-1901	6.33	2.54	101	48
K-1902	6.52	5.33	44.9	21.7
ECR-1997 [34]	6.5-8.5	6.0	--	1000
WHO (4th edition) [35]	6.5-8.5	--	--	600

The pH value of all samples was within 6.33-6.79. The pH of rainwater during the pre-monsoon season was less among whole year which is due to the lower concentrations of nitrate and sulphate [36]. It indicates that the rainwater is slightly acidic during pre-monsoon compared to monsoon."Clean" or unpolluted rain has an acidic pH, but usually no lowers than 5.7, because carbon dioxide and water in air react together to form carbonic acid, a weak acid according to the following reaction [37].

$$H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq)$$

The values of pH were below the neutral values (pH=7.0) due to present trace gases in the atmosphere. Jun Xiao reported that large inputs of soil dusts and coal combustion during the winter and spring led to higher values of major ions and pH values during dry seasons than wet seasons at Xi'an city in China [38]. Dissolved oxygen (DO) of pre-monsoon samples was lower than that of monsoon samples. The dissolved oxygen content was found to be less than 3.0 mg/L during the period of pre-monsoon which was less than the desirable amount of dissolved oxygen in drinking water. The value of DO of pre-monsoon season is lower due to the excess of dust in the air.

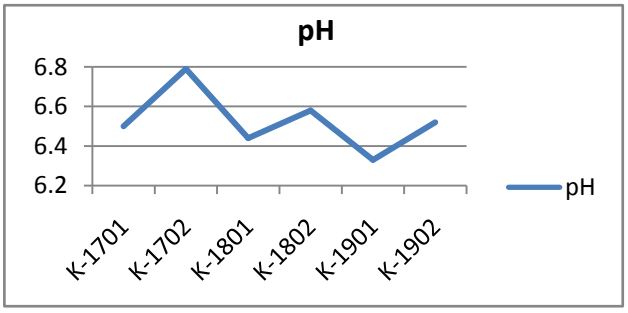

Figure 2. Variation in pH of rainwater

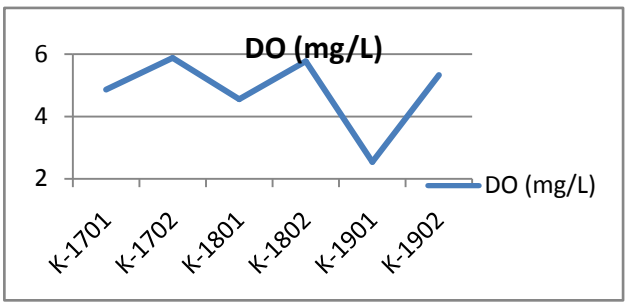

Figure 3. Variation in DO of rainwater

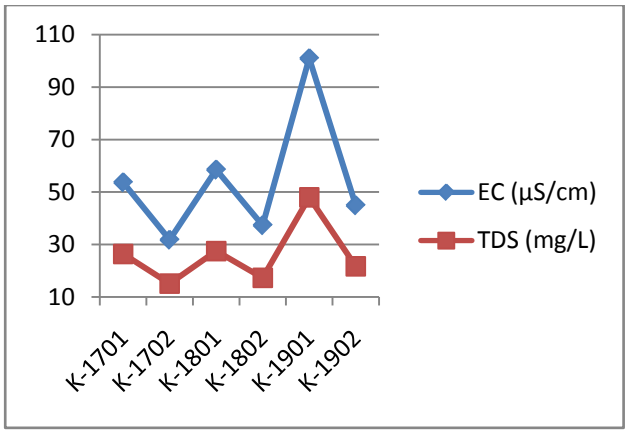

Figure 4. Variation in EC and TDS of rainwater

Electrical conductivity and total dissolved solids of pre-monsoon samples were higher than that of monsoon samples. Electrical conductivity of rainwater reflects the impact of atmospheric particulate matter on the precipitation chemistry. Rainwater conductivity is mainly contributed by water-soluble ions, the value being related to the total sum of cations and anions in the rainwater. Low rainwater conductivity is an indicator of good atmospheric environmental quality. The total dissolved solids (TDS) in rainwater, originating from particulate matter suspended in the atmosphere usually range from 2 mg/l to 20 mg/L. However, the study disagreed with the finding since total dissolved solids concentration has gone beyond the 20 m/l limit and probably due to the high concentration of particulate matter in the atmospheric air. The value of collected samples pH, DO, EC and TDS was within acceptable limit of Environment Conservation Rules (ECR)-1997, Bangladesh. It was observed that there was no salinity in collected rain water samples.

The acidity value of rain water was higher during the period of pre-monsoon compared to monsoon. Where acidity value was higher, there dissolved carbon-di-oxide value was higher. The low pH found in samples indicates high presence of CO_2 with trace amount of SO_2 NO_2 in the atmosphere as a result of excessive bush burning within the environs. The value of acidity and dissolved carbon-di-oxide was below of acceptable limit of drinking water. Alkalinity value of rainwater was higher than that of acidity value. Bi-carbonate value was between 19-24 mg/L as $CaCO_3$.

Table 3. Physico-chemical quality parameters of Rainwater

Sample ID	Acidity (mg/L) as $CaCO_3$	CO_2 (mg/L) as $CaCO_3$	Alkalinity (mg/L) as $CaCO_3$	Bi-Carbonate (mg/L) as $CaCO_3$	Hardness (mg/L) as $CaCO_3$	Ca (mg/L)	Mg (mg/L)
K-1701	6.67	5.87	16.8	20.49	68.59	14.21	8.04
K-1702	5.59	4.92	15.6	19.02	63.42	13.08	7.47
K-1801	9.50	8.36	18.4	22.44	78.94	15.47	9.79
K-1802	7.38	6.49	17.2	20.98	70.64	14.90	8.12
K-1901	12.11	10.65	19.5	23.78	89.07	17.91	10.77
K-1902	9.09	8.00	18.9	23.06	82.75	16.88	9.86
ECR-1997 [34]	--	--	--	--	200-500	75	30-65
WHO (4th edition) [35]	--	--	500	--	--	100	30

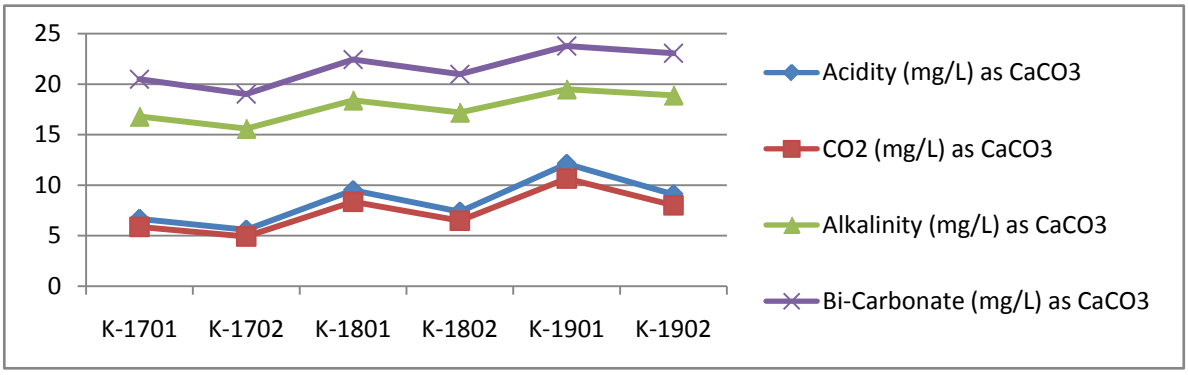

Figure 5. Variation in Acidity, CO_2, Alkalinity and Bi-carbonate of rainwater

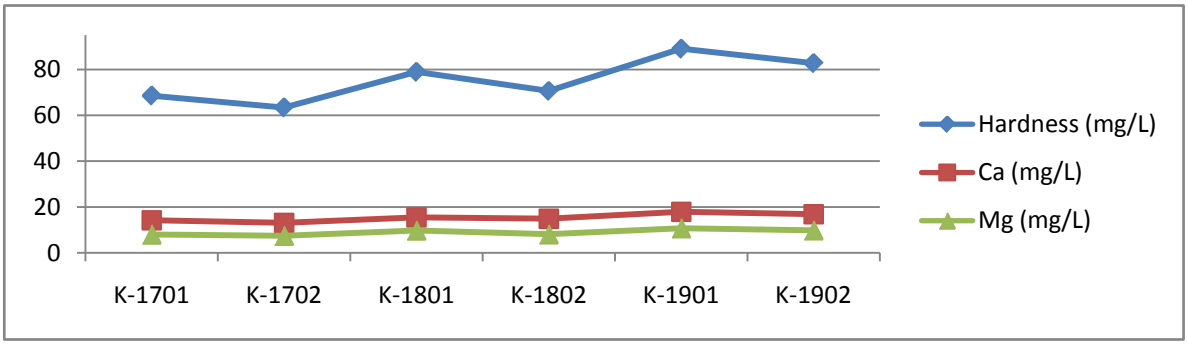

Figure 6. Variation in Hardness, Ca and Mg of rainwater

Table 4. Anions of Rainwater

Sample ID	Fluoride (mg/L)	Chloride (mg/L)	Nitrite (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Sulphate (mg/L)
K-1701	< 0.5	< 1.0	< 1.0	< 1.0	6.33	5.22
K-1702	< 0.5	< 1.0	< 1.0	< 1.0	3.12	5.03
K-1801	< 0.5	< 1.0	< 1.0	< 1.0	7.05	5.35
K-1802	< 0.5	< 1.0	< 1.0	< 1.0	3.45	5.21
K-1901	< 0.5	< 1.0	< 1.0	< 1.0	8.88	5.97
K-1902	< 0.5	< 1.0	< 1.0	< 1.0	3.89	5.44
ECR-1997 [34]	1.0	150-600	< 1.0	--	10	400
WHO (4th edition) [35]	--	250	--	--	50	250

Total hardness concentration of the rainwater ranged from 63.42 to 89.07 mg/L as $CaCO_3$, while calcium concentration ranged from 13.08 to 17.91 mg/L and magnesium concentration ranged from 7.47 to 10.47 mg/L. Calcium and Magnesium were found at a significant level in all samples.Ca & Mg are essential for the human body. Calcium is part of bones and teeth. In addition, it plays a role in neuromuscular excitability (decreases it), good function of the conducting myocardial system, heart and muscle contractility, intracellular information transmission and blood coagulability. Magnesium plays an important role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, ATP metabolism, transport of elements such as Na, K and Ca through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction etc. Metal ions As, Cd, Pb, Hg and Cr were found in below the detection limit of AAS for collected rainwater samples.. It indicates rain water is safe potable water. Arsenic was found in water, soil, sediment, fruits and vegetable in Khulna city [39]. Consumption of heavy metal of the foodstuffs could lead a potential health risk to human. That's why rain water harvesting is needed for drinking and agricultural purposes to ensure healthy life-style.

Fluoride, chloride, nitrite and bromide value were below than detection limit of Ion Chromatography (IC). Nitrite value was observed more than 5.0 mg/L during pre-monsoon season but less than 3.0 mg/L during monsoon season. This can be attributed to the presence of higher particulate matter such as smoke, dust, suspended soot in the air is responsible for more nitrite value during pre-monsoon compared to monsoon. Vehicle emissions control reduces emissions of nitrogen oxides from motor vehicles.

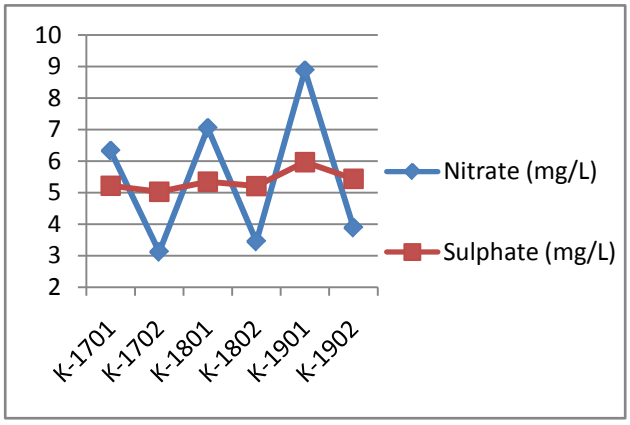

Figure 7. Variation in SO_4^{2-} and NO_3^- of rainwater

It was observed that the average concentration level of PM2.5 and PM10 measured were 70-196 μg/m^3 and 110-333 μg/m^3 respectively during the monitoring month of December, 2018 in Khulna city. Usually in the dry seasons the pollution level reached highest peak compare to the wet season. The annual average of SO_2 and NO_X in the air of Khulna city in 2016 was 14 ppb and 42 ppb respectively. In the dry season, when rainfall is low and wind speeds are low, the airborne material pollution is high [34]. Sulphate value of rainwater was about 5.0 mg/L. There was no significant change of sulphate value for season variation.

4. Conclusion

The present study revealed that stored rainwater is suitable for drinking purposes in terms of physical and chemical quality. Rainwater of monsoon season is better than that of pre-monsoon season in Khulna city due to the differences in the air masses reaching the sampling location from different sources like factories, nearby passenger terminal, busier traffic condition(s) and more importantly local atmospheric circulation. Increase in atmospheric dust, especially in the pre-monsoon, are quite clear from the values of total alkalinity, EC, pH, total hardness and TDS. Rainwater does not contain any salinity. According to ECR-1997 and WHO's drinking water guideline, the quality of rainwater in Khulna city is within the standard limit. Rainwater is potential alternative source of potable water in coastal region. Therefore it is suggested that harvested rainwater should be used for drinking and agricultural purposes to reduce pressure of ground water and public awareness should be created.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] Hasan, M.M., Ahmed, K.M., Sultana, S., Rahman, M.S., Ghosh, S.K. and Ravenscroft, P., "Investigations on groundwater buffering in Khulna-Satkhira coastal belt using managed aquifer recharge", *Groundwater of South Asia* , pp. 453-462, 2018.

[2] Barlow, P.M. and Reichard, E.G., "Saltwater intrusion in coastal regions of North America", *Hydrogeology Journal*, *18*(1), 247-260, 2010.

[3] Karro, E., Marandi, A. and Vaikm R, "The origin of increased salinity in the Cambrian–Vendian aquifer system on the Kopl Peninsula, northern Estonia", *Hydrogeol Journal*, 12, 424-435, 2004.

[4] Shammi, M., Karmakar, B., Rahman, M.M., Islam, M.S., Rahman, R. and Uddin, M.K. "Assessment of salinity hazard of irrigation water quality in monsoon season of Batiaghata Upazila, Khulna District, Bangladesh and adaptation strategies", *Pollution*, 2(2), 183-197, 2016a.

[5] Corwin, D.L., Rhoades, J.D. and S ˇ imu°nek, J. "Leaching requirement for soil salinity control: steady-state versus transient models", *Agricultural Water Management*, 90(3), 165-180, 2007.

[6] Mondal, M.K., Tuong, T.P. and Sattar, M.A. "Quality and groundwater level dynamics at two coastal sites of Bangladesh: implications for irrigation development", *2nd International Program on Water and Food*, Addis Ababa, Ethiopia, November 10-14, 2008.

[7] Bahar, M.M. and Reza, M.S. "Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh", *Environmental Earth Sciences*, 61(5), 1065-1073, 2010.

[8] Islam, S.M.D., Majumder, R.K., Uddin, M.J., Khalil, M.I. and Alam, M.F., "Hydrochemical characteristics and quality assessment of groundwater in patuakhali district, southern coastal region of Bangladesh", *Expo Health*, 4, 11-30, 2016b.

[9] Islam, S.M.D., Bhuiyan, M.A.H., and Ramanathan, A.L. "Climate change impacts and vulnerability assessment in coastal region of bangladesh: a case study on Shyamnagar upazila of Satkhira district", *Journal of Climate Change*, 1(1-2), 37-45, 2015.

[10] Srinivas, Y., Aghil, T.B., Oliver, D.H., Nair, C.N. and Chandrasekar, N. "Hydrochemical characteristics and quality assessment of groundwater along the Manavalakurichi coastTamil Nadu", *Applied Water Science*, 2015.

[11] Ahmed, M.F., Ahuja, S., Alauddin, M., Hug, S.J., Lloyd, J.R., Pfaff, A., Pichler, T., Saltikov, C. and Stute, M. "Epidemiology: ensuring safe drinking water in Bangladesh", *Science*, 314, 1687-1688, 2006.

[12] Ahmed, K.M. *Groundwater contamination in Bangladesh*, Water resources planning and management, University Press, Cambridge, 2011, 529-560.

[13] Chowdhury, N.T., "Water management in Bangladesh: an analytical review", *Water Policy*, 12, 32-51, 2010.

[14] [BBS] Bangladesh Bureau of Statistics, *Bangladesh National Drinking Water Quality Survey of 2009* (NDWQS), with UNICEF, 2011.

[15] Joseph, T., Dubey, B. and McBean, E.A. "A critical review of arsenic exposures for Bangladeshi adults", *Science of The Total Environment*, 527-528:540-551, 2015.

[16] Rahman, M.M., and Bhattacharya, A.K. "Salinity intrusion and its management aspects in Bangladesh", *Journal of Environmental Hydrogel*, 14, 1-8, 2006.

[17] Mahmuduzzaman, M., Ahmed, Z.U., Nuruzzaman, A.K.M. and Ahmed, F.R.S. "Causes of salinity intrusion in coastal belt of Bangladesh", *International Journal of Plant Research*, 4, 8-13, 2014.

[18] Ravenscroft, P., *Groundwater resources and development in Bangladesh: background to the arsenic crisis, agricultural potential, and the environment*, University Press, Dhaka, 2003, 43-86.

[19] Khan, A., Ireson, A., Kovats, S., Mojumder, S.K., Khusru, A., Rahman, A., and Vineis, P "Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change", Environmental *Health Perspectives*, 119:1328-1332, 2011.

[20] Khan, A., Scheelback, P.F., Shilpi, A.B., Chan, Q., Mojumder, S.K., Rahman, A., Haines, A., Kovats, S. nd Vineis, P. "Salinity in drinking water and the risk of (pre)eclampsia and gestational hypertension in coastal Bangladesh: a case-control study", *PLOS One*, 9(9): e108715, 2014.

[21] Abedin, M.A., Habiba, U. and Shaw, R. "Community perception and adaptation to safe drinking water scarcity: salinity, arsenic, and drought risks in coastal Bangladesh", *International Journal of Disaster Risk Science*, 5,110-124, 2014.

[22] Available from https://en.wikipedia.org/wiki/Khulna [Last accessed May 05, 2020]

[23] Lee, M., Kim, M., Kim, Y. and Han, M. "Consideration of rainwater quality parameters for drinking purposes: a case study in rural Vietnam", *Journal of environmental management*, 200, 400-406, 2017.

[24] Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., Fisher-Jeffes, L. N., Ghisi, E., Rahman, A., Furumai, H. and Han, M. "Urban rainwater harvesting systems: Research, implementation and future perspectives", *Water research*, 115,195-209, 2017.

[25] Zhu, Q., Gould, J., Li, Y., and Ma, C. *Rainwater harvesting for agriculture and water supply Science Press*, 2015.

[26] HO, M.S., Suhaimi, A.R., Rasyikah, M.K., Ahmad Jamaluddin, S., Huang, Y.F. and Farah, M.S. *Policies And Incentives For Rainwater Harvesting In Malaysia*, 2009.

[27] Akter, A. and Ahmed, S., 2015. "Potentiality of rainwater harvesting for an urban community in Bangladesh", *Journal of Hydrology*, 528, 84-93, 2015.

[28] Jalais A. *Forest of tigers: people, politics and environment in the Sundarbans*, Routledge, 2014.

[29] Clesceri, L. S., Greenberg, A. E. and Eaton, A. D. *Standard methods for examination of water and waste water, 20th ed*, American Public Health Association, Washington, DC, 1998.

[30] Ahsan, M. A., Satter, F., Siddique, M. A., Akbor, M. A., Ahmed, S., Shajahan, M. and Khan, M. A. R. "Chemical and physicochemical characterization of effluents from the tanning and textile industries in Bangladesh with multivariate statistical approach", *Environmental monitoring and assessment*, 191, 575, 2019.

[31] Islam, A.R.M.T., Islam, H.T., Mia, M.U., Khan, R., Habib, M.A., Bodrud-Doza, M., Siddique, M.A.B. and Chu, R., "Co-distribution, possible origins, status and potential health risk of trace elements in surface water sources from six major river basins, Bangladesh", *Chemosphere*, 249,126180, 2020.

[32] Islam, M.E., Reza, A.S., Sattar, G.S., Ahsan, M.A., Akbor, M.A. and Siddique, M.A.B., "Distribution of arsenic in core sediments and groundwater in the Chapai Nawabganj district, Bangladesh", *Arabian Journal of Geosciences*, 12(3), 99, 2019.

[33] Habib, M.A., Islam, A.R.M.T., Bodrud-Doza, M., Mukta, F.A., Khan, R., Siddique, M.A.B., Phoungthong, K. and Techato, K. "Simultaneous appraisals of pathway and probable health risk associated with trace metals contamination in groundwater from Barapukuria coal basin, Bangladesh", *Chemosphere*, 242, 125183, 2020.

[34] Available from http://www.doe.gov.bd/ [Last accessed May 05, 2020].

[35] Cotruvo, J.A. "WHO guidelines for drinking water quality: first addendum to the fourth edition", *Journal-American Water Works Association*, *109* (7), 44-51, 2017.

[36] Budhavant, K. B., Rao, P.S., Safai, P.D. and Ah, K. "Chemistry of monsoon and post-monsoon rains at a high altitude location, Sinhagad, India", *Aerosol and Air Quality Research*, 9, 65-79, 2009.

[37] Roughton, F.J. "The kinetics and rapid thermochemistry of carbonic acid", *Journal of the American Chemical Society*, 63, 2930-2934, 1941.

[38] Xiao, J. "Chemical composition and source identification of rainwater constituents at an urban site in Xi'an", *Environmental earth sciences*, 75(3), 209, 2016.

[39] Hossain, M.F. "Arsenic contamination in Bangladesh—an overview", *Agriculture, ecosystems & environment*, 113(1-4), 1-6, 2006.