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Water quality indices to assess the spatiotemporal variations of Dhaleshwari river in central Bangladesh

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ABSTRACT

Different water quality indices were determined to assess the spatiotemporal variations of Dhaleshwari river, specially, where effluent from the central effluent treatment plant (CETP) of newly shifted tannery industrial park was discharged. Thirty physicochemical parameters were examined to evaluate the drinking water quality index (DWQI), irrigation water quality index (IWQI), heavy metal pollution index (HPI) and contamination index (C_d). Pearson's correlation coefficient was also utilized to understand the interrelationship and coherence pattern among the parameters and indices. DWQI values using CCME method were within the '*Poor*' (0–44) range (37 at both upstream and junction and 34 at the downstream) and those using W.A. method were at '*Poor*' (51–75) and '*Unsuitable*' (> 100) level (52 at upstream and 63 at downstream and 103 at the junction). IWQI values showed the '*Excellent*' (0–25) quality status (a range of 19.2–20.3). Considering heavy metal pollution, HPI values revealed '*Critical*' (> 100) condition of water, and C_d values (> 3) emphasized '*High*' contamination of the river water. Temporally, water quality deteriorated in the winter season compared to the monsoon and post-monsoon season. Spatial changes in water quality in junction and downstream side clearly indicated the negative impact of tannery industrial park. Different indices were positively correlated either very strongly or strongly. This study will provide an index-based baseline data that will help the local people in the vicinity of tannery industrial park envisage the different applications of the river water and the policymakers take conservation strategies to save the river Dhaleshwari as well.

1. Introduction

Rivers, one of the most important and recognized surface water resources, play a vital role in the survival of all the living forms as well as in maintaining the sustainable water-cycle and ecosystem. Rivers not only act as a main, reliable and easily accessible source of water for different applications (domestic, industrial, agricultural, transportation, tourism and other purposes) in a watershed but also offer receiving places of wastewater (industrial), sewage (residential) and runoffs (urban, suburban, agricultural and stormwater) (Godwin and Oborakpororo, 2019; Mir et al., 2017; Panda et al., 2016; UNESCO, 2011). Therefore, keeping in mind the two terms 'Quantity' and 'Quality', in one side, human civilizations were developed along the rivers since ancient times and on the other side, the advancement of human civilization continued to put serious questions to the safe use of river water for different purposes.

With the time progression, the regular monitoring and assessment of the quality of river water considering both spatial and temporal variations are becoming a vital issue (Poonam et al., 2013). According to literature, several methods (index methods, statistical analysis methods, biological analysis methods) are found for assessing the river water quality (Bharti and Katyal, 2011; Elshemy and Meon, 2011; Sener et al., 2017).

Water quality index (WQI) is widely recognized and used as one of the most effective approaches to assess the water pollution status (Abbasi and Abbasi, 2012; Alobaidy et al., 2010; Lumb et al., 2011). WQI, a unitless single number, describes the overall nature of the water simply (e.g., poor, good, excellent, etc.) at a particular location. It is computed from the combination of several water quality data generated through comparing the monitored values with the regulatory standards (Al-Shujairi, 2013; Rai et al., 2012). Basically, WQI is a mathematical presentation of the complex water quality data that is understandable and useable by general people as well as decision and policymakers.

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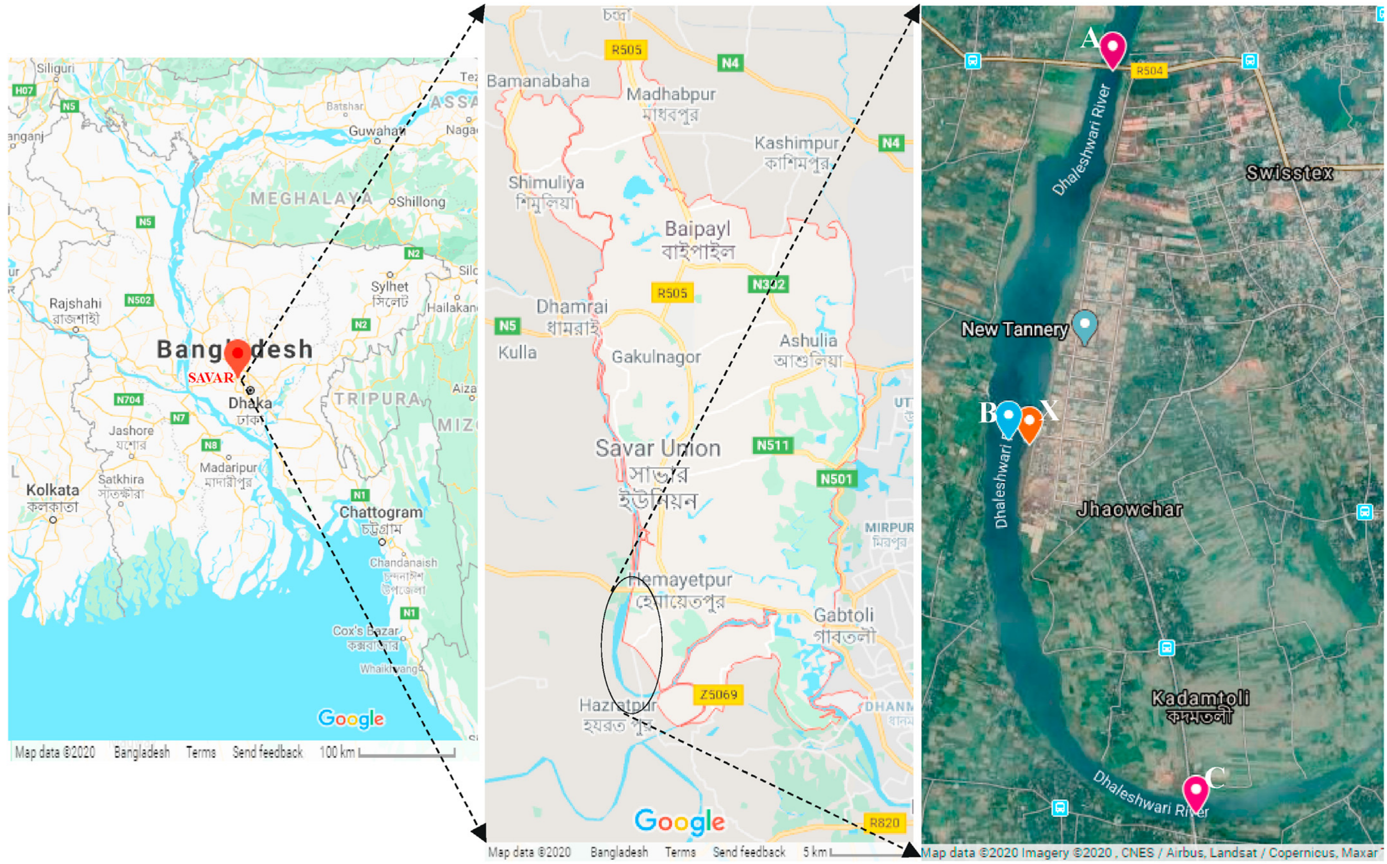

Fig. 1. Study area with sampling stations.

Table 1
Details of sampling stations.

Sl no.	Stations	Locations (Long. and Lat.)	Depth (ft) (winter season)	Remarks
1	STATION A	23°47′54.52″ N 90°14′39.95″ E	12	Upstream side
2	STATION B	23°46′34.57″ N 90°14′15.15″ E	45	Junction place
3	STATION C	23°45′13.19″ N 90°14′59.73″ E	5	Downstream side

Table 2
Analytical methods for the parameters.

Parameters	Analytical methods
pH, DO and EC	HQ 40d multi-parameter with PHC3OH, LDO101 and MTC101probes, respectively (HACH company)
NH_4-N, NO_2-N, NO_3-N, TN, TP, COD, TSS, TDS, SO_4^{2-}, Turbidity, and Color	HACH DR 6000 spectrophotometer and HACH DRB 200 reactor block based on standard procedures, as described by the supplier
Alkalinity	As $CaCO_3$ by titration method
Total hardness, Cl^- and free chlorine	digital HACH procedure
BOD_5	manometric instrument (HACH BOD TRAK II) and an incubator operated at 20 °C for five days
Heavy metals	Atomic Absorption Spectrophotometry (AAS)

Simultaneously it eliminates the subjective assessments of water quality and biasness of individual water quality experts (Chowdhury et al., 2012; Miller et al., 1986; Kannel et al., 2007; Misaghi et al., 2017). WQI was first proposed by Horton (1965) in the United States considering 10 most common water quality variables, and then Brown et al. (1970) assigned weights to the individual water quality parameter. Later, many modifications have been considered for WQI concept and validated by several researchers worldwide (Cude, 2002; Debels et al., 2005; Dede et al., 2013; Ewaid, 2017; Manaj et al., 2012; Prasad and Kumari, 2008; Reza and Singh, 2010; Saeedi et al., 2009; Tsegaye et al., 2006). The National Sanitation Foundation's Water Quality Index (NSF-WQI), the Canadian Council of Ministers of the Environment's Water Quality Index (CCME-WQI), the Oregon Water Quality Index (OWQI), the British Columbia Water Quality Index (BCWQI), are well-known examples.

Also, the metal quality indices including Heavy Metal Pollution Index (HPI), Metal Index (MI), Contamination Index (C_d) have been applied for assessing the water resources concerning metals (Backman et al., 1997; Bhuiyan et al., 2015; Mohan et al., 1996; Prasanna et al., 2012). Detail procedures along with the merits and demerits of each index were described by Tyagi et al. (2013).

Bangladesh is locally known as "Nodi-matrik desh". 'Nodi' means river; 'Matrik' means motherly (as a mother gives birth and nurture her child, Bangladesh is also a delta made from rivers and the countless rivers crisscrossing the country nurture the landscape) and 'desh' means country. Once the rivers were lifeblood of Bangladesh but pollution of river water becoming a major national concern, especially due to rapid industrialization around riverside without having proper environmental consideration (Roy et al., 2014; Sener et al., 2017).

The Dhaleshwari river, the important left bank distributaries of the river Jamuna, is 160 km long with an average depth of about 37 m, flows along with central Bangladesh (Ahmed et al., 2016; Ahsan et al., 2018). This river contributes immensely to the socio-economic development in its vicinity as well as the country. According to the local inhabitants of the Tannery Industrial Park area, the physical condition of the river water of Dhaleshwari has started to deteriorate after the shifting of tannery

Table 3
Water quality parameters for irrigation applications: standards and % of samples

Index method	Category	References	FAO'94 standard	% of samples
pH	$7.0 \leq pH \leq 8.0$ High suitable	Ayers and Westcot, 1985; Saleh, 2016	8.5	83.3
	$6.5 \leq pH < 7.0$; $8.0 < pH \leq 8.5$ Medium suitable			16.7
	$pH < 6.5$ or $pH > 8.5$ Low suitable			0
EC (μS/cm)	C1: 150–250 Excellent	Islam et al., 2017; UCCC, 1974	3000	8.3
	C2: 251–750 Good			16.7
	C3: 751-2250 Doubtful			50
	C4 and C5: >2250 Unsuitable			25
TDS (mg/L)	< 450 Excellent	Islam et al., 2017; Joshi et al. 2009	2000	75
	450–2000 Good			25
	> 2000 Fair			0
TH (mg/L)	< 75 Soft	Shammi et al., 2016, Islam et al., 2017	–	0
	75–150 Moderately hard			100
	150–300 Hard			0
	> 300 Very hard			0
Cl^- (mg/l)	< 140 High suitable	Ayers and Westcot, 1985; Simsek and Gunduz, 2007	1063	100
	140 – 350 Medium suitable			0
	> 350 Low suitable			0
SO_4^{2-} (mg/L)	< 20 Recommended	Ayers and Westcot, 1985; Saleh, 2016	960	33.3
NO_3-N (mg/L)	< 5 Excellent	Ayers and Westcot, 1985; Simsek and Gunduz, 2007	10	100
	5-30 Good			0
	> 30 Not suitable			0
NH_3-N (mg/L)	–		5	91.7
Ca (mg/L)	400	–	400	100
Mg (mg/L)	60	–	60	100
Na (mg/L)	919	–	919	100
K (mg/L)	2	–	2	8.3
Cd (mg/L)	0.01	–	0.01	100
Cu (mg/L)	0.2	–	0.2	100
Fe (mg/L)	5.0	–	5	75
Ni (mg/L)	0.2	–	0.2	100
Pb (mg/L)	5	–	5	100
Zn (mg/L)	2	–	2	100
SAR	< 10 Excellent	Ayers and Westcot, 1985; Simsek and Gunduz, 2007	15	100
	10–18 Good			0
	18–26 Fair			0
	> 26 Poor			0
SSP	< 20 Excellent	Islam et al., 2017	–	16.7
	20–40 Good			83.3
	40–80 Fair			0
	> 80 Poor			0
% Na	< 40 Recommended	US SL, 1954	–	100
	> 40 Not Recommended			0
MAR	< 50 Excellent	Ayers and Westcot, 1985; Gupta and Gupta, 1987	–	91.7
	> 50 harmful to soil			8.3
KR	< 1 Excellent	Shammi et al., 2016; Kelly, 1940; Kelly, 1951	–	100
	>1 bad water, high level of Na+			0
	> 3 unsuitable Excess levels of Na+			0

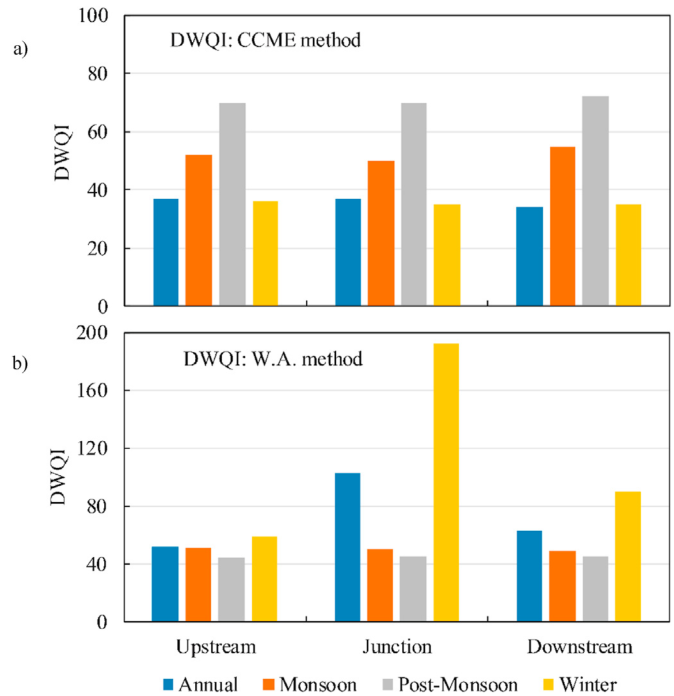

Fig. 2. Drinking water quality index of the river water at different locations in different seasons a) CCME method b) Weighted arithmetic method.

industries, and these are also reported in several newspapers. Even some alarming news published in the media including improper functioning of the CETP, illegal discharge outlets into the river bypassing the main CETP line, etc. (Anam, 2019; Chowdhury, 2017; Imam, 2018; Karim, 2019; Rahman, 2018; Rahman, M. 2018; Roy, 2018; Sujan 2019). Currently, the impact, of the discharged effluent of CETP from tannery industrial park, on the river water quality at the adjacent area is not exactly known. Hence, this study is very significant for the region. Furthermore, still now, there are no index-based water quality assessment studies concerning this important urban river of Bangladesh.

Therefore, the current study aims at determining several water quality indices to evaluate the pollution status of the Dhaleshwari river and also at finding out the spaiotempotal variations of the river water quality due to impact of newly shifted tannery industrial park.

To the best of our knowledge, this will be the first index-based water quality assessment study of Dhaleshwari river, which will help the local people in the vicinity of tannery industrial park envisage the different applications of the river water and also the policymakers take conservation strategies to save the river Dhaleshwari.

2. Methods

2.1. Study area details

As per objective, the study was conducted on the specified segment of the Dhaleshwari river in the vicinity of the Savar Tannery Industrial Park. This segment is bounded on the North-East by the Dhalla Bridge (approximately 2 km in the upstream side from the industrial park area) and the South-West by Itavora Bridge (approximately 2 km in the downstream side from the industrial park area). As a whole, in the vicinity of Savar Tannery Industrial Park, a total of 4 km stretch of the river was covered.

2.2. Sampling details

Fig. 1 shows the map of the study area with sampling locations. Water samples collected from 3 different locations of the river include: One

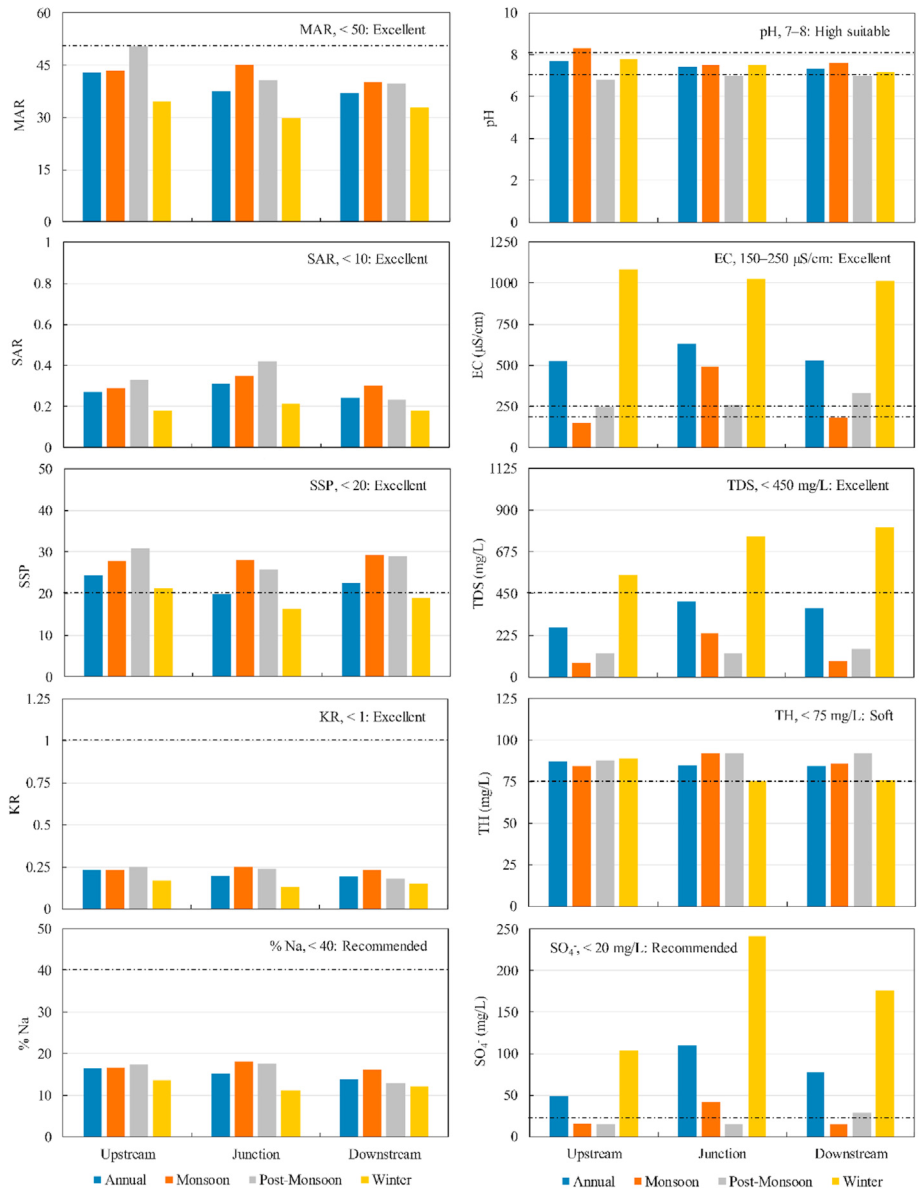

Fig. 3. Status of different water quality parameters for irrigation applications: MAR, SAR, SSP, KR, % Na, pH, EC, TDS, TH and SO_4^{2-}.

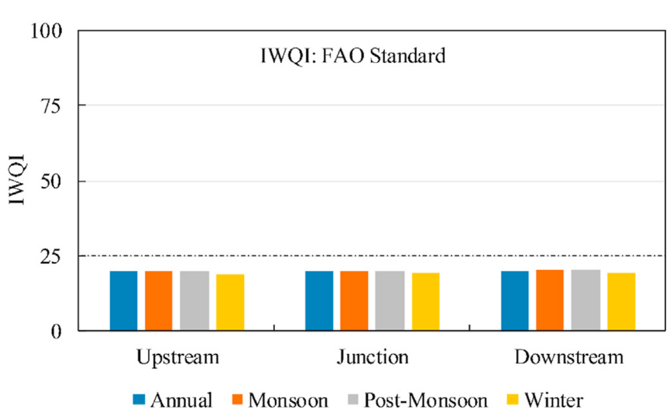

Fig. 4. Irrigation water quality index (IWQI) of the river water at different locations in different seasons.

location at upstream side denoted as Station A; one in downstream side denoted as Station C; another was at junction place, marked as Station B, where the effluent from Central Effluent Treatment Plant (CETP) was discharged from outlets (denoted as X in Fig. 1) into the river. The sampling locations were decided from satellite imagery and a reconnaissance visit of the area. Details of sampling stations are tabulated in Table 1.

Sampling was conducted at all the stations in three different seasons: a rainy Monsoon (July–September), a Post-Monsoon (October–November) and a dry Winter (December–February) season in the years 2018–2019, since the seasonal variation affects the level and fate of the pollutants in the river water extensively (Khatun et al., 2016; Shahid, 2010a, b). A total of 24 water samples were collected from 3 sampling stations in 8 consecutive months. Samples of 2 L were collected from each station at the fixed time of the fixed day in the selected months.

River water samples from all three stations were collected along the mid-stretch of the river and from a depth of about 30 cm from the river surface to avoid wave turbulence and debris. Collected samples were immediately sent to the laboratories for analyses and were stored at 4 °C if required.

Table 4
Water quality characteristics (mean value) at different sites in different seasons.

Sl No.	WQ parameter	Unit	Standard for DW		Upstream				Junction				Downstream			
			WHO	BD	A	M	PM	W	A	M	PM	W	A	M	PM	W
Physical parameters																
1	Color	Pt-Co	15	15	108.75	59.33	42	202.67	91.50	62	38	156.67	73.13	32.67	45	132.33
2	Turbidity	JTU	5	10	154.96	360.77	21.31	38.26	120.17	280.6	21.82	25.32	83.03	195.52	16.41	15.09
3	TDS	mg/L	1000	1000	267.11	77.17	128.7	549.33	407.20	236.50	132.05	761.33	371.58	86.70	149.25	804.67
4	TSS	mg/L	–	10	103.13	239.33	11.5	28	57.13	125	18	15.33	58.88	139.67	6.5	13
Chemical parameters																
5	pH	—	6.5-8.5	6.5-8.5	7.70	8.28	6.76	7.76	7.36	7.48	7.01	7.46	7.29	7.56	7.02	7.20
6	Alkalinity (as $CaCO_3$)	mg/L	130	130	125	70.33	85.5	206	113.13	73.33	87.5	170	142	69	89.5	250
7	EC	μS/cm		1000	524.69	150.33	248.8	1083	631.08	487.77	256.15	1024.33	530.41	183.83	326.4	1013
8	TH as $CaCO_3$	mg/L	500	200-500	86.75	84	88	88.67	85.38	92	91.5	74.67	83.50	86	91.50	75.67
9	Cl^-	mg/L	250	150-600	13.01	9	15	15.68	18.39	12.33	23.5	21.03	21.88	14	40	17.68
10	SO_4^{2-}	mg/L	400	400	48.63	15.67	15	104	109.63	41.33	13.5	242	78	13.33	29	175.33
11	Free Cl_2	mg/L	–	0.2	0.08	0.09	0.11	0.05	0.09	0.08	0.16	0.05	0.06	0.05	0.11	0.04
Oxygen regime																
12	DO	mg/L		6	4.54	6.93	5.76	1.33	5.12	6.99	4.93	3.39	4.82	6.16	5.69	2.89
13	BOD	mg/L	–	0.2	0.63	0	0	1.67	1.06	2	0	0.83	1.25	1	0	2.33
14	COD	mg/L	–	4	9.63	2.67	0	23	9.63	11.33	0	14.33	4.13	5.33	0	5.67
Nutrients																
15	TN	mg/L		0	3	0.67	2	6	7.38	9	4	8	6.25	1.33	2	14
16	NH_3-N	mg/L	–	0.5	2.07	1.78	0.2	3.60	2.34	1.69	0.49	4.22	3.70	1.48	0.64	7.95
17	NO_2-N	mg/L		<1.0	0.06	0.07	0.02	0.07	0.14	0.24	0.03	0.12	0.05	0.01	0.04	0.10
18	NO_3-N	mg/L	10	10	0.48	0.27	0.65	0.57	1.14	2.30	0.6	0.34	0.35	0.17	0.75	0.27
19	TP	mg/L		6	0.21	0.17	0	0.40	0	0	0	0	0	0	0	0
Heavy metal																
20	Pb	mg/L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
21	Fe	mg/L	0.3	1	2.73	6.04	1.02	0.56	2.73	5.32	1.07	1.26	2.44	5.58	0.66	0.49
22	Cu	mg/L	1	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
23	Zn	mg/L	5	5	0.005	0.01	0.005	0.01	0.02	0.01	0.005	0.03	0.01	0.01	0.005	0.01
24	Cd	mg/L	0.003	0.005	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
25	Cr	mg/L			0.04	0.02	0.02	0.08	0.37	0.02	0.02	0.94	0.10	0.02	0.02	0.24
26	K	mg/L		12	4.13	4.83	6.45	1.87	4.61	4.90	6.6	3	5.13	6.40	7.35	2.37
27	Ca	mg/L		75	7.98	8.73	8.65	1.77	15.13	10.37	18.35	17.73	10.10	10.41	10	9.87
28	Mg	mg/L		30-35	3.69	4.12	5.39	2.13	5.60	5.23	7.65	4.60	3.67	4.20	4	2.93
29	Na	mg/L	200	200	3.57	4.19	5	2	5.63	5.43	8.4	3.97	3.56	4.60	3.4	2.63
30	Ni	mg/L		0.1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

DW: Drinking water; BD: Bangladesh; A: Annual; M: Monsoon; PM: Post-Monsoon; W: Winter

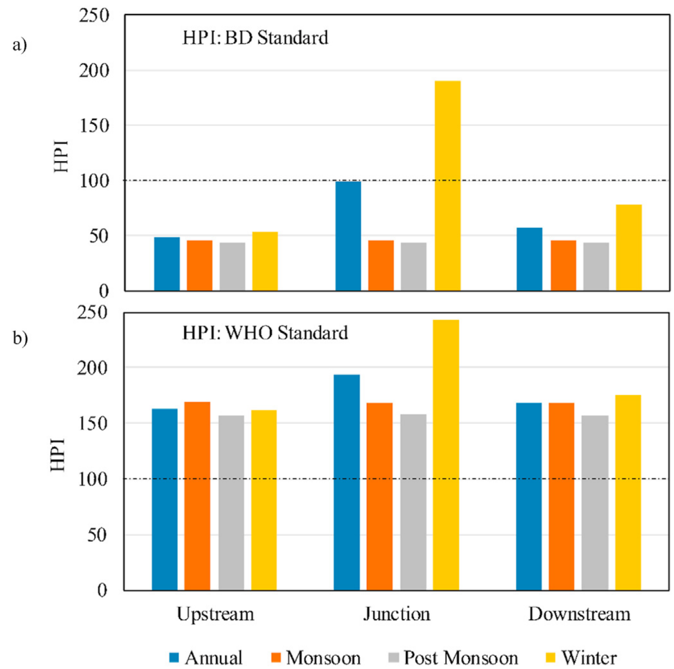

Fig. 5. Heavy metal pollution index of the river water at different locations in different seasons a) Bangladesh standard b) WHO standard.

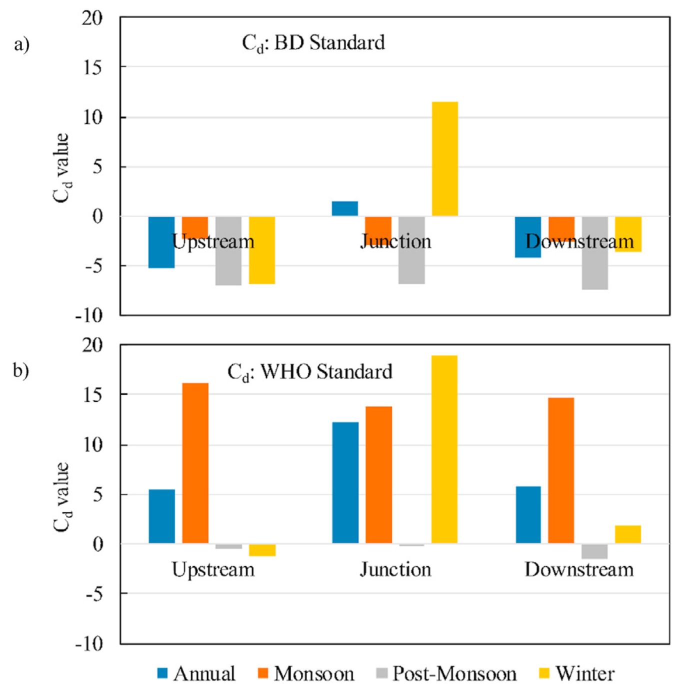

Fig. 6. Contamination index of the river water at different locations in different seasons a) Bangladesh standard b) WHO standard.

2.3. Analytical procedures

A maximum number of 30 water quality parameters (including 4 physical, 7 chemical, 5 nutrients, 3 oxygen concerned and 11 heavy metals) were tested for the river water according to the standard procedure, APHA (1998) (Table 2). The studied parameters include pH, color, turbidity, solid contents (total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), alkalinity, total hardness, chlorides (Cl^-), sulfate (SO_4^{2-}), free chlorine, dissolved oxygen (DO),

Table 5
Pearson's linear correlation matrix of DWQI and water quality parameters.

	DWQI	pH	EC	Alkalinity	COD	DO	TDS	Cl^-	SO_4^{2-}	TN	TP	Fe	Cr	K	Ca	Mg	Na
DWQI	1																
pH	.369	1															
EC	**.926****	.118	1														
Alkalinity	**.793***	.061	**.922****	1													
COD	**.840****	.401	**.783***	.693	1												
DO	-.643	.139	**-.764***	**-.891****	-.664	1											
TDS	575	-.158	**.802***	**.876****	.599	**-.867****	1										
Cl^-	-.335	-.644	-.151	.116	-.194	-.355	.132	1									
SO_4^{2-}	.378	-.251	.485	.537	.687	**-.784***	.663	.444	1								
TN	.298	-.156	.572	.616	.211	-.477	**.830***	-.127	.202	1							
TP	.626	.524	.537	.455	.313	-.162	.269	-.687	-.318	.408	1						
Fe	-.453	.491	-.599	-.642	-.156	.705	-.603	-.364	-.374	-.415	-.092	1					
Cr	**.994****	.338	**.906****	**.769***	**.843****	-.647	.538	-.284	.413	.221	.560	-.472	1				
K	-.622	-.536	-.575	**-.733***	**-.707***	**.709***	-.573	.025	-.434	-.277	-.463	.149	-.596	1			
Ca	325	-.224	.369	.175	-.149	-.013	.164	-.351	-.306	.376	.404	-.601	.309	.324	1		
Mg	-.627	-.425	-.617	**-.742***	**-.781***	.668	-.543	-.075	-.511	-.201	-.373	.052	-.610	**.901****	.446	1	
Na	**-.818***	-.362	**-.815***	**-.859****	**-.903****	**782***	-.682	.015	-.607	-.311	-.438	.254	**-.805***	**.871****	.205	**.950****	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 6
Pearson's linear correlation matrix of IWQI and different water quality parameters for irrigation applications.

	IWQI	pH	EC	TH	TDS	SO_4^{2-}	Cl^-	K	Ca	Mg	Na	Fe	MAR	SAR	SSP	% Na	KR
IWQI	1																
pH	-.200	1															
EC	**-.681***	.081	1														
TH	.335	-.286	**-.632***	1													
TDS	**-.642***	.086	**.967****	**-.780****	1												
SO_4^{2-}	**-.600***	.130	**.912****	**-.840****	**.969****	1											
Cl^-	.138	-.230	.011	.223	.012	.039	1										
K	**.667***	-.323	**-.898****	**.658***	**-.861****	**-.810****	.363	1									
Ca	.004	-.366	.024	-.148	.123	.252	.313	.102	1								
Mg	.375	-.499	**-.629***	.473	**-.592***	-.512	.000	**.596***	**.611***	1							
Na	.413	-.413	**-.692***	.518	**-.641***	**-.587***	.055	**.653***	**.584***	**.956****	1						
Fe	.127	.542	-.464	.088	-.449	-.377	**-.632***	.130	-.227	.126	.186	1					
MAR	.469	-.189	**-.843****	**.680***	**-.866****	**-.873****	-.230	**.704***	-.289	.560	.538	.392	1				
SAR	.404	-.381	**-.786****	**.641***	**-.772****	**-.737****	-.121	**.687***	.360	**.925****	**.953****	.349	**.721****	1			
SSP	**.601***	-.079	**-.921****	**.766****	**-.958****	**-.951****	-.035	**.837****	-.316	.446	.492	.455	**.910****	**.664***	1		
% Na	.313	-.174	**-.757****	**.635***	**-.785****	**-.798****	-.454	.532	-.045	**.683***	**.719****	**.603***	**.825****	**.885****	**.758****	1	
KR	.443	-.192	**-.866****	**.722****	**-.894****	**-.904****	-.322	**.683***	-.109	**.679***	**.715****	.539	**.911****	**.882****	**.876****	**.973****	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 7
Pearson's linear correlation matrix of different water quality indices.

	DWQI-CCME	DWQI-WA	IWQI	HPI-BD	HPI-WHO	C_d-BD	C_d-WHO
DWQI-CCME	1						
DWQI-WA -.621	1						
IWQI	**.849****	-.558	1				
HPI-BD	-.572	**.997****	-.518	1			
HPI-WHO	-.575	**.978****	-.485	**.981****	1		
C_d-BD	-.563	**.926****	-.451	**.930****	**.983****	1	
C_d-WHO	-.370	.453	-.152	.452	.613	**.743***	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

five days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total phosphate (TP), total nitrogen (TN), ammonium-nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), Pb, Fe, Cu, Zn, Cd, Cr, K, Ca, Mg, Na, and Ni. All the heavy metals were tested in the laboratory of NGO-Forum, Bangladesh, and the rests were tested in the Environmental Engineering and Chemistry laboratory, University of Asia Pacific (UAP), Bangladesh.

2.4. *Water quality index (WQI)*

2.4.1. *Canadian Council of Ministers of the environment water quality index (WQI: CCME)*

The calculation of index scores in CCME WQI method is obtained as stated in the literature (CCME, 2001; Khan et al., 2005; Lumb et al., 2006):

$$WQI = 100 - \frac{\sqrt{\left(F_1^2 + F_2^2 + F_3^2\right)}}{1.732}$$

where.

F_1, F_2 and F_1 represent as Scope (number of variables, whose objectives are not met), Frequency (number of times by which the objectives are not met) and Amplitude (the amount by which the objectives are not met), respectively, and are calculated as follows:

$$F_1 = \frac{no.\ of\ failed\ variables}{total\ no.\ of\ variables} \times 100$$

$$F_2 = \frac{no.\ of\ failed\ tests}{total\ no.\ of\ tests} \times 100$$

$$F_3 = \frac{nse}{0.01nse + 0.01}$$

$$nse = \frac{\Sigma excursion}{total\ number\ of\ tests}$$

$$excursion = \frac{failed\ tests\ test}{standard\ value} - 1$$

Water quality is categorized in five different categories based on the WQI scores: *Poor* (0–44), *Marginal* (45–64), *Fair* (65–79), *Good* (80–94), and *Excellent* (95–100).

2.4.2. *Weighted Arithmetic Water Quality Index Method (WQI: W.A.)*

Weighted arithmetic WQI method uses for categorizing the water quality based on the grade of purity employing the most commonly measured water quality variables (Balan et al., 2012; Chauhan and Singh, 2010; Chowdhury, 2012; Rao et al., 2010; Tripaty and Sahu, 2005). The following equations are used for the calculation of WQI (Brown et al., 1972):

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

$$W_i = \frac{K}{S_i}$$

$$Q_i = \frac{(V_i - V_0) \times 100}{(S_i - V_0)}$$

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}}$$

where.

V_i is the concentration of ith parameter in the analyzed water.

V_0 is the ideal value of ith parameter in pure water and $V_0 = 0$ (except for pH = 7.0 and for DO = 14.6 mg/L).

S_i is recommended standard value of ith parameter.

W_i is the unit weight for each water quality parameter.

K is the proportionality constant.

The rating of water quality according to this WQI is given as *Excellent* (0–25), *Good* (26–50), *Poor* (51–75), *Very Poor* (76–100), and *Unsuitable* (> 100).

2.5. Irrigation water quality index (IWQI)

The use of poor quality water for irrigation purposes can cause harm to soil (hazards of salinity, sodicity, alkalinity, toxicity; reduction of water infiltration rate; and consequently deterioration of soil fertility) and plants (reduction of phosphorus availability, plants' osmotic activity, plants' growth; and delayed of crop maturity and consequently reduction of crop yield).

IWQI was measured according to the "Weighted Arithmetic Water Quality Index Method" as described in the above section. But here FAO'94 irrigation water quality standards (stated in Table 3) were followed to compute the IWQI. Similar categories like drinking water quality index were used to classify the water for the purpose.

In addition to IWQI, in this study, nineteen environmental parameters were selected to assess the suitability of Dhaleshwari river water for irrigation applications. The parameters include magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR), percentage sodium (% Na), soluble sodium percentage (SSP), Kelly's ratio (KR), the potential of hydrogen number (pH), total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), chloride (Cl^-), sulfate (SO_4^{2-}), Nitrate (NO^{3-}), lead (Pb), iron (Fe), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr) and nickel (Ni). The recommended standard values for irrigation water of these parameters are presented in Table 3. Their significance and calculations were described in the following sections.

2.5.1. Magnesium adsorption ratio (MAR)

Magnesium adsorption ratio (MAR) (also known as Magnesium Content or Magnesium Ratio (MR)), a relative concentration of calcium and magnesium of water, is one of the most important qualitative criteria in determining the quality of water for irrigation (Joshi et al., 2009). Generally, calcium and magnesium maintain a state of equilibrium in waters and more magnesium in water makes the soil more alkaline that adversely affects the crop yields (Nishanthiny et al., 2010). This ratio is calculated by the following formula (Paliwal, 1972):

$$\text{MAR} = \frac{(\text{Mg}) \times 100}{(\text{Ca} + \text{Mg})} (\text{concentrations are in meq/L})$$

2.5.2. Sodium adsorptions ratio (SAR)

The assessment of sodium concentration as sodium adsorption ratio (SAR) is important while considering the suitability of water for irrigation as it affects the soil salinity, hardness and infiltration rate (Subramani et al., 2005; Todd, 1980). The higher the Na concentrations concerning Ca and Mg, the higher the SAR (Vyas and Jethoo, 2015). This sodium hazard is also linked to several factors such as soil types, salinity, etc. For instance, sandy soils may more tolerate high SAR water (Vasanthavigar, 2010). The SAR is computed as follows (Raghunath, 1987; Richards, 1954):

$$SAR = \frac{\text{Na}}{\sqrt{(\text{Ca} + \text{Mg})/2}} (\text{ions are expressed in meq/L})$$

2.5.3. Percentage sodium (% Na)

Percentage Sodium is another important factor to study sodium hazard assessing water suitability for irrigation, since the high percentage of sodium in water stunts the plant growth and also reduce soil permeability (Mishra, 2005). It is calculated as shown below (Islam et al., 2017; Todd, 1980):

$$\% \, Na = \frac{(\text{Na}) \times 100}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} (\text{ions are expressed in meq/L})$$

2.5.4. The soluble sodium percentage (SSP)

It represents the percentage of sodium and potassium against all cationic concentration and calculated as follow (Shammi et al., 2016; Todd, 1980):

$$SSP = \frac{(\text{Na} + \text{K}) \times 100}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \ (\text{ions are expressed in meq/L})$$

2.5.5. Kelly's ratio (KR)

Kelly's ratio is used for the classification of water for irrigation purposes where sodium is measured against calcium and magnesium that represents the alkali hazard. The ratio is calculated by using the following formula (Kelly, 1951):

$$\text{KR} = \frac{(\text{Na}) \times 100}{(\text{Ca} + \text{Mg})} (\text{ions are expressed in meq/L})$$

2.5.6. Specific water quality parameters for irrigation applications

The pH of water influences the carbonate equilibrium, heavy metal content and the relative ratio of nitrogen components, which in turn influences soil quality and plant growth. Lower pH influences the adsorption of calcium, magnesium and aluminum by plants while a higher pH of water provides a suitable environment for the plant's uptake of several metals and nutrients. (Ayers and Westcot, 1985; Gupta and Gupta, 1987; Pescod, 1985; Simsek and Gunduz, 2007).

Electrical conductivity (EC) is monitored to quantify the salinity of the water. The excessive concentration of EC reduces the osmotic activity of plants that interferes with the absorption of water and nutrients from the soil (Tatawat and Singh, 2008).

Total dissolved solids (TDS) are also an important element for irrigation water since many of the toxic solids may cause harm to the plants. Both EC and TDS values are interrelated and an indication of saline water in the absence of non-ionic dissolved constituents (Michael, 1992).

Sulfate ion (SO_4^{2-}) is the main contributor to the total salt content in irrigation waters that benefits crop yields but high sulfate ions reduce phosphorus availability to plants (Saleh, 2016).

Nitrate (NO_3^-) is the primary source of nitrogen to most plants which is commonly provided as fertilizer. However, excessive amounts of nitrate could result in a reduction in crop production (Fedkiw, 1991; Simsek and Gunduz, 2007).

Chloride (Cl^-) is another ion commonly found in irrigation waters. A high amount of Cl^- causes burns or deaths of leaf tissue. Cl^- is not adsorbed or held back by soils, therefore it moves readily with the soil-water, and taken up by the crop, moves in the transpiration stream, and accumulates in the leaves (Pescod, 1985).

Among the heavy metals, lead (Pb), iron (Fe), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni) also have effects on irrigation water quality in some extent.

The recommended values of these parameters are presented in Table 3.

2.6. Heavy metal pollution index (HPI)

Surface water pollution can be addressed by the heavy metal pollution index (HPI) that represents the combined influence of individual heavy metal on the overall quality of water. The following equation, based on the weighted arithmetic quality means, is the expression of the HPI (Abdel-Satar et al., 2017; Mohon et al., 1996; Prasad and Bose, 2001; Prasad and Kumari, 2008; Prasad and Mondal, 2008):

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

W_i is the assigned weightage to every heavy metal and the value lies between 0 and 1.

n is the total number of metals measured.

Q_i is the quality rating of ith metal given as:

$$Q_i = \frac{V_i}{S_i} \times 100$$

V_i is the measured value of the ith metal in μg/L.

S_i is the standard limit of each metal in water.

In this study, two standard criteria were considered: Bangladesh drinking water quality standards (DoE, 1997) and WHO drinking water quality standards (WHO, 2011).

Generally, HPI score 100 is considered as '*Critical*'.

2.7. Contamination index (C_d)

The contamination index indicates the relative contamination of individual metal and establishes the overall effects of all metals. It is expressed as follows (Abdel-Satar, 2017; Backman et al., 1997):

$$C_d = \sum_{i=1}^{n} C_{fi} \text{ and } C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

C_{fi} is the contamination factor for ith metal.

C_{Ai} is the measured value for ith metal.

C_{Ni} is the maximum allowable value of ith metal.

The resultant C_d values are grouped into three classes: high (C_d>3), medium (C_d= 1–3) and low (C_d<1).

2.8. Pearson correlations

The relationships among different studied variables of river water were also calculated using the Pearson correlation matrix using IBM SPSS Statistics 20.

3. Results and discussion

3.1. Overall results

The mean values of 30 water quality parameters at three different sites (upstream, junction and downstream) of the river in three different seasons (monsoon, post-monsoon and winter) were tabulated in Table 4. Annual mean values of the parameters, drinking water standard values given by the WHO and Bangladesh are also stated in the same Table. The results indicated that out of 19 parameters (excluding heavy metal), 14 parameters exceeded the Bangladesh standard for drinking water quality either spatially or seasonally. The concentrations of the studied heavy metals in the river water followed a decreasing order of Ca > K > Mg > Na > Fe > Cr > Pb > Ni > Cu > Zn > Cd and only Cr concentration in the winter season exceeded the standard values.

3.2. Water quality index: drinking (DWQI)

Fig. 2 shows the calculated drinking water quality index values of the Dhaleshwari river. According to the CCME method (Fig. 2a), the annual WQI values at the three different locations were found 37 at both the upstream and the junction and 34 at the downstream side of the river. All the values were within the range of the '*Poor*' scale (0–44). The lowest value at the downstream side exhibited the worst condition indicating the effects of the discharged effluent into the river from tannery industrial park. Similar quality status, i.e., '*Poor*' was also observed in the winter season (upstream: 36, junction: 35 and downstream: 35). In monsoon, the values were 52, 50 and 55 at upstream, junction and downstream, respectively, indicating '*Marginal (45–64)*' status. In contrast, the highest WQI values were in post-monsoon season along the river stretch (upstream: 70, junction: 70 and downstream: 72) and the range was within '*Fair (65–79)*'.

In contrast to CCME method, a high favorable value gives a low statistical value to the index in the weighted arithmetic index method. From this study, an almost similar trend in river water quality status was also found according to the weighted arithmetic method (Fig. 2b). The annual river water quality showed '*Poor*' at upstream (52) and downstream side (63), and '*Unsuitable*' (103) at the junction. Higher values were found in winter at all the locations emphasizing '*Poor*' (WQI: 59), '*Unsuitable*' (WQI: 192) and '*Very poor*' (WQI: 90) at upstream, junction ad downstream respectively. In monsoon the status was '*Good*' (WQI:49 at downstream) to '*Poor*' (WQI: 51 and 50 at upstream and junction). Whereas, similar to CCME, along the river stretch, '*Marginal*' quality status (upstream: 44, junction: 45 and downstream: 45) was observed in post-monsoon.

The worst conditions exist in the winter season due to the low flow of the river water. In contrast, the reason for more improved quality conditions in the post-monsoon season might be the rainfall in the monsoon and the high flow of the river. Considering spatial factors, the quality deteriorated at junction and downstream indicating pollution due to tannery industrial park. According to WQI analyses, river water should not be used for drinking purposes without treatment.

3.3. Water quality index: irrigation (IWQI)

The suitability of Dhaleshwari river water quality in terms of irrigation purpose was assessed considering a total of 23 water quality parameters with annual average values, values from three different seasons and in three different locations. Fig. 3 and Table 3 represent the status of considered different quality parameters of the river water in terms of irrigation applications.

In the present study, the annual MAR of the river water was found 37 to 42.9 which was below 50, indicating '*Excellent*' quality of water concerning magnesium content for irrigation.

In this study, another criterion, SAR values were found as < 0.5 considering both temporal and special cases whereas the value of '*Excellent*' level is 10. The significantly low value of SAR for Dhaleshwari river water can be categorized as the water of excellent category and can be used for irrigation on almost all soil types with an insignificant danger of the development of harmful levels of exchangeable sodium.

The calculated values of SSP for all sites in all seasons were found '*Excellent*' to '*Good*' condition for irrigation. The SSP values were found at the upstream: 27.8, 31.0 and 21.2 in monsoon, post-monsoon and winter, respectively; at the junction: 28.0, 25.8 and 16.5 in monsoon, post-monsoon and winter, respectively; at downstream: 29.3, 29.1 and 18.9 in monsoon, post-monsoon and winter, respectively. And the annual values were 24.3, 20.0 and 22.6 at upstream, junction and downstream, respectively. The values were in the '*Good*' range (20–40) except in the winter season at the junction (16.5) and at downstream (18.9), which were in the '*Excellent*' category (SSP < 20).

The recommended value of the sodium percent (% Na) value in water is < 40 for irrigation purposes and during this study the annual values were found as 16.5, 15.2 and 13.8 at upstream, junction and downstream, respectively. The values indicated the suitability of the river water for irrigation throughout the year.

The annual values of KR in the study were within a range from 0.19 to 0.23, which were well satisfied with the '*Excellent*' range (KR < 1). Therefore, like % Na, the river water of the selected stretch, in terms of KR, is suitable for irrigation purposes.

In temporal consideration, the parameters MAR, SAR, SSP, % Na and KR were decreased in the winter season. And in spatial consideration, the parameters were in decreasing trend from upstream to the downstream side.

pH (annual average value) was found within a range of 7.0–8.0 considering all the seasons and locations indicating the category of '*High suitable*' of water for irrigation application as it satisfied the standard range.

The average annual EC values were 525 μS/cm at upstream, 631 μS/cm at the junction and 530 μS/cm at the downstream and therefore the river water could be categorized as '*C2-Good*' (EC: 251–750 μS/cm) as per standard (Table 3). A similar category was observed in the post-monsoon season. In monsoon season the water category was '*C1-Excellent*' both at upstream (150 μS/cm) and downstream (184 μS/cm). In contrast, during winter the water quality was deteriorated to the '*C3-Doubtful*' category at all three stations having EC values more than 1000 μS/cm.

TDS was found at the junction: 237 $\pm$ 220 mg/L, 132 $\pm$ 47 mg/L and 762 $\pm$ 157 mg/L in monsoon, post-monsoon and winter respectively; at downstream: 87 $\pm$ 2 mg/L, 149 $\pm$ 98 mg/L and 805 $\pm$ 263 mg/L in monsoon, post-monsoon and winter respectively; at upstream: 77.2 $\pm$ 7.6 mg/L, 129 $\pm$ 41 mg/L and 550 $\pm$ 81 mg/L in monsoon, post-monsoon and winter respectively. The average annual values were 267 mg/L at upstream, 407 mg/L at the junction and 372 mg/L at downstream. The results emphasized that the water quality was at '*Excellent*' level (TDS $<$ 450 mg/L) except in the winter season when it fell under the '*Good*' category (TDS: 451–2000 mg/L) during the study period.

In terms of TH values, the river water was found at '*Moderately Hard*' level (TH: 75–150 mg/L) for irrigation purposes. The average annual values were within a range of 84–87 mg/L. Higher values were observed in post-monsoon (both at junction and downstream: 92 mg/L) and in contrast, lower values were in the winter season (at the junction: 75 mg/L and at downstream 76 mg/L).

During this study period and within the selected river stretch, the annual average SO_4^{2-} values were very high (49 mg/L, 110 mg/L and 78 mg/L at upstream, junction and downstream, respectively) in comparison with the standard recommended value ($SO_4^{2-} < 20$ mg/L recommended). Therefore, the values indicated '*Not Recommended*' status for irrigation application. Especially in the winter season, the river water quality was worst (104 mg/L at upstream, 242 mg/L at the junction and 176 mg/L at downstream) to use in irrigation. Higher values in the winter season might be due to the low river flow and the high evaporation of water and in the junction and downstream, may be evident the effect of discharged effluent into the river.

The concentrations of Cl^- ad NO_3^- were recorded very low than that of the standard values and fell within the irrigation water quality classification stand of '*High suitable*' and '*Excellent*' as stated in Table 3 and Table 4.

Except for Fe and K only, in some months of monsoon and post-monsoon seasons, concentrations of all other nine heavy metals include Ca, Mg, Na, Cd, Cr, Cu, Ni, Pb and Zn satisfied the standard quality values set for irrigation purpose.

Concerning the irrigation water quality index (IWQI), determined considering the irrigation water standard values given by FAO, 94 (Table 3) using the weighted arithmetic method, Fig. 4 shows the index results. It was evident that the river water was at the '*Excellent*' category (IWQI < 25) to use for irrigation purposes having decimal variations and a range 19.2–20.3 in spatial and temporal considerations.

3.4. Heavy metal pollution index (HPI)

The river water pollution due to heavy metals is one of the key concerns in most of the metropolitan cities of developing countries. Heavy metals are regarded as serious pollution of the aquatic ecosystem because of their environmental persistence and toxicity effects on all forms of living organisms since they cannot be naturally degraded and that leads to bioaccumulation and biomagnification (Goher et al., 2014). The calculated HPI values are presented in Fig. 5. The computed annual values of HPI considering the drinking water quality standard set by Bangladesh government showed the water quality of upstream and downstream sides were well below than the critical pollution index score for drinking water i.e. 100, whereas the value was marginally critical at junction place where effluent from CETP discharged into the river (Fig. 5a). Among the three different seasons, winter season showed high HPI values (upstream: 53.3; junction: 190.5; downstream: 78.7) and considering spatial variation, the water quality at junction place (annual: 99.6; monsoon: 45.7; post-monsoon: 44.0; winter: 190.5) was the most vulnerable.

In contrast, when WHO drinking water standards were considered to compute the HPI (Fig. 5b), the water quality showed '*Critical*' condition (HPI more than 150) at all the stations in all the seasons in terms of heavy metal contamination. Furthermore, junction place as spatial (annual: 193.3; monsoon: 167.6; post-monsoon: 157.6; winter: 242.8) and winter season as temporal (upstream: 161.5; junction: 242.8; downstream: 174.8) were the most prone.

3.5. Contamination index (C_d)

Fig. 6 represents the contamination index values. The annual average C_d values, computed using Bangladesh drinking water standard, at the upstream and downstream sides can be categorized as low whereas at the junction place the C_d value was 1.5, indicating the medium category. The study suggests that water quality at junction place in the winter season was much inferior ($C_d = 11.4$) to the set standard high level ($C_d > 3$; '*High*' contamination).

In contrast, the computed annual C_d values, using the WHO standard, showed a high contamination level at all the stations (average annual values of C_d were 5.5, 12.3, 5.8 at the upstream, junction, and downstream sides, respectively). Similar results of high contaminations were also observed in monsoon season, whereas only in the post-monsoon season the values were in low limit at all the stations. In the winter season, the water quality was of a medium category at downstream and the worst category at the junction place as compared with the upstream side. Negative value represents very low contamination scenario. The frequency of appearing negative values were more in numbers while considering BD standard (Fig. 6 (a)), but while considering the WHO standard (Fig. 6 (b)), it was opposite. This is because, some water quality parameters are higher in BD standard than that of WHO. Eventually, the results of C_d emphasized that the discharged effluent from the tannery industrial park had direct impact on the river water quality at the junction place.

3.6. Pearson correlation matrix

Pearson's correlation coefficient was used to show the interrelationship and coherence pattern among the river water quality parameters and indices. The analyzed correlation coefficient values among DWQI and physico-chemical are given in Table 5. Strong ($p < 0.01$) and significant correlation ($p < 0.05$) were observed in the river water samples and indices. DWQI showed strong positive correlations with EC ($r = 0.926$), COD ($r = 0.840$) and Cr ($r = 0.994$), and positive correlations having 95% confidence level with alkalinity. In contrast, DWQI showed negative correlation with Na ($p < 0.05$; r = -0.818).

The EC showed a positive correlation having 99% confidence level with alkalinity (r = 0.922) and Cr (r = 0.906) and having 95% confidence level with TDS (r = 0.802) and COD (r = 0.783), whereas, it showed negative correlation with DO (r = -0.764) and Na (r = -0.815) with a value of $p < 0.05$. Negative correlation of DO with SO_4^{2-} (r = -0.784, $p < 0.05$), alkalinity (r = -0.891, $p < 0.01$) and TDS (r = -0.867, $p < 0.05$) was found which may signify that increased concentration of SO_4^{2-} ions, carbonate salts and dissolved solids interfere with the solubility of oxygen. The correlations among DO, EC and TDS suggested that DO value decreased with increasing EC and TDS value, probably due to the increase of ionic constituent as well as organic matter in the water body that was discharged through CETP-Effluent. TN was found positively correlated with TDS (r = 0.830 and $p < 0.05$). COD was positively correlated with Cr (r = 0.843) having 99% confidence level in contrast it showed negative correlation with K (r = -0.707, $p < 0.05$), Mg (r = -0.781, $p < 0.05$) and Na (r = -0.859, $p < 0.01$). Among the heavy metals, strong positive correlations between K–Mg (r = 0.901), K–Na (r = 0.871), Na–Mg (r = 0.950) were observed whereas Na and Cr showed significant negative correlations. pH showed weak and very weak positive correlations with half the parameters and negative correlations with another half the parameters. From the correlation matrix, it was evident that EC, Alkalinity, COD, Cr and Na concentrations in the river water were the governing factors for DWQI.

Concerning irrigation applications of the river water, Pearson linear correlation matrix was generated from analysis results using 17 parameters (IWQI, pH, EC, TH, TDS, SO_4^{2-}, Cl, K, Ca, Mg, Na, Fe, MAR, SAR, SSP, % Na and KR), the most effective water quality parameters (Table 6). The obtained results indicated very strong positive correlations between EC and TDS, SO_4^{2-}; TH and SSP, KR; TDS and SO_4^{2-}, K and SSP; Mg and Na, SAR; Na and SAR, % Na, KR. All of the different ratios were also correlated positively and very strongly with each other (MAR, SAR, SSP, % Na and KR) except SAR–SSP (strongly). But all those ratios showed opposite correlations with SO_4^{2-}, TDS and EC. A very strong and negative correlation was observed between K and EC, TDS and SO_4^{2-}. Strongly and positively correlated parameters were TH and K, MAR, SAR, % Na; K and Mg, Na, MAR, SAR, KR; Ca and Mg, Na; Mg and % Na, KR; Fe and % Na. In contrast, a strong but negative correlation was EC and TH, Mg, Na; TDS and Mg, Na; SO_4^{2-} and Na; Cl- and Fe. IWQI had a strong correlation with K and SSP positively whereas with EC, TDS and SO_4^{2-} negatively. pH showed weak and very weak negative correlations with all the parameters except four (EC, TDS, SO_4^{2-}, Fe) parameters.

All the above results revealed that the discharged effluent from the tannery industrial park significantly affects the DWQI and IWQI of the river water.

The results of Pearson's linear correlation matrix of different water quality indices are presented in Table 7. The results indicated a very strong and positive correlation between DWQI-WA and HPI, C_d-BD; IWQI and DWQI-CCME; C_d-BD and HPI. Both HPI (BD and WHO) showed a positive and very strong correlation with each other whereas both C_d showed just a strong correlation.

3.7. *Suggested remedial measures*

To prevent this pollution, the most effective means is to ensure the proper and round the clock functioning of the existing CETP. Besides, it is essential to close the outlets that are discharging the tannery effluent directly into the river bypassing the CETP. In both cases, regular and proper monitoring by the appropriate authority is crucial. Natural and/or low-cost treatment technologies such as floating wetlands, simple clay-based ceramic filter units could be applied to some extent prior to the use of the river water for various purposes.

4. Conclusions

Different water quality indices were determined to evaluate the pollution status of Dhaleshwari river and to assess the impact of the establishment of Tannery Industrial Park on the river as well.

The river water quality was found within the '*Poor*' (0–44) range (37 at both the upstream and the junction and 34 at the downstream) basing on the drinking water quality index (DWQI) using CCME method and it was found at '*Poor*' (51–75) and '*Unsuitable*' (> 100) level (52 at upstream and 63 at downstream and 103 at the junction) using W.A. method. IWQI values showed the '*Excellent*' (0–25) quality status (a range of 19.2–20.3) of the river water although seven parameters (SSP, EC, TDS, TH, SO_4^{2-}, Fe and K) exceeded the set quality standard in some cases. Considering heavy metal pollution, HPI values revealed '*Critical*' (> 100) condition of the river water. Contamination index (C_d) values emphasized that the contamination of river water was at '*Low*' to '*Medium*' level with respect to BD standard but was at '*High*' level with respect to the WHO standard.

Temporally, water quality deteriorated in the winter season and as per spatial consideration, junction and downstream side showed more pollution indicating the negative impact of tannery industrial park.

The Person's correlation results confirmed that the different water quality indices were significantly affected by the discharged effluent from the tannery industrial park. Besides, the indices were positively correlated with each other either very strongly or strongly.

This study will provide an index-based baseline data so local people in the vicinity of tannery industrial park can find the suitability of different applications of the river water. Moreover, it will allow policymakers to formulate conservation strategies to save the river Dhaleshwari.

Conflict of interest

The authors declare that they have no conflict of interest.

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Declaration of competing interest

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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Appendix A. Supplementary data

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