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Seasonal variations in heavy metal contamination of surface water in vicinity of industries and Western Yamuna Canal of Yamuna Nagar (Haryana), India

Manju Sharma, Smita Chaudhry

Abstract: Heavy metal pollution is a major environmental problem worldwide because of the long standing toxicity and bioaccumulation of these metals. The risk of heavy metal contamination is pronounced in the environment adjacent to large industrial complexes, and cities historically located along rivers, because the rivers provide transportation and have traditionally been a convenient place to discharge waste. In this study the heavy metals (Cd, Cr, Cu, Mn, Ni) contamination of surface water in vicinity of industries (sugar mill, paper mill, thermal power plant) and along Western Yamuna Canal (WYC) in Yamunanagar were determined in summer and winter seasons. The concentration of Cr and Cd were found higher in summer whereas Mn, Ni and Cu concentrations were found higher in winter season. In the water samples of industrial vicinity, the average concentration of Cd and Ni in summer and winter season respectively were higher than desirable limit. From the analysis it is inferred that the concentration of heavy metals in water samples from vicinity of sugar mill industry were higher than the paper mill and thermal power plant. Along WYC the metal concentrations in water samples were found to decrease with increasing distance from the industrial area. Mn concentration was within permissible limit in all sampling sites of WYC, whereas Ni concentration was very high in the second year of samplings. In WYC and industrial vicinity water samples, all the heavy metals show positive correlation among themselves suggesting that a common mechanism regulates their abundance. Total mean concentration of heavy metals in WYC and around industrial water samples was found to decrease in the order of Ni > Cu = Cr > Mn > Cd and Mn > Ni Cu = Cr > Cd respectively.

Index Terms: **Heavy metals, paper mill, sugar mill, surface water, thermal power plant, Western Yamuna Canal**

I. INTRODUCTION

Pollution of the environment by heavy metals is a major environmental problem world-wide because of the long standing toxicity and bioaccumulation. Heavy metals are omnipresent in the environment, occurring in varying concentration in air, bedrock, soil and water [1]. Metals in aquatic environment originate naturally by weathering of soil and rock, erosion, forest fires and volcanic eruptions and anthropogenically by industrial effluents, agricultural drainage, domestic discharges, atmospheric deposition, waste disposal including dumping, and combustion of fossil fuels, mining and refining operations [2-8]. Heavy meals are widely used in automobiles, mining industries, pesticides, house-hold appliances, dental amalgams, paints, photographic papers, photochemicals etc. [9,10]. Among various natural water resources, rivers are highly polluted by toxic metals due to the direct discharge of municipal and industrial effluents into the rivers [11]. Industries and cities have historically been located along rivers because the rivers provide transportation and have traditionally been a convenient place to discharge waste. Agricultural activities have tended to be concentrated near rivers, because river floodplains are exceptionally fertile due to the many nutrients that are deposited in the soil when the river overflows, therefore, the analysis of toxic pollutants in river water has received great attention. The risk of heavy metal contamination is pronounced in the environment adjacent to large industrial complexes [12]. Yamuna basin covers about 11% of total land area of India [13] with more than 10000 large and medium and more than 1 million small scale working industries [14]. In Haryana industrial growth has taken place mainly on the banks of river Yamuna [15]. Considerable work has been carried out on Yamuna river water quality flowing through Haryana and Delhi [11, 15 - 19]. However, heavy metal pollution of water in the Western Yamuna Canal (WYC) has received very little attention. Yamunanagar is the second biggest industrial town of Haryana. There are many industries like sugar mill, paper mill, starch mill, distillery, cement, metal industries, ply board and thermal power plant etc. All these industries discharge their waste into western Yamuna canal. Therefore in the present study an attempt has been made to investigate the distribution and enrichment of heavy metals

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cadmium (Cd), nickel (Ni), copper (Cu), chromium (Cr) and manganese (Mn) of surface water in vicinity of selected industries and Western Yamuna Canal of Yamunanagar.

II. METHODOLOGY

A. Study area

Yamuna Nagar district of Haryana located in north – eastern part of Haryana state with total geographical area 1756 sq.km lies between 29º 55': 30º 31' north latitudes and 77º 00': 77º 35' east longitudes, comprises 4% of total area of state. Population explosion, uncontrolled urbanization and industrialization caused a high rate of waste generation in Yamuna Nagar. The river Yamuna, a major tributary of river Ganga [20], originates from the Yamunotri glacier near Banderpoonch peaks in the Mussourie range of the lower Himalayas at an elevation of about 6387 meters above mean sea level in district Uttarkashi. Arising from the source, river Yamuna flows through a series of valleys for about 200 kms. It travels a total length of 1,376 km and has a drainage system of 366,233 km^2 (about 42% of the Ganga river basin and about 11% of India's total land area). Yamuna river basin covers 80 districts of seven states, partly covering Uttrakahand, Himachal Pradesh, Haryana, Uttar Pradesh, Madhya Pradesh and Rajasthan and covers the entire state of Delhi [19]. In the upper segment flowing through Poanta Sahib Yamuna River reaches Hathnikund/Tajewala in Yamunanagar district of Haryana state, where the river water is again diverted into Western Yamuna Canal and Eastern Yamuna Canal for irrigation. The Western Yamuna Canal (WYC) command area is located between the north latitudes 28°20' and 30º29'and east longitudes 75°48' and 77°35' and comprises the eastern, central and southern parts of the state of Haryana. It has a geographical area of about 13,543 sq km, spread over 49 blocks in the districts of Karnal, Panipat, Sonepat, Rohtak and Jhajjar and partly in the districts of Hisar, Bhiwani, Jind, Yamunnagar, Gurgaon and Rewari. The total length of the WYC with all its branches is 325 km [21]. All domestic and industrial discharges from the Yamunanagar are let out into this canal.

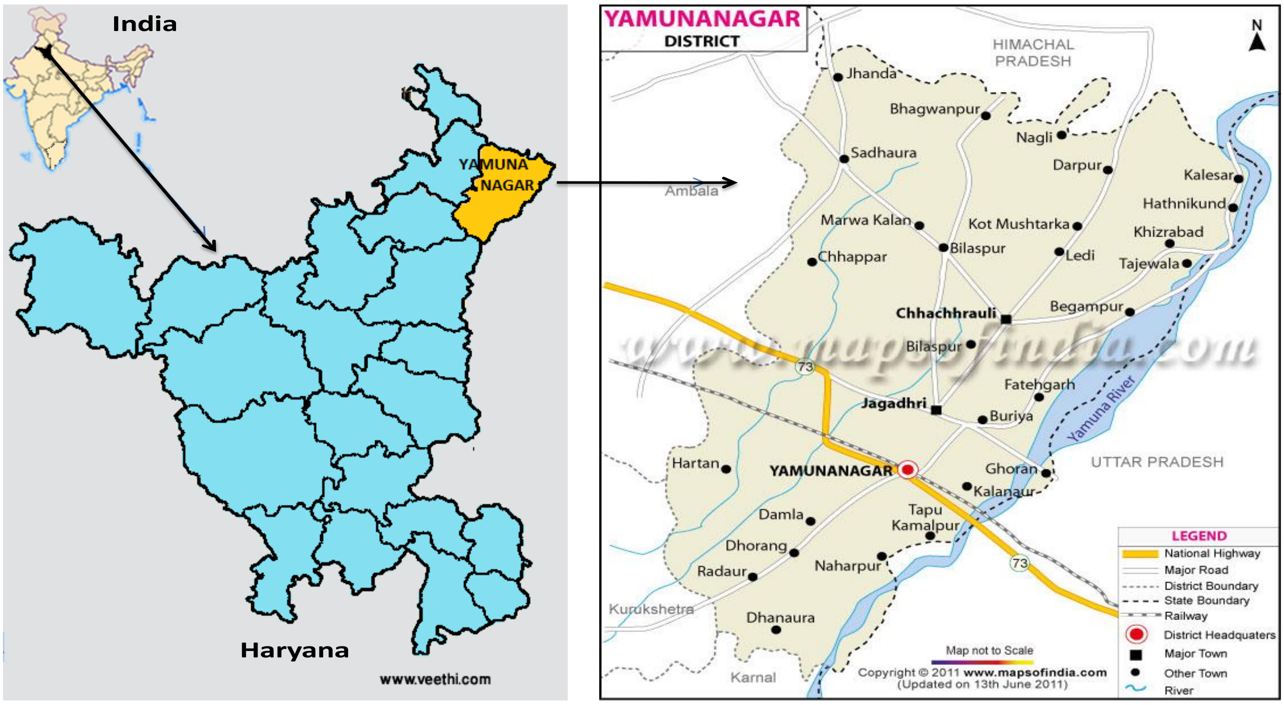

Fig.1. Location map of study area

B. Sampling

The sampling sites selected within the Yamuna Nagar city were three different industrial areas namely paper mill, sugar mill, thermal power plant and Western Yamuna Canal belt approximately 15 km stretch from Hamida Area Bridge to Buriya bridge. A total of 9 sampling sites for the collection of water from industries, three from each industry named SM 1-3, PM 1-3, TPP 1-3, within the 100 m periphery of each industry and 20

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sampling sites from of WYC approximately 500 m apart (WYC1-20) were selected. Sampling of surface water was done in June 2010, January 2011, June 2011 and January 2012 in each summer and winter season in vicinity of selected industries and Western Yamuna Canal.

Samples were collected in polyethylene bottles pre-cleaned with HNO_3 and deionized water according to standard methods [22]. The samples were acidified with concentrated nitric acid (1.5 ml concentrated nitric acid per litre of sample) and transported to the laboratory in the same day of collection and kept refrigerated (4ºC). Physiochemical parameters (pH, EC, TDS, DO) were measured with multiparameter kit of Merck model (304-i). The metal concentration in the water samples were determined using atomic absorption spectrophotometer model (AA-7000, Shimadzu). The instrument was calibrated by standard solutions from Merck with known concentration of heavy metals. After analysis of every 10 samples, blank and control standards were analysed to minimise the error. To assess the contamination level of heavy metals all analysis was replicated three times, mean, median, minimum, maximum, and standard deviation of water samples were also performed. Correlation among metal concentrations in the waters samples were evaluated using Pearson correlation coefficient.

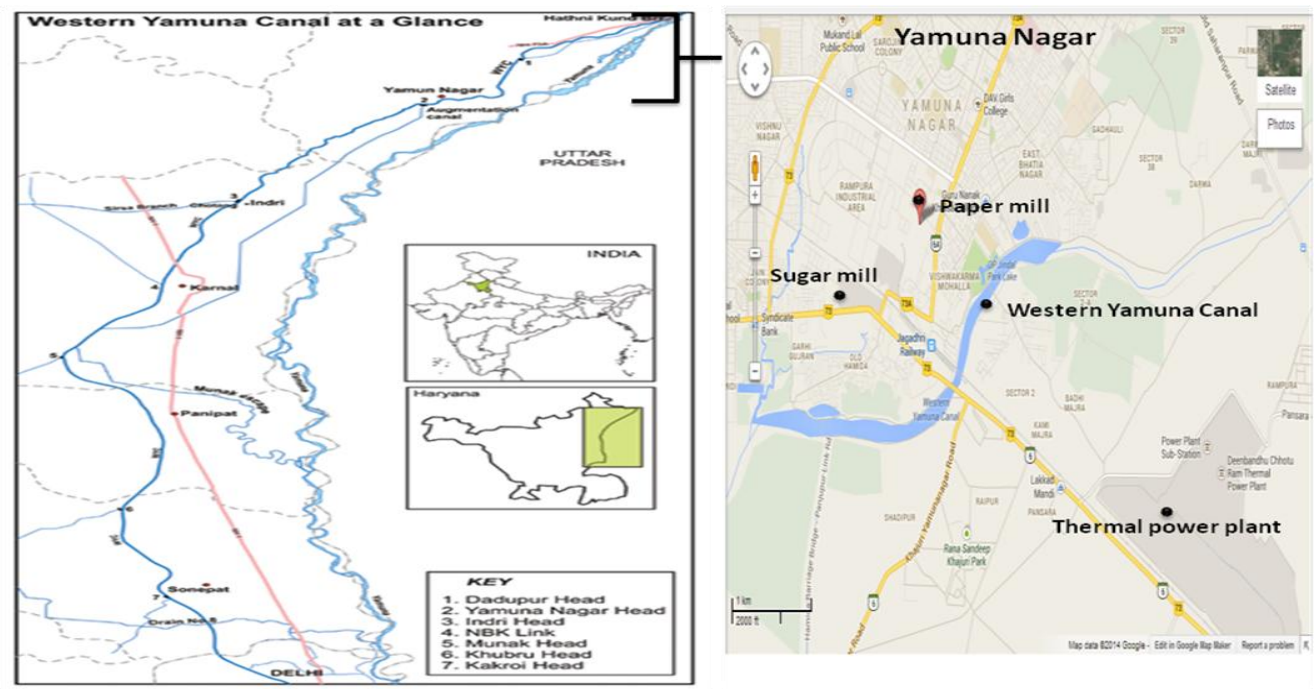

Fig. 2. Map showing Western Yamuna Canal and selected industries

III. RESULTS AND DISCUSSIONS

Mean concentration of basic physicochemical parameters and heavy metals of summer and winter season, in vicinity of selected industries and WYC are shown in Table 1 & 2. It is apparent from the results that the concentrations of metal ions vary significantly in different industrial sites and WYC.

The seasonal average pH values were slightly acidic in sugar mill samples and varied between 6.29±0.26 (SM-2) to 7.45±0.35 (PM-3) in industrial and 7.11±0.15 (WYC-1) to 7.90±0.06 (WYC-9) in WYC sampling sites. Lower acidic pH increases the bio-availability of heavy metals [23]. Conductivity is a good and rapid method to measure the total dissolved ions, higher the value of dissolved solids, greater the amount of ions in water [24]. The average concentration of EC and TDS of summer and winter season varied between 0.29±0.05 (TPP-1) to 2.26±0.09 (SM-1) mS/cm and 161.79±20.44 (TPP-1) to 1396.400±58.55 (SM-3) mg/L in industrial water samples respectively. The content of EC and TDS were higher in winter season that might be due to more inflow of organic and inorganic waste in winter rainfall of January and February months. Dissolved oxygen is a useful index of water quality [10, 25]. The average concentration of dissolved oxygen varied between 1.61±0.31 to 5.83±2.00 mg/L at SM-3 and TPP-3 respectively and 4.00±2.65 to 6.71±2.19 mg/L at WYC-1 and

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WYC-8 respectively. EC exhibited positive correlation whereas DO showed negative correlation with almost all parameters in both industrial and WYC, as with rise in the value of most of these parameters increase the EC and decrease the DO concentration. Higher content of DO was reported in winter season due to increase in dissolution of oxygen with decrease in temperature.

The total mean concentration of heavy metals in WYC and in industrial vicinity water samples decreased in the order of Ni > Cu = Cr > Mn > Cd and Mn > Ni > Cr = Cu > Cd respectively. Jain [17] also reported lower concentration of Cd in Yamuna river sediments. Whereas the percentage of heavy metals which exceeded the desirable limit of WHO [26] in industrial vicinity and WYC water samples were in the order of Cd > Ni> Cr > Cu = Mn and Cd > Ni > Cr = Cu > Mn respectively. Rawat [27] and Sehgal [18] also reported that industries are the primary source of heavy metals contamination in Yamuna.

Cadmium is a highly toxic metal not known to have any beneficial effects for plants and animals and mainly enters the environment through industrial and agricultural activities [28]. Total average mean concentration of cadmium varied from 0.021 to 0.027 and 0.003 to 0.012 mg/L in industrial and Western Yamuna Canal water samples respectively. The maximum value of cadmium was found in industrial water samples. About 94% of industrial area water samples and 80% of WYC water samples exceeded the desirable limit (0.003mg/L) of WHO [26]. The sites nearer to industrial area showed more concentration of cadmium in WYC. The concentration of cadmium was higher in summer season (0.040 and 0.009 mg/L) and lower in winter season (0.008 and 0.004 mg/L) at industrial and WYC respectively. Cadmium showed positive correlation with all heavy metals studied in industrial and WYC water samples, but showed a significant positive correlation with chromium (r=0.565), copper (r=0.829) and nickel (r=0.531) in WYC water samples (Table 4). The use of cadmium as alloy, coating material, in plastics, paint pigments in industries might be the reason of high concentration of cadmium in industrial vicinity water samples.

Table 1. Mean concentration of physiochemical parameters of industrial and WYC water samples

	pH		EC		TDS		DO	
Site	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
S.M. 1	5.920±0.83	6.905±0.05	2.199±0.23	2.326±0.40	1351.665±252.20	1428.865±341.58	1.460±0.04	2.045±0.23
S.M. 2	6.100±0.54	6.470±0.44	2.218±0.25	2.150±0.17	1376.665±216.85	1290.900±228.96	1.445±0.04	2.030±0.81
S.M. 3	6.380±0.10	6.625±0.52	2.203±0.23	2.265±0.32	1355.000±247.49	1437.800±220.33	1.390±0.03	1.825±0.86
P.M. 1	7.070±0.01	7.495±0.49	1.028±0.10	0.890±0.28	595.000±60.81	503.135±87.02	1.805±0.98	2.040±0.91
P.M. 2	7.160±0.13	7.180±1.03	0.759±0.37	1.181±0.66	464.165±305.24	711.665±486.96	3.140±1.36	2.985±1.55
P.M. 3	7.200±0.04	7.700±0.06	0.934±0.60	2.114±9.80	577.165±456.56	1087.115±1045.73	2.595±0.33	4.365±0.30
T.P.P. 1	7.245±0.21	5.695±2.16	0.254±0.02	0.324±0.15	147.335±13.67	176.235±50.11	4.015±3.01	7.005±0.63
T.P.P. 2	7.040±0.06	7.605±0.45	0.519±0.39	0.709±0.33	277.835±166.64	424.135±250.97	3.990±0.75	7.440±0.30
T.P.P. 3	7.115±0.01	7.535±0.23	0.315±0.14	0.670±0.34	214.165±104.89	403.865±252.49	4.420±0.04	7.245±0.50
W.Y.C. 1	7.000±0.40	7.210±0.07	0.927±0.97	0.302±0.04	122.735±59.97	169.670±1.41	2.125±0.71	5.875±1.77
W.Y.C. 2	7.125±0.37	7.430±0.21	0.808±0.85	0.323±0.02	104.785±48.73	183.435±16.64	3.770±0.86	6.235±0.47
W.Y.C. 3	7.595±0.04	7.240±0.06	0.802±0.85	0.296±0.05	101.415±43.48	168.250±2.01	5.175±2.09	6.970±1.61
W.Y.C. 4	7.595±0.04	7.430±0.40	1.086±1.24	0.319±0.00	118.135±28.01	184.575±31.93	5.020±2.02	7.055±1.93
W.Y.C. 5	7.845±0.11	7.200±0.23	0.960±1.06	0.323±0.01	113.330±40.06	187.980±33.45	5.865±2.76	7.200±1.411
W.Y.C. 6	7.780±0.13	7.760±0.01	0.903±1.00	0.318±0.00	105.875±35.18	182.960±30.59	5.205±2.21	7.805±0.95
W.Y.C. 7	7.760±0.07	7.525±0.42	0.899±0.99	0.323±0.01	108.620±40.47	185.580±33.81	5.405±2.20	7.840±0.99

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W.Y.C.8	7.550±0.37	7.730±0.08	0.951±1.03	0.337±0.00	117.820±47.83	193.785±34.58	5.160±2.12	8.260±1.61
W.Y.C. 9	7.940±0.07	7.855±0.01	0.983±1.08	0.301±0.03	117.540±43.66	170.190±13.94	5.295±2.23	7.625±0.69
W.Y.C. 10	7.750±0.07	7.780±0.23	0.948±0.98	0.408±0..09	127.165±63.87	239.205±88.92	5.055±1.87	7.395±1.12
W.Y.C. 11	7.420±0.41	7.940±0.30	0.915±0.92	0.359±0.02	129.450±72.29	209.005±39.61	4.710±2.66	7.130±1.87
W.Y.C.12	7.585±0.06	7.845±0.25	0.903±0.88	0.353±0.01	133.075±79.77	203.290±39.54	4.875±2.16	7.255±1.99
W.Y. C. 13	7.525±0.12	8.065±0.01	0.824±0.79	0.351±0.01	124.405±77.89	205.465±39.79	4.605±1.22	7.240±1.87
W.Y.C. 14	7.500±0.23	7.870±0.17	0.799±0.77	0.331±0.01	118.875±75.24	186.525±28.56	4.995±1.22	6.890±1.03
W.Y.C. 15	7.450±0.25	7.395±0.23	0.856±0.84	0.345±0.02	124.450±73.71	194.935±45.63	5.080±1.63	7.375±1.41
W.Y.C. 16	7.435±0.28	7.720±0.16	0.799±0.78	0.364±0.05	117.000±70.24	210.660±60.80	5.335±1.58	7.660±1.46
W.Y.C. 17	7.455±0.36	7.805±0.16	0.790±0.76	0.344±0.02	116.830±71.88	194.000±49.96	5.400±1.60	7.290±0.79
W.Y.C. 18	7.325±0.25	7.705±0.32	0.767±0.73	0.342±0.03	114.955±71.59	195.760±48.69	5.320±1.68	7.225±0.98
W.Y.C. 19	7.345±0.16	8.010±0.88	0.752±0.73	0.335±0.02	110.270±65.96	195.590±41.38	5.325±1.80	7.530±1.60
W.Y.C. 20	7.290±0.16	7.605±0.37	0.751±0.74	0.333±0.02	108.455±63.82	192.560±44.17	5.45±1.69	6.885±0.12

The mean concentration of chromium ranged between 0.017 to 0.071 mg/L and 0.031 to 0.049 mg/L in industrial and WYC water samples respectively. In summer and winter season about 40% and 9% of water samples respectively in all selected sites exceeded the limit of WHO [26] & BIS [29] 0.05mg/L. Chromium exhibited positive correlation with copper (r=0.640) and cadmium (r=0.565) in WYC (Table 4) and with copper (r=0.935), manganese (r=0.886) and nickel (r=0.518) in industrial sites (Table 3). About 17% of industrial and 38% of WYC water samples had copper concentration higher than desirable limit of WHO [26] and BIS [29]. In comparing the data, winter season showed more enriched concentration of copper in water samples in both industrial and WYC water samples. Copper concentration ranged from 0.023 (PM-2) to 0.061 (SM-1) mg/L and 0.018 (WYC-20) to 0.065 (WYC-1, 2) mg/L in industrial and WYC water samples respectively. Copper exhibited a significant positive correlation with chromium and manganese in all selected sites whereas in WYC water samples copper also positively correlated with cadmium (r=0.829) shown in **Table** 4.

Table 2. Heavy metal concentration (mean ± S.D) in western Yamuna canal water samples (mg/L)

Sites	Cadmium		Chromium		Copper		Manganese		Niickel	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
W.Y.C. 1	0.014±0.00	0.009±0.00	0.045±0.02	0.052±0.02	0.053±0.00	0.077±0.02	0.029±0.03	0.032±0.03	0.063±0.07	0.112±0.14
W.Y.C. 2	0.016±0.00	0.009±0.00	0.048±0.01	0.051±0.01	0.055±0.00	0.076±0.01	0.030±0.03	0.028±0.04	0.057±0.06	0.112±0.14
W.Y.C. 3	0.011±0.00	0.006±0.00	0.050±0.01	0.041±0.01	0.054±0.01	0.075±0.01	0.031±0.03	0.028±0.02	0.056±0.05	0.110±0.14
W.Y.C. 4	0.013±0.00	0.007±0.00	0.050±0.00	0.043±0.01	0.046±0.00	0.072±0.03	0.031±0.03	0.011±0.01	0.059±0.06	0.101±0.13
W.Y.C. 5	0.009±0.00	0.006±0.00	0.058±0.00	0.039±0.01	0.047±0.00	0.073±0.03	0.029±0.03	0.033±0.02	0.042±0.04	0.122±0.16
W.Y.C. 6	0.007±0.00	0.006±0.00	0.055±0.02	0.035±0.00	0.037±0.00	0.058±0.02	0.026±0.03	0.028±0.03	0.027±0.02	0.114±0.15
W.Y.C. 7	0.009±0.00	0.006±0.00	0.056±0.01	0.037±0.01	0.037±0.00	0.061±0.02	0.027±0.03	0.026±0.03	0.023±0.02	0.100±0.13

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W.Y.C. 8	0.008±0.00	0.004±0.00	0.061±0.02	0.037±0.00	0.038±0.00	0.067±0.02	0.027±0.03	0.030±0.04	0.050±0.06	0.108±0.14
W.Y.C. 9	0.006±0.00	0.005±0.00	0.059±0.03	0.025±0.02	0.033±0.00	0.064±0.02	0.029±0.03	0.029±0.04	0.054±0.06	0.092±0.12
W.Y.C. 10	0.007±0.00	0.004±0.00	0.067±0.03	0.024±0.02	0.036±0.01	0.067±0.01	0.031±0.02	0.027±0.03	0.047±0.05	0.100±0.13
W.Y.C. 11	0.008±0.00	0.004±0.00	0.070±0.030	0.020±0.02	0.028±0.02	0.070±0.01	0.030±0.02	0.026±0.03	0.056±0.07	0.108±0.14
W.Y.C. 12	0.009±0.00	0.004±0.00	0.067±0.04	0.023±0.02	0.021±0.01	0.065±0.00	0.027±0.02	0.042±0.01	0.053±0.06	0.085±0.11
W.Y.C. 13	0.0085±0.00	0.003±0.00	0.067±0.05	0.026±0.02	0.018±0.01	0.047±0.01	0.024±0.02	0.023±0.03	0.054±0.06	0.101±0.14
W.Y.C. 14	0.009±0.00	0.002±0.00	0.037±0.00	0.024±0.02	0.016±0.01	0.050±0.01	0.025±0.02	0.033±0.02	0.054±0.07	0.091±0.12
W.Y.C. 15	0.008±0.00	0.002±0.00	0.046±0.01	0.023±0.02	0.009±0.00	0.046±0.01	0.024±0.02	0.024±0.03	0.056±0.07	0.085±0.11
W.Y.C. 16	0.009±0.00	0.002±0.00	0.074±0.04	0.023±0.02	0.014±0.00	0.041±0.01	0.023±0.02	0.020±0.02	0.055±0.07	0.098±0.13
W.Y.C. 17	0.008±0.00	0.002±0.00	0.067±0.04	0.024±0.02	0.017±0.00	0.041±0.01	0.024±0.02	0.018±0.02	0.055±0.07	0.109±0.15
W.Y.C. 18	0.007±0.00	0.002±0.00	0.064±0.03	0.021±0.02	0.016±0.00	0.031±0.01	0.023±0.02	0.020±0.02	0.049±0.06	0.088±0.12
W.Y.C. 19	0.006±0.00	0.002±0.00	0.051±0.05	0.021±0.02	0.010±0.00	0.030±0.02	0.022±0.02	0.022±0.02	0.047±0.07	0.103±0.14
W.Y.C. 20	0.006±0.00	0.001±0.00	0.048±0.06	0.021±0.02	0.008±0.00	0.037±0.02	0.020±0.02	0.020±0.02	0.051±0.06	0.096±0.13

Table 3. Correlation among physiochemical parameters and heavy metals concentration in industrial vicinity water samples (significance level 0.05)

	pH	**EC**	**TDS**	**DO**	**Cd**	**Cr**	**Cu**	**Mn**	**Ni**
pH	1								
EC	-0.587	1							
TDS	-0.587	0.999	1						
DO	0.432	-0.853	-0.842	1					
Cd	-0.152	0.681	0.678	-0.843	1				
Cr	-0.716	0.797	0.798	-0.516	0.341	1			
Cu	-0.559	0.751	0.755	-0.502	0.402	0.935	1		
Mn	-0.666	0.672	0.666	-0.502	0.262	0.886	0.833	1	
Ni	-0.032	0.605	0.614	-0.275	0.448	0.518	0.581	0.375	1

Table 4. Correlation among physiochemical parameters and heavy metals concentration in Western Yamuna Canal water samples (significance level 0.05)

	pH	**EC**	**TDS**	**DO**	**Cd**	**Cr**	**Cu**	**Mn**	**Ni**
pH	1								
EC	0.245	1							
TDS	0.384	0.349	1						
DO	0.691	0.071	0.153	1					
Cd	-0.603	0.237	-0.393	-0.681	1				

Cr	-0.117	0.423	0.023	-0.151	0.565	1			
Cu	-0.295	0.534	-0.295	-0.398	0.829	0.64	1		
Mn	0.029	0.332	-0.012	-0.255	0.393	0.275	0.655	1	
Ni	-0.497	0.042	-0.165	-0.55	0.531	0.415	0.472	0.114	1

The mean concentration of manganese varied between 0.02 (TPP-1) to 0.96 (SM-1) in industrial vicinity and 0.020 (WYC-20) to 0.034 (WYC-12) mg/L in WYC water samples. Manganese concentration was found within the permissible limit 0.3 mg/L [26] in all samplings except only in winter 2011 from SM-1 and SM-2 site with an average value of 2.001 and 0.949 mg/L respectively. Mn exhibited a significant positive correlation with Cr (r=0.886) & Cu (r=0.833) in industrial vicinity and with Cu (0.655) in WYC water samples. Raju [7] also inferred positive correlation of Mn with Cu. Nickel concentration ranged between 0.066 (PM-1) to 0.112 (SM-1) and 0.096 (SM-2) to 0.117 (PM-3) in summer and winter season respectively in vicinity of industrial area. Whereas in water samples of WYC nickel concentration ranged between 0.023 (WYC-7) to 0.063 (WYC-1) mg/L and 0.085 (WYC-15) to 0.122 (WYC-5) mg/L in summer and winter season respectively. In rivers, nickel is transported mainly as a precipitated coating on particles and in association with organic matter [30]. Ni exhibited positive correlation with Cd (r=0.531), whereas showed negative correlation with pH (r=-0.497) TDS (r=-0.165), and DO (r=-0.550) in WYC water samples. In industrial vicinity all water samples crossed the desirable limit of WHO 0.07 mg/L in summer 2011 and winter 2012. In WYC 85% of water samples in summer 2011 and 100% of water samples in winter 2012 crossed the permissible limit of WHO. An increase in nickel concentration in second year of analysis was revealed, which may be due to flood events in monsoon season in the second year of study. Intense rainfall within a short time caused chemical weathering, transport of rocks and soil from the upper Yamuna basin to lower Yamuna basin and dumping of municipal sewage in to canal also lead to elevated Ni in the canal [31]. Wen [32] also revealed soil erosion was the main reason for higher concentration of dissolved Ni in flood season. Industries dealing with electroplating, coal and oil combustion, electrical equipment, catalysts, pigments, batteries etc. also release Ni as their effluents [12-13].

In WYC and industrial water samples, heavy metals Cd, Cr, Cu, Mn and Ni show positive correlation among themselves suggesting that a common mechanism regulates their abundance. A higher concentration of Cu, Mn & Ni was recorded in winter season in our study, whereas Al Saadi [33] reported these heavy metals high in spring season that may be due to difference in the geography and pattern of seasons in the areas of studies [34]. Higher concentration of heavy metals in winter might be due to low pH and microbial activity resulting in the adsorption and precipitation of elements on sediment particles [35-36].

IV. CONCLUSION

It is evident from the study that heavy metal concentrations were higher in water samples from vicinity of sugar mill industry followed by paper mill and thermal power plant. Other small units of industries such as pharmaceuticals, starch and automobiles repair and maintenance workshops near sugar mill also contribute to higher content of heavy metals in water samples. In WYC water samples, the metal concentrations were found to decrease with increasing distance from the industrial area. This shows the influence of the industrial activities on Western Yamuna Canal. In industrial vicinity concentration of Cd was much higher in summer season. Among all metals Ni and Cd concentration was recorded abundant in both industrial vicinity and WYC water samples, whereas Mn concentration was recorded within the permissible limit in all selected sites except at SM-1 and SM-2 of winter 2011 sampling. The higher concentration of Cd and Cr was recorded in summer season whereas Cu, Mn, & Ni in winter season. Increase in nickel concentration in winter 2012 may be due to flood in rainy season of 2011. Special attention should be paid to mitigate pollution from industrial sources. To improve the water quality in industrial areas and WYC, effluent discharge from various industries should be treated to an adequate extent. The industries should not be allowed to dispose their waste water into the canal. Special attention should be paid to mitigate pollution from industrial sources and constant monitoring of Western Yamuna Canal water quality is needed.

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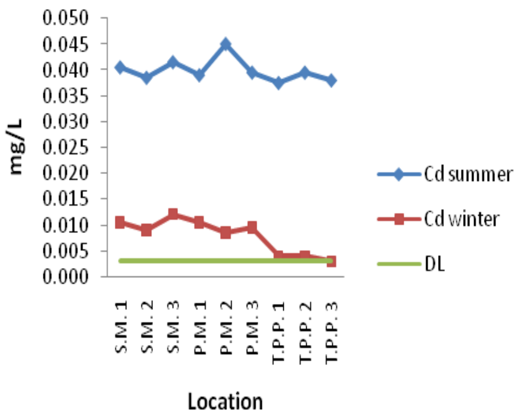
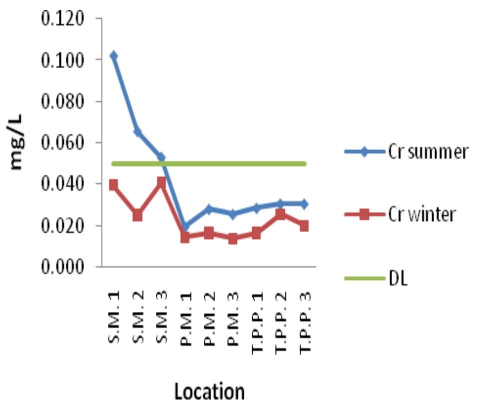
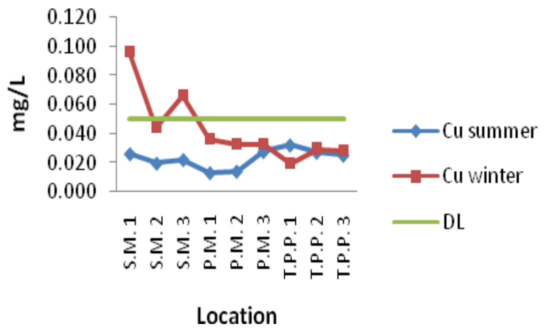
Concentration of Cd in industrial vicinity water samples



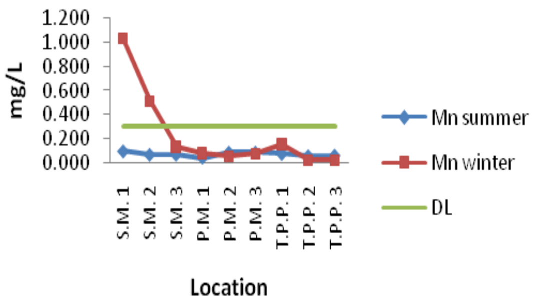
Concentration of Cr in industrial vicinity water samples



Concentration of Cu in industrial vicinity water samples



Concentration of Mn in industrial vicinity water samples



Concentration of Ni in industrial vicinity water samples

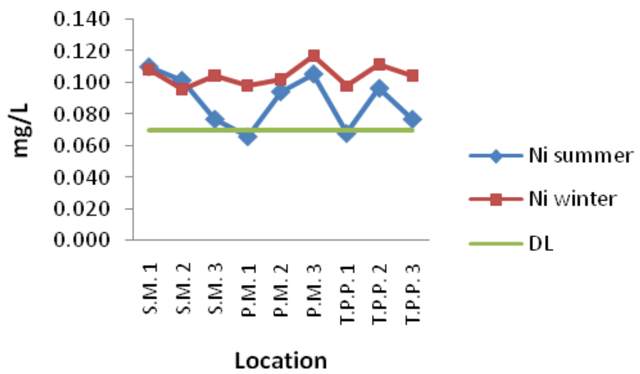


Fig. 3 Mean heavy metal concentration of water samples in vicinity of selected industries
DL- desirable limit of WHO [26]

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AUTHOR BIOGRAPHY

Manju Sharma, Research Scholar, Institute of environmental studies, Kurukshetra University, Kurukshetra, Haryana.

Smita Chaudhry, Director, Institute of environmental studies, Kurukshetra University, Kurukshetra, Haryana.