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Ecological and Health Risks Assessment of Levels of Heavy Metals in Drinking Water of Baghdad City, Iraq

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ABSTRACT

Background and Objective: Public health is at risk in drinking water due to toxic substances which may have adverse health effects on humans. Based on untreated urban wastewater and manufacturing, farming and other man-made operations, drinking water supplies are vulnerable to contaminates in this region. Consequently, maintaining the health of drinking water is a rising concern in Iraq. The study aimed to estimate levels of heavy metals in the drinking water of Baghdad City, Iraq. **Materials and Methods:** To evaluate the quality of drinking water, the samples measured nine concentrations of heavy metals (Iron (Fe), Aluminum (Al), Lead (Pb), Zinc (Zn), Nickel (Ni), Cadmium (Cd), Fluoride (F), Manganese (Mn) and Copper (Cu) in drinking water samples from eleven water treatment plants (11WTPs) in Baghdad City to improve public health interventions. **Results:** Heavy metal concentrations were measured using an atomic absorption spectrometer (Model Phoenix-986 AAS) and contrasted with permissible limits established by Iraqi Guidelines and Water Chemical Limits Requirements (417/2011) and the World Health Organisation (WHO). Heavy metal concentrations were used to measure health risk assessments using the HPI and MI models. The results showed that mean HPI values for all seasons except in spring were 91,697 above the critical pollution index value of 100, indicating that 11WTPs are critically polluted with heavy metals. **Conclusion:** The MI results have been used to achieve the heavy metal toxicity among the sampling stations. Furthermore, no work was done on HPI and MI models in Baghdad city related to 11WTPs.

KEYWORDS

Health risk assessment, drinking water, heavy metals, pollution, metal index heavy metal pollution index (HPI)

INTRODUCTION

Human beings are continuously subjected to numerous harmful chemicals in our atmosphere, which may contribute to complicated diseases such as endocrine destruction, genotoxic carcinogen, leukemia, dermatitis, enteritis, liver cirrhosis and respiratory diseases[1]. Both such man-made hazardous chemicals will eventually reach water source. Such toxic chemicals from domestic wastewater, irrigation, factories and other human activities penetrate waterways, streams and groundwater and can contaminate drinking water[2-4]. Contamination of drinking water with heavy metals is a public health issue because of their ingestion and human accumulation. Chemical pollutants in drinking water can present major threats to

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human safety directly via the intake, absorption and inhalation pathways[5,6]. Thus, in recent years, the study of water pollution by heavy metals has been the primary concern of environmental scientists[5]. Treatment plants (11WTPs) in Baghdad City have the capacity to generate 2.8 million liters of drinking water per day for consumers[7,8]. The majority of 11WTPs use conventional water treatment systems, which are divided into three phases: Pretreatment (filtration and aeration process), prechlorination (coagulation and flocculation process) and post-treatment (sedimentation and filtration process)[9,10]. In recent years, quality indices (WQIs) have been useful for health risk assessment by drinking water exposure to toxic heavy metals[11]. The possible effect of heavy metals on human health helps to quickly assess. The value of >1 for MI is a warning threshold even if the concentration of (Ci) for all elements is less than the maximum permitted value (MACi)[12]. The Metal Index has been used as an indicator for drinking water.

The metal index (MI) another index used for drinking water is a model that takes into consideration the possible additive effect of heavy metals on human health which helps to quickly assess the overall quality of drinking water and the value of >1 for MI is a warning threshold even if the mean concentration (Ci) for all elements is less than the maximum permitted value (MACi)[12]. The aim of study was to estimate levels of heavy metals in drinking water of Baghdad City, Iraq.

MATERIALS AND METHODS

Study site: The study field, located in middle Iraq's City of Baghdad, is situated between Latitudes 33°14'-33°25' N and Longitudes 44°31'-44°17' E, with millions of inhabitants covering a total region of 1000 km^2. Water treatment plants (11WTPs) in Baghdad City relied on Table 1 for the treatment of raw water from the Tigris River for their drinking water.

Experimental methods: From September 2018 to August 2019, water samples were obtained monthly across four seasons, in the current analysis. After the delivery of drinking water to the houses through the water supply network, the treated water samples were obtained using clean polyethylene bottles from the eleven treatment plants (11WTPs). All drinking water samples for heavy metals (Fe, Al, Cr, Pb, Zn, Ni, Cd, Ag, Mn and Cu)[13].

Calculations of the model HPI: The evaluation of water quality works based on heavy metal concentration. The heavy metal pollution index (HPI) was formulated by Dede *et al.*[12]:

$$Wi = \frac{K}{Si\ standard} \quad (1)$$

Where:

Wi = Unit weightage of the ith parameter

K = Constant of proportionality can be calculate from formula proposed by Al-Dulaimi and Younes[5] and Al-Mayah *et al.*[6]

Si = Iraqi accepted drinking water quality standard prescribed by (417/2011) as shown in Table 1

The quality rating (Qi) of the parameter is calculated by:

$$Qi = \sum_{n=1}^{n} \frac{Mi - Ii}{Si - Ii} \times 100 \quad (2)$$

Where:

Mi = Monitored value of heavy metal of ith parameter can be obtained from Table 3

Ii = Ideal value of the ith parameter by Eldaw *et al.*[14], Mensoor and Said[15]

Si = Iraqi accepted drinking water quality standard prescribed by Issa and Alshatteri[11]

– = Indicates numerical difference of the two values, ignoring the algebraic sign

Table 1: Features of drinking water treatment plants (11WTPs) in Baghdad City, involved in this study

ID	Name of station (WTPs)	Design capacities	Location (area)	Year of establishment	Network situated
1	Al-Karkh	1,300,000 m^3/day	Al-Karkhside	1984	Medium
2	Sharq Dijla	90,000 m^3/day	Al-Rusafa side	1978	Medium
3	Al-Sader	90,000 m^3/day	Al-Rusafa side	2013	Good
4	Al-Baldiat	225,000 m^3/day	Al-Rusafa side	2012	Good
5	Al-Kadhimiya	112,5000 m^3/day	Al-Karkhside	2011	Good
6	Al-Karama	220,000 m^3/day	Al-Karkhside	1953	Medium
7	Al-Wathba	130,000 m^3/day	Al-Rusafa side	1932	Bad
8	Al-Qadisya	140,000 m^3/day	Al-Karkhside	1965	Medium
9	Al-Dora	113,000 m^3/day	Al-Karkhside	1982	Medium
10	Al-Wahda	72,000 m^3/day	Al-Rusafa side	1959	Medium
11	Al-Rasheed	90,000 m^3/day	Al-Rusafa side	1963	Bad

Table 2: Illustration of MI-WQI categories

MI-WQI values	Rating	Class
<0.3	Very pure	I
0.3-1.0	Pure	II
1.0-2.0	Slightly affected	III
2.0-4.0	Moderately affected	IV
4.0-6.0	Strongly affected	V
>6.0	Seriously affected	VI

Finally, the HPI model is then calculated as follows:

$$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \tag{3}$$

Where:

Wi = Unit weightage of the ith parameter

Qi = Quality rating

Calculations of the model MI: The metal index (MI) was proposed by Caeiro *et al.*[10]. This index can be calculated value manually by the following equation:

$$MI = \sum_{i=1}^{n} \frac{Ci}{(MAC)\ i}$$

Where:

MI = Metal index

Ci = Mean concentration of each metal

MAC = Maximum allowed concentration for each metal that can be obtained from the standard (Table 2)

RESULTS AND DISCUSSION

Spatial and temporal variations of heavy metals concentration: The findings of this study indicate that drinking water content in most 11WTPs in Baghdad City is not appropriate for customers. Annual mean heavy metal concentrations in drinking water samples follow the order of Fe>Cu>Zn>Al>F>Mn >Pb>Ni>Cd as shown in Table 3 and Fig. 1. The results were compared with the chemical limits of Iraqi Criteria and Standards of Water (417/2011) and the drinking water quality standards of the World Health Organization (WHO)[14,15]. Most heavy metal concentrations in drinking water exceeded the permissible limits except for Zn and F for Iraqi requirements and Zn, Ni, F, Mn and Cu for WHO standards. High

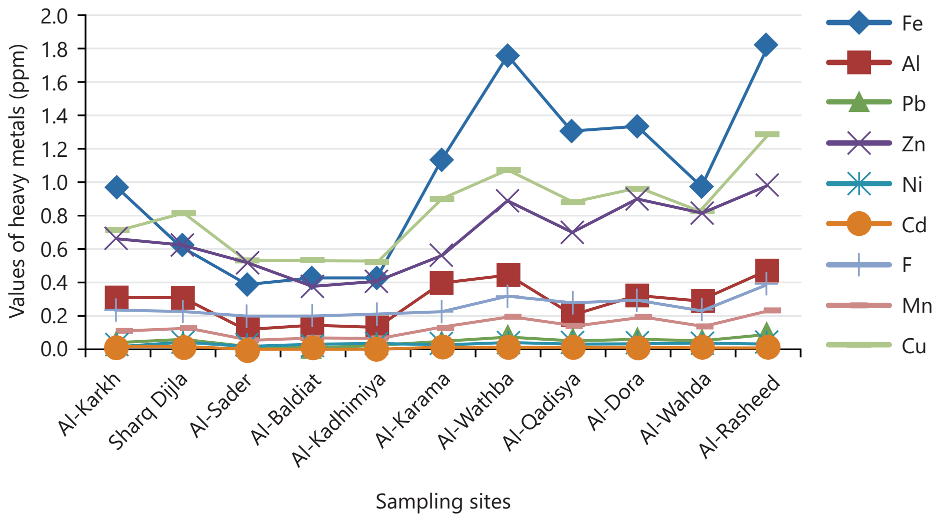

Fig. 1: Annual mean of heavy metal concentrations at 11WTPs of Baghdad City

Table 3: Annual mean of heavy metal concentrations at different WTPs of Baghdad City

ID	WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)
1	Al-Karkh	0.964	0.312	0.037	0.657	0.0274	0.0035	0.229	0.114	0.708
2	Sharq Dijla	0.616	0.305	0.0423	0.622	0.0319	0.0037	0.225	0.126	0.814
3	Al-Sader	0.384	0.118	0.025	0.515	0.0215	0.0031	0.192	0.057	0.529
4	Al-Baldiat	0.419	0.129	0.0173	0.370	0.0233	0.0034	0.194	0.073	0.528
5	Al-Kadhimiya	0.427	0.133	0.0283	0.398	0.0218	0.0033	0.206	0.065	0.526
6	Al-Karama	1.131	0.39	0.042	0.558	0.0298	0.0041	0.221	0.128	0.903
7	Al-Wathba	1.748	0.443	0.0685	0.882	0.0364	0.0047	0.319	0.194	1.067
8	Al-Qadisya	1.2989	0.217	0.0496	0.695	0.0325	0.0042	0.274	0.146	0.884
9	Al-Dora	1.324	0.326	0.0588	0.891	0.0336	0.0044	0.291	0.185	0.962
10	Al-Wahda	0.965	0.285	0.0453	0.817	0.0326	0.0038	0.228	0.136	0.824
11	Al-Rasheed	1.821	0.472	0.0821	0.975	0.0385	0.0049	0.381	0.234	1.285
WHO standard		0.3	0.2	0.01	3	0.07	0.003	1.5	0.4	2
(2017)[15,26]		0.3	0.2	0.01	3	0.02	0.003	1.0	0.1	1

concentrations of heavy metal in 11WTPs are due to the source of drinking water from the Tigris River primarily induced by untreated sewerage inflows from rural, residential and industrial establishments. On the other hand, lack of worker experience in the 11WTPs and differences in purification process efficiency as well as rehabilitation and corrosion of distribution network pipes were the main reasons why the concentrations of heavy metals in drinking water increased. Exposure to elevated amounts of heavy metals in drinking water can contribute to acute and persistent poisoning, such as osteodystrophy, Alzheimer's disease, organ injury, lung cancer, cirrhosis, harm to the liver, nervousness and even death[16-18].

Heavy metal pollution index (HPI): The summary of drinking water sample HPI model values from all 11 sampling sites (11WTPs) and all seasons is presented in Table 4-7. Based on the estimated HPI model of the studied heavy metals by drinking water consumption, mean values for all seasons have adverse health effects for consumers except for spring (HPI = 91.697), because the values obtained are above the critical pollution index of 100. In the order of Al-Rasheed>Al-Wathba>Al-Dora>Al-Qadisya>Al-Karama> Al-Wahda>Sharq Dijla>Al-Karkh>Al-Kadhimiya>Al-Baldiat>Al-Sader, HPI indices for WTPs in the research region were identified. The actual cause for this fluctuation in the HPI values at these WTPs was variations in concentrations of heavy metals, outdated network pipes, irregular repairs, industrial runoff and other intense human activities.

For the same reasons, it was noted in Fig. 2 that the water treatment plants (WTPs) deteriorate in the downstream trend of the Tigris River from north to south within the City of Baghdad. Furthermore, previous studies[19-21] supported the current study (Table 8).

Table 4: Calculate HPI-WQI of WTPs during autumn (September, October, November, 2018)

	Qi										
WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)	SUM WIQI	HPI-WQI value
Al-Karkh	238	101.5	330	31.73	105	130	95.2	87	93.6	266.6	9.581
Sharq Dijla	240	135	230	24.5	90	106.7	9.9	73	89.3	229.7	8.256
Al-Sader	124	68.5	190	25.03	110	106.67	9.4	64	58.3	223.1	8.017
Al-Baldiat	103.4	95	130	11.66	125	116.67	12.2	98	97.2	200.3	7.199
Al-Kadhimiya	110	91.5	140	27.17	110	116.67	2.6	69	84.1	219.5	7.89
Al-Karama	98	157.5	590	23.76	90.5	90	9.3	82	75.3	289.5	10.40
Al-Wathba	280	105	590	33	155	130	8.3	82	75.6	323.2	11.61
Al-Qadisya	250.3	147	450	27.63	115	110	8.5	96	89.4	293.6	10.55
Al-Dora	192.4	132.5	530	27.1	125	103.3	7.5	78	92.6	290.3	10.43
Al-Wahda	183.4	104	330	32.77	135	126.67	1.3	98	90.3	267.1	9.601
Al-Rasheed	244.7	110	741	32.9	135	126.6	11.3	95	85.6	348.9	12.538
Wi	3.33	5.00	0.198	6.613	9.92	0.661	1.984	0.10	0.02	∑Wi = 27.826	
Total HPI value = 105.542											

Table 5: Calculate HPI-WQI of WTPs during winter (December, January, February, 2019)

	Qi										
WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)	SUM WIQI	HPI-WQI value
Al-Karkh	67	46.5	190	12.8	55	103.4	6.6	41	46.3	213.3	7.667
Sharq Dijla	72	41	530	25.1	95	86.67	9	35	73.1	273.6	9.834
Al-Sader	85.7	44	150	14.7	90	70	8	65	53	187.4	6.736
Al-Baldiat	67.34	34.5	170	9.37	7.5	90	8.5	39	41.1	191.7	6.890
Al-Kadhimiya	45.7	46	180	5.13	9.5	80	9.2	38	39.1	195.6	7.031
Al-Karama	131.4	90	450	27.8	120	93.3	12	71	80.3	266.3	9.572
Al-Wathba	190.4	105.5	620	31.1	130	110	13	99	72.2	313.2	11.25
Al-Qadisya	84	49	550	22.84	90	96.67	62	95	82.5	285.1	10.24
Al-Dora	139.7	68	580	26.84	125	106.7	11	73	87.1	301.3	10.83
Al-Wahda	117.7	36	290	20.4	110	96.7	11	53	61.9	234.7	8.436
Al-Rasheed	239	65	910	29.94	105	106.7	15	86	25.2	365.5	13.14
Wi	3.33	5.00	0.198	6.613	9.92	0.661	1.984	0.10	0.02	∑Wi = 27.826	
Total HPI value = 101.626											

Table 6: Calculate HPI-WQI of WTPs during spring (March, April, May, 2019)

	Qi										
WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)	SUM WIQI	HPI-WQI value
Al-Karkh	177.7	99	180	23.36	61	83.34	11.6	19	41.1	199.5	7.172
Sharq Dijla	33.67	76	210	7.43	59.5	70	13.5	58.5	11.4	196.1	7.048
Al-Sader	35.67	46	160	11.7	81	70	8.4	81	42.4	188.4	6.772
Al-Baldiat	31	40.5	150	16.9	71.5	93.34	9.1	64.4	30.2	193.7	6.963
Al-Kadhimiya	29.67	49.5	180	10.36	78.5	73.34	8.9	49.1	28.5	200.5	7.207
Al-Karama	108	92.5	170	27.1	72.5	80	9.3	89	61.1	223.4	8.031
Al-Wathba	175	137	580	25.53	102.5	116.7	8.2	97	97.2	307.8	11.06
Al-Qadisya	38.33	39.5	150	17.86	68.5	73.33	11.5	84.7	31.1	227.5	8.177
Al-Dora	171	55	450	25.13	85.5	73.33	10.9	81.6	67.8	249.7	8.975
Al-Wahda	66	95	190	7.03	62.5	76.67	11	96.2	51.3	198.1	7.122
Al-Rasheed	245.7	96	820	31.6	127.5	130	31.2	113	85.9	366.4	13.17
Wi	3.33	5.00	0.198	6.613	9.92	0.661	1.984	0.10	0.02	∑Wi = 27.826	
Total HPI value = 91.697											

Metal index (MI): Table 8, 9 summarizes the classification and experimental findings of the 11WTP model for low-quality water with MI value of 155.93, indicating that the 11WTPs are seriously impaired by metal contamination, this was in accordance with a survey performed by 17-20. From the results of this analysis for 11WTPs, it was observed that the MI values for all the samples under review were >1 suggesting that

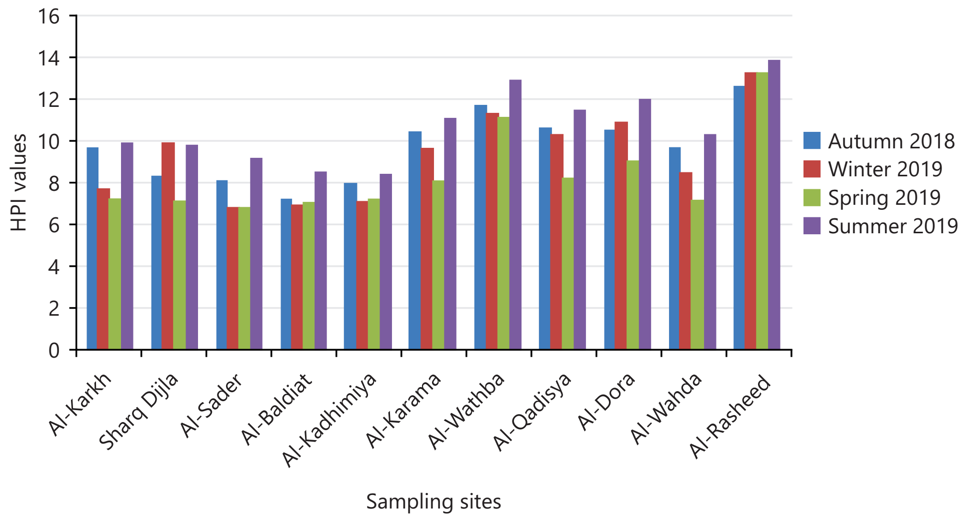

Fig. 2: Spatial and temporal variations of HPI values in the 11WTPS at Baghdad City

Table 7: Calculate HPI-WQI of WTPs during summer (June, July, August, 2019)

	Qi										
WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)	SUM WIQI	HPI-WQI value
Al-Karkh	167	97.5	381	19.76	168.5	116.67	18.5	112	99.5	274.2	9.856
Sharq Dijla	109.3	85	331	22.43	135	130.67	15.5	139	95.7	270.1	9.708
Al-Sader	133.7	58.5	305	17.87	109.5	116.66	11	105	57.2	252.2	9.065
Al-Baldiat	77	74.5	243	11.43	115.5	103.4	12	112	42.9	235.1	8.450
Al-Kadhimiya	117.6	79	235	10.43	119	110	13	109	58.7	231.6	8.324
Al-Karama	158.3	131.5	495	23.23	174.5	130	17	122	92.4	306.6	11.02
Al-Wathba	185.6	136.5	624	28.37	206	159.6	19.2	153	102.1	355.7	12.785
Al-Qadisya	145.7	106.5	517	24.4	142.5	127	17.3	166	122.7	316.3	11.367
Al-Dora	129.6	78.5	593	31.87	175	139	19.6	121	97.5	331.2	11.905
Al-Wahda	125	84	405	19.9	184.5	123.4	17	126	98.2	284.6	10.23
Al-Rasheed	265	161.5	792	31.83	210	162.33	19.8	194	109.3	382.8	13.759
Wi	3.33	5.00	0.198	6.613	9.92	0.661	1.984	0.10	0.02	∑Wi = 27.826	
Total HPI value = 116.112											

Table 8: Mean MI-WQI of WTPs during four seasons

Heavy metals (ppm)	Mean concentrations (Ci)	Highest permitted value (MAC)i*	MI
Fe	0.9816	0.3	3.272
Al	0.2845	0.2	1.422
Pb	0.0418	0.01	4.18
Zn	0.6709	3	0.224
Ni	0.0297	0.02	1.487
Cd	0.0039	0.003	1.3
F	0.2509	1	0.2509
Mn	0.1325	0.1	1.325
Cu	0.8209	1	0.8209
∑ MI = 14.602			

*Iraqi criteria and standards of water's chemical limits and ICS: 13.060.20 number 417/2011

there is a possible health risk for those consuming drinking water in the City of Baghdad, especially in the last five stations (Al-Wathba, Al-Qadisya, Al-Dora, Al-Wahda and Al-Rasheed), as can be seen in Fig. 3. Due to the broad flow of waste from medical Baghdad District, chemical and mineral processing plants, plant oil factories, textile mills and Rostamia sewage stations, which are located in this study area, a major change occurred at these stations during the study time[22-26].

Table 9: MI-WQI recorded at different sampling WTPs

		MI											
ID	WTPs	Fe (ppm)	Al (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Cd (ppm)	F (ppm)	Mn (ppm)	Cu (ppm)	∑MI-WQI value	MI-WQI scale	Water quality rating
1	Al-Karkh	3.213	1.56	3.7	0.219	1.37	1.3	0.229	1.14	0.708	13.43	>6.0	Seriously affected
2	Sharq Dijla	2.05	1.525	4.53	0.207	1.59	1.3	0.225	1.26	0.814	13.5	>6.0	Seriously affected
3	Al-Sader	1.28	0.59	2.5	0.171	1.075	1.033	0.192	0.57	0.529	7.94	>6.0	Seriously affected
4	Al-Baldiat	1.396	0.645	1.73	0.123	1.165	1.13	0.194	0.73	0.528	7.64	>6.0	Seriously affected
5	Al-Kadhimiya	1.423	0.665	2.83	0.132	1.09	1.1	0.206	0.65	0.526	8.62	>6.0	Seriously affected
6	Al-Karama	3.77	1.95	4.2	0.186	1.49	1.366	0.221	1.28	0.903	15.36	>6.0	Seriously affected
7	Al-Wathba	5.826	2.215	5.85	0.294	1.82	1.57	0.319	1.94	1.067	20.90	>6.0	Seriously affected
8	Al-Qadisya	4.329	1.085	4.96	0.231	1.625	1.4	0.274	1.46	0.884	16.24	>6.0	Seriously affected
9	Al-Dora	4.413	1.63	5.21	0.297	0.168	1.47	0.291	1.85	0.962	16.31	>6.0	Seriously affected
10	Al-Wahda	3.216	1.425	4.13	0.272	1.53	1.3	0.228	1.36	0.824	14.28	>6.0	Seriously affected
11	Al-Rasheed	6.07	2.36	6.41	0.325	1.925	1.64	0.381	2.34	1.285	22.73	>6.0	Seriously affected
Total MI value = 155.93													

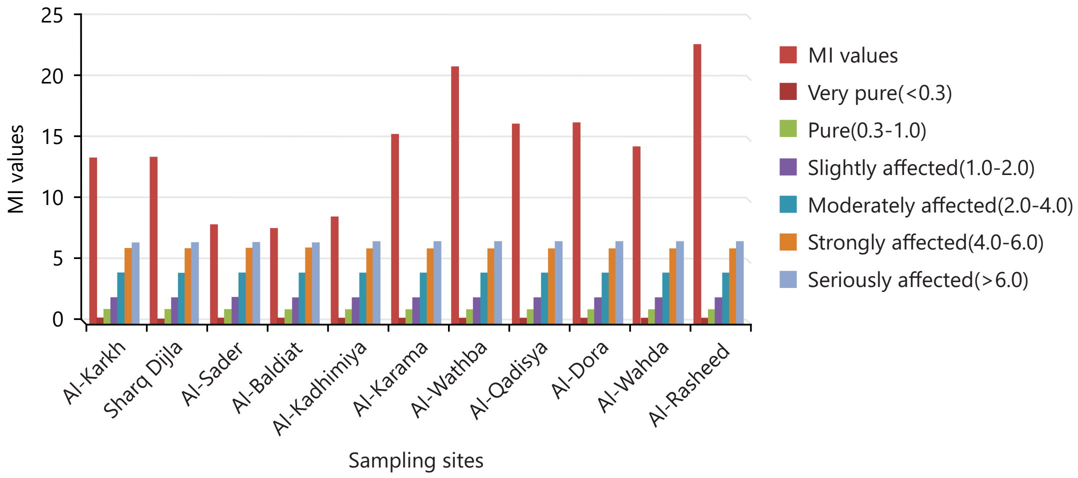

Fig. 3: MI values for all studied metals in each sample in WTPs

CONCLUSION

The results of HPI and MI models revealed that all WTP drinking water samples are unsuitable for human consumption as per the total MI value (155.93) and the annual mean HPI value (103.744), respectively. Due to their high concentrations in drinking water, people are most exposed to Fe, Pb, Al, Ni and Cd among all the prominent heavy metals examined in this study, while they are least exposed to Zn, F, Cu and Mn. In addition, the proposed MI and HPI models can provide accurate and reliable information on quality of drinking water and will serve as a useful tool for future sustainable management of WTPs.

SIGNIFICANCE STATEMENT

Public health is at risk in drinking water due to toxic substances which may have adverse health effects on humans. Consequently, maintaining the health of drinking water is a rising concern in Iraq. Estimate levels of heavy metals in the drinking water of Baghdad City, Iraq need to be studied. Heavy metal concentrations were measured using an atomic absorption spectrometer and contrasted with permissible limits established by Iraqi Guidelines and Water Chemical Limits Requirements. Heavy metal concentrations were used to measure health risk assessments using the HPI and MI models. The MI results have been used to achieve the heavy metal toxicity among the sampling stations. Furthermore, no work was done on HPI and MI models in Baghdad City related to 11WTPs.

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