ORIGINAL ARTICLE

Environmental assessment of heavy metal pollution of Diyala River within Baghdad City

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Abstract

Water quality index (WQI), pollution index (PI), and metal index (MI) were applied in the last reach of Diyala River, Baghdad, Iraq with regard to ten heavy metals (Cd, Cr, Cu, Ni, Pb, Mn, Fe, Zn, Ag, and Cn). These indices were applied to historical data along with the data obtained from the present study in order to acquire a historical heavy metal assessment of the river reach. The results of WQI showed that the water quality of the reach of interest declined from excellent in the year of 1999 to unsuitable in 2007 then good in 2008 to unsuitable once again in the years of 2009–2015. The PI indicated that Cd, Cr, and Pb were the most affecting elements all over the years. The MI was found to be a threshold of warning during all years but with different levels. The impact of Al-Rustimiyah Wastewater Treatment Plants (WWTPs) on the water quality was evident due to the lack of heavy metal treatment units within the plants. It is recommended to add such units to the WWTPs and to reduce the local electricity generators that contribute with great amounts of contaminants.

Keywords Water quality index · Pollution index · Metal index · Heavy metals · Diyala River

Introduction

One of the worldwide problems regarding pollution of aquatic environment is the accumulation of heavy metals, due to their toxic effect on the living being (Mac-Farlane et al. 2006). The increased population and the expanded economic activities would lead to various uses of water and by that rise the stress in terms of water quality (Chougule et al. 2009).

The water quality of any water body is affected by its sources and supplies in terms of their quality and quantity (Alobaidy et al. 2010), in which heavy metals mostly come from anthropogenic activities (Akoto et al. 2008; Shakir et al. 2016).

Water quality indices are valuable tools used in demonstrating the ecological factors' effect on water quality (Ewaid and Abed 2017). It integrates multiple water quality parameter data into a single number that rates the health of the ecosystem. This number justifies the water quality into classes varying from excellent to very poor. It can easily be interpreted and understood by political decision-makers, non-technical water managers, and the public (Al-Saboonchi et al. 2011). Several water quality indices have been developed and applied around the world (Prasad and Kumari 2008; Reza and Singh 2010; Manoj et al. 2012; Dede et al. 2013); they differ in the way of translating the values of the parameters (Lumb et al. 2011; Abbasi and Abbasi 2012).

Iraqi aquatic environment is seriously contaminated with heavy metals (Al-Haidarey et al. 2010; Al-Obaidy et al. 2016a). Diyala River, being one of the Tigris River tributaries, was proved to be one of the most polluted rivers in Iraq (Mohammed 1985, 1999; Musa 2009; Al-Anbari and Jumaa 2010; Al-Ghabban 2010; Al-Sudani 2014; Al-Samawi and Al-Hussaini 2015, 2016a, b; Al-Hussaini 2016; Al-Hussaini and Al-Samawi 2017), especially at its last part where the raw and treated effluents of Al-Rustimiyah wastewater treatment plants (WWTPs) discharge into it before its confluence with Tigris River in about 15 km. Al-Rustimiyah WWTP is the oldest sewage network in Iraq, in which third of Baghdad population are served (Shakir et al. 2017).

The objectives of this research study were to evaluate the historical changes in the heavy metals' concentration at the last reach of Diyala River before its confluence with Tigris

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River and its effect on the environmental assessment of the river reach. This is done by calculating pollution indices of heavy metal for previous data and comparing them with that of the present study.

Materials and methods

The case study

Previously, 11.3% of Tigris River's total water income was contributed by Diyala River (Al-Shhrbly 1986). During the last few decades, Diyala River was continually polluted with different sources along its path, having the last part as the most contaminated.

The river reach under investigation was taken opposite Al-Rustimiyah WWTPs about 15 km before its confluence with Tigris River. The reach was 7 km in length, and was divided into nine sites having the first site upstream from all the effluents of the WWTPs into the river while the other eight sites were selected according to the points of discharge into the river. Figure 1 illustrates the map of the study area and the sampling sites. The coordinates of each location along with its description is shown in Table 1.

Fig. 1 The study area. Reproduced with Permission from Image (2017)

Table 1 Coordinates and description of sampling sites

Site no.	Description	Longitude	Latitude
1	Upstream point	44°32′ 16.66″E	33°17′ 31.77″N
2	Bypass R3 point	44°32′ 16.42″E	33°17′ 29.18″N
3	Outfall R3 point	44°32′ 15.95″E	33°17′ 19.33″N
4	Bypass R2 point	44°32′ 16.21″E	33°16′ 27.87″N
5	Outfall R2 point	44°32′ 2.08″E	33°16′ 16.32″N
6	Outfall R01 point	44°31′ 42.68″E	33°16′ 25.83″N
7	Bypass R01 point	44°31′ 43.00″E	33°16′ 39.04″N
8	Army channel point	44°31′ 36.55″E	33°16′ 47.68″N
9	Downstream point	44°31′ 34.23″E	33°16′ 46.71″N

Samples collection

Historical water quality data of heavy metals related to the river reach of interest were collected in the years 1999 (Mohammed 1999), 2007 (Al-Ghabban 2010), 2008 (Musa 2009), 2009 (Al-Anbari and Jumaa 2010), and 2013–2014 (Al-Sudani 2014).

For the present study, in order to cover all seasonal variations in the study area, water samples were collected from the nine sites for a whole year starting from April 2014 to March 2015. The samples were collected at about 15 cm depth of water in pre-rinsed, with de-ionized water, polypropylene bottles. The samples were refrigerated at 4 °C until reaching the laboratory where the collected samples were filtered (Whatman 0.45 μm) and acidified with nitric acid in order to reach a pH below 2.0. That is done to minimize precipitation and adsorption on container walls (Abdulla 2013).

Samples analysis

The collected samples were analyzed for the heavy metals concentrations (Cd, Cr, Cu, Ni, Mn, Pb, Fe, Zn, and Ag) by the atomic absorption spectroscopy in the laboratories of the Environmental Research Center, University of Technology, Baghdad, Iraq. They were conducted according to the Standard Method for Examination of Water and Wastewater (APHA 2012).

Water quality indices

Three types of indices are chosen in this study according to the availability of data: the water quality index (WQI), pollution index (PI), and metal index (MI). The calculations and evaluations of the selected indices are shown in Table 2.

The WQI, in this study, is determined with regard to the heavy metal concentrations by using the weighted arithmetic index method. All the measured parameters contribute in the final value of the WQI. The PI is usually based on the concentration of the individual metal, which means that each metal has its own PI value. The MI evaluates the total trend of metals in the study area, and by that summarizes the status of the study area by one value; the higher the MI value, the worse is the water quality. The standard values for the present study, Table 3, are taken from the Iraqi stream standard according to the criteria of Iraqi legislation of water sources preservation system number 2 (A-1) dated 2001(Ministry of Environment 2001).

Results and discussion

Table 4 illustrates the statistical analysis of the measured parameters. The three indices were applied to the obtained data in order to display the historical heavy metal water quality of Diyala River. Figure 2 shows the WQI of heavy metal for Diyala Rive throughout the years, while Table 5 reveals the historical evaluation of the WQI. Details of the WQI for the nine sites taken in this study are illustrated in Table 6,

**Table 2** The calculations and evaluations of the selected indices

Index	Parameters	Evaluation	Ref.
$WQI = \frac{\sum Q_i W_i}{\sum W_i}$ $W_i = \frac{K}{V_{si}}$ $K = 1 \Big/ \sum \left(1/V_{si}\right)$ $Q_i = \left[\frac{C_i}{V_{si}}\right]$	WQI: water quality index Qi: quality rating Wi: relative weight K: proportionality constant V_{si}: standard value. C_i: measured value.	WQI < 50: Excellent. 0 < WQI < 100: Good 100 < WQI < 200: Poor 200 < WQI < 300: Very poor WQI > 300: Unsuitable	Cude (2001), Al-Obaidy et al. (2016b), Ramakrishnaiah et al. (2009)
$PI = \frac{\sqrt{\left(\frac{C_i}{S_i}\right)^2_{max} + \left(\frac{C_i}{S_i}\right)^2_{min}}}{2}$	PI: pollution index Ci: measured value Si: standard value	PI <: no effect 1 < PI < 2: slightly affected 2 < PI < 3: moderately affected 3 < PI < 5: strongly affected PI > 5: seriously affected	Caerio et al. (2005)
$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)}$	MI: metal index Ci: measured value MAC: max. allowable concen	MI > 1: is a threshold of warning	Tamasi and Cini (2004)

Table 3 Iraqi stream standard for heavy metals (Ministry of Environment 2001)

Element	Iraqi standard (mg/L)
Cd	0.005
Cr	0.05
Cu	0.05
Ni	0.1
Mn	0.1
Pb	0.05
Fe	0.3
Zn	0.5
Ag	0.01
Cn	0.02

Table 4 Statistical summary of Diyala River's heavy metals

Parameter	Min	Max	Mean	Standard Deviation
Cd	0.0928	0.0005	0.0334	± 0.0256
Cr	1.3181	0.0000	0.1528	± 0.2084
Cu	0.2165	0.0000	0.1204	± 0.0628
Ni	0.6003	0.0000	0.2543	± 0.1725
Mn	0.5623	0.0000	0.2313	± 0.1508
Pb	1.8202	0.1044	0.7875	± 0.4188
Fe	1.2102	0.3163	0.6766	± 0.3364
Zn	5.9384	0.0204	2.9515	± 2.7981
Ag	0.0075	0.0000	0.0013	± 0.0028
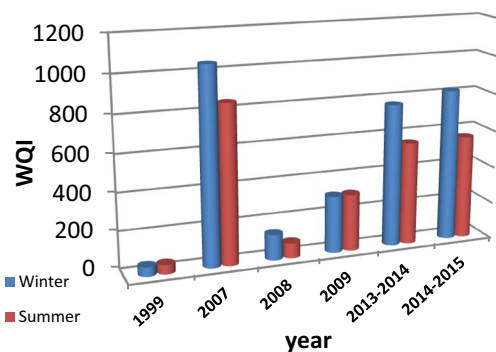
Fig. 2 Historical changes in the WQI of Diyala River

Table 5 The historical evaluation of WQI of Diyala River

Year	WQI evaluation		Reference
	Winter	Summer	
1999	Excellent	Excellent	Mohammed (1999)
2007	Unsuitable	Unsuitable	Al-Ghabban (2010)
2008	Poor	Good	Musa (2009)
2009	Unsuitable	Unsuitable	Al-Anbari and Jumaa (2010)
2013–2014	Unsuitable	Unsuitable	Al-Sudani (2014)
2014–2015	Unsuitable	Unsuitable	The present study

while Table 7 represents the effect of each element on the river reach (PI). Finally, Fig. 3 depicts the MI for the river reach along the years.

Figure 2 shows an excellent evaluation for the heavy metal WQI during 1999 followed by a rapid declination at 2007, where the WQI reaches its highest levels. WQI in the year of 2008 gives a good WQI then it gets worse through the years 2009–2015 (Table 5). This trend of ups and downs in the WQI can be attributed to the fact that Diyala River, at the reach of interest, was flushed with high quantities of water releases from the upstream Hamrin Dam during 2008 (Ministry of Water resources 2015) as an attempt to washout the accumulated contaminants in the river reach. This process led to the decrease of WQI during 2008, but, and since the upstream water releases was not repeated, due to its bad influence on the downstream receiving Tigris River, the WQI collapsed once again throughout the following years.

As for the seasonal difference in the WQI for the same year (Fig. 2 and Table 6), the higher WQI during winter can be explained due to the presence of excess rainfalls during winter that leads to the washout of the drainage area that contains local electric generators, among others, which produce large amounts of contaminant, especially heavy metals. Some of the wastes produced by the generators are directed into the sewer network reaching Al-Rustimiyah WWTPs, in which there are no heavy metal treatment units and by that the heavy metals are directed into Diyala River with the WWTPs effluents. The second part of generator wastes are spilled on the surrounding land being washed out with rain and reaching Diyala River as well. The contribution of Al-Rustimiyah WWTPs with heavy metals to Diyala River is obvious, since the upstream site (number 1) has a lower WQI than the other sites that are located downstream the effluents of the WWTPs, as shown in Table 6.

The same historical trend was found for the MI during the years (Fig. 3) which confirms the consistency of the WQI. The MI was found to be a threshold of warning during all years but with different levels.

From the evaluation of the PI shown in Table 7, it was found that Cd, Cr, and Pb were the most affecting elements all over the years, as Pb is one of the side products of the electric generators mentioned before.

Conclusions

It can be concluded from this study that the water quality status of the last reach of Diyala River has suffered a greet deficiency during the last few decades having 2007 as the peak of heavy metals contamination. The year 2008 shows a recovery of the water quality followed by a rapid declination throughout 2009–2015. Al-Rustimiyah WWTPs increases the lack in the WQI due to the absence of heavy

Table 6 WQI throughout the river reach for the present study

Site No.	1	2	3	4	5	6	7	8	9
Winter	506	684	830	720	800	893	892	1051	1008
Summer	264	358	421	429	469	450	490	535	560

Table 7 PI evaluation of each element throughout the years

| Metals	1999	2007	2008	2009	2013–2014	2014–2015
Cd	–	–	No effect	Strongly effected	–	Seriously effected
Cr	–	Seriously effected	–	No effect	Seriously effected	Seriously effected
Cu	–	–	No effect	No effect	Seriously effected	Moderately effected
Ni	–	–	–	No effect	–	Moderately effected
Mn	no effect	–	–	No effect	Seriously effected	Moderately effected
Pb	Slightly effected	–	Strongly effected	No effect	–	Seriously effected
Fe	No effect	No effect	–	–	Strongly effected	Moderately effected
Zn	No effect	–	No effect	No effect	–	Seriously effected
Ag	–	–	–	–	–	No effect
Cn	–	Seriously effected	–	–	–	–
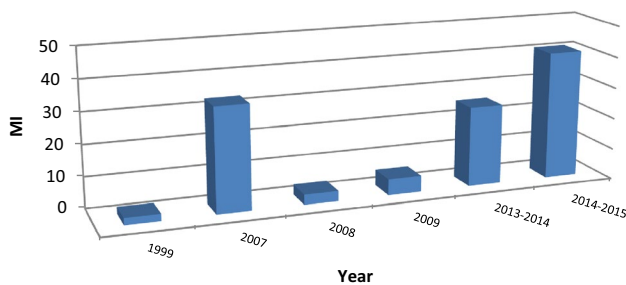
Fig. 3 Historical changes in the MI of Diyala River

metal treatment units. It is proven from the status of river water that it has been unsuitable for human uses for more than two decades.

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