Water Quality Pollution Indices to Assess the Heavy Metal Contamination, Case Study: Groundwater Resources of Asadabad Plain In 2012

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A-R-T-I-C-L-E I-N-F-O

Article Notes:
Received: Apr. 2, 2016
Received in revised form: Jul. 28, 2016
Accepted: Aug. 16, 2016
Available Online: Sep. 20, 2016

Keywords:
Heavy Metals
Water Quality
Asadabad Plain
Iran

A-B-S-T-R-A-C-T

Background & Aims of the Study: Due to the increasing pollution of water resources, tow documented methods: the Heavy metal potential index (HPI) and the Heavy metal evaluation index (HEI) were evaluated for their suitability for contamination monitoring of heavy metals (As, Zn, Pb, Cd and Cu) contamination in groundwater resources of Asadabad Plain during spring and summer in 2012.

Materials & Methods: In this analytical observational study, concentrations of heavy metals have been evaluated at 30 important groundwater sampling stations. For this purpose, collect samples in pre-cleaned, acid-soaked polyethylene bottles. Add 2 mL conc HNO_3/L sample and mix well. Cap tightly and store in refrigerator until ready for analysis. Metal concentrations were determined using inductively coupled plasma- optical emission spectrometry (ICP-OES).

Results: The results showed that mean concentrations of As, Zn, Pb, Cd and Cu in groundwater samples in spring season were 52.53±13.62, 15.51±23.45, 10.10±2.80, 4.48±1.80 and 8.63±10.87 µg l^{-1}, respectively and in summer season were 57.60±16.90, 14.99±17.66, 9.28±2.46, 4.57±1.73 and 10.45±10.30 µg l^{-1}, respectively. Therefore the mean values of indices in samples from spring and summer seasons were 25.61 and 27.28 respectively for HPI and were 9.29 and 8.88 respectively for HEI, and indicates low contamination levels. Comparing the mean concentrations of the evaluated metals with WHO permissible limits showed a significant difference ($P<0.05$). Thus, the mean concentrations of the metals were significantly lower than the permissible limits.

Conclusions: Despite of the heavy metal pollution of the groundwater resources in Asadabad Plain is lower than WHO permissible limits, but the irregular and long-term usage of agricultural inputs, use of wastewater and sewage sludge in agriculture, over use of organic fertilizers and establishment of pollutant industries can threaten the groundwater resources of this region and cause adverse effect for consumers.

Please cite this article as: Sobhanardakani S, Yari AR, Taghavi L, Tayebi L, Application of water quality pollution indices to assess the heavy metal contamination, Case study: groundwater resources of Asadabad Plain in 2012. Arch Hyg Sci 2016;5(4):221-228.

Background

Heavy metals are one of the most poisonous and serious groups of pollutants due to their high toxicity, abundance, and ease of accumulation from human and other various species. The behavior of heavy metals in the environment depends on their inherent chemical properties (1).

Pollution of the natural environment by heavy metals is a worldwide problem because these metals are permanent and most of them have toxic effects on living organisms when they exceed a certain concentration (2).

Water is one of the most important factors for every living organism on this planet. The 3% of global fresh water is large enough to meet the requirements of man for millions of years (1). The pollution of water resources by heavy metals released from various sources as a consequence of industrialization and urbanization have been an increasing worldwide concern for the last few decades (1,3,4). In this regard, groundwater contamination can occur by infiltration recharge from surface water, direct migration and inter-aquifer exchange (5). Therefore various pollution indices have been develop and apply for assessing water quality pollution for human consumption with respect to metal contamination (1,6). The objective of water quality indices is to turn complex water quality data into information that is understandable and used by the public. A single number cannot tell the whole story of water quality parameters that are not included in the index. However, a water quality indices such as Heavy metal pollution index (HPI) and Heavy metal evaluation index (HEI) based on some very important parameters can provide a single indicator of water quality (7). In general, water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of a lake and river with number (8).

Iran is located within the dry and semi dry regions and groundwater is an important water source for drinking water, agricultural and industrial uses in many regions of this country. So that the estimation results indicate that almost 90% of the required water in Iran is secured through the use of groundwater resources (9,10). Due to groundwater is one of the major sources of drinking water in the study area, so it was important to assess the ground water quality with respect to heavy metal contamination.

Aims of the study:

The present study was carried out to assessment and monitoring of heavy metals (As, Zn, Pb, Cd and Cu) pollution in groundwater resources of Asadabad Plain using water quality pollution indices (HPI and HEI).

Materials & Methods

Study area

Asadabad Plain with aquifer area about 962 km^2 and 1650 m above the sea level is located in southwest of Hamedan township in the west part of Iran (11).

Sampling and sample analysis

Groundwater samples were collected from 30 different locations including open and tube wells in 3 replicates to evaluate the heavy metal contamination during spring and summer seasons in 2012. Figure 1 shows the sampling stations in the study area. The sampling locations were selected on the basis of different land use pattern, including agricultural and residential areas. The samples were taken in pre-cleaned, acid-soaked 200 ml polyethylene bottles to avoid unpredictable changes in characteristic as per standard procedures (12,13). The collected samples were filtered (Whatman no. 42), preserved with 6N of HNO_3 (suprapur Merck, Germany) and keep at 4 °C for further analysis (12,14). Concentrations of heavy metals (As, Zn, Pb, Cd and Cu) in samples were determined using inductively coupled plasma- optical emission spectrometry (ICP-OES) (Varian, 710-ES, Australia).

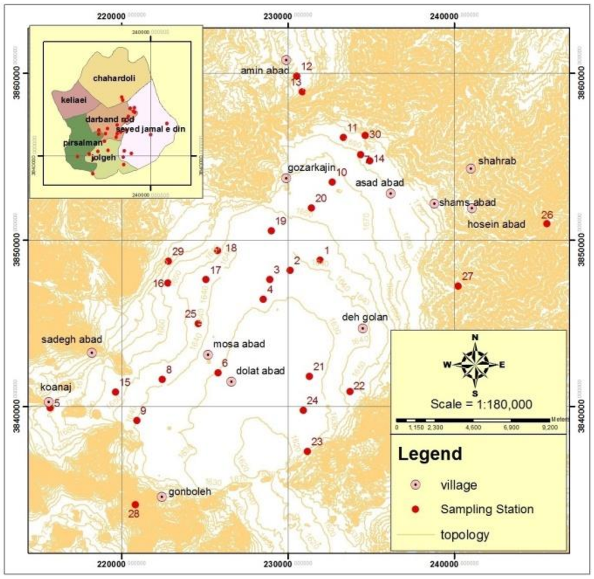

Figure 1) Map of sampling stations

Evaluation methods

Two documented methods evaluated in this study are the heavy metal pollution index (HPI) proposed by Prasad and Bose (2001) (15), and the heavy metal evaluation index (HEI) proposed by Edet and Offiong (2002) (14).

Heavy metal pollution index (HPI)

The HPI represent the total quality of water with respect to heavy metals. The HPI is based on weighted arithmetic quality mean method and developed in two steps. First by establishing a rating scale for each selected parameter giving weightage and second by selecting the pollution parameter on which the index is to be based. The rating system is an arbitrarily value between zero to one and its selection depends upon the importance of individual quality considerations in a comparative way or it can be assessed by making values inversely proportional to the recommended standard for the corresponding parameter (14,16-18). In computing the HPI, Prasad and Bose (2001) (15) considered unit weightage (W_i) as a value inversely proportional to the recommended standard (S_i) of the corresponding parameter as proposed by Reddy (1995) (19).

The HPI model (Mohan et al., 1996) (18) is given by

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

where Q_i is the sub-index of the i_{th} parameter. W_i is the unit weightage of the i_{th} parameter and n is the number of parameters considered. The sub-index (Q_i) of the parameter is calculated by

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

Where M_i is the monitored value of heavy metal of i_{th} parameter, I_i is the ideal value of the i_{th} parameter and S_i is the standard value of the i_{th} parameter. The sign (−) indicates numerical difference of the two values, ignoring the algebraic sign. Low heavy metal pollution (HPI<100), heavy metal pollution on the threshold risk (HPI=100) and high heavy metal pollution (critical pollution index) (HPI>100. If the samples have heavy metal pollution index values greater than 100, water is not potable (14-16,18).

In computing the HPI for the present study, As, Zn, Pb and Cu were used. The weightage (W_i) was taken as the inverse of MAC, S_i the WHO standard for drinking water and I_i the guide value for the chosen element (Table 4).

Heavy metal evaluation index (HEI)

Heavy metal evaluation index is a way of estimating the water quality with focus on heavy metals in water samples (20). The water quality index classify into three categories which include: low heavy metals (HEI <400), moderate to heavy metals (400 <HEI < 800) and high heavy metals (HEI> 800). The index is calculated from the following equation (21):

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac}$$

Where H_c is the monitored value of the i_{th} parameter and H_{mac} the maximum admissible concentration of the i_{th} parameter (14,20).

Statistical analysis

To test the correlation matrix between elements, correlation between computed indices average and correlation between mean concentration of elements and computed indices, Pearson Correlation Coefficient was performed using the SPSS 18.0 (SPSS Inc., Chicago, IL, USA) statistical package.

Results

In the present study levels of As, Zn, Pb, Cd and Cu in groundwater samples of Asadabad Plain during spring and summer in 2012 were determined. Tables 1 and 2, shows the mean concentrations of five elements in the water samples during spring and summer respectively. Also the correlation matrix between elements for spring and summer seasons are presented in Table 3.

The results indicate that mean concentrations of As, Zn, Pb, Cd and Cu in groundwater samples collected from Asadabad Plain in spring season were 52.53±13.62, 15.51±23.45, 10.10±2.80, 4.48±1.80 and 8.63±10.87 μg l^{-1}, respectively and in summer season were 57.60±16.90, 14.99±17.66, 9.28±2.46, 4.57±1.73 and 10.45±10.30 μg l^{-1}, respectively.

The results of Pearson Correlation Coefficient at 1% level of significance (P<0.01), show significant correlation between the following pairs Zn/Pb, Zn/Cu and Cd/Cu in water samples for spring and summer seasons. These indicate that these metals are the main contributory parameters.

The computed HPI and HEI values for each location, correlation between index values and concentration of metal and correlation between different indices values for spring and summer seasons are presented in Tables 5 to 7 respectively.

Table 1) Concentration of metals (μg l^{-1}) in groundwater samples collected from Asadabad Plain in spring season

Station	As	Zn	Pb	Cd	Cu
1	42.12	54.90	10.08	4.24	23.10
2	36.68	93.37	8.38	4.09	36.20
3	72.92	37.68	10.54	4.10	7.21
4	52.18	6.80	9.16	3.90	4.11
5	52.69	3.64	10.42	4.03	4.56
6	62.99	4.04	8.54	4.10	9.58
7	59.21	5.99	10.40	4.16	8.62
8	47.58	3.58	5.28	4.30	1.88
9	64.39	8.72	10.61	4.12	5.22
10	36.31	2.86	9.83	4.21	10.42
11	38.49	6.82	7.07	4.08	6.67
12	52.24	6.46	10.54	4.03	0.72
13	30.49	7.25	8.62	4.64	3.24
14	45.73	6.84	11.72	4.05	6.38
15	57.43	3.86	0.91	4.27	3.24
16	38.77	5.64	11.44	4.13	4.10
17	52.18	89.30	14.74	13.94	52.84
18	54.37	4.12	13.16	3.10	11.32
19	69.70	4.78	12.61	4.44	3.31
20	68.13	9.96	10.10	4.17	6.40
21	48.10	5.50	10.85	4.30	4.53
22	66.92	5.28	5.25	4.32	8.99
23	68.97	26.43	11.10	4.31	1.88
24	66.60	6.20	14.04	4.14	0.79
25	20.68	7.09	10.90	4.20	2.61
26	50.33	8.53	9.99	4.13	7.16
27	54.78	5.44	10.57	4.45	8.15
28	53.53	4.90	10.11	4.14	7.25
29	75.76	19.50	13.53	4.06	2.16
30	35.78	9.70	12.65	4.34	6.29

Min	**36.31**	**2.86**	**0.91**	**3.10**	**0.72**
Max	**75.76**	**93.37**	**14.74**	**13.94**	**36.20**
Mean	**52.53**	**15.51**	**10.10**	**4.48**	**8.63**
S.D.	**13.62**	**23.45**	**2.80**	**1.80**	**10.87**

Table 2) Concentration of metals (μg l^{-1}) in groundwater samples collected from Asadabad Plain in summer season

Station	As	Zn	Pb	Cd	Cu
1	53.45	41.32	10.01	4.32	10.11
2	38.48	81.23	11.47	4.46	11.46
3	77.22	19.98	7.96	4.02	7.36
4	49.62	9.57	9.40	4.32	9.42
5	68.66	9.06	12.23	4.21	9.75
6	65.03	4.74	6.23	4.09	7.24
7	49.04	7.70	13.98	4.48	8.95
8	69.67	7.47	11.03	4.36	9.18
9	75.70	7.83	11.32	4.07	6.35
10	44.48	8.73	10.49	4.34	9.37
11	22.98	9.56	8.56	4.50	5.90
12	52.18	9.26	8.13	4.21	4.58
13	41.11	10.20	4.81	4.26	12.66
14	69.28	16.96	6.66	4.47	0.26
15	57.43	9.66	8.17	4.19	8.14
16	88.91	9.75	15.17	4.46	8.05
17	75.53	69.27	6.67	13.67	59.77
18	39.12	8.93	11.01	3.81	2.16
19	29.80	9.79	8.51	3.99	8.98
20	83.02	9.57	10.00	4.45	11.79
21	58.51	9.69	9.16	4.25	10.93
22	57.02	8.76	8.12	4.01	10.77
23	45.70	8.27	12.94	4.36	7.70
24	61.17	9.50	10.72	4.17	5.36
25	44.98	8.15	7.99	4.47	6.74
26	78.76	8.28	9.53	4.51	10.25
27	81.54	8.80	6.90	4.34	7.15
28	34.83	7.07	5.22	3.90	27.18
29	56.40	11.68	7.62	4.18	8.73
30	58.46	9.06	8.55	4.39	7.13
Min	**22.98**	**4.74**	**4.81**	**3.81**	**0.26**
Max	**83.02**	**81.23**	**15.17**	**13.67**	**59.77**
Mean	**57.60**	**14.99**	**9.28**	**4.57**	**10.45**
S.D.	**16.90**	**17.66**	**2.46**	**1.73**	**10.30**

Table 3) Correlation matrix between elements

	As	Zn	Pb	Cd	Cu
			Spring		
As		-0.073	0.105	-0.019	-0.162
Zn			0.184	0.589**	0.881**
Pb				0.276	0.179
Cd					0.748**
			Summer		
As		-0.019	0.150	0.219	0.100
Zn			-0.008	0.595**	0.551**
Pb				-0.168	-0.271
Cd					0.890**

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

Table 4) Standard used for the indices computation (11)

	W	S	I	MAC
As	0.02	50	10	50
Zn	0.0002	5000	3000	5000
Pb	0.70	100	10	1.50
Cd	0.30	5.00	3	3
Cu	0.001	1000	2000	1000

W weightage (1/MAC)
S Standard permissible in ppb
I Highest permissible in ppb
MAC Maximum admissible concentration/upper permissible

Table 5) Evaluation indices

Station	Spring		Summer	
	HPI	**HEI**	**HPI**	**HEI**
1	20.07	9.01	21.75	9.20
2	18.77	7.74	24.18	9.93
3	19.87	9.87	20.05	8.20
4	16.15	8.46	22.01	8.71
5	17.76	9.35	22.57	10.94
6	20.09	8.33	21.80	6.82
7	19.98	9.51	26.91	11.80
8	24.76	5.91	23.91	10.21
9	19.80	9.74	20.16	10.42
10	19.42	8.69	21.97	9.34
11	19.71	6.85	23.99	7.67
12	17.83	9.42	21.49	7.87
13	26.37	7.91	24.21	5.46
14	18.71	10.09	27.26	7.32
15	30.30	3.18	21.42	8.00
16	19.33	9.78	29.73	13.39
17	166.59	15.59	162.69	10.53
18	6.27	10.91	14.32	9.40
19	26.29	11.28	16.87	7.61
20	20.33	9.49	25.10	9.82
21	21.83	9.63	21.60	8.71
22	26.02	6.29	18.79	7.90
23	23.19	10.22	24.19	11.00
24	22.82	12.07	20.46	9.77
25	19.06	9.08	25.06	7.72
26	18.80	9.05	26.13	9.44
27	24.15	9.63	25.78	7.69
28	19.18	9.20	18.30	5.51
29	21.70	11.89	21.64	7.61
30	23.19	10.60	24.12	8.34
Mean	**25.61**	**9.29**	**27.28**	**8.88**

Table 6) Correlation between index values and concentration of metals

Parameter	HPI		HEI	
	r	***P***	***r***	***P***
	Spring			
As	0.016	0.934	0.210	0.265
Zn	0.578**	0.001	0.321	0.084
Pb	0.242	0.198	0.956**	0.000
Cd	0.997**	0.000	0.520**	0.003
Cu	0.735**	0.000	0.350	0.058
	Summer			
As	0.250	0.183	0.405*	0.027
Zn	0.583**	0.001	0.187	0.323
Pb	-0.168	0.374	0.910**	0.000
Cd	0.999**	0.000	0.214	0.255
Cu	0.891**	0.000	0.061	0.751

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

Table 7) Correlation between different indices values

	r	***P***
	Spring	
HPI vs. HEI	0.494**	0.006
	Summer	
HPI vs. HEI	0.220	0.244

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

Discussion

The metal concentrations (As, Zn, Pb, Cd and Cu) were significantly different between sampling stations. However, the heavy metal concentrations were found within the WHO permissible limit.

The computed HPI shows that the values in spring season vary between 6.27 to 166.59 (mean 25.61) and in summer season vary between 14.32 to 162.69 (mean 27.28) and for 96% of locations are lower than 100 the critical index value for drinking water. The computed HEI shows that the values in spring season vary between 3.18 to 15.59 (mean 9.29) and in summer season vary between 5.46 to 13.39 (mean 8.88) and indicate low heavy metal pollution for all sampling stations. Also in earlier studies (6,14-16,21,22-27), the HPI and HEI of ground and surface water from various regions around the world were found to be

lower than critical index value for drinking water.
A comparison between the indices and heavy metal concentration show very strong correlation with Pb and Cd for spring and summer samples. This indicates that Pb and Cd are the main contributory parameters. Also the correlation between HPI and HEI is significant in spring season. Therefore the two existing methods, the HPI and the HEI provide same results.

Conclusions

In order to assess the groundwater resources of Asadabad Plain, 180 groundwater samples were taken. Five elements including As, Zn, Pb, Cd and Cu in the samples were measured and were used in calculating HPI and HEI indices. Based on the indices results, heavy metal pollution is not observed in any cases, therefore, water samples of the study area have been identified suitable for drinking. According to the correlation matrix, Pb and Cd have a great role in the quality of water samples. Therefore the water quality indices proved to be a very useful tool in evaluating overall pollution of the ground water. However, the values of HPI and HEI indices in groundwater collected from Asadabad Plain are totally below the critical values but severe precautions consideration such as manage the use of agricultural inputs, prevention of use of wastewater and sewage sludge in agriculture, control of over use of organic fertilizers and establishment of pollutant industries are recommended in this area.

Footnotes

Conflict of Interest:

The authors declare no conflict of interest.

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