



Groundwater quality assessment using the water quality pollution indices in Toyserkan Plain

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Abstract

Background: Iran is located within the dry and semi dry regions, thus almost 90% of the required water is secured via the use of groundwater. Owing to the increasing pollution of water resources, this study was performed to evaluate water quality pollution indices for heavy metals (As, Zn, Pb and Cu) contamination monitoring in Toyserkan Plain during spring and summer in 2012.

Methods: A total of 20 ground water wells were chosen randomly. The samples were filtered (0.45 µm) and kept cool in polyethylene bottles. Samples were taken for the analysis of metals, the former was acidified with HNO₃ to pH lower than 2. Metal concentrations were determined using ICP-OES.

Results: The results revealed that the mean values of contamination index (C_d), heavy metal pollution index (HPI) and heavy metal evaluation index (HEI) in samples for spring season were -2.81, 9.74 and 1.20, respectively and were -2.67, 9.51 and 1.32, respectively in samples for summer season and this indicates low contamination levels. Comparing the mean concentrations of the evaluated metals with WHO permissible limits demonstrated a significant difference ($P < 0.05$). Thus, the mean concentrations of the metals were significantly lower than the permissible limits.

Conclusion: Although the heavy metal pollution of the ground water in Toyserkan Plain is not higher than permissible limits, the irregular and long-term utilization of agricultural inputs, use of wastewater and sewage sludge in agriculture, over utilization of organic fertilizers and establishment of pollutant industries can threaten the ground water, and cause irreversible damages in this area.

Keywords: Heavy metals, Groundwater, Water quality pollution indices, Toyserkan Plain

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Introduction

Urbanization, industrialization, agriculture and exploitation of natural resources, are basic activities associated with living in contemporary societies that imposed pollutant loads especially toxic metals into natural cycles like soil, water and air cycles (1,2). Nowadays, globally, heavy metals have been taken into consideration owing to their toxicity, ability to accumulate in the biota and adverse health effects even at low concentrations (3-5). One of the most important properties of heavy metals, which differentiate them from other toxic pollutants, is that they are not easily biodegradable in the environment (2,6). Apart from the potential toxicity of heavy metals to living organisms, these pollutants are stable in the environment and tend to accumulate in the tissues of plants and animals (7). Water cycle due to the dynamism and its constant nature is more exposed to pollution when compared to the soil

and atmosphere cycles (5). Water resources are very important for mankind existence and economical development. People around the globe have utilized groundwater as a source of drinking water, and even today more than 50% the world's population depends on groundwater for survival (8,9). So, the contamination of these resources by heavy metals is a serious ecological problem.

Metals like Cu, Fe and Zn, are essential metals since they play important roles in biological systems, while As, Hg and Pb are toxic, even in trace amounts (10,11). It should be noted that the essential metals can also produce toxic effects at high concentrations (11,12).

Arsenic is a widely distributed metalloid, occurring in the biosphere. The combustion of fossil fuel for production of energy and smelting of non-ferrous metals are two significant processes that lead to the contamination of the environment, especially the source of atmospheric pollution



for this element. Other sources of As are arsenical pesticides, chemicals such as chromated copper arsenate used for the manufacturing of wood preservatives (13).

Zinc is an essential structural and functional element in biological systems which often catalyzes reactions, binds to substrates by favoring various reactions via the mediation of redox or oxidation–reduction reactions, through reversible changes in the oxidation state of the metal ions. Of course, Zn harms some physiological activities such as breathing and causes other diseases (14,15).

Lead may damage the kidney and cause symptoms of chronic toxicity, such as poor reproductive capacity, impaired organ function, tumors, blood pressure and hepatic abnormalities (16). In addition, Pb can also affect brain activity by interfering with neurotransmitter release and synapse formation. Exposure to Pb via the accidental ingestion of Pb paint, inhalation of traffic exhaust fumes and the consumption of Pb-contaminated food can cause the reduction of IQ, learning disabilities, hyperactivity, slow growth, impaired hearing and antisocial behaviors (17-19).

Copper is one of the most abundant trace elements with vitamin-like impact in human body and living systems and is found in a wide range of foods eaten by humans such as nuts, many fruits and vegetables, red meat, shellfish, and in many vitamin supplements. Despite the small amount of Cu (50-120 mg) found in the human body, it plays a crucial role in different kinds of biochemical processes (20). Copper which is an essential micronutrient for growing plants should be supplied via organic and artificial fertilizers for healthy hormone secretion, nerve conduction, and the growth of bones and connective tissue. A constant diet of Cu, even at entirely allowable limits, can break down the barrier that keeps undesirable toxins from entering the brain, and an increase in the production of beta-amyloid. On the other hand, critical doses of Cu can cause inflammation in the brain tissues, anorexia, fatigue, hair loss, acne, allergies, depression, premenstrual syndrome, migraines, anxiety, childhood hyperactivity, panic attacks, kidney and liver dysfunction, strokes elevated cholesterol, adrenal hyperactivity and insufficiency, learning disorders, autism and cancer (21).

Quality indices employ a series of reproducible judgments to compile the effects of all the pollution parameters and are a useful and relatively easy method to evaluate the composite influence of overall pollution (22). For heavy metal contamination assessment in water resources, several methods were developed. The Contamination index, the Heavy metal potential index and the heavy metal evaluation index (HEI) are pollution indices which help in assessing the present level of pollution (23).

Iran is located within the dry and semi dry regions, thus almost 90% of the required water is secured via the use of groundwater (24). Owing to the geological structure of Toyserkan township especially minerals containing As, Zn, Pb, and Cu (25), and also rapid agricultural growth in Toyserkan Plain, discharge of heavy and toxic metals into groundwater resources of this region via overutilization

of agricultural inputs like chemical and organic fertilizers especially phosphorus fertilizers, zinc sulfate and metal-containing pesticides are on the increase. Therefore, this study was conducted for the assessment of water quality pollution indices for heavy metals (As, Zn, Pb and Cu) contamination monitoring in Toyserkan Plain during spring and summer in 2012.

Methods

Study area

The study was carried out in Toyserkan township in Hamedan province which is located in the western part of Iran. The area of Toyserkan Plain is 792 km². Drinking water for residents of the Toyserkan township is supplied from 1243 wells, 400 springs and 220 aqueducts (25).

Sampling and sample analysis

In this study, based on the Cochran's sample size formula, groundwater samples were collected from 20 wells with depth of 10 to 90 m and discharge on the range of 1 to 6 L/s basis of different land use pattern, including agricultural and residential areas from open and tube wells to assess the heavy metal contamination during spring and summer seasons in 2012. Figure 1 illustrates the sampling stations in the study area. The samples were collected in acid washed 200 mL polyethylene bottles to prevent unpredictable changes in characteristic as per standard procedures (26). The collected samples were filtered (Whatman no. 42), preserved with 6N HNO₃ (Suprapur Merck, Germany) and kept at a temperature of 4°C for further analysis (26,27). Concentrations of heavy metals (As, Zn, Pb and Cu) in water samples were determined employing ICP-OES (Varian, 710-ES, Australia).

Valuation methods

Three documented methods evaluated in this study are the contamination index (C_d), heavy metal pollution index (HPI) and HEI developed or proposed by Backman et al, Prasad and Bose, and Edet and Offiong, respectively (27-29).

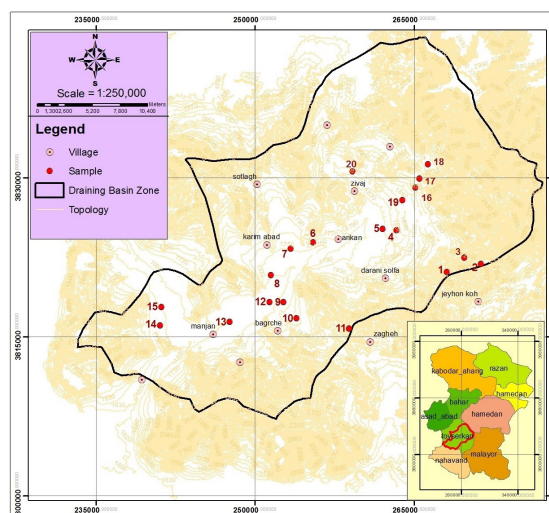


Figure 1. Map of sampling stations.

The contamination index

In this method, the quality of water is evaluated by the calculation of the degree of contamination. The C_d is computed separately for each sample of water analyzed, as a sum of the contamination factors of individual components exceeding the upper permissible value. Hence, the C_d summarizes the combined effects of several quality parameters considered harmful to household water. The contamination index is calculated from Equations 1 and 2:

$$Cd = \sum_{i=1}^n C_{fi} \quad (1)$$

where

$$C_{fi} = \frac{CA_i}{CN_i} - 1 \quad (2)$$

C_{fi} indicates contamination factor for the i th component, CA_i indicates analytical value for the i th component, C_{Ni} indicates upper permissible concentration of the i th component (N denotes the 'normative value') (2,27).

The resultant C_d value identifies areas of varying contamination levels which are grouped into three categories as follows: $C_d < 1$ (low), $C_d = 1-3$ (medium) and $C_d > 3$ (high) (5,27).

The upper permissible concentration value (C_{Ni}) was taken as the maximum admissible concentration (MAC).

Heavy metal pollution index

The HPI represents the total water quality with respect to heavy metals and based on weighted arithmetic quality mean method. The HPI is developed in two steps. The first is by establishing a rating scale for each selected parameter giving weightage and second is by selecting the pollution parameter on which the index is to be based. The rating system is an arbitrarily value between 0 to 1 and its selection depends on the importance of individual quality considerations in a comparative way or it can be evaluated by making values inversely proportional to the recommended standard for the corresponding parameter (2,27,30,31). In computing the HPI, Prasad and Bose (29) considered unit weightage as a value inversely proportional to the recommended standard (S_i) of the corresponding parameter as proposed by Reddy (32).

The HPI model is presented in Equation 3 (31):

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (3)$$

where Q_i = the sub-index of the i th parameter, W_i = the unit weightage of the i th parameter and n = the number of parameters considered. The sub-index of the parameter is calculated by Equation 4:

$$Q_i = \sum_{i=1}^n \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \quad (4)$$

where M_i indicates the monitored value of heavy metal of i th parameter, I_i indicates the ideal value of the i th parameter and S_i indicates 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 HPI values greater than 100, water is not potable (2,27,29,31).

In computing the HPI for the present study, As, Zn, Pb and Cu were utilized. The weightage (W_i) was taken as the inverse of MAC, S_i the World Health Organization (WHO) standard for drinking water and I_i the guide value for the chosen element (Table 1).

Heavy metal evaluation index

HEI focuses on heavy metals in water samples for estimating the water quality (33). The water quality index is classified into three categories which include $HEI < 400$ (low heavy metals), $400 < HEI < 800$ (moderate to heavy metals) and $HEI > 800$ (high heavy metals). The index is calculated from Equation 5 (5):

$$HEI = \sum_{i=1}^n \frac{H_c}{H_{mac}} \quad (5)$$

where H_c is the monitored value of the i th parameter and H_{mac} the MAC of the i th parameter (27,33).

Results

The results of the heavy metal concentrations in ground water samples for spring and summer seasons are given in Tables 2 and 3. Also the correlation matrix between elements for spring and summer seasons are presented in Table 4.

The results indicate that As, Zn, Pb and Cu concentrations in groundwater samples collected from Toyserkan Plain in spring season ranged from 0.08 to 7.48, 0.12 to 15.64, 0.09 to 5.50 and 0.89 to 13.58 $\mu\text{g/L}$, respectively.

The results indicate that As, Zn, Pb and Cu concentrations in groundwater samples collected from Toyserkan Plain in summer season ranged from 0.57 to 7.21, 0.41 to 16.42, 0.19 to 4.46 and 6.54 to 15.76 $\mu\text{g/L}$, respectively.

Correlation at 5% level of significance ($P > 0.05$) demonstrated no significant correlation between the following pairs: As and Zn, Pb, Cu; Zn and Pb; Cu and Pb and Cu in water samples for spring and summer seasons.

The computed C_d , 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 given in Tables 5 to 7, respectively.

The computed C_d demonstrates that the mean values in

Table 1. Standard used for the indices computation (27)

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

Abbreviations: W; weightage (1/MAC); S; standard permissible in ppb; I; highest permissible in ppb; MAC, maximum admissible concentration/upper permissible.

Table 2. Concentration of As, Zn, Pb and Cu ($\mu\text{g L}^{-1}$) in groundwater samples collected from Toyserkan Plain in spring season

Station	As	Zn	Pb	Cu
1	7.48	3.75	1.13	7.78
2	4.20	1.80	0.10	8.49
3	6.21	10.27	0.09	7.22
4	0.40	2.57	1.61	0.89
5	3.28	6.05	1.06	6.67
6	2.06	3.41	0.17	9.93
7	5.62	7.42	4.38	13.58
8	1.79	15.64	1.70	11.51
9	6.44	11.20	5.50	9.16
10	3.56	3.61	1.12	10.44
11	4.62	1.62	1.25	9.08
12	0.08	1.05	1.27	10.34
13	7.04	0.40	0.31	10.25
14	0.35	0.17	3.96	11.83
15	1.18	1.17	2.43	11.86
16	3.81	1.05	2.37	12.06
17	2.96	0.12	0.52	5.57
18	3.50	0.29	2.80	5.83
19	3.78	3.20	1.10	5.80
20	5.20	2.14	0.42	3.56
Mean	3.68 ± 2.24	4.24 ± 3.85	1.66 ± 1.51	8.59 ± 3.19

Table 3. Concentration of As, Zn, Pb and Cu ($\mu\text{g/L}$) in groundwater samples collected from Toyserkan Plain in summer season

Station	As	Zn	Pb	Cu
1	0.57	4.75	1.55	12.60
2	3.23	8.55	2.39	6.54
3	5.06	8.83	1.39	13.14
4	5.83	3.23	1.78	11.65
5	3.45	11.07	1.78	11.13
6	7.08	4.18	0.46	11.93
7	0.76	10.24	1.64	12.91
8	3.91	9.08	1.05	13.25
9	7.21	16.42	1.34	12.72
10	5.75	9.83	0.19	12.74
11	7.11	3.73	4.46	11.42
12	3.37	0.94	3.00	15.76
13	3.89	8.54	1.98	12.25
14	5.26	2.66	1.98	12.72
15	2.10	3.53	2.58	12.15
16	3.86	0.41	1.53	13.02
17	3.23	0.87	1.43	13.39
18	3.22	1.74	1.16	13.30
19	3.06	1.28	1.49	13.31
20	1.86	16.03	3.74	13.83
Mean	3.99 ± 1.93	6.30 ± 4.89	1.85 ± 1.01	12.49 ± 1.71

spring and summer seasons were -2.80 and -2.67, respectively, and indicate low contamination. The computed HPI shows that the mean values in spring and summer seasons were 9.74 and 9.51, respectively and are lower than 100, the critical value for drinking water for all the locations. Moreover, the computed HEI shows that the mean values in spring and summer seasons were 1.20 and 1.32, respec-

tively and indicate low heavy metal pollution.

A comparison between the indices and heavy metal concentration demonstrates significant correlation with Pb for spring and summer samples (Table 6). This indicates that Pb is the main contributory parameter. Moreover, the correlation between C_d , HPI and HEI is significant (Table 7). Therefore, the three existing methods; the Contamination index, the HPI and the HEI provide same results.

Discussion

In order to assess the groundwater resources of Toyserkan Plain, groundwater samples were collected from 20 wells. Four elements including As, Zn, Pb and Cu in the samples were measured and used in calculating C_d , HPI and HEI indices. The results demonstrated that the mean concentration of metals in samples in spring season ($\mu\text{g L}^{-1}$) were 3.68 ± 2.24 for As, 4.24 ± 3.85 for Zn, 1.66 ± 1.51 for Pb and 8.59 ± 3.19 for Cu, respectively (Table 2). In addition, the mean concentration of metals in samples in summer season ($\mu\text{g L}^{-1}$) were 3.99 ± 1.93 for As, 6.30 ± 4.89

Table 4. Correlation matrix between elements

	As	Zn	Pb	Cu
Spring				
As		0.219	-0.380	-0.009
Zn			0.230	0.163
Pb				0.378
Summer				
As		0.030	-0.125	-0.115
Zn			0.018	-0.161
Pb				-0.061

Table 5. Evaluation indices

Station	Spring			Summer		
	C_d	HPI	HEI	C_d	HPI	HEI
1	-3.09	10.06	0.91	-2.94	10.08	1.06
2	-3.84	11.40	0.16	-2.33	9.00	1.67
3	-3.81	11.27	0.19	-2.96	9.94	1.04
4	-2.92	10.02	1.08	-2.67	9.36	1.31
5	-3.22	10.43	0.78	-2.73	9.52	1.27
6	-3.83	11.47	0.16	-3.54	10.80	0.46
7	-0.95	6.68	3.25	-2.88	9.97	1.12
8	-2.82	9.83	1.18	-3.21	10.38	0.79
9	-0.19	5.42	3.81	-2.95	9.84	1.05
10	-3.17	10.34	0.83	-3.74	11.19	0.26
11	-3.06	10.12	0.93	-0.87	6.49	3.13
12	-3.14	10.41	0.86	-1.92	8.32	2.08
13	-3.64	10.97	0.36	-2.59	9.39	1.41
14	-1.34	7.50	2.66	-2.56	9.30	1.44
15	-2.34	9.10	1.66	-2.22	8.86	1.77
16	-2.33	8.97	1.67	-2.89	9.84	1.11
17	-3.59	11.02	0.41	-2.97	10.02	1.03
18	-2.06	8.53	1.94	-3.15	10.32	0.85
19	-3.18	10.34	0.81	-2.93	9.97	1.07
20	-3.61	10.98	0.39	-1.45	7.63	2.55
Mean	-2.81	9.74	1.20	-2.67	9.51	1.32

Table 6. Correlation between index values and concentration of metals

Parameter	C_d		HPI		HEI	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Spring						
As	0.007	0.978	-0.056	0.815	0.015	0.948
Zn	0.240	0.308	-0.250	0.287	0.244	0.299
Pb	0.999 ^a	0.000	-0.996 ^a	0.000	0.998 ^a	0.000
Cu	0.381	0.097	-0.376	0.102	0.390	0.089
Summer						
As	-0.067	0.779	-0.003	0.990	-0.068	0.777
Zn	0.020	0.993	-0.022	0.926	0.021	0.929
Pb	0.998 ^a	0.000	-0.991 ^a	0.000	0.998 ^a	0.000
Cu	-0.068	0.777	0.080	0.737	-0.067	0.780

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

Table 7. Correlation between different indices values

	<i>r</i>	<i>P</i>
Spring		
C_d vs. HPI	-0.999 ^a	0.000
C_d vs. HEI	0.999 ^a	0.000
HPI vs. HEI	-0.998 ^a	0.000
Summer		
C_d vs. HPI	-0.997 ^a	0.000
C_d vs. HEI	1.000 ^a	0.000
HPI vs. HEI	-0.997 ^a	0.000

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

for Zn, 1.85 ± 1.01 for Pb and 12.49 ± 1.71 for Cu, respectively (Table 3). The higher values of metals concentration in summer season compared to spring season may be due to reduced aquifer recharge and reduced dilution of pollutants as a result of increase in water temperature during the summer season.

Based on the results, heavy metal pollution is not observed in any cases. According to Table 5, the values of C_d , HPI and HEI indices were found in the range of -3.84 to -0.19, 5.42 to 11.47 and 0.16 to 3.81, respectively, in spring season. The highest values of C_d , HPI and HEI were found in the sample collected from stations number 9, 6 and 9, respectively. Furthermore, during summer season, the values of same indices are increased up to -3.74 to -0.87, 6.49 to 11.19 and 0.26 to 3.13, respectively. The highest values of C_d , HPI and HEI in this season were found in the sample collected from station number 11, 10 and 11, respectively. The higher values of C_d , HPI and HEI may be due to agricultural activities during spring and summer seasons. The C_d , HPI and HEI values of the samples within study area are found below the critical pollution index (100), and this indicates that the water is not critically polluted with respect to studied heavy metals and is suitable for drinking.

Nevertheless, the values of these three indices in groundwater collected from Toyserkan Plain are totally below the critical values, but severe precautions such as managing the use of agricultural inputs (chemical fertilizers and metal-containing pesticides), use of wastewater and sewage sludge in agriculture, over utilization of organic fertilizers

and establishment of pollutant industries must be taken into consideration in this area. In this regard, Sobhanardakani (34) evaluated water quality pollution indices for groundwater resources of Ghahavand Plain in Hamedan province and reported that mean values of C_d , HPI and HEI in samples for spring 2012 were -2.27, 9.01 and 1.73, respectively and were -1.95, 8.69 and 2.04, respectively in samples for summer 2012 and indicates low contamination levels. Sobhanardakani et al (35) analyzed As, Zn, Pb, Cd and Cu content in groundwater resources of Asadabad Plain in Hamedan province in 2012 and reported that 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. Nazari and Sobhanardakani (36) analyzed As and Zn concentrations in groundwater resources of Qaleh Shahin Plain in Kermanshah province and reported that the HPI values in winter 2014 vary between 1.09 to 11.4 (mean 6.11) and vary between 1.83 to 22.8 (mean 8.78) in summer 2014 and are lower than 100, the critical value for drinking water for all the sampling stations. Sobhanardakani and Nazari (37) analyzed Pb and Cd concentrations in groundwater resources of Qaleh Shahin Plain in Kermanshah province and reported that the HPI values in winter 2014 vary between 0.32 to 7.69 (mean 4.73) and vary between 8.92 to 13.90 (mean 11.74) in summer 2014 and are lower than 100, the critical value for drinking water for all the sampling stations.

Conclusion

According to the findings, heavy metal pollution was not observed in any water samples. So, groundwater samples of the Toyserkan Plain have been identified as suitable for drinking but based on the correlation matrix (Table 6), Pb has a great role in the quality of water samples. This indicates that the water quality indices proved to be a very useful tool in evaluating overall pollution of the groundwater resources. Finally, it can be concluded however, that the values of these three indices in groundwater samples collected from Toyserkan Plain are totally below the critical values. Nevertheless, it is recommended that severe precautions should be taken for controlling the sources of

groundwater pollution in this area.

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Ethical issue

The authors certify that all data collected during the study is presented in this manuscript, and no data from the study has been or will be published separately.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated in the study design, literature search, writing of the manuscript, and data acquisition, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript

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