Journal of Hydrosciences and Environment
ISSN: 2345-5608

Evaluation of Groundwater by Using GIS and a Heavy Metal Pollution Indices in Sirjan Plain, Iran

N.Fathi[1*], L.Sadegh Kasmaei[2]

1, Ph.D. Water Engineering , Head of research group, Regional Water Company ,Kerman, Iran
2. Assistant Professor Agricultural and Natural Resources Research and Education Center , Golestan, Iran

ARTICLEINFO

Article history:

Received: 1 Oct 2023
Accepted: 9 Oct 2023

Keywords:

HEI

HPI

Groundwater

Pollution

Heavy metals

ABSTRACT

Drinking water containing heavy metals above the maximum permissible limits cause potential risk to human health. The aim of this study was to investigate the heavy metals concentrations in groundwater to prevent the risk on the public health and assess the heavy metal pollution index (HPI, HEI) for water supply quality within the Sirjan plain in Iran. For this purpose, groundwater samples were taken from 22 exploitation wells and concentration of heavy metals including As, Cd, Fe, Al, Se, Mo, Ba and V analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP- MS) in June 2017. The results showed a HEI values determined for the groundwater samples collected in the Sirjan Plain region all indicated a low degree of pollution. While, the HPI values in the Sirjan Plain region indicated a medium and high degree of pollution. These results can be taken into consideration in planning for the management of water source polluting factors in order to provide safe water in the region.

1. Introduction

Today heavy metals pollution of the groundwater is one of the serious environmental problems. Heavy metals occurrence in waters from naturals such as chemical weathering of minerals and soil leaching or anthropogenic sources (such as industrial and domestic effluents, urban storm, water runoff, landfill leachate, mining activities, atmospheric sources etc (Biswas et al. 2017). Although few heavy metals are essential for human health, an excess amount of these metals can have negative effects (USEPA, 2015). Heavy metal pollutants in groundwater can accumulate in the human body over time and cause many diseases (Avigliano and Schenone, 2015), such as by damaging kidney functioning, the neurological system, and ossification process (Lohani et al., 2008). Therefore, it is very important to assess the quality of groundwater with respect to heavy metals in order to maintain the provision of safe drinking water for people. Recently, many researchers have evaluated heavy metal contamination in groundwater throughout different areas of the world (Zakhem and Hafez.,2015, Vetrimuruganet al.,2016., Chiamsathit et al.,2020). For example, Qiao et al. (2020) estimated the spatial distributions of heavy metals and assessed the health risk due to arsenic and other heavy metals in groundwater samples from the Guanzhong Plain region of China. Ukah et al. (2019) examined the extent of heavy metals contaminations in water, possible sources of water pollution, groundwater quality index, ecological risk and human health risks (both non-carcinogenic and carcinogenic) associated with ingesting groundwater resources in densely populated Ajao industrial area, Lagos State, Nigeria. Bhuiyan et al.

[*]*Corresponding author's email : negarfathi1386@yahoo.com*
DOI: 10.22111/jhe.2023.46828.1101

(2010) evaluated heavy metal pollution in irrigation and drinking water systems in the vicinity of a coal mining area in northwestern Bangladesh. In Iran, the springs, hand-dug wells, and deep wells are used for drinking purposes. Since the quality of drinking water, especially in terms of heavy metal concentration, affects the life of a large number of people, monitoring the water resources for ensuring the community health is of great significance. Groundwater is the only source of potable freshwater in Sirjan Plain, Iran. In this plain, Groundwater resources are important as sources of drinking and irrigation water for local residents area. In addition, the Sirjan Plain region is characterized by arid and semiarid areas where water resources are lacking and the groundwater level is deep. However, it is challenging to protect groundwater quality from pollution, especially rural areas. Realizing the importance of the presence of heavy metals in groundwater used for drinking purpose and the impact it will have on human health, such a study will be of immense use. So it is required to have a good understanding of the quality and spatial distribution of groundwater in the study area regarding heavy metal contamination. The main objectives of the present study are as follows: 1) to estimate the spatial distributions of heavy metals in groundwater in the Sirjan Plain region; 2) to assess the health risk to humans due to drinking groundwater containing heavy metals with the help of heavy metal pollution index metal pollution index (HPI) and the heavy metal evaluation index (HEI). Therefore, it is hoped that the paper will provide insights for groundwater development, monitoring, management and sustainability in the area.

2. Materials and Methods

2.1. Study area

Sirjan Plain is situated to the southwest of Kerman Province, southeast Iran. The case study, which covers an area of about 3,982 km2, is located within the coordinates of 54° 57′ to 56° 26′ E and 28° 47′ to 29° 58′ N. It has a population of about 324,000 and an economic system based on agricultural and industrial activities. The springs, hand-dug wells, and deep wells are used for drinking purposes in this area. The only freshwater source in this plain is the groundwater available for drinking purposes. In this area, the groundwater is extensively consumed for irrigating agricultural farmlands (mostly pistachio lands) and as the water source for livestock (Khodabakhshi, 2015; Shahidasht and Abbasnejad, 2011). Sirjan is the largest city of the plain. The region has a semi-arid climate with an average annual temperature of 17.5℃ (Soltani et al., 2017) and average annual precipitation of 156 mm (Rahnama and Mirabbasi, 2010). The area has average potential evaporation of 3,250 mm annually and a humidity range of 27% to 48%. The minimum and maximum heights of the area are 1,650 and 3,813 m above sea level, respectively (Mirabbasi and Eslamian, 2010). The sampling sites and the study area's geographic location are presented in Fig. 1.

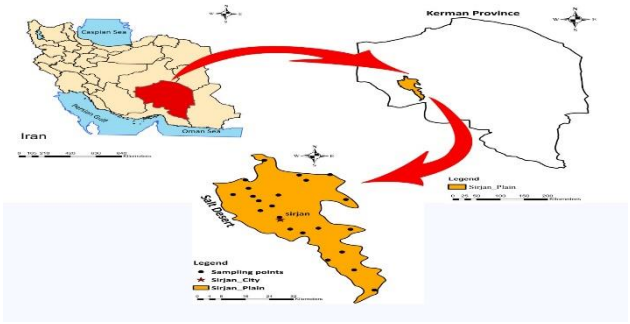


Fig. 1. The geographic location of the study area along with the sampling sites in the Sirjan Plain Iran

2.2. Sample collection and analysis

To achieve the research objectives, a total of twenty-two groundwater samples were collected from different parts of the basin and available water resources in a highly scattered pattern.

The results of geological investigation indicated that the Sirjan plain consists of a single layer unconfined aquifer (Rahnama and Mirabbasi, 2009). In the present study, Samples were taken from wells with a depth of 20 - 130 m. Due to the consecutive drought years and overexploitation of the aquifer system, groundwater level dropped. This has lead to the groundwater level drawdown and increase in contribution of Neogene red beds for supplying groundwater (Dehbandi et al., 2019).

The samples were gathered from wells drilled in the plain in June 2017 (Fig. 1). These samples were extracted following 15 min of pumping and then kept in pre-rinsed polyethylene bottles with a low density and capacity of 1000 ml. Each sample was acidified by the addition of pure nitric acid (69%, Merck) to reach a pH level below 2 for the analysis of heavy metals.

In the laboratory, heavy metals (As, Cd, Fe, Al, Se, Mo, Ba and V) were determined using inductively coupled plasma-mass spectrometry (ICP-MS) device. Analytical and instrumental quality assurance and quality control (QA/QC) was evaluated using sample duplicates and certified reference standards that indicate a precision of better than ±10% for the obtained results.

2.3. Evaluation indices

2.3.1. Heavy metal pollution index

The heavy metal pollution index (HPI) is a rating technique that provides the composite influence of individual heavy

metal on the overall quality of water (Tiwari et al., 2015). Hence, many researchers have used HPI as a comprehensive tool to determine the overall quality of water based on heavy metals (Kumar et al. 2012; Ravindra et al. 2019). HPI depends on numerous factors such as unit weightage of a metal (Wi) and prescribed standard permissible limits (Si) for each metal (Ravindra et al. 2019). Weighted arithmetic index method was used, as mentioned in Eq. 1:

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

Where Wi is the unit weightage of ith heavy metal; which is inversely proportional to the maximum permissible concentration Si, and defined as,

$$W_i = \frac{1}{S_i} \quad (2)$$

The proportionality constant (Mohan et al., 1996; Prasad et al., 2014) is considered as 1 for all the parameters. Qi is the sub-index of the ith parameter, and n is the number of heavy metals measured. Qi was determined with equation (3):

$$Q_i = \frac{|M_i - I_i|}{(S_i - I_i)} \quad (3)$$

Mi = Measured concentration of the ith parameter,

Ii = Highest desirable concentration of the ith parameter, Si = Maximum permissible concentration of the ith parameter which used the international standards (WHO). The higher the calculated HPI, the higher will be the risks of damage to the health after drinking contaminated water. Generally, a HPI value greater than 100 is considered as critical HPI, i.e., having the potential to cause harm to living beings.

2.3.2. Heavy metal evaluation index

HEI was used to evaluate the overall quality of water in terms of heavy metals. HEI was calculated with equation (4):

$$HEI = \sum_{i=1}^{n} \frac{H_C}{H_{MAC}} \quad (4)$$

where HC is the measured concentration of the ith heavy metal and HMAC is the maximum allowable concentration (MAC) of the ith heavy metal.

3. Results and Discussion

3.1. Spatial distributions of heavy metals in groundwater

Spatial interpolation using inverse distance weighted method in Arc GIS was performed for all the outcomes obtained from the analysis of groundwater samples collected in Sirjan Plain. Arc GIS software, version 10.7, was used to perform the geo-statistical analysis and the results obtained are shown in Fig.2. Groundwater is influenced by natural factors and anthropogenic activities, and the environmental conditions also varied among the different sites, thereby leading to the diverse distributions of the heavy metals. Table 2 shows descriptive statistics for heavy metals in the groundwater samples. The mean concentrations of the heavy metals were in the following order: Fe>As>V>Ba>Al>Se>Mo>Cd. According to the safe water standards defined by the World Health Organization (WHO) (2017), which are similar to the Iran water quality standard (2006) (Table 2), the concentrations of some heavy metals in the shallow groundwater samples exceeded the safe limits, such as those of As and Mo (Figure 2). In the groundwater samples, the concentration of As exceeded the safe limit in 22 groundwater samples

Table 2. Descriptive statistics for heavy metals of groundwater samples

Parameter (ppb)	No	Min	Max	Mean	CV	Std.deviation	WHO[a]	ISIRI[b]
Fe	22	10	1100	194	0.67	288.04	300	300
Al	22	7	130	31.22	0.82	37.7	200	200
As	22	1	195	57.14	0.89	63.8	10	10
Cd	22	0.1	0.39	0.25	0.25	0.997	5	5
Mo	22	0.81	6.36	2.31	1.9	1.21	70	5
Se	22	0.4	6.4	3.31	2.38	1.39	10	10
V	22	5.3	88	40.39	1.45	27.84	100	
Ba	22	9.29	91.6	34.42	1.53	22.4	700	

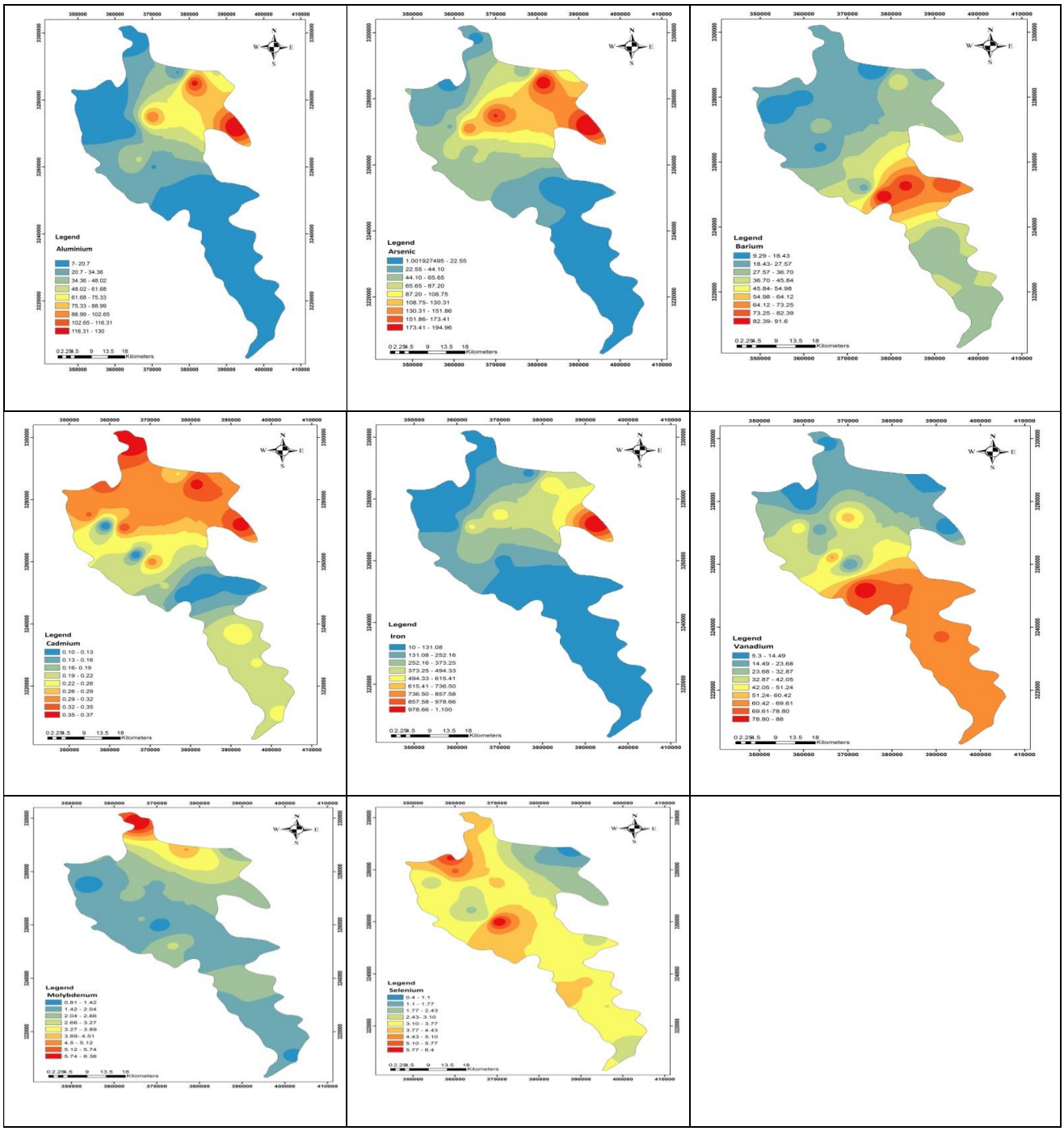


Fig 2. Spatial distribution of heavy metals in the groundwater of Sirjan plain

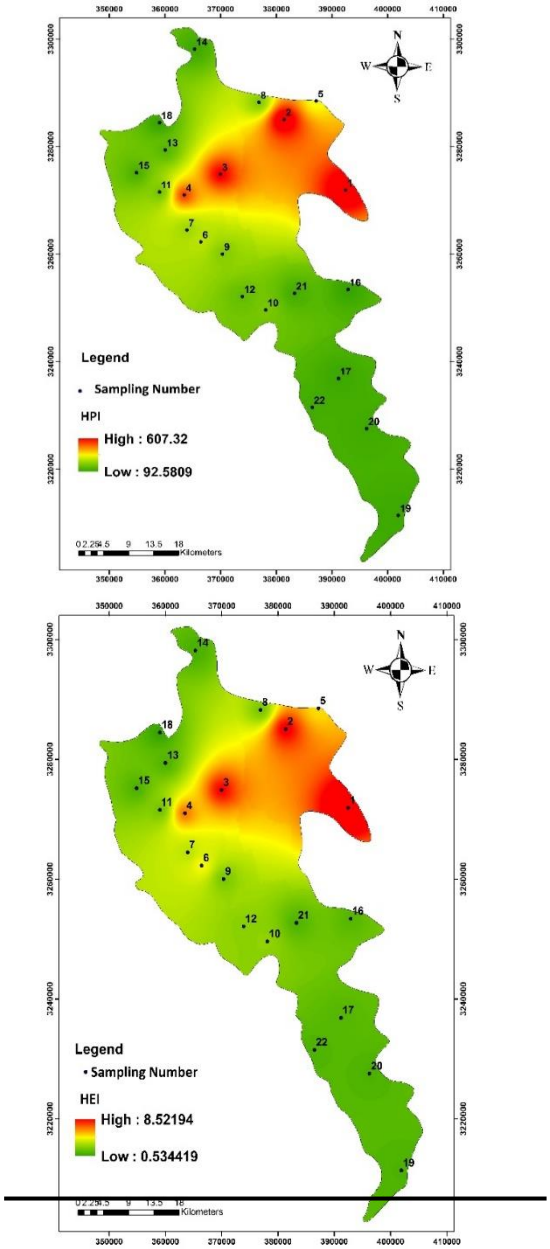
3.2. Heavy Metal Pollution Index and Heavy metal evaluation index results

HPI and HEI have been employed to evaluate the total heavy metal pollution in groundwater samples in many previous studies (Yari and Sobhanardakani, 2016; Sobhanardakani, 2017). Bhuiyan et al. (2010) assigned the HPI results to three pollution categories comprising: low HPI < 50, medium HPI = 50–100, and high HPI > 100. Bhuiyan et al. (2010) also classified the HEI results into three pollution categories comprising: HEI < 40 indicating a low degree of pollution, HEI = 40–80 indicating a medium degree of pollution, and HEI > 80 indicating a high degree of pollution. As shown in Figure 3, the HEI values determined for the groundwater samples collected in the Sirjan Plain region all indicated a low degree of pollution. While, the HPI values in the Sirjan Plain region indicated a medium and high degree of pollution. In table 4, shown Classification of heavy metal pollution index. Accordingly, 9.1% and 90. 9% of the samples are in the Medium pollution and highly pollution classification respectively.

Table4 -Classification of heavy metal pollution index (HPI)

Sampling Number	Percentage of samples	HPI	category
–	0	<50	Low pollution
17 , 18	9.1	50-100	Medium pollution
1-16, 19-22	90.9	>100	High pollution

Fig. 3. HEI and HPI values for samples in the Sirjan Plain



4. Conclusion

In this study, we collected 22 groundwater samples and assessed the groundwater quality in the Sirjan Plain region in terms of As and other heavy metals (Cd, Fe, Al, Se, Mo, Ba and V) based on various evaluation indices in order to evaluate the potential health risks for humans. Analysis of groundwater samples indicated that levels of the concentrations of some heavy metals in the shallow groundwater samples exceeded the safe limits, such as those of As and Mo. The HPI and HEI values for the groundwater samples collected in the Sirjan Plain region indicated that the HEI values all indicated a low degree of pollution. While, the HPI values in the Sirjan Plain region indicated a medium and high degree of pollution. So that, 9.1% and 90. 9% of the samples are in the Medium pollution and highly pollution classification respectively. Therefore, it is recommended to include metals in routine monitoring of the groundwater as a part of ‘water in sirjan plain safely plan and to frame evidence-based policies to mitigate groundwater contamination.

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