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Application of GIS for the identification and demarcation of selective heavy metal concentrations in the urban groundwater

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Abstract: Groundwater is the most appropriate and widely used source of drinking water, which is increasingly threatened by pollution from industrial and agricultural activities. To check the severity of the problem, 156 groundwater samples were collected from various depths (60–110 ft) of 52 different localities in Faisalabad city, the third largest metropolis in Pakistan, and analyzed for the metals (Zn, Cu, Cd, Ni, Pb, Mn and Fe) concentration in 2009. Quantification was done by using Flame Atomic Absorption Spectrophotometer technique and the results were compared with WHO standards for drinking water quality. Results showed that the levels of Cu, Mn and Fe were below the WHO standards while the concentrations of Zn, Cd, Ni and Pb were above the recommended levels of safe drinking water. Correlation analysis among the occurrence of these heavy metals revealed a highly significant and positive correlation of Mn with Zn and Fe. A significant and positive correlation of Cd was also found with Cu and groundwater depth showing that there is strong association between Cu-Cd pair and that the Cd concentration varies with depth of groundwater in the study area. Regional patterns of heavy metals occurrence were mapped using Geographical Information System (GIS) for the identification and demarcation of risk areas. The concentration maps may be used by policymakers of the city to mitigate groundwater pollution.

Keywords: heavy metals; groundwater contamination; Faisalabad; pollution mitigation

1 Introduction

Water is one of the essentials that support all forms of life on earth and is a finite commodity

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on the globe. Safe drinking water is a fundamental human right and is essential for the protection of public health and environment. Only 2.8% of the total water on earth is fresh water; the rest is in the form of salt water. Some 75% of the fresh water is frozen as the glaciers and icecaps. Thus, less than 1% of the total water that is present in rivers and underground resources is available to meet our present day requirements (Prasad and Narayana, 2004).

Groundwater is the most appropriate and widely used source of drinking water, which is increasingly threatened by pollution from industrial and agricultural activities. The natural water deterioration is an emerging environmental issue throughout the world. The problems become acute where natural pollutants are intensified by anthropogenic activities (Ahmad *et al*., 2004). The groundwater pollution is mainly caused by disposing of industrial effluents directly into the nearby drains, rivers, streams, ponds, ditches and open fields or agricultural lands (Ullah *et al*., 2009). Metals are discharged to groundwater by untreated wastes from industries, traffic, municipal wastes, hazardous waste sites, agricultural fields and accidental oil spillages from tankers (Igwilo *et al*., 2006). The metals and metal ions thus discharged into the environment (soil and water) may enter into the food chain and affect the health of plants and animals (Ahmad *et al*., 2008; Ahmad *et al*., 2010; Fardous *et al*., 2010; Ahmad *et al*., 2011; Rehman *et al*., 2013). The movement of different metal and ions in soil is under the influence of various soil related properties (Ibrahim *et al*., 2012). These metals need to be removed from the media (Irfan *et al*., 2013).

Studies have been carried out upon the quality of groundwater in terms of heavy metal concentrations in different cities of Pakistan including Peshawar (Ilyas and Sarwar, 2003), Skardu (Lodhi *et al*., 2003), Kasur (Tariq *et al*., 2008), Islamabad (Kausar and Zulfiqar, 2009), Sialkot (Ullah *et al*., 2009), Lahore (Akhter *et al*. , 2010), Tando Allahyar (Majidano and Khuwahar, 2009), Dera Ismail Khan (Ahmad and Anwar, 2011) and Kohistan (Said *et al*., 2011). No study was carried out in the near past in Faisalabad city on a large scale except one at small scale (Rashid *et al*., 1996).

Keeping in view the importance of potable water and associated hazardous effects of trace metal ions, the present study was conducted to assess the quality status of groundwater from different localities in Faisalabad city, the third largest metropolis in Pakistan, with the following specific objectives: (i) to assess and map the quality of groundwater with respect to heavy metal (Zn, Cu, Cd, Ni, Pb, Mn and Fe) concentration and compare it with WHO standards for drinking water quality, and (ii) to analyze correlation among the occurrence of these heavy metals.

2 Materials and methods

Groundwater samples from motor driven pumps at different depths ranging from 60 to 110 ft were collected for analysis of metal concentration (Zn, Cu, Cd, Ni, Pb, Mn, and Fe) in December 2009. Grab representative 156 groundwater samples in triplicates were collected randomly from 52 different localities of Faisalabad city area. Samples were collected in pre-cleaned 500 ml polyethylene bottles. During the collection of groundwater samples special emphasis was given to the localities where groundwater was the only source of drinking water. Groundwater samples collected from each locality were plotted on the street map of

Faisalabad city. Site identification was marked on Faisalabad city map. Figure 1 shows the major localities of Faisalabad city and the groundwater sampling sites.

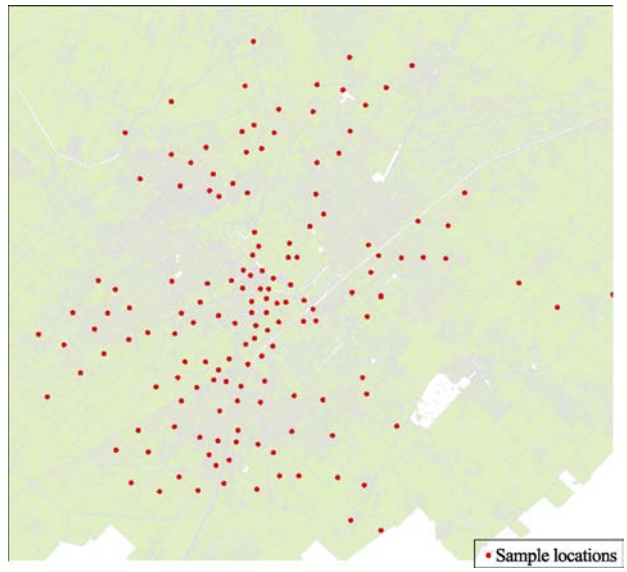

Figure 1 Groundwater sampling locations shown on the street map of Faisalabad city

2.1 Analysis of heavy metal and GIS mapping

Atomic Absorption Spectrophotometer (Model: Varian Spectra AA 250 Plus) with air-acetylene based method was used for the determination of heavy metals in water. ArcGIS version 10.0 was used to map the heavy metals concentration in groundwater from different urban areas of Faisalabad city. It is full-featured GIS software for visualizing, managing, creating, and analyzing geographic data. The sampling sites were marked in ArcMap with the help of their coordinates and maps of heavy metals in groundwater were produced. The Inverse Distance Weighted (IDW) interpolation technique was used for this purpose. IDW uses the measured values surrounding the prediction location to predict a value for any non-sampled location, based on the assumption that things that are close to one another are more alike than those that are farther apart.

2.2 Statistical tools

Multivariate data analysis was carried out using statistical package Minitab (version 13.2) for analysis of variance (ANOVA), Pearson's correlation and comparison of means.

3 Results and discussion

The present study was undertaken to determine the suitability of groundwater for drinking purpose with respect to heavy metal concentrations. The precise estimation of heavy metals in the water samples was made through chemical analysis and statistical approach. Analysis of variance (ANOVA) test showed that there was no statistically significant difference ($p>0.05$) for Zn, Cd and Ni concentration of groundwater among different localities of Faisalabad city. However, Pb and Fe levels of groundwater sampled revealed a highly significant difference ($p<0.01$) showing that concentration of these elements varied significantly from place to place. Another significant difference ($p<0.05$) was evaluated for Cu and Mn concentration in groundwater of Faisalabad city. The study of comparison of means showed that mean Zn content from the studied localities was 0.224 ± 0.37 ppm. While, mean level (ppm) for Cu, Cd, Ni, Pb, Mn and Fe was 0.038 ± 0.02, 0.02 ± 0.01, 0.046 ± 0.02, 0.024 ± 0.01, 0.012 ± 0.01 and 0.024 ± 0.01, respectively (Table 1).

Table 1 Comparison of means ± SD (standard deviation) of concentrations (ppm) for studied heavy metals at all sampling sites

Sr. No.	Sampling locations	Zn ± SD	Cu ± SD	Cd ± SD	Ni ± SD	Pb ± SD	Mn ± SD	Fe ± SD
1	Pathanwala	0.239±0.3	0.033±0.0	0.017±0.01	0.041±0.02	0.03±0.02	0.011±0.01	0.016±0.01
2	Rashid Abad	0.322±0.3	0.03±0.01	0.011±0.01	0.051±0.02	0.029±0.02	0.017±0.02	0.031±0.02
3	Saif Abad	0.271±0.2	0.028±0.0	0.021±0.01	0.039±0.02	0.029±0.02	0.011±0.01	0.019±0.01
4	Shadab Colony	0.454±0.5	0.048±0.0	0.028±0.01	0.045±0.02	0.009±0.01	0.009±0.01	0.012±0.01
5	Ali Housing Colony	0.099±0.0	0.028±0.0	0.013±0.02	0.047±0.02	0.012±0.01	0.02±0.01	0.012±0.01
6	Gulfishan Colony	0.401±0.4	0.032±0.0	0.01±0.01	0.054±0.01	0.021±0.01	0.011±0.01	0.011±0.01
7	Sheikh Colony	0.078±0.0	0.025±0.0	0.017±0.02	0.057±0.01	0.036±0.01	0.018±0.01	0.019±0.01
8	Liaquat Abad	0.546±0.4	0.026±0.0	0.007±0.01	0.05±0.02	0.026±0.01	0.005±0.01	0.007±0.01
9	Liaquat Town	0.422±0.6	0.034±0.0	0.005±0.01	0.033±0.03	0.017±0.01	0.012±0.01	0.015±0.01
10	Afghan Abad	0.436±0.3	0.032±0.0	0.021±0.01	0.051±0.01	0.01±0.01	0.016±0.01	0.024±0.01
11	Guru Nanak Pura	0.139±0.1	0.035±0.0	0.016±0.02	0.057±0.01	0.024±0.01	0.006±0.01	0.019±0.01
12	Gulberg	0.136±0.1	0.024±0.0	0.003±0.01	0.038±0.01	0.007±0.01	0.006±0.01	0.014±0.01
13	Jinnah Colony	0.438±0.6	0.048±0.0	0.038±0.01	0.030±0.02	0.013±0.01	0.014±0.01	0.031±0.01
14	GC University	0.19±0.08	0.022±0.0	0.019±0.01	0.036±0.01	0.021±0.01	0.015±0.01	0.026±0.01
15	UAF	0.326±0.3	0.034±0.0	0.019±0.01	0.036±0.02	0.025±0.01	0.011±0.01	0.019±0.01
16	Raza Abad	0.333±0.4	0.052±0.0	0.018±0.02	0.053±0.01	0.016±0.01	0.008±0.01	0.018±0.01
17	G.M. Abad	0.265±0.1	0.035±0.0	0.017±0.01	0.061±0.01	0.021±0.01	0.014±0.01	0.019±0.01
18	MarziPura	0.098±0.1	0.05±0.02	0.019±0.01	0.04±0.02	0.022±0.01	0.014±0.01	0.016±0.01
19	NIBGE	0.215±0.2	0.033±0.0	0.015±0.01	0.05±0.01	0.008±0.01	0.016±0.01	0.045±0.01
20	NIAB	0.089±0.0	0.043±0.0	0.021±0.01	0.049±0.01	0.006±0.01	0.015±0.01	0.022±0.01
21	AARI	0.078±0.0	0.04±0.02	0.021±0.02	0.045±0.02	0.02±0.01	0.008±0.01	0.016±0.01
22	Ayub Colony	0.041±0.0	0.039±0.0	0.022±0.02	0.03±0.01	0.033±0.02	0.014±0.01	0.022±0.01
23	Pertap Nagar	0.02±0.01	0.057±0.0	0.032±0.01	0.056±0.01	0.022±0.01	0.011±0.01	0.019±0.01
24	Nazim Abad	0.125±0.1	0.031±0.0	0.025±0.02	0.04±0.01	0.013±0.01	0.007±0.01	0.028±0.01
25	Khalid Abad	0.172±0.0	0.04±0.03	0.028±0.02	0.072±0.01	0.03±0.02	0.008±0.01	0.018±0.01
26	HerchernPura	0.321±0.4	0.054±0.0	0.023±0.01	0.037±0.02	0.012±0.01	0.002±0.01	0.02±0.01
27	SanatPura	0.219±0.2	0.028±0.0	0.018±0.02	0.044±0.01	0.03±0.01	0.016±0.01	0.03±0.01
28	DiglosPura	0.092±0.0	0.034±0.0	0.02±0.01	0.056±0.01	0.036±0.02	0.009±0.01	0.024±0.02
29	Clock Tower	0.066±0.0	0.029±0.0	0.024±0.01	0.051±0.01	0.026±0.01	0.023±0.01	0.026±0.02
30	Jhang Road	0.045±0.0	0.023±0.0	0.034±0.01	0.049±0.01	0.02±0.02	0.005±0.01	0.019±0.01
31	Jinnah Garden	0.12±0.08	0.069±0.0	0.035±0.02	0.034±0.01	0.021±0.01	0.022±0.01	0.017±0.01
32	DHQ	0.494±0.6	0.068±0.0	0.017±0.01	0.043±0.01	0.025±0.02	0.009±0.01	0.022±0.01
33	Allied Hospital/PINUM	0.673±0.4	0.036±0.0	0.012±0.01	0.062±0.01	0.032±0.02	0.022±0.01	0.033±0.01
34	Sargodha Road	0.252±0.2	0.037±0.0	0.021±0.01	0.045±0.01	0.038±0.02	0.008±0.01	0.034±0.01
35	Gulistan Colony	0.124±0.1	0.054±0.0	0.032±0.01	0.063±0.01	0.049±0.01	0.009±0.01	0.025±0.02
36	Abdullah Pur	0.066±0.0	0.03±0.01	0.023±0.01	0.047±0.01	0.025±0.01	0.007±0.01	0.025±0.01
37	Canal Road	0.054±0.0	0.049±0.0	0.016±0.01	0.029±0.02	0.013±0.01	0.007±0.01	0.034±0.02

(*to be continued on the next page*)

(*Continued*)

Sr. No.	Sampling locations	Zn ± SD	Cu ± SD	Cd ± SD	Ni ± SD	Pb ± SD	Mn ± SD	Fe ± SD
38	Madina Town	0.511±0.3(	0.038±0.0	0.017±0.01	0.035±0.0	0.022±0.0	0.007±0.0	0.034±0.0
39	Officers Colony	0.117±0.0(	0.058±0.0	0.028±0.01	0.065±0.0	0.023±0.0	0.003±0.0	0.032±0.0
40	Satiana Road	0.196±0.1	0.039±0.0	0.026±0.01	0.037±0.0	0.047±0.0	0.015±0.0	0.043±0.0
41	Batala Colony	0.05±0.03	0.041±0.0	0.013±0.01	0.038±0.0	0.026±0.0	0.019±0.0	0.02±0.01
42	Peoples Colony	0.206±0.1	0.032±0.0	0.021±0.02	0.046±0.0	0.016±0.0	0.015±0.0	0.034±0.0
43	D Ground	0.054±0.0	0.055±0.0	0.03±0.01	0.042±0.0	0.009±0.0	0.017±0.0	0.033±0.0
44	WarisPura	0.103±0.0(	0.02±0.01	0.032±0.01	0.056±0.0	0.033±0.0	0.01±0.01	0.033±0.0
45	Jaranwala Road	1.14±1.84	0.03±0.01	0.033±0.01	0.055±0.0	0.032±0.0	0.013±0.0	0.017±0.0
46	Dhuddiwala	0.328±0.2	0.031±0.0	0.009±0.01	0.043±0.0	0.056±0.0	0.023±0.0	0.032±0.0
47	Samundari Road	0.083±0.0	0.048±0.0	0.024±0.01	0.041±0.0	0.007±0.0	0.008±0.0	0.015±0.0
48	Amin Abad	0.027±0.0	0.036±0.0	0.014±0.01	0.054±0.0	0.015±0.0	0.009±0.0	0.018±0.0
49	Mehmood Abad	0.034±0.0	0.029±0.0	0.029±0.01	0.048±0.0	0.016±0.0	0.006±0.0	0.03±0.02
50	Nisar Colony	0.054±0.0	0.039±0.0	0.016±0.01	0.033±0.0	0.055±0.0	0.005±0.0	0.037±0.0
51	Jawala Nagar	0.042±0.0	0.039±0.0	0.017±0.01	0.039±0.0	0.027±0.0	0.007±0.0	0.025±0.0
52	Nawabanwala	0.248±0.3(	0.038±0.0	0.019±0.01	0.04±0.02	0.032±0.0	0.01±0.01	0.031±0.0
	Grand total	0.224±0.3	0.038±0.0	0.02±0.01	0.046±0.0	0.024±0.0	0.012±0.0	0.024±0.0

3.1 Correlation among heavy metal concentrations

The interrelationship or association among all the heavy metals studied was evaluated by Pearson correlation analysis (Table 2).

Table 2 Relationship among different heavy metals for all sampling sites (Pearson Correlation among different heavy metals)

	Zn	Cu	Cd	Ni	Pb	Mn	Fe
Cu	0.038 ^{NS} P=0.634	1.00					
Cd	–0.066 ^{NS} P=0.414	0.160* P=0.045	1.00				
Ni	0.025 ^{NS} P=0.757	–0.014 ^{NS} P=0.865	–0.024 ^{NS} P=0.770	1.00			
Pb	0.056 ^{NS} P=0.487	–0.091 ^{NS} P=0.257	–0.031 ^{NS} P=0.702	0.044 ^{NS} P=0.582	1.00		
Mn	0.207** P=0.010	–0.110 ^{NS} P=0.173	0.010 ^{NS} P=0.903	–0.071 ^{NS} P=0.382	0.072 ^{NS} P=0.373	1.00	
Fe	–0.033 ^{NS} P=0.678	–0.052 ^{NS} P=0.516	0.112 ^{NS} P=0.162	–0.088 ^{NS} P=0.272	0.139 ^{NS} P=0.083	0.208** P=0.009	
Depth (ft)	–0.072 ^{NS} p=0.371	0.084 ^{NS} p=0.297	0.163* p=0.043	0.038 ^{NS} p=0.641	–0.010 ^{NS} p=0.906	–0.037 ^{NS} p=0.643	0.093 ^{NS} p=0.251

*=Significant (P<0.05); **=Highly significant (P<0.01); NS=Non-significant (P>0.05)

The relationship among all the heavy metals (Zn, Cu, Cd, Ni, Pb, Mn and Fe) studied was found non-significant (p>0.05) revealing that there is no correlation between them with a few exceptions [Mn-Zn (p = 0.010), Mn-Fe (p = 0.009) and Cu-Cd (p = 0.045)]. In other words, the concentration of these metals does not depend upon each other. A highly significant (p<0.01) and positive correlation of Mn was observed with Zn (r = 0.207), this result is

in agreement with earlier observations of Farooq *et al.* (2010). They estimated levels of selected heavy metals such as Cd, Cr, Cu, Fe, Ni, Zn, Mn, Hg and Pb in water samples used for irrigation from the catchment area of Malir River, a sub-urban eastern area of Karachi. In this study Mn showed a positive correlation with Zn pointing out that Mn concentration of groundwater increases with an increase in Zn level and vice versa. Similarly, another highly significant (p<0.01) and positive correlation of Mn was observed with Fe (r=0.208), indicating that Mn level of groundwater increases with an increase in Fe level and vice versa. The present study also contradicted the findings of Farooq *et al.* (2010), where Fe showed a negative correlation with all detected metal ions such as Cd, Cr, Cu, Fe, Ni, Zn, Mn, Hg and Pb in water samples used for irrigation from the catchment area of Malir River, sub-urban eastern area of Karachi. In the present study significant and positive correlation was found between Cu and Cd. The study conducted by Mastoi *et al.* (2008) also revealed that the concentration of Cu was significantly and positively correlated with the concentration of Ni (r = 0.804, p<0.01), Co (r = 0.974, p<0.05) and Cd (r = 0.903, p<0.05). Another finding of the study by Mastoi *et al.* (2008) was significant and positive correlation between the concentrations of Ni (r = 0.991, p<0.01) and Zn (r = 0.921, p<0.05) which is not substantiated by the present study, as non-significant relationship was observed (p>0.05) between Ni and Zn. Another significant (p<0.05) and positive relationship was found between Cu and Cd showing that there is strong association between Cu and Cd concentration of groundwater in the study area. Pearson's correlation revealed that there was non-significant (p>0.05) and positive relationship between these metal pairs, i.e., Zn-Cu (p = 0.634), Zn-Ni (p = 0.757), Zn-Pb (p = 0.487), Cd-Mn (p = 0.903), Cd-Fe (p = 0.162), Ni-Pb (p = 0.582), Pb-Mn (p = 0.373) and Pb-Fe (p = 0.083). From this correlation analysis it was found that the increase in the concentration of one metal will increase the concentration of the other respective metal pair. Another non-significant (p>0.05) and negative relationship was found between these metal pairs, i.e., Zn-Cd (p = 0.414), Zn-Fe (p = 0.678), Cu-Ni (p = 0.865), Cu-Pb (p = 0.257), Cu-Mn (p = 0.173), Cu-Fe (p = 0.516), Cd-Ni (p = 0.770), Cd-Pb (p = 0.702), Ni-Mn (p = 0.382) and Ni-Fe (p = 0.272). From this correlation analysis it was found that that increase in the concentration of one metal will decrease the concentration of the other respective metal pair. The study conducted by Akoto and Adiyiah (2007) also found no correlations between metal concentrations in the drinking water samples. They determined the trace metals and some physiochemical properties in drinking water samples from the Brong Ahafo region of the Republic of Ghana.

Another study conducted by Lodhi *et al.* (2003) concluded that there was no co-linearity among the metals. They analyzed drinking water quality in Skardu and other northern areas of Pakistan for various parameters like pH, DO, EC, suspended solids, hardness, alkalinity, NO_2, Na, SO_4, Cl and K and for heavy metals like Fe, Cr, Zn, Mn, Cu, Ni, Co and Pb.

The study conducted by Majidano and Khuwahar (2009) found significant and positive relationship between Fe and Zn, Mn and Cd, Cu and Zn, Ni and Cd. This relationship is not substantiated by the present study as no such significant relationship was evaluated. The study conducted by Santos *et al.* (2000) revealed the strongest associations corresponded to the coexistence of Zn–Cd and Pb–Cu opposite to the finding of the present study, where non-significant (p>0.05) and negative correlation was found between Zn and Cd (with r = –0.066). Similarly no correlation was observed between Pb and Cu (p = 0.091).

In the present study no significant correlation was observed between Pb and Ni concentration of groundwater. This result is in agreement with the findings of Akoto and Adiyiah (2007); Lodhi *et al.* (2003) while contradicted by the findings of Tariq *et al.* (2008). Tariq *et al*. (2008) estimated levels of selected metals Na, Ca, Mg, K, Fe, Mn, Cr, Co, Ni, Cd, Pb and Mn in groundwater samples from Kasur, a significant industrial city of Pakistan and found significantly positive correlation between Pb and Ni.

Relationship of concentration of studied heavy metals with groundwater depth was evaluated showing significant ($p<0.05$) and positive correlation between cadmium concentration and groundwater depth, while correlation for all other metals with depth was found non-significant ($p>0.05$).

Correlation analysis showed that there was negative relationship of zinc, lead and manganese level with depth of groundwater, while concentrations of copper, nickel and iron showed positive correlation with groundwater depth. The statistical distribution of the studied heavy metal concentrations was compared with WHO standards (Table 3).

Table 3 Distribution of heavy metals in groundwater of Faisalabad

Heavy metals	Concentrations of heavy metals (ppm)				
	Min	Max	Mean	SD	WHO Value
Zn	0.008	3.265	0.224	±0.374	3.000
Cu	0.011	0.088	0.038	±0.015	2.000
Cd	0.002	0.050	0.020	±0.012	0.003
Ni	0.007	0.085	0.046	±0.017	0.020
Pb	0.002	0.065	0.024	±0.014	0.010
Mn	0.001	0.033	0.012	±0.007	0.500
Fe	0.004	0.061	0.024	±0.010	0.300

SD = standard deviation

3.2 Comparison of heavy metal concentrations with WHO standards

In the present study, contents of Zn (0.008–3.265), Cd (0.002–0.050), Ni (0.007–0.085) and Pb (0.002–0.065) levels were found above the recommended level of drinking water for human health set by WHO. The guideline values for drinking water set by WHO for Zn, Cd, Ni and Pb are 3.0 ppm, 0.003 ppm, 0.02 ppm and 0.01 ppm, respectively. In the study conducted by PCRWR (2006) also found cadmium concentration above WHO standard in 15% of water collected from 13 locations covering the major water sources of Faisalabad city.

Concentrations of Cu (0.011–0.088 ppm), Mn (0.001–0.033 ppm) and Fe (0.004–0.061 ppm) were found under the safe limits set by WHO. The standard values set by WHO for Cu, Mn and Fe are 2.0 ppm, 0.5 ppm and 0.3 ppm, respectively. Total number of samples and percentage values for all the heavy metals studied in the groundwater samples from different localities of Faisalabad city area that were found above and below WHO guideline values for drinking water are presented in Figures 2 and 3, respectively.

3.3 Spatial distribution of heavy metals in groundwater

Metal concentrations were mapped using GIS to identify and demark risk areas in terms of human exposure to heavy metal concentrations in groundwater from different urban areas of

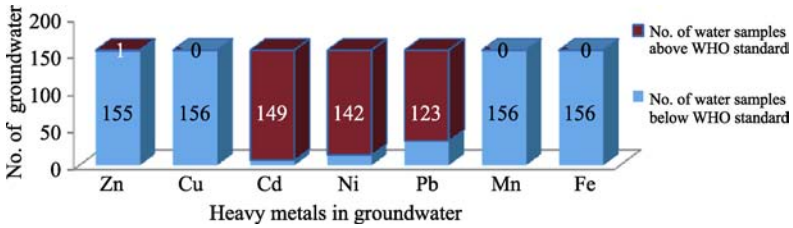

Figure 2 Number of groundwater samples above/below WHO standard

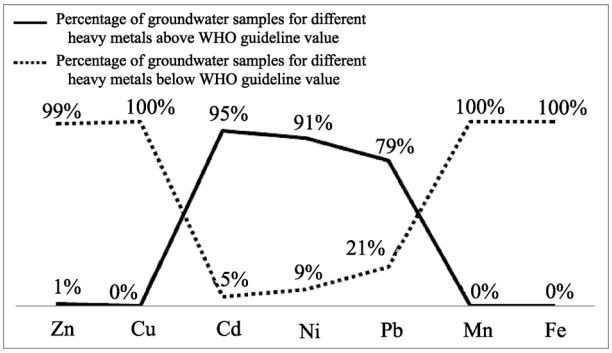

Figure 3 Percentage of groundwater samples above/below WHO guideline value

Faisalabad city. GIS mapping revealed that there is wide dispersion of values of all the heavy metals (Zn, Cu, Cd, Ni, Pb, Mn and Fe) in groundwater of Faisalabad urban area.

The spatial distribution of Zn concentration is displayed in Figure 4 showing the highest concentration (3.265 ppm) in the sample collected from Jaranwala Road area that was beyond the WHO guideline value (3.0 ppm). The reason behind this high Zn concentration is, because the site is located near National Fertilizer Company (NFC), a fertilizer industry while in the majority of the samples the Zn concentrations varied from 0–1 ppm.

Great variation was found in the concentration of Cu in groundwater among different localities. All the samples were found within the safe limits (below 2.0 ppm) set by WHO as it is displayed by Figure 5. Figure 6 displays the spatial distribution of Cd concentration among different localities. Cd concentrations in majority of the samples were found above the WHO standard (0.003 ppm). While the samples collected from Gulberg, Sheikh Colony, GM Abad, Nisar Colony, Dhuddiwala and Peoples Colony were well within the safe limits. The lowest Cd concentration found was 0.002 ppm in the groundwater samples.

The spatial distribution of Ni concentration is shown in Figure 7, where Ni content was found above WHO standard (0.02 ppm). The highest concentration (0.085 ppm) was found in Khalidabad area where hosiery industry is housed and possibly releases Ni contaminated effluents.

Similarly Pb concentrations revealed great variation among different localities as it is displayed in Figure 8, where the highest level of Pb was found in Dhuddiwala area possibly due to seepage Pb rich effluent from the nearby sewage drain named “Dhudiwala Minor”. The same was found at minimum concentration in the sample taken from the area of NIAB. Spatial variation of Mn (Figure 9) and Fe concentration (Figure 10) showed that all the groundwater samples were under the prescribed limit set by WHO. There was a great variation in groundwater depth among various sampling points in different localities of Faisalabad city

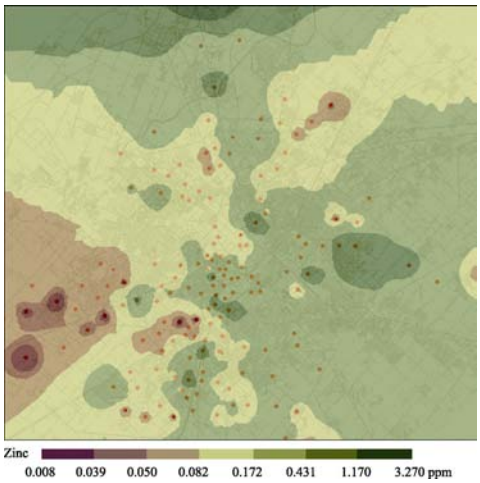

Figure 4 Zn level in groundwater of Faisalabad city in 2009

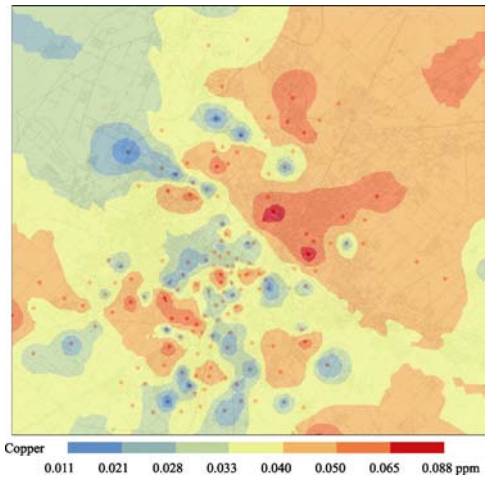

Figure 5 Cu level in groundwater of Faisalabad city in 2009

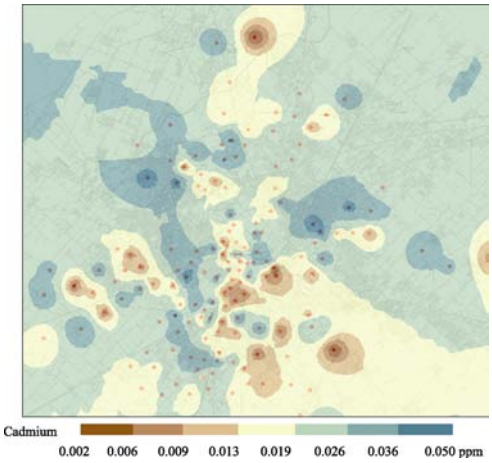

Figure 6 Cd level in groundwater of Faisalabad city in 2009

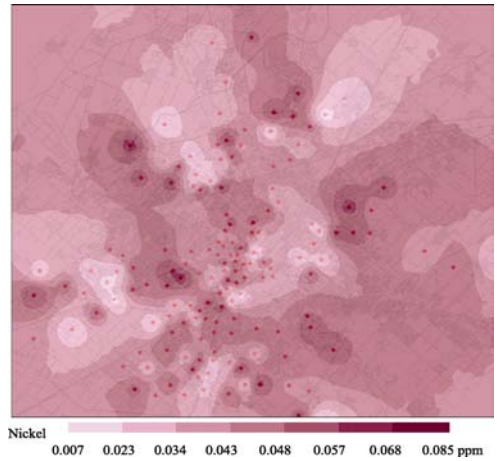

Figure 7 Ni level in groundwater of Faisalabad city in 2009

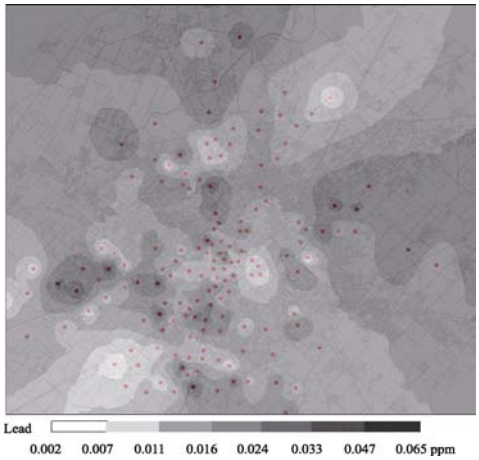

Figure 8 Pb level in groundwater of Faisalabad city in 2009

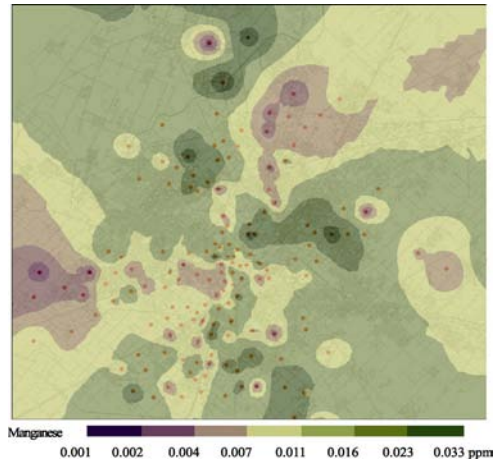

Figure 9 Mn level in groundwater of Faisalabad city in 2009

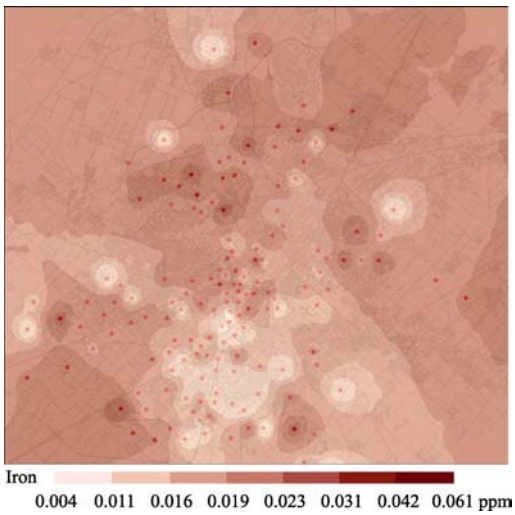

Figure 10 Fe level in groundwater of Faisalabad city in 2009

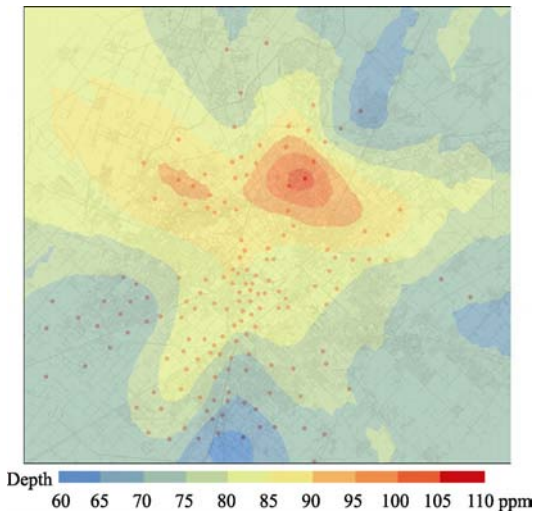

Figure 11 Depth of samples at different locations of Faisalabad city

(Figure 11). A possible reason is the difference in level of groundwater pumping in various areas that depends on the intended use of water (e.g., domestic or agricultural) and size of population.

4 Conclusions

The present study revealed that the levels of Cu, Mn and Fe were found below the recommended guideline values for drinking water set by World Health Organization (WHO); i.e., 2.0, 0.50 and 0.30 ppm, respectively. While the concentrations of Zn, Cd, Ni and Pb in groundwater were found above the recommended level of drinking water set by WHO; *i.e.*, 3.0, 0.003, 0.02 and 0.01 ppm, respectively for human health. No significant correlation (p>0.05) was found among the occurrence of studied heavy metals with a few exceptions (Mn-Zn, Mn-Fe and Cu-Cd). A highly significant and positive correlation (p<0.01) of Mn was found with Zn (p = 0.010 and r = 0.207) and Fe (p = 0.009 and r = 0.208) indicating that Zn and Fe level of groundwater increases with an increase in Mn level and vice versa. Another significant and positive correlation (p<0.05) was found between Cu and Cd (p = 0.045 and r = 0.160) showing that there is strong association between Cu and Cd concentrations of groundwater in the study area. Groundwater monitoring results were mapped using GIS to show the regional patterns of occurrence of heavy metal concentrations in groundwater of Faisalabad city.

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