Risk Zone Mapping of Lead Pollution in Urban Groundwater

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Abstract: Groundwater samples (n = 230) were collected from various parts of the Karachi City (Pakistan), Karachi is an urban coastal City situated at the southern most part of the Pakistan along the Arabian Sea. The groundwater samples were subjected to electrothermal atomic absorption spectroscopy (EAAS) for the analysis of Pb. Variable Pb levels were observed in groundwater samples from different parts of the city. The relative higher concentrations of Pb were found in the industrial area of the Lyari River vicinity and along the coastal belt. GIS risk zone model based on disjunctive kriging were generated and areas associated with higher risk for Pb contamination were classified on the map. The outcomes of the study stressed that GIS spatial analysis could be a useful tool for the assessment and forecasting of health risk in complex urban environmental setup.

Keywords: Lead, heavy metals, risk mapping, GIS, groundwater, urban pollution, Karachi, Pakistan, health hazarads.

INTRODUCTION

Heavy metals are stable and persistent environmental contaminants since they cannot be degraded or destroyed. Among the heavy metals, lead (Pb) is generally toxic for human health and higher concentrations of lead can cause anemia, vomiting, loss of appetite, damage of brain, liver and kidney, intestinal colic, headaches, double vision, mental disturbance, anxiety, delerium, convulsions, coma, muscular weakness, loss of memory etc. [1-5].

The problem of groundwater pollution due to rapid urbanization and industrialization has become a heated topic of high-risk environment [6-9]. Karachi City comprises of more than two thousand industries of various nature and sizes discharging their almost untreated effluents of about 72 million gallons per day into the natural and manmade drainage networks, which drain mainly through local rivers Malir and Lyari [10]. The shortage of potable water supply has led inhabitants of Karachi to exploit groundwater accumulated in the alluvial part of the soil from seldom rainfall and the outflow of polluted waste of River Lyari and Malir. The groundwater has, therefore become a matter of great concern for the inhabitants of Karachi with a population of more than 15 million, which is nearly 10% of the whole population of Pakistan [11].

Geographical Information System (GIS) play a vital role for analysis and in formulating the quick mitigation plans for high risk environments [12], as envisaged for the present study. Keeping in view the present known functions of GIS, it has been used to process and plot the data of the present work for the preparation of spatial geochemical distribution of the lead contamination investigated to evaluate their possible impacts on the groundwater quality. The presence of metal pollution in the groundwater creating possible health hazards in different parts of the Karachi City. A fundamental step in groundwater resources management and environmental planning is the assessment of the risk expected after the occurrence of natural [13] or anthropogenic hazardous events [14].

Realizing the toxic effects of lead to the inhabitant, present study has been designed to evaluate the health risks associated with the groundwater in a complex urban environment. GIS has been utilized to prepare the high risk zone identification and evaluation to predict the possible hazardous consequences to health at present and at future.

MATERIALS AND METHODS

The shallow groundwater samples were collected from different parts of the Karachi City. The study area

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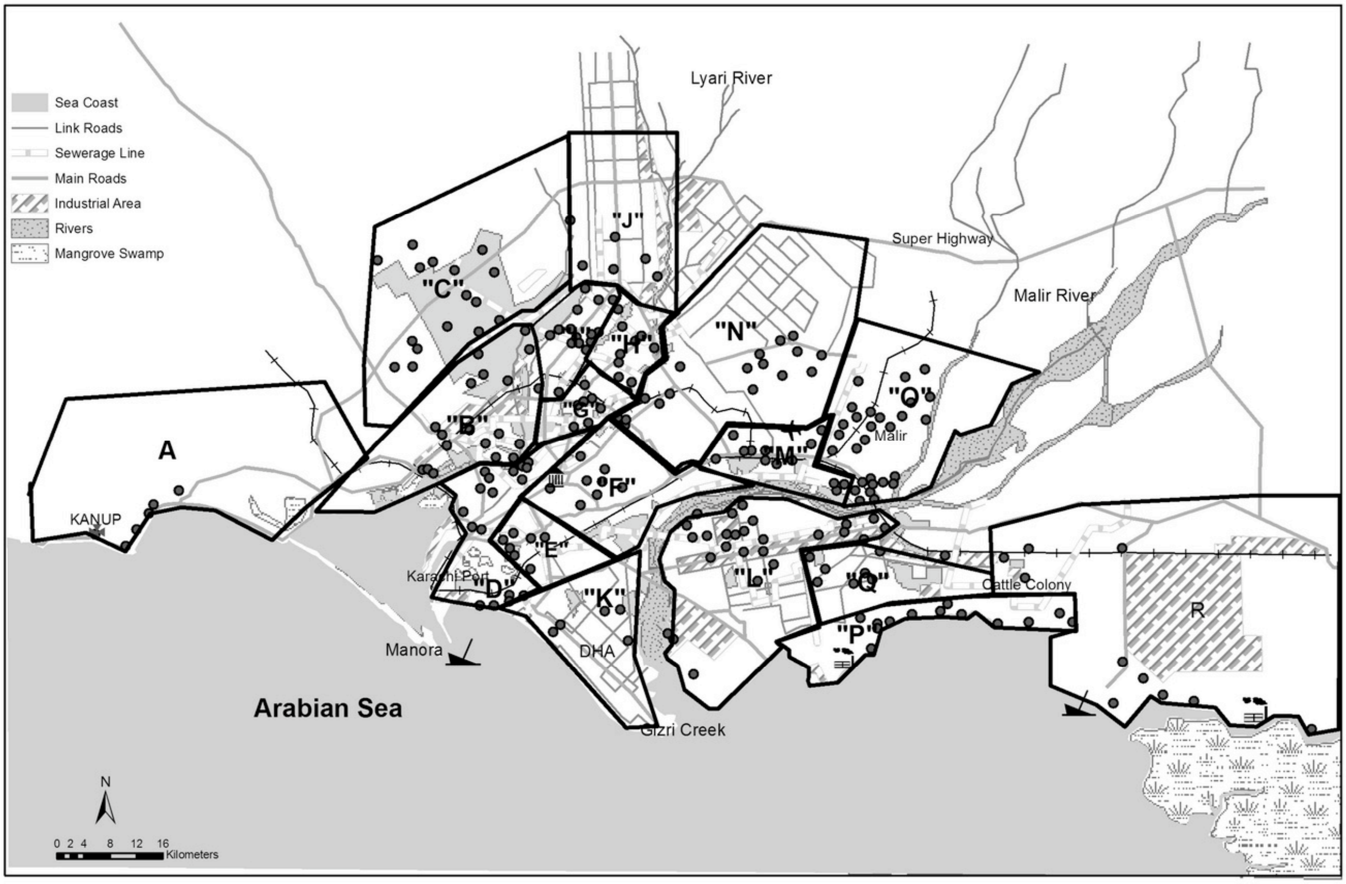

Figure 1: Map shows localities and sampling sites selected for the collection of groundwater samples.

was distributed and marked as localities from “A” to “R”, these localities encompasses populated areas of the Karachi City (Figure **1**). Groundwater samples (2 x 1000 ml) from each location were taken, after the very first drawn of the water form the source, to minimize the error that may arose because of the over-night contact contamination of rust and other metals [15]. Analysis of lead in shallow groundwater samples were performed according to the US EPA method 239.2 [16] by electrothermal atomic absorption spectroscopy (EAAS). Briefly, 20 µl of sample, working standards and quality control standards contain lanthanum nitrate (10 ml of lanthanum nitrate for 100 ml of sample solution; 1 ml of lanthanum nitrate contain 50 mg of lanthanum) were injected into the furnace with continuous purge gas (Argon) on a Perkin-Elmer AAnalyst 700 atomic absorption spectrometer. Temperature program for the furnace was set as drying temperature at 125^0C for 30 sec; ashing at 500^0C for 25 sec; atomizing temperature was set at 2700^0C for 10 sec and wavelength was set at 283.3 nm.

Data quality objectives (DQO) were implemented by strict quality assurance (QA) and quality control (QC) procedures throughout the study. The level of accuracy and QC for the determination of lead concentration was comprised of measurements of Standard Reference Material (SRM), the determination of spike recovery and measurements of duplicates for each batch of samples. National Institute of Standard & technology, Department of Commerce, USA (NIST) standard reference material SRM 1643d (trace elements in water) was used for the evaluation. Percentage recoveries of SRM ranged between 83.2% and 113% with % RSDs for the mean recoveries below 7.2 %. The percent recoveries for the matrix spike samples ranging from 73% to 109% with the % RSD for the mean recoveries falling below 12.4%. Whereas, the percent relative standard deviation (% RSD) for eleven duplicate samples analyzed was less than 8.3%.

Spatial geochemical distribution map of the lead was generated through spatial interpolation technique. The interpolation was performed through Inverse distance weighted (IDW) interpolation, a geostatistical tool used, to determine cell values using a linearly weighted combination of a set of sample points [17]. Applying DK technique, the original data have been transformed to a Gaussian distribution using Hermite polynomials and then the variogram of the transformed variable was calculated and modeled through ArcGIS® software. Using the variogram, the indicators for each of the threshold or background value is estimated. Estimates of these indicators were given by the estimated probabilities grouped into five classes i.e. No risk, Low risk, Moderate Risk, High risk and Very high risk with respect to threshold / background value and shown by gradient of colour from light to dark respectively. Estimates of the probability of impact for lead concentration in term of risk zones modeling were performed by Disjunctive Kriging (*DK*) technique. The *DK* allows to evaluate, at a given time t, the conditional probability (*CP*) that the concentration of pollutant in groundwater exceeds a given threshold at a specific location of the study area.

RESULTS AND DISCUSSION

A summary of the each locality, the overall minimum, maximum and median lead concentrations in

Table 1: Distribution of Lead (Pb) Concentrations [µg.l^{-}] in Various Localities of the Karachi City

Locality Area(s)	Locality	Locality Description	Minimum	Maximum	Mean
Hawk's bay	A	Beach area, Air Force Base, Nuclear Power Plant, Few industries, salt refining, thin population	2.10	8.29	5.68
SITE	B	Largest industrial zone of Sind Industrial trading Estate (SITE), low income population, poor infrastructure	3.22	10.85	6.39
Orangi /Baldia	C	One of the largest rehabilitated area, thickly populated, number of cottage industries, poor drainage and sanitation conditions	1.02	7.89	3.55
Old City	D	Coastal area, seaport, metal works, cottage industries, old city area, thickly populated	1.02	6.22	4.34
Saddar	E	City center, business hub, low to middle income population, heavy vehicle traffic	2.21	17.2	5.21
PECHS	F	Variety of population mix, on eastern part of the Lyari river, moderate sanitation pouring into the Lyari river	4.38	10.11	7.36
Liaqutabad	G	Thickly populated, number of cottage industries, low to middle income population, unorganized industrial activities from toxic chemicals to food stuffs	5.17	18.6	9.48
Mansoora	H	Planed and structured infrastructure, middle to high income population, very few cottage industries	1.36	9.83	4.52
Taimuria	I	Well planed means of communication and sanitation conditions, now industry, middle to high income population group	1.62	22.12	8.32
North Karachi	J	Covers industrial area of North Karachi, thickly populated area, low to middle income population group, number of cottage industries are in operation	2.22	13.56	8.01
Clifton / DHA	K	High income population group, planed area with infrastructure, western side facing Arabian Sea, Eastern side on the downstream part of Malir River and Gizri creek area	2.32	19.2	5.68
KITE	L	Covers the Korangi Industrial Trading Estate (KITE) area, thickly populated, low income population, conglomerates of industrial units, mostly lather tanning, textile dyeing and processing units	2.25	15.08	6.21
Air Port /Shah Faisal	M	Well expanded human settlement, civil air port, eastern part of Malir River, low to middle income population, poor to moderate sanitation conditions	1.22	11.95	6.07
Gulistan-e-Johar/ Gulshan-e-Iqbal	N	Newly established residential area, no industrial activity, army and air force base, ammunition depot, middle to high income population	2.22	26.2	9.33
Malir	O	Covers the eastern and western banks of Malir River, Landhi Industrial Estate (LITE), few agricultural activities, thickly populated area, low income population group, poor infrastructure	2.32	10.2	5.50
Ibrahim Hydri	P	On the eastern coastal belt of Karachi, fisherman population, fishries, abundant chlor-alkali industry	2.7	12.2	6.11
Landhi/LITE	Q	Low income population, dairy farming, largest metal work industry, few industries of LITE industrial area	2.45	29.6	16.88
Port Qasim	R	Eastern industrial area of Port Qasim, Pakistan Steel Mills, auto manufacturing plants, chemical, fertilizer plants, thin population, second seaport of the country	2.22	14.7	5.64

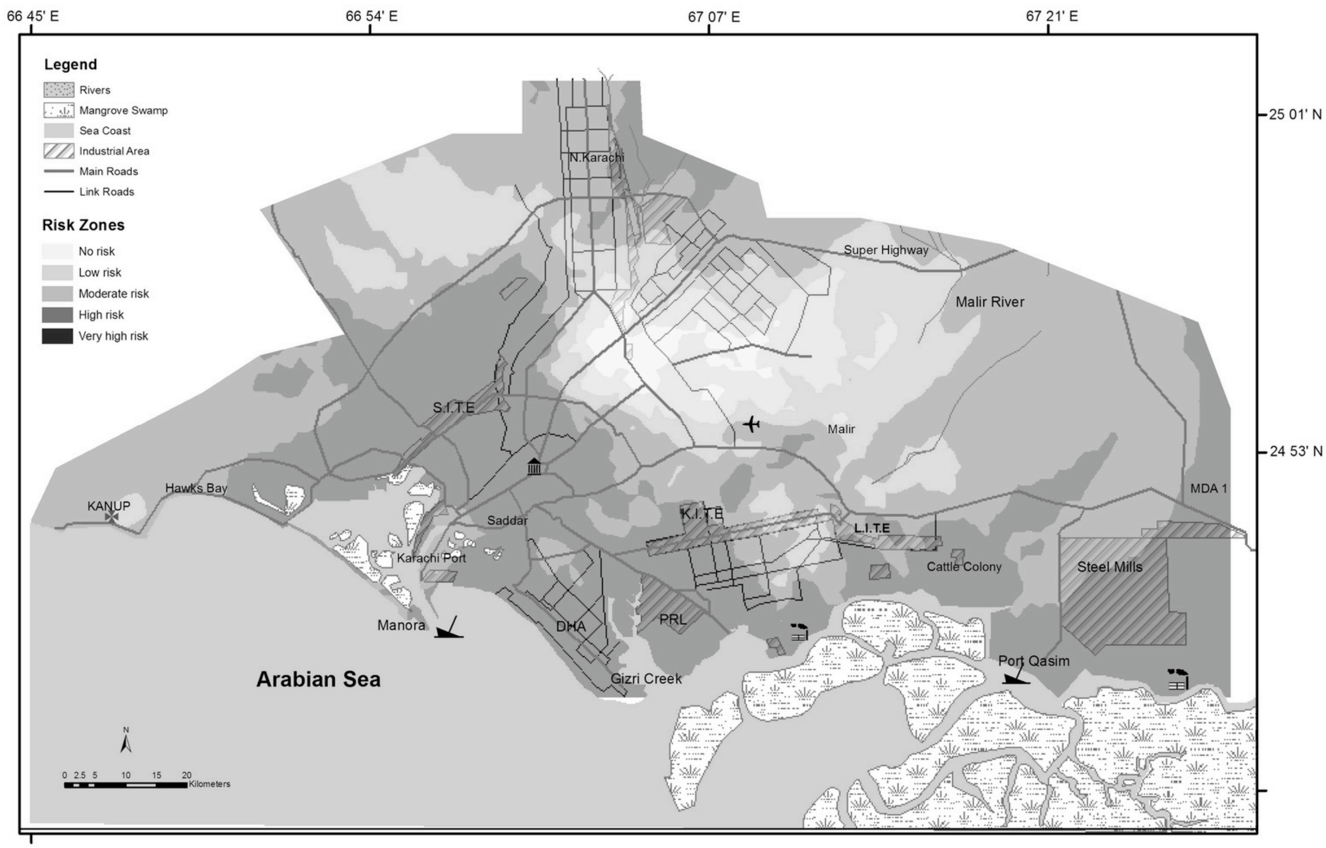

Figure 2: Risk zone classification for lead level in groundwater based on estimated background value.

the groundwater of each location are given in the Table **1**. These results show that the levels of lead concentration are subject to a wide variability and the mean value(s) are significantly affected by large variations in metal concentrations.

In general, the overall assessment of the degrees of lead contamination shows association with two major population groups occupying the Lyari and Malir river valleys. Enrichment of the lead contamination apparently controlled by some of the local factors like clay fractions, organic constituents, relative porosity of the soil medium, and the amount of percolating lead polluted effluents. The relative higher lead concentrations in the Lyari River vicinity are observed along its left bank which is dominant of industrial areas and heavily populated with low income social structure. Sind Industrial Trading Estate (SITE) appeared to be the major contributor of these relative higher lead levels. SITE area encompasses a variety of industries i.e. heavy steel and alloy manufacturing industries, electroplating and auto batteries manufacturing and re-manufacturing of used batteries, chemicals manufacturing and processing industries, pharmaceutical manufacturing industries, textile processing and dying units, paints and pigments manufacturing industries. In addition to untreated industrial effluents, the city waste of densely populated localities also discharged into the Lyari River without any treatment. In contrast to observed lead levels in the Lyari River vicinity, the Malir River vicinity and its localities contain comparatively lower levels of lead concentration in the groundwater samples. This trend of comparative lower lead levels can be attributed to the nature of industries and their effluents operating in KITE area, which mainly comprised of lather tanning, food spice processing and pharmaceutical manufacturing industries. Fairly higher concentration of lead was also observed in the Port Qasim and adjoining areas as compare to the recommended value of 10 ppb [18]. The anomalous nature of lead concentration in various parts of the city groundwater samples is considered to be a source of hazardous environment to the inhabitants from health point of view.

Two different maps (Figures **2** and **3**) of probabilistic risk zones for lead level were generated by *DK* technique based on the estimated background value for this study and the WHO guideline [18] respectively. The estimated background value of 5.39 ppb of lead

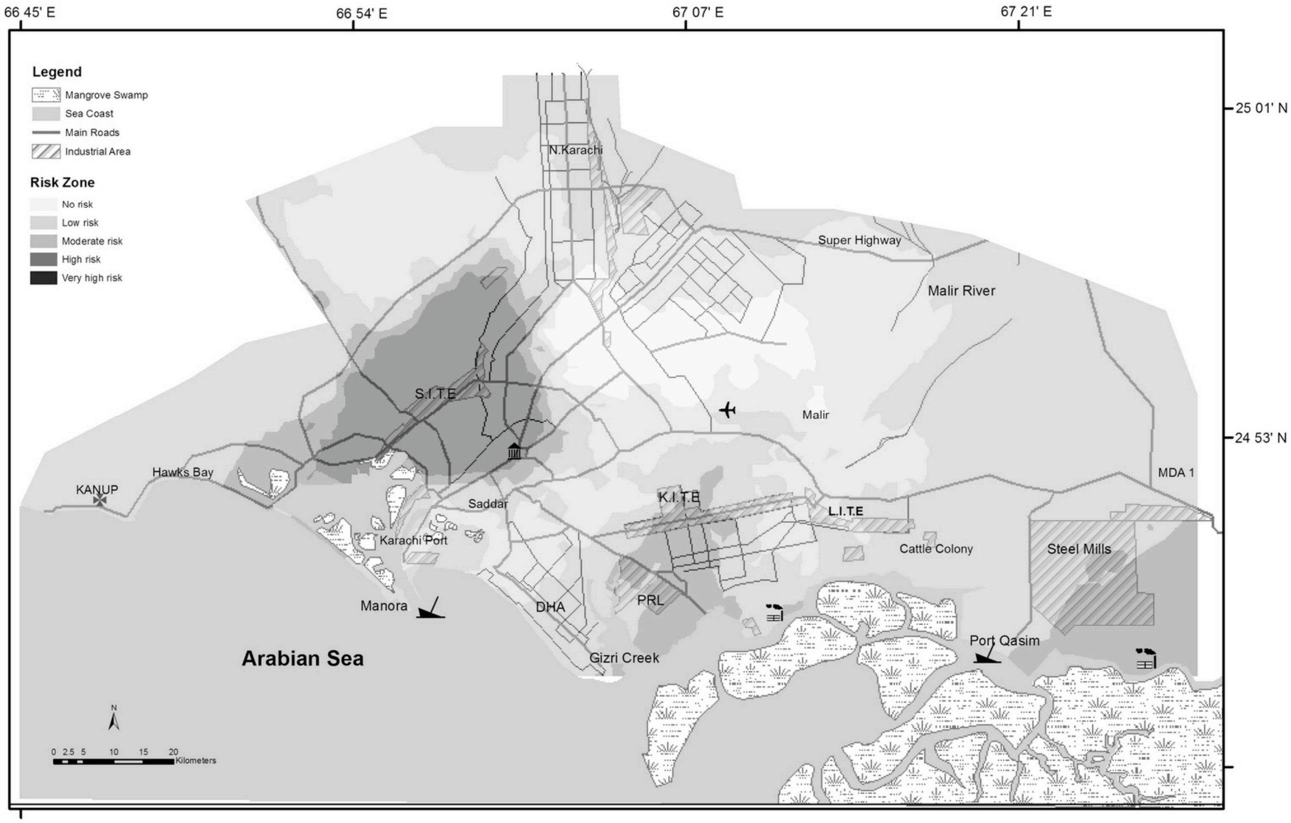

Figure 3: Risk zone classification for lead level in groundwater exceed WHO guideline value (10 ppb).

shows an alarming situation as far as the spatial risk zone distribution is concerned (Figure **3**). It is observed that the distribution of the lead covers the areas of heavily populated localities, industrial regions, crowded traffic areas, cottage industry areas and the livestock farming areas. The organized and unorganized sectors (cottage industry) of the industrial complexes, and the exhausts of transportation activities, which are consuming lead or the lead products, appeared to be the major stakeholders for causing the very high risk zones in the south-central areas of the city in both the maps (Figures **2** and **3**). The only area marked very high risk zone covers the most densely populated residential areas, industrial area of SITE and the business hub area where the vehicles movement is very high. The effluents rich in lead, pouring through the Malir and Lyari rivers onto the beaches of the Arabian Sea, could percolate into the subsoil can be encountered in the shallow aquifers. The observed higher risk zone area along the Karachi coastal area can be attributed to this vicious cycle of contamination.

CONCLUSION

In general, GIS found to be a powerful tool for environmental monitoring, assessment, management and mitigation programs and particularly for the large, multi-nature, and complex urban environmental setups. Interactive relationship of the pollution data can be seen with respect to different demographic and industrial information layers. This interactive mechanism has identified the pollution hot spot of lead and its possible contributing sources.

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REFERENCES

[1] Goyer RA. Toxic effects of metals. In: Amdur MO, Doull J, Klaassen CD, editors. Toxicology. 4th edition Pergamon Press Inc. 1992.

[2] Gossel TA, Bricker JD. Principles of clinical toxicology. Raven Press N.Y. 1994.

[3] Bellinger DC. Lead neurotoxicity and socioeconomic status: Conceptual and analytical issues. Neurotoxicology 2008; 29(5): 828-32. http://dx.doi.org/10.1016/j.neuro.2008.04.005

[4] Marchwinska WE, Dziubanek G, Skrzypek M, Hajok I. Study of the health effects of long-term exposure to cadmium and lead in a region of Poland. Int J Environ Health Res 2101; 20(2): 81-6.

[5] Bierkens J, Buekers J, Van Holderbek M, Torfs R. Health impact assessment and monetary valuation of IQ loss in pre-

school children due to lead exposure through locally produced food. Sci Total Environ 2011; doi:10.1016/j.physletb. 2003.10.071.

[6] Onodera S, Saitob M, Sawanoc M, Hosonod T, Taniguchie M, Shimadaf J, Umezawag Y, Lubish RF, Buapengi S, Delinomh R. Effects of intensive urbanization on the intrusion of shallow groundwater into deep groundwater: Examples from Bangkok and Jakarta. Sci Total Environ 2008; 404 (2-3): 401-0. http://dx.doi.org/10.1016/j.scitotenv.2008.08.003

[7] Hayashi T, Tokunaga T, Aichi M, Shimada J, Taniguchi M. Effects of human activities and urbanization on groundwater environments: an example from the aquifer system of Tokyo and the surrounding area. Sci Total Environ 2009; 407(9):3165-72. http://dx.doi.org/10.1016/j.scitotenv.2008.07.012

[8] Vizintina G, Souvent P, Veselič M, Curk BC. Determination of urban groundwater pollution in alluvial aquifer using linked process models considering urban water cycle. Journal of Hydrology 2009; 377(3-4); 261-73. http://dx.doi.org/10.1016/j.jhydrol.2009.08.025

[9] Kazemi GA. Impacts of urbanization on the groundwater resources in Shahrood, Northeastern Iran: Comparison with other Iranian and Asian cities. Phys Chem Earth 2011; 36(5-6): 150-9. http://dx.doi.org/10.1016/j.pce.2010.04.015

[10] Siddique A, Zaigham NA, Mallick KA, Mumtaz M, Saied S. Geochemical and Geostatistical Investigations of Chromium Pollution in Groundwater. Water Environ Res 2008; 80(2), 149-53. http://dx.doi.org/10.2175/106143007X220824

[11] Khan MA, Rahman A, Lee HK. Domestic water contamination in rapidly growing mega cities of Asia: Case of Karachi, Pakistan. Environ Monit Assess 1997; 44: 339–60. http://dx.doi.org/10.1023/A:1005747732104

[12] ESRI. Working with ArcView Spatial Analyst. ESRI Educational Services, Environmental Systems Research Institute Inc. California, USA. 1998

[13] Gundersen P, Callesen I, and DeVries W. Nitrate leaching in forest ecosystems is related to forest floor C/N ratios. Environ Pollut 1998; 102: 403–7. http://dx.doi.org/10.1016/S0269-7491(98)80060-2

[14] Van der Eerden LJM, DeVisser PHB, VanDijk CJ. Risk of damage to crops in the direct neighbourhood of ammonia sources. Environ Pollut 1998; 102; 49–53. http://dx.doi.org/10.1016/S0269-7491(98)80014-6

[15] Duncon PH, Harison M. Cleaning methods for polyetylene containers prior to the determination of trace metals in fresh water samples. Anal Chem 1981; 53(34): 344-50.

[16] United State Environmental Protection Agency (US EPA). Methods for Chemical Analysis of Water and Wastewater; EPA-600/4-79-020; U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Support Laboratory: Cincinnati, OH, USA. Method 239.2. 1978.

[17] Keith CC.Getting started with GIS. Prentice Hall, USA. 1997.

[18] World health organization (WHO). Guidelines for drinking-water quality. Health criteria and other supporting information. Vol.3. Geneva. 2004.

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