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Assess arsenic distribution in groundwater applying GIS in capital of Punjab, Pakistan

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Abstract

Arsenic contamination of groundwater resources threatens the health of millions of people worldwide, particularly in the densely populated river deltas of Southeast Asia. Arsenic causes health concerns due to its significant toxicity and worldwide presence in portable water. The major sources of arsenic pollution may be natural process such as dissolution of arsenic containing minerals and anthropogenic activities. Lahore is groundwater dependent city, arsenic contamination is a major issue of portable water and has recently been most environmental health management issue especially in the plain region, where population density is very high. GIS was used in this study for visualizing distribution of arsenic groundwater concentration through geostatistics analysis technique, and exposure risk zones for two years (2010 and 2012). Town's data was compared and concentration variation evaluated. ANOVA test was also applied to compare concentration between cities and years. Arsenic concentrations widely range 7.3–67.8 and 5.2–69.3 $\mu g L^{-1}$ in 2010 and 2012, respectively. Over 71 % area is represented arsenic concentration range from 20 to 30 $\mu g L^{-1}$ in both analyzed years. However, in 2012 arsenic concentration over 40 $\mu g L^{-1}$ has covered 7.6 % area of Data Gunjbuksh and 8.1 % of Ravi Town, while over 90 % area of Allama Iqbal, Aziz Bhatti and Samanabad Town contain arsenic concentration between 20–30 $\mu g L^{-1}$. ANOVA test depicts concentration probability less than 0.05, while differences were detected among towns. In light of current results, it needs urgent step to ensure groundwater protection and preservation for future.

1 Introduction

Limited groundwater resources are most important source of drinking water in nature. The availability of safe and reliable sources of water is an essential pre-requisite for the establishment of a stable community (Saikia et al., 2012). The degradation of groundwater quality arising from urbanization, industrialization, and agricultural activity is a serious global problem. Arsenic (As) is one of the hazardous metalloids presents in the drinking water, resulting from both anthropogenic and geogenic sources (Baig et al., 2009). Arsenic contamination in ground water is a problem worldwide (Kondo et al., 1999; Saxena et al., 2004). The contamination of groundwater with arsenic is one of the serious problems encountered in developing countries (Jahanzaib, 2012). In these countries the problem is further aggravated due to the lack of proper management, unavailability of professionals and financial constraint (PCRWR, 2005). As other developing countries of the world, Pakistan is also facing critical water shortage and pollution. The country has essentially exhausted its available water resources; so it is considered as water stressed (Dang et al., 2014) and is likely to have a water scarcity in the near future (Hashmi et al., 2009a).

More than 150 million people are affected worldwide by arsenic contamination in 70 countries, out of which 50 million people in Bangladesh and 30 million people in India are at risk (Ravenscroft et al., 2008). Since ancient times, arsenic was known as a plant and animal poison, and large oral doses (above 600 mg As L^{-1} in food or water) of inorganic arsenic can result to death (ATSDR, 2007). The World Health Organization estimates 1.7 million deaths and 54.2 million Disability Adjusted Life Years (DALYs) lost worldwide per year due to unsafe water, hygiene and sanitation. Arsencosis is the effect of arsenic poisoning, usually over a longer period such as from 5 to 20 years (WHO, 2001). Generally inorganic arsenic species are more toxic than organic forms of arsenic present in living organisms, including humans and other animals (Meharg et al., 2002). Long term exposure also leads to skin cancer, bladder cancers, kidney and lung, and diseases of blood vessels of the legs and feet, and possibly diabetes, high blood pressure and reproductive disorders (Azizullah et al., 2011).

Contamination of groundwater arsenic in Punjab (Chouhan et al., 2010), Pakistan, has been reported (Farooqi et al., 2007a, b), where it was related that groundwater in a shallow aquifer at 20–27 m depth is heavily polluted (maximum As concentration 2.4 mg L^{-1}). In the province of Punjab, over 20 % and in the province of Sindh, around 36 % of the population is exposed to arsenic contamination above WHO limits. Arsenic contamination has emerged as a serious public health concern in Pakistan (Azizullah et al., 2011). In this regard, the Government of Pakistan has undertaken many initiatives with the assistance from UNICEF since 1999. As a result of these initiatives, the presence of arsenic contamination has been recognized and consequently an arsenic mitigation program, at national level has already been launched by the government of Pakistan with the assistance being provided by UNICEF (Fatmi et al., 2009). Alarming levels of ground water arsenic concentration has been observed during the course of water quality surveys conducted by PCRWR during 2001, 2003 and 2004 (Jahanzaib, 2012).

A great majority (≈ 70 %) of the population in Pakistan obtains water from ground aquifers. However; surface water is another main source of water for drinking and other domestic purposes (Aziz, 2005). Therefore this work firstly focused on groundwater sources, and then summarized the arsenic risk zones through computer codes. Furthermore the various water-linked health problems were shown due to arsenic contamination reported in the country (Saikia et al., 2012). However, considering international standards for safe and drinkable water, only 25.61 % (rural 23.5 and 30 % urban) of the population in Pakistan have access to this basic need (Rosemann, 2005). Drinking water supplied by municipalities (especially urban areas) to the public is mostly contaminated with infectious microorganisms or hazardous chemicals (WWF, 2007).

High concentration of As and other physio-chemical parameters in surface and groundwater has been previously reported from several South-Asian countries Bangladesh (Halim et al., 2009), China (Xie et al., 2009), and India (Gupta et al., 2000). Like neighboring countries, Pakistan is also facing serious public health problems due to As contamination in portable water supply. In Pakistan, high As concentrations have been reported in different parts of the country such as Jamshoro (Baig et al., 2009), Manchar lake (Arain et al., 2009), Lahore and Kasur (Farooqi et al., 2007b) and Muzaffargarh District (Nickson et al., 2005). The Pak EPA and WHO recommended permissible limits for arsenic in drinking water 50 and 10 $\mu g L^{-1}$, respectively. It was estimated that at the current EPA standard/WHO maximum permissible limit of

50 µg L^{-1}, the lifetime risk of dying from liver cancer, lung, kidney, or bladder from drinking 1 L water day^{-1} could be as high as 13 per 1000 persons (Sharma et al., 2009). Unfortunately, due to poor financial condition and lack of modern technology, still no project is going to cope with arsenic problem in groundwater in Pakistan. However, current research identifies potential arsenic infiltration points, which must be close or mange to control arsenic transportation towards groundwater in Lahore city.

This study aimed to determine arsenic distribution in groundwater system of most populated area of Lahore city. The main emphasis was on evaluation of the pollutant in drinking water and its health risk. Geostatistics analyst technique was applied to develop As distribution zones for two different years, which was helped to understand high and low risk area. Current research portrayed comprehensive diagram through GIS software of arsenic distribution, and will be great helpful for further more detailed risk analysis in study area. Arsenic concentration was identified through multivariate statistical techniques for potential point and non-point contamination sources. Furthermore arsenic sources, risk areas, concentration trend, identified various health problems were summarized due to arsenic-effected water and also suitable suggestions were proposed to protect regional aquifer. Therefore, the present manuscript has been focus on three objectives, (1) Identification of arsenic high risk areas, (2) compare arsenic trend in towns with time and (3) diagnosed local arsenic infiltration sources.

2 Study area

2.1 Location description

Lahore is a rapidly growing city lying between latitudes 31°20′ and 31°50′ N and longitudes 74°05′ and 74°37′ E in the province of Punjab, Pakistan. The study area is located on the east bank of the famous Ravi River. Its boundaries extend from the Hudiara Drain in the south, across the Ravi River to Degh Nala in the west, then northward to Muridke on the General Trunk Road and finally eastward to the border with India 27 km (Fig. 1). Lahore is located on a low alluvial plain, an area undergoing rapid development with little concern for the geo-environmental consequences.

In 1901 the population of Distract Lahore was 0.203 million, but it increased to more than 5 million by 1990. From 1981 to 1998, the population increased 3.32 % annually and now exceeds 10 million, with a growth rate of 3.3 % $year^{-1}$ (SWMD, 2007). The city of Lahore is divided into nine administer towns, which provide services and facilities to local communities. Present study focused on high populated dense areas of eight towns (Aziz Bhatti, Allama Iqbal, Data Ganj Baksh, Gulberg, Nishtar, Ravi, Samanabad and Shalimar town) on the base of available groundwater chemical data. Allama Iqbal, Wagah and Nishtar Towns are still undergoing development, thus large areas of them are still devoted to industrial and agricultural activities. The current study area includes about 332 km^2 and had a population in 2011 of about 7.6 million. Groundwater chemical data from the investigated areas were used to identify zones of potential contamination. A rapidly growing population, increasing groundwater depletion, pollution and scarcity are considered the biggest challenges for this groundwater-dependent city.

2.2 Climate, geology and hydrogeology of study area

Both the temperature and rainfall vary greatly from season to season with a mean temperature that ranges from 34 °C in June to 12 °C in January and an average rainfall of 575 mm $year^{-1}$, which can vary from 300 to 1200 mm. The evapotranspiration is about 1750 mm $year^{-1}$, which is the principal reason why extensive irrigation is needed for agricultural purposes (NESPAK, 1993 in Gabriel and Khan, 2010).

The study area is generally flat (altitude ranges from 208 to 213 m above sea level) and slopes to the south and southwest with an average gradient of 1 : 3000. In many part of the city gradients are as low as 0.3–0.4 m km^{-1}. Modern soils in the area consist of silt, clay, loamy clay and sand, however, loamy clay gradually increases with distance from the Ravi River (Khan et al., 2008). The aquifer underlying the Lahore area is composed of unconsolidated alluvial sediments; composed of varying proportions of

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silt, sand and clay. Previous studies have shown that the alluvial sediments are typically more than 400 m thick, and that they were deposited by the present-day and ancestral tributaries of the Indus River during Pleistocene-Recent time (Greenman et al., 1970). The surface soils consist mainly of permeable, organic-poor Aeolian sediment on the terraces and layers of sand and silt on the alluvial flood plain. The alluvial sediments occasionally reach several thousand feet in thickness (Greenman et al., 1970).

In Lahore the groundwater table currently varies between 14 and 43 m (WASA, Lahore), and is dropping an average of 0.84 m $year^{-1}$. Thus, the increasing withdrawal of potable water means that the main city area is facing a rapid groundwater decline. Study was conducted to determine water table and was observed that from 1960 to 1987 it dropped more than 15 m in some parts of Lahore (Gabriel and Khan, 2010). Currently, the groundwater moves from North to South at a velocity 1–1.5 cm day^{-1} (Schnoor, 1996). The Ravi River has always been the main recharge source for the aquifer but since 1960, increased consumption by India has seriously affected the regional recharge efficiency. Estimates suggest that more than 65 % of the rainfall in the basin could potentially be utilized for agriculture, groundwater recharge and drainage outflow, thus an assessment of potential groundwater contamination is needed to provide a guideline for future water resource management in Lahore.

2.3 Groundwater contamination sources

Ravi river moreover presently receives 47 % of all municipal and industrial pollution load discharged into all the rivers of Pakistan (Sami, 2001). The Hudiara drain receives effluents from India with high concentrations of pollutants and then collects additional contaminated waste water from Pakistan before flowing into the Ravi River. The waste water from various sources contains organic, inorganic, industrial, municipal and animal waste, as well as fertilizers and insecticides, which seep through the soil and significantly degrade the groundwater quality. The groundwater quality near the Ravi River is much poorer than that at a distance, and poses a serious public health hazard (Dhakyanaika et al., 2010). There are three active waste dumps around Lahore, all of which are unplanned and which contribute significant amounts of groundwater pollution. At least three-fourths of the total waste generated in Lahore every day (3800 tons) is dumped at these sites without proper treatment. Landfill sites along the Ravi River are open dumps that continually pollute the soil, groundwater and river water. The contaminants seep into the groundwater through weak soil layers.

3 Methodology

3.1 Geostatistics analysis

Methodology used in current study is based on various techniques applied as far as concern data processing, statistic calculation and comparison to understand arsenic pollution problem in different parts of Lahore city. A topographic map (1 : 50 000) was used to develop the base map of the study area. Using the Integrated Land and Water Information System (ILWIS), groundwater quality map of arsenic concentration was prepared and classified for spatial analysis, which involved two phases: phase I involved preparation of a thematic map, whereas phase II was focused on development of groundwater quality zones. The groundwater samples were collected from production wells (depth between 600 and 800 feet), and 268 samples were selected for developing risk maps for both 2010 and 2012 years.

Geostatistics analyst technique applied and ArcGIS10.1 was used to develop arsenic groundwater distribution maps. Various interpolation methods are also popular but the geostatistical technique has a superior number of functions for data analysis, e.g. exploratory spatial data analysis tools can be used to handle statistical properties and can be used to create various types of maps (probability, prediction, quantile, simple and ordinary) using kriging and co-kriging. Geostatistics analysis required a range of neighbor points to take average value for final analysis map, maximum and minimum neighbor values are 8 and 4 applied respectively.

Similar to IDW, Kriging is tool which weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \qquad (1)$$

Where:

$Z(s_i)$ = the measured value at the ith location

λ_i = an unknown weight for the measured value at the ith location

s_0 = the prediction location

N = the number of measured values

In addition, auxiliary tools are available for data transformation, declustering and detrending. Ordinary and Indicator kriging provide two different types of information; Ordinary Kriging is useful for developing contamination potential prediction maps, whereas Indicator kriging is best for identification of probability. Database tables were developed for arsenic with XY coordinates and the concentration of pollutants. These tables were used to create suitable variogram models to portray the spatial structure of Arsenic using GIS software (logarithms were applied to the data where the distribution was not normal). Ordinary Kriging was then used to interpolate the variogram models and their parameters. Arsenic concentration range was evaluated town wise and assessed base on the water quality standards stipulated by the WHO and PSQCA standards.

3.2 Statistical analysis

The means and others descriptive statistic parameters were calculated using the Excel spreadsheet. For the arsenic concentration distribution, the concentrations were ranged within classes according to WHO and PSQCA limits, and column graph was

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used to display the distributions according to years and towns. Analyses of variance (ANOVA) were performed using SPSS (Statistical Package for the Social Sciences) software on the arsenic concentration variable with factors such as year and town. These analyzes were completed by multiple means comparison tests of Newman–Keuls literature to identify the degree of significance of the mean differences observed between years and towns factors.

4 Results and discussion

4.1 Geostatic data processing

The second biggest city of Pakistan is facing serious groundwater problem. Arsenic contaminated groundwater was identified in many areas in Pakistan (Azizullah et al., 2011) especially in most dense populated urban areas. Figure 4a and b depict the spatial distribution of arsenic concentration in the Lahore city area for the 2010 and 2012 years. Arsenic concentration in whole area varies from 7.3 to 67.6 $\mu g L^{-1}$ for 2010 and for 2012 years its range is between 5.4 and 69.3 $\mu g L^{-1}$. Pakistan Council of Research in Water Resources (PCRWR) conducted a study to assess arsenic in Lahore city in 2009 and explored that mostly groundwater samples had concentration over 50 $\mu g L^{-1}$. Arsenic contamination presence is variegated with time in all towns and concentration increasing trend is regarded as risk for local community because it directly affects their health through municipal water supply. High arsenic concentration can be noted near the location where; landfill sites, polluted river, industries dominant regions and vicinity area of farming activities are in progress. Various studies supported about mention statement for example, a study was launched to detect arsenic local sources, where human activities were found culprit of improper disposal of municipal and industrial effluents and agrochemicals are the main factors contributing pollutants into surface and groundwater sources (Azizullah et al., 2011).

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Ravi Town is regarded as hub for unhygienic and anti-environmentalism activities, because the unplanned dumping sites, river loaded with toxic effluent, dense but undeveloped community areas, and factories are badly damage local eco-system and creating environmental problems. A Pakistani international newspaper claimed in an article which published in 2004 that untreated domestic and industrial waste are directly discharge into rivers and canals which is deteriorated groundwater quality in Lahore city (Dawn International Newspaper, 13 April 2004). Arsenic highest concentration was detected at bank of canals and rivers near industrial and dense populated areas (Masuda et al., 2010).

Regional aquifer shows that the non-engineering landfill sites, drains, industrial sectors and agriculture activities in Shalmar Town and Nishtar Town are also prominent contamination resources. However, rest of towns are exhibited the arsenic concentration range below $40\,\mu g\,L^{-1}$, even it is much higher then WHO ($10\,mg\,L^{-1}$) guideline but satisfied PAQCS ($50\,mg\,L^{-1}$) standard.

Study area was classified into five categories to discover arsenic concentration potential level, which the arsenic range was noted between 5.2 and $69.3\,\mu g\,L^{-1}$. A study reveals that at Lahore city 15 locations exceeds the PSQCA limit while over 47 sites had arsenic concentration ranging between 40 and $50\,\mu g\,L^{-1}$ (Sonia, 2012).

Over 71 % area is affected with contamination where arsenic concentration range is from 20 to $30\,\mu g\,L^{-1}$ in both analysed years. Area with high concentration range (40–$50\,\mu g\,L^{-1}$) has been increased with 0.5 % each year, while arsenic concentration (10–$20\,\mu g\,L^{-1}$) area decreased 1.3–0.7 % from 2010 to 2012. Therefore, it can be predicted that arsenic concentration trend has been increased from low to high concentration with time and high risk area disperse widely while comparing both diagrams (Fig. 4a and b). A survey on WASA Tube-wells did in 130 locations in Lahore city and all water samples contained arsenic quantity over WHO limit, while 26 % samples showed concentration values higher than PSQCA standard (Hudson-Edwards et al., 2010). Arsenic infiltration along other pollutants would promote with time and will cover more area (Masuda et al., 2010). It can be noted during town wise comparison that in 2010 only Data Gunjbuksh

Town hold 7.24 % of its total area impacted concentration range 40–50 $\mu g L^{-1}$, while remaining seven towns contains Arsenic concentration value < 40 $\mu g L^{-1}$.

However, in 2012 contamination density severely increased 7.6 % of the area in Data Gunjbuksh Town and 8.1 % area in Ravi Town, which showed arsenic concentration (40–50 $\mu g L^{-1}$). Over 90 % areas in Three Towns (Allama Iqbal Town, Aziz Bhatti Town and Samanabad Town) of both study years were found having arsenic concentration limit within 20–30 $\mu g L^{-1}$. Tremendously variation in arsenic concentration in all selected towns has directly link with local human activities and the pollutants sources in particular area. Previous studies reveal study area is affected with arsenic and other pollutants (Farooqi et al., 2007a, b); even local grown food items have arsenic concentration. Water quality is Pakistan, especially Punjab providence is not safe for domestic and drink (Azizullah et al., 2011; Hudson-Edwards et al., 2010).

4.2 Data process

Before developing final map by geostatistics analyst, some data process steps, data trend and selection of few options are very important. The data distribution frequency histogram graph developed with ten equal classifications and bar display a good representation of data but data points of 2010 are more close to reference line compare to 2012 (Fig. 2). A log transformation was applied to the skewed data, and in current case, the data transformation makes the distribution close to normal. Statistics summary of the datasets are also presented with histogram diagram. Mean, median and skewness calculated values 3.2409, 3.2465 and −0.2558 respectively, while Kurtosis value (3.0378) is also closed to normal range. However, 2010 data presentation and statistic calculation are much better than 2012. Generally, QQ plots are popular to assess equality dataset distribution in a study area. The diagram (Fig. 4c and d) represent data is normally distributed because almost all points are close or over on the 45° reference line, in Fig. 4c data arrangement is demonstrated well. Log and arcsine transformations were applied to the data within the Normal QQ Plot to assess

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their normal distribution. Semivariogram/Covariance cloud depicted good strength of statistical correlation of distance; also 3-D-trend analysis was applied and found both polynomial curves appeared fit and having good relation between data.

4.3 Town wise data comparison

In this part, groundwater chemical analysis results are discussed according to arsenic concentration samples percentage in whole study area. Two drinking water standards (WHO and PSQCA) are considered to evaluate arsenic risk potential in local groundwater system. Arsenic maximum permissible limit for WHO is 10 and 50 $\mu g L^{-1}$ is declared for PSQCA criteria. In 2010, about 1.12 % samples concentrations was below 10 $\mu g L^{-1}$, while 4.10 % samples showed value over PSQCA prescribed range. UET analysed 165 WASA tube-wells water samples and detected 1.2 % samples had arsenic value higher than PSQCA prescribed standard, while arsenic content in rest of the samples was between 10 and 50 $\mu g L^{-1}$. In 2012, 20.61, 92.53 and 4.85 % of water samples were found within 10, 10–50 and over 50 $\mu g L^{-1}$, respectively. It was observed that number of samples (with arsenic concentration < 10 and > 50 $\mu g L^{-1}$) slightly increased in 2012 as compare to 2010. Over all condition is extremely terrible that in 2010 over 98 % and in 2012 more than 97 % groundwater samples concentration value higher than WHO criteria. In 2009, Pakistan Council of Research in Water Resources (PCRWR) identified during a study about 40 % collected water samples had arsenic concentration over PSQCA limit (Gabriel et al., 2010). However, 92 % samples showed the pollutant concentration range between 10 and 50 $\mu g L^{-1}$, which identified groundwater serious issues in future with increasing its concentration level.

The diagram (Fig. 4) depicts town-wise arsenic contamination results and mostly water samples have arsenic concentration degree from 10 to 50 $\mu g L^{-1}$ in both selected years. There are four towns (Samanabad, Gulberg, Data Gunj Baksh and Shalamer) having few samples which satisfied WHO standard, while rest of towns concentration limit was over 10 $\mu g L^{-1}$. Gulberg, Data Gunj Baksh, Ravi, and Allama Iqbal towns are regarded most contaminated where few samples showed the concentration range

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more than 50 µg L^{-1}. Hudson-Edwards conducted an important study about arsenic distribution in various locations of Lahore city in 2010, Data Gunj Baksh, Samanabad and Shalamer Towns were explored with high concentration, while Gulberg and Ravi towns showed arsenic range from 10 to 100 µg L^{-1} (Hudson-Edwards et al., 2010). Locations near landfill sites, river bank and industrial zones were predicted most contaminated. Over 1000 µg L^{-1} arsenic contents were detected across bund road in Ravi Town and two union councils of Samanabad Town (Hudson-Edwards et al., 2010). Previous studies are verifying current results.

The collected samples from Aziz Bhatti Town and Nishter Town have the concentration during 2010 and 2012 below 50 µg L^{-1} (PSQCA standard). In all towns, all samples had Arsenic values around 5.2–69.3 µg L^{-1} with widely varying but average had not much difference. These results verify that the risk of arsenic contamination in different towns link with River Ravi and landfill sites, which are indicated serious groundwater problems, should be taken seriously action, and that there is an urgent need to test shallow groundwater to evaluate the high-risk area. Because all the samples were collected from second aquifer and tube-wells installed about depth 600–800 feet. Mostly agriculture, industrial and rural areas (having no access to government water supply system) are using shallow water which can be expected more contaminated. Due to dense populated area, groundwater abstraction is higher than recharge (Gabriel et al., 2010) this is why cone has been develop in local groundwater system, which is facilitating pollutants to move towards selected area. It is strongly needed to eliminate pollutants sources from study area as well as vicinity area, so that contamination should not transport towards high pumping area.

4.4 Arsenic concentration variation among towns and years

The average values of arsenic concentrations calculated for the towns were between 21.756 and 31.253 mg L^{-1} in 2010 and 21.817 and 31.144 µg L^{-1} in 2012. The lowest and highest values of the concentration were observed for Samanabad Town and

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Gulberg Town, respectively. Table 1 displays the results of the ANOVA test and means comparison between towns and years. Analyze of the results show that there is no difference of concentration between years for all of the cities ($Pr > 0.05$), most probably, due to short period of time. Oppositely, different result was observed when comparing values of the concentration between towns for each year. Differences were observed for each year as displays the values of the probability in Table 1, which shows value less than 0.05. No difference of Arsenic concentration was observed between groups of different towns such as Data Gunjbaksh Town, Gulburg Town, Nishter Town, Ravi Town; Azia Bahati Town, Iqbal Town, Shallimar Town; and Samanabad Town which is single in its groups while some differences were observed between groups.

The rapid growth of the urban population in Lahore has resulted in unplanned settlements, solid waste management, groundwater stress and environmental issues. Water resources in urban centers of Pakistan are facing great stress and quality problem (Halim et al., 2009; Hudson-Edwards et al., 2010). Agricultural activities are major causes for arsenic high concentration in groundwater, even industrial and municipal untreated waste water directly drain into drains, river and open places. The principal source of Arsenic for groundwater in Lahore is agriculture activities, industrial effluents, urban sewage leakage, landfill sites, open drains and polluted river Ravi. Some groundwater samples were found to have arsenic values well above the desirable limits. Due to high pumping groundwater flow from vicinity areas towards urban areas and already cone has been created into groundwater system (Gabriel et al., 2010).

This shows that the prediction map is a useful tool for the identification of areas at risk of arsenic contamination, but that understanding the local geology as a function of depth is of vital importance for specific areas. In fact, the severity of arsenic contamination has caused a serious panic for the people in Lahore city. It is felt that groundwater arsenic contamination has been reported in arsenic detected countries. This is the worst case of mass poisoning the world has ever experienced. Alarm bells are now ringing in urban area of Pakistan since arsenic in groundwater has emerged as a serious problem across the country. Pakistan Council of Research in Water

Resources (PCRWR) conducted a comprehensive study in 23 major cities of Pakistan to assess water quality from 2002 to 2006. It was discovered that an average 84–89 % of water samples unfit for human consumption. The problem is made more complex by the fact that the contamination is occurring below the ground where it cannot be easily identified.

4.5 Arsenic geological and anthropogenic sources in study area

Arsenic contamination in water resources has emerged as a serious public health concern in Pakistan, especially Lahore city. From above discussion and literature review has explored that local geological composition and anthropogenic activities are regarded as major sources of arsenic high concentration. Arsenic is regarded as mobile element, which circulates in different forms into air, water and soil (Peterson et al., 1981; Savory et al., 1989). Arsenic is known as poisonous substance, which is released into water bodies from certain human activities and Earth's crust (Ul-Haque et al., 2007). Generally, arsenic originates from natural and anthropogenic sources, such as; industrial waste, mining activities, farming, weathering effects on rocks, and atmospheric deposition (Patel et al., 2005). Occurrence of arsenic into local water system also depends on regional geology, hydrogeology, geochemical characteristics of the aquifer, and climate changes (Ul-Haque et al., 2007). Lee discovered over 200 mineral species of arsenic (60 % are arsenates, 20 % sulphides and sulphosalts and rest of regarded as arsenides, oxides and silicates) in the Earth sediments (Lee et al., 1996).

Regional aquifer of Lahore is small part of vast Indus basin system. Sediments ingredients of Indus River and linked tributaries (Nickson et al., 2005), farming activities fertilizer (Campos, 2002) and various local industrial waste (Rehman et al., 2008) have been indicated as primary sources of As. A study was conducted on a village near Lahore (located on Indus River tributaries) has serious contamination concentration of arsenic in shallow aquifers and surface soil (Farooqi et al., 2007b, 2009). EPA, Pakistan reveals during a study that in the Lahore district arsenic concentration in ambient air is

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230–2230 $ng\,m^{-3}$ (JICA and Pakistan EPA 2000). However, groundwater in Pakistan is being contaminated by raw sewage irrigation and land disposal of industrial effluents and through the use of deep soakage pits and heavy application of fertilizers and pesticides. The intrusion of saline water into the fresh water zone is a result (Jahanzaib, 2012). Arsenic poison in groundwater near Lahore causes bone deformity disease in habitants, especially in children (Farooqi et al., 2003). A senior WASA officer explored that arsenic among other heavy metal is being seep into the ground due to sewage leakage. Current paper analysis also has been proved that Lahore city groundwater resources have serious arsenic concentration, which is risk for local community.

As sensitivity of water pollution, the Government of Pakistan has initiated comprehensive survey with the assistance of UNICEF since 1999. Arsenic contamination has been detected in many parts of county especially urban areas and consequently arsenic mitigation program has been launched under UNICEF supervision (Fatmi et al., 2009). However, the above discuss depicts that there are many cause and sources of arsenic infiltrate into groundwater system, the main sources in Lahore area are geological structure, industrial effluents, sewage leakage and other anthropogenic sources.

5 Conclusions and recommendations

This study has presented the most latest available data on water quality in Lahore. The GIS approach was adapted to analyze and present map arsenic contaminant risk map of Lahore city. Attempt was made to provide an overview of the extent and severity of the problem, it's probable causes and effects. Groundwater sources in the city area are highly polluted and not safe for human consumption as most of the pollutants exceed the quality standards for drinking water. Bacteriological and chemical pollution of public drinking water have been the cause of waterborne diseases in many parts of the country. The followings are the most important findings of the research.

Arsenic concentrations widely range 7.3–67.8 and 5.2–69.3 $\mu g L^{-1}$ in 2010 and 2012, respectively. It explores concentration increasing trend which is risky for local community.

Data GunjBaksh and Ravi Town are most polluted among towns where highest risk (arsenic concentration 40–50 $\mu g L^{-1}$) area 7.6 and 8.1 %, respectively. While in Allama Iqbal, Aziz Bhatti and Samanabad Town all analysed water samples have concentration value below 30 $\mu g L^{-1}$. Over 97 % water samples arsenic concentration limit higher than WHO prescribed guideline in both years, which indicates groundwater serious issues in future with increasing its concentration level.

During ANOVA test the results show that there is no difference of concentration between years for all of the cities ($Pr > 0.05$). Differences were observed for each year as displays the values of the probability, which shows value less than 0.05.

The current patterns of groundwater pumping and waste disposal are leading to the depletion of groundwater aquifers and the contamination of shallow aquifers, thereby threatening the ability of future residents to access water.

Four anthropogenic sources are identified: fertilizers, polluted river, unorganised landfill sites and industrial waste. High risk areas are identified near these locations. Mitigation of pollutants is due to developed cone in groundwater system and heavy capacity tube-wells.

The following recommendations can be suggested in response of the current research outcomes, which may help to control or diminish the problems of deteriorating water quality in second biggest city of Pakistan.

There should be introduced a regular monitoring system for regional groundwater. Local authorities should be provided facilities for monitoring and purification of drinking water.

Solid waste, Industrial and municipal effluents disposal should be strictly observed and all industries and municipal corporations should be forced to adapt wastewater treatment measures. Infiltration of landfill leachate from local non-engineering sites must stop immediately and establish new environmental friendly landfill sites.

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Farmer community can play very important role in protection and preservation of groundwater resources by proper/minimize use of pesticide and fertilizers. All related field's experts should conduct comprehensive investigation on the sources and causes of arsenic contamination in regional aquifer and suggest solid solutions to get rid this problem.

Groundwater depletion and developed cone width should also be monitor, which is also strong reason for arsenic infiltration. Most policy solutions to water scarcity that have been under discussion and implementation merely increase the number of storage reservoirs and aquifer recharge capacity.

Unfortunately, general public are still unaware of arsenic contamination and its hazardous effects. Public awareness campaigns should be launched to educate the population about the importance of safe drinking water and arsenic polluted water health effects.

Finally, on the basis of results it was concluded that due to As contamination in the study area, springs and streams water should not be used without treatment for drinking purposes and the government of Pakistan are suggested to provide the alternatives of drinking water through water supply schemes.

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Table 1. Two factor means comparison of arsenic concentration.

Town	2010	2012	*Pr> F*
Aziz Bahati Town	24.800^{aAB}	24.607^{aAB}	0.948
Data Gunj Baksh Town	29.341^{aA}	29.026^{aAB}	0.8807
Gulberg Town	31.253^{aA}	31.144^{aA}	0.9647
Allama Iqbal Town	27.965^{aAB}	27.324^{aAB}	0.8442
Nishter Town	28.825^{aA}	29.063^{aAB}	0.9479
Ravi Town	29.595^{aA}	30.173^{aA}	0.8763
Samanabad Town	21.756^{aB}	21.817^{aB}	0.9785
Shalamer Town	25.782^{aAB}	25.586^{aAB}	0.9423
Pr> F	0.0082[2]	0.0337[1]	

For a given year or city, the values associated with the same group of letters are not statistically different from each other at 5 %.
The lower case letters refer to comparisons of concentration between years and those in capital, the comparison between cities.
[1] Significant test at 5 %.
[2] Highly significant test at 1 %.

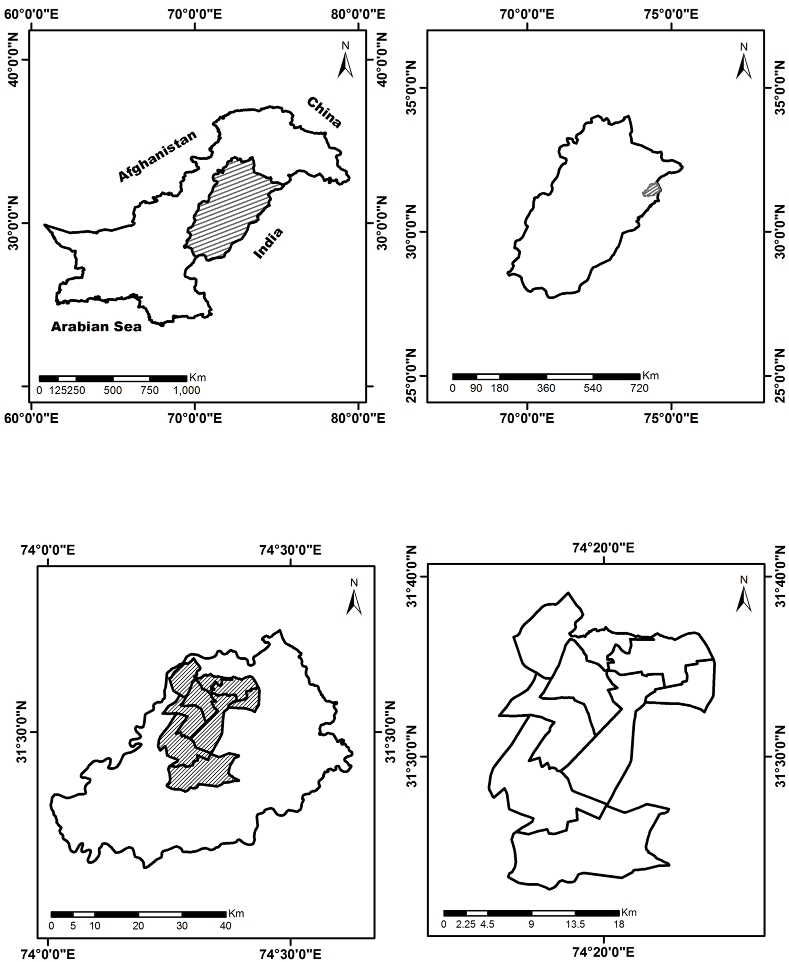

Figure 1. Location map of selected area at distract Lahore.

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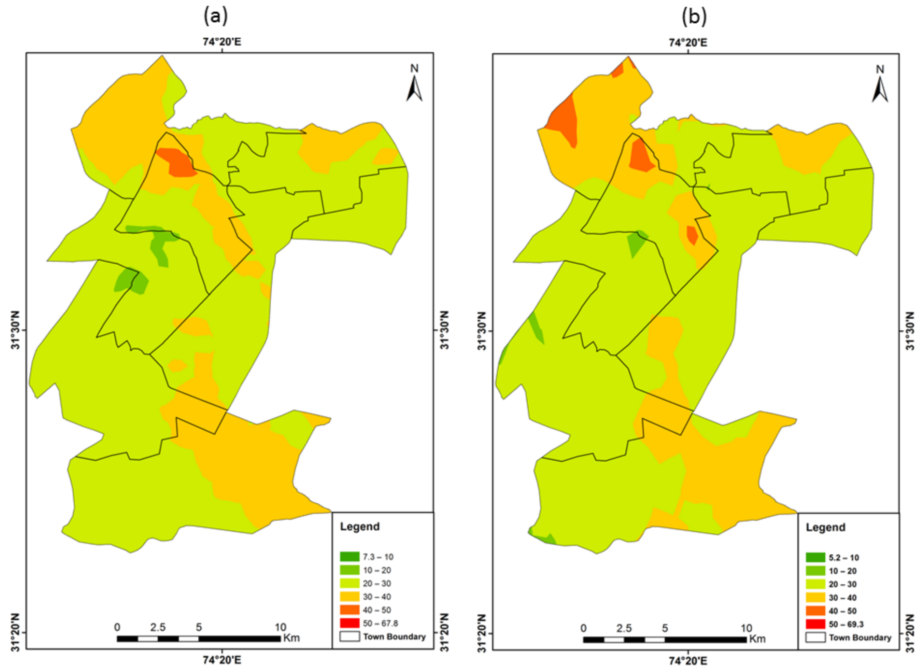

Figure 2. Arsenic concentration distribution map develop through Geostatistics analysis technique for 2010 **(a)** and 2012 **(b)**.

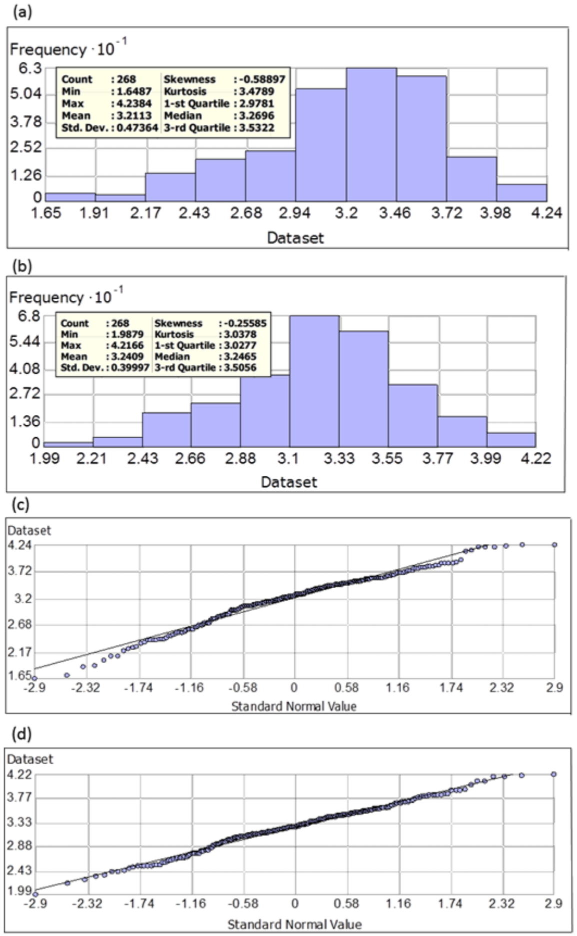

Figure 3. Display data process/trend in histogram (**a** 2012, **b** 2010) and Normal QQ plot (**c** 2012, **d** 2010).

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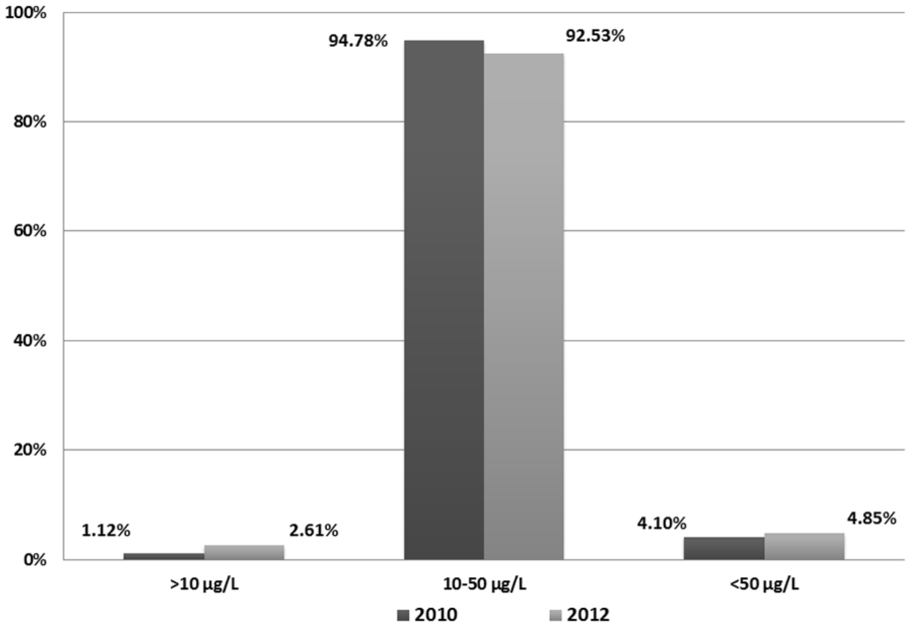

Figure 4. Percentage number of samples with arsenic concentration range (as WHO and PSQCA standard).

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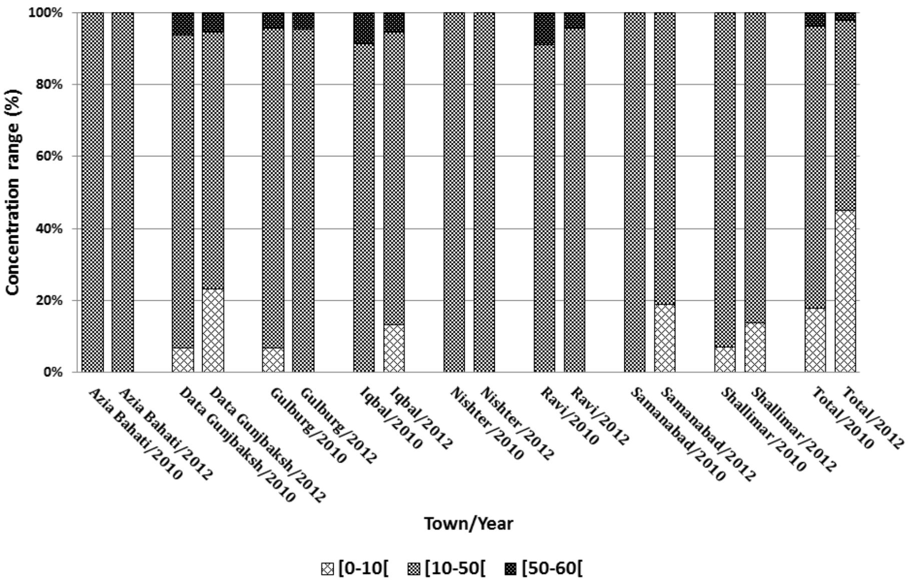

Figure 5. Change in concentration range with years in different towns.

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