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Research Article

Arsenic contamination in the deep tube wells of Kathmandu Valley, Nepal

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Abstract

A study was conducted at 13 different areas of Kathmandu Valley to know the status of arsenic in deep tube wells in post monsoon and winter in 2009 and 2010. The depth of the deep tube wells ranged from 75 m to 304 m. The study was also carried out to know the correlations between depths of the deep tube wells and arsenic concentration. The collected samples were analyzed as per standard method using spectrophotometer. The correlations of arsenic concentration in different season (post monsoon and winter) were also studied. 92.31% of deep tube wells in post monsoon and winter exceeded permissible values of World Health Organization guideline value 0.01 mg/L for drinking water but 38.46% deep tube wells in post monsoon and 46.15% of deep tube wells in winter exceeded permissible values of Nepal Drinking Water Standard of 0.05 mg/L. There was strong positive correlation in arsenic concentration between post monsoon and winter(r=0.94, p<0.001). There was weak but positive correlation between arsenic concentration and depth of deep tube wells in winter (r=0.23, p=0.451). There was very weak correlations between arsenic concentration and depth of deep tube wells in post monsoon (r=0.055, p=0.859). The trend distribution maps were generated for arsenic in post monsoon and winter.

***Key words*:** Correlation, Depth, GIS, Post monsoon, Winter

Introduction

Arsenic contamination of drinking water is one of the major problems in the world. Arsenic poses health risks and health problems. Arsenic contamination of groundwater has been reported from many countries including Bangladesh, India, Vietnam, Argentina, China and USA (Hossain, 2006). Arsenic contaminations of ground water also have been reported in Nepal. Arsenic concentration in the groundwater of Kathmandu Valley, Nepal is one of the major concerns while assessing groundwater quality. The permissible limit for arsenic in drinking water as recommended by World Health organization (WHO) is 0.01 mg/L (WHO, 2008). Nepal has also set drinking water quality standard of arsenic 0.05 mg/L (GoN/MPP, 2006).

More than 50 % of the world's population depends on groundwater for drinking (Fry, 2005). For many rural and small communities, groundwater is the only source of drinking water (Hani, 1990). Since groundwater moves through rocks and subsurface soil, it has a lot of opportunity to dissolve substances as it moves. Furthermore, they are widely distributed as anthropogenic pollutants (Rangsivek & Jekel, 2005).

The present permanent population of the Valley water supply service area is estimated at over 2.1 million with a water demand of 195 MLD. The total water production in wet and dry seasons is about 140 MLD and 100 MLD respectively. The ground water is depleting due to over extraction and surface water catchments are becoming degraded (ADB/KUKL, 2010).

Over the last few decades, groundwater has become one of the major water resources of Kathmandu Valley. In Kathmandu Valley, groundwater was first exploited for water supply in1970. Development of groundwater resources began in earliest in 1984. In 1987, the groundwater extraction rate from Nepal Water Supply Corporation (NWSC); wells had nearly quadrupled the 1984 extraction. It is important to note that about 45% of the total municipal water supply is fulfilled by groundwater resources in Kathmandu Valley. Additional industrial use of the municipal supply is not permitted for new major industries; therefore, groundwater is only the source of the water (AI, 2002).

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Kathmandu is a close basin. The clayey aquifer and the deep aquifers are rich in organic matter and are in reduced condition evident from low oxidation reduction potential (mostly negative). These aquifer-pockets with organic matter activities have potential for the release of arsenic. The redox environment of the deep aquifers of the Kathmandu Basin could have changing, probably due to continuous pumping of water and gases. This could lead the condition favorable for arsenic release (Gurung, 2007).

Arsenic concentrations have been reported in groundwater of Kathmandu Valley. Vulnerability of arsenic in deep tube wells in Kathmandu Valley is a very critical issue due to its negative impact on health as a high percentage of water demand in the valley is met through ground water resources. A study carried out by Maharjan et al. (2009) revealed that water samples from 149 shallow tube wells and 87 dug wells were tested for arsenic concentration in pre-monsoon and 122 deep tube wells were tested in pre-monsoon and monsoon. A study carried out in 41 shallow tube wells has confirmed existence of arsenic in shallow tube wells of Kathmandu Valley though in low level (Shrestha et al., 2010).

Groundwater survey of Kathmandu Valley reported the presence of arsenic and the concentrations were below WHO (1993) guidelines values (Jha et al., 1997). A study carried out by Amatya (2002) found that the arsenic concentration of some samples exceeded the national guideline value. Similar study carried out by JICA/ENPHO (2005) revealed that the ground water resources of Kathmandu Valley are highly vulnerable to arsenic contamination, particularly in deep aquifers (>200 m) of several samples exceeded 0.200 mg/L. These studies have confirmed the existence of arsenic in ground water of Kathmandu Valley.

This study examines the concentration of arsenic deep tube wells of Kathmandu Valley. It also establishes correlation between depth of the tube wells and arsenic concentration and correlations between the arsenic concentrations in different seasons (post monsoon and winter). It also evaluates the distribution patterns of arsenic by spatial interpolation techniques in GIS.

The objectives of the study were:

i) to determine concentration of arsenic in deep tube wells of Kathmandu Valley
ii) to show the relationships between depth of the tube wells and arsenic concentration

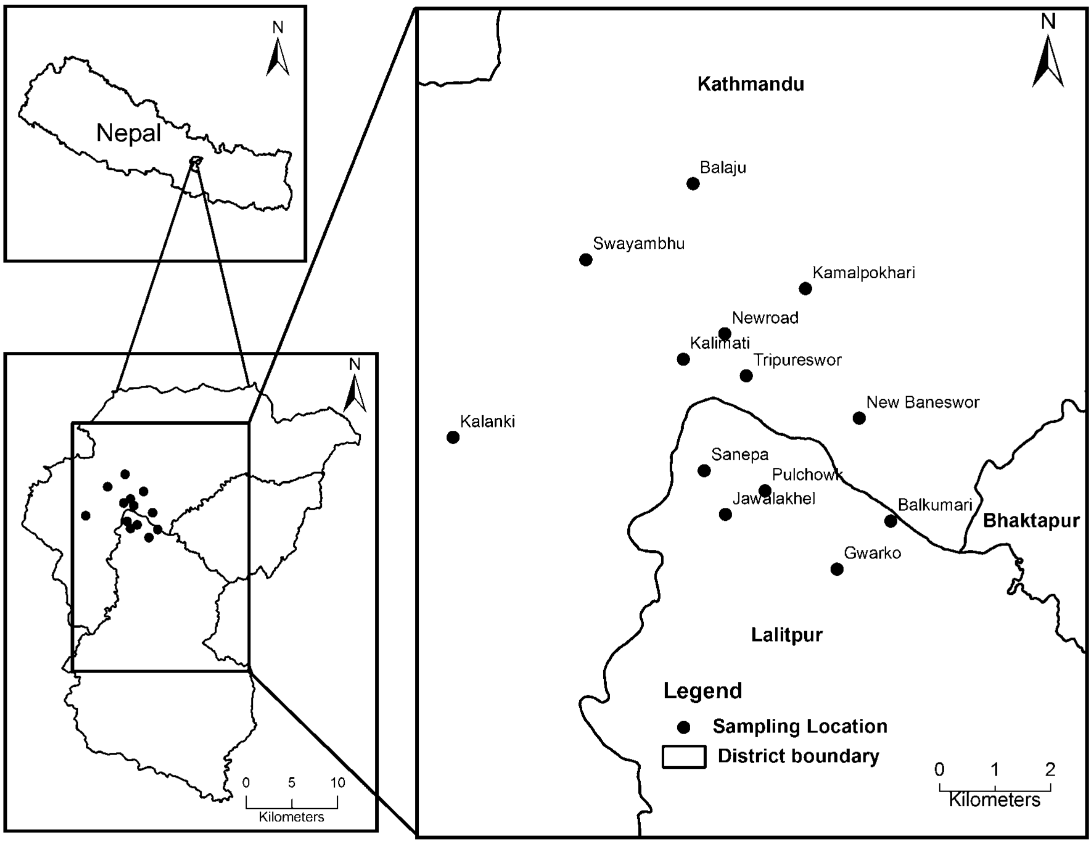

Fig. 1 Study area and sampling location in the study area

iii) to show the seasonal variation of arsenic concentration in deep tube wells

iv) to evaluate the distribution patterns of arsenic by spatial interpolation techniques in GIS

Materials and Methods

Study area

Kathmandu Valley covers an area of roughly 500 km^2 centered on 27°42' N, 85°22' E. It is located in the central part of Nepal (Fig. 1). The average altitude of the Valley floor is about 1350 m above sea level and the surrounding hills are about 2800 m above sea level. The climate of the region is semi tropics, warm and temperate; and annual precipitation is 1639.7 mm (CBS, 2008). The precipitation is dominated by monsoon rainfall, which lasts for the months of July to September and contributes 80 % of annual precipitation (JICA, 1990).

Kathmandu Valley is small intra-mountain Valley. The Kathmandu Valley occupies an intermontane basin containing up to 500 m of a thick band of Pliocene-Quaternary fluvio-lacustrine sediments (Yoshida & Igarashi, 1984). The deep aquifer system can be divided into three groundwater zones based on hydrogeological considerations. The northern zone, forming the main aquifer, has the upper deposits composed of unconsolidated and highly permeable micaceous quartz and gravel materials. The coarse sediments in the northern part of the Valley represent delta deposits and facies that are influenced by the processes of delta progradation and paleo-lake fluctuation. In the central zone, the upper deposits are composed of impermeable very thick stiff black clay with peat and lignite bands. Unconsolidated low permeable coarse sediments underlying the clay bed constitute a confined aquifer. The urban cores of Kathmandu and Lalitpur (Patan) are located in this middle region. The formation of the southern part is characterized by a thick impermeable clay and basal gravel of low permeability (Dixit & Upadhya, 2005; Sakai, 2001).

Water sampling and analysis

The study was carried out in 13 different areas of Kathmandu and Lalitpur municipalities of Kathmandu Valley (Fig. 1)The study covered the deep tube wells of 75-304 m depth. In each area, 13 households with deep tube wells were chosen to collect the water samples. Groundwater samples from each sampling sites geo-positions were determined using global positioning systems (GPS).

Random sampling technique was used to collect ground water samples. The water samples were taken in post monsoon (month of October 2009) and winter (month of February 2010). A set of samples were collected in the sampling bottles randomly after pumping water for five minutes before sampling to get the representative sample of the tube well. The bottles were labeled with the sample code number. Those samples were preserved and then brought to the laboratory for analysis. The collected samples were analyzed in the laboratory of Central Department of Environmental Science, Tribhuvan University, Kathmandu as per standard method. Silver diethyl dithio carbamate (SDDC) method was used for analysis of arsenic (APHA/AWWA/WEF, 1998). Calibration curve was prepared by using Microsoft Office Excel (2007). The concentrations of the arsenic were computed on the basis of calibration curve. Microsoft Office Excel (2007) was used for statistical analysis.

GIS and spatial analysis

Nepal adopted Universal Transverse Mercator (UTM) projection for the base mapping of the country with some modifications suited to its shape. This is named as Modified Universal Transverse Mercator Projection (MUTM). So, all the spatial data layers were maintained in a standard Nepalese coordinate system of Modified Universal Transverse Mercator, Central Meridian 84° Longitude (i.e., MUTM84).

The draft and thematic maps were generated and digitized. Geostatistics are widely used to estimate the spatial variability and distribution of field data with uncertainty (Cressie, 1985). Kriging is one of the geostatistical tools applied to analyze spatial horizontal distribution of field data. Kriging interpolation was applied to analyze spatial horizontal distribution of arsenic in groundwater. The software used for spatial analysis was ArcGis version 9.3.

Results and Discussion

The arsenic concentration of the deep tube wells of Kathmandu Valley has been measured for post monsoon and winter. The deep tube wells exceeded arsenic concentration 0.05 mg/L in post monsoon was 38.5 % and 46.2 % in winter. The deep tube well showed arsenic concentration less than 0.01 mg/L was 7.7 % in both post monsoon and winter. The deep tube wells showed arsenic concentration in between 0.04 mg/L and 0.05 mg/L in post monsoon was 15.4 % and 15.4 % in winter (Table 1).

Table 1 Arsenic level classification in post monsoon and winter

Arsenic (mg/L)	Number (%) tube wells in post monsoon	Number (%) tube wells in winter
< 0.01	1 (7.7)	1 (7.7)
0.01-0.05	7 (53.8)	6 (46.2)
> 0.05	5 (38.5)	6 (46.2)
Total	**13 (100.0)**	**13 (100.0)**

The highest arsenic concentration was measured in a deep tube well of Gwarko (depth 275 m) in winter was 0.105 mg/L and followed by 0.095 mg/L in a deep tube well in Kalanki (depth 259 m). The concentrations of arsenic in those areas in post monsoon were reduced to 0.065 mg/L and 0.076 mg/L, respectively. The lowest arsenic concentration measured in a deep tube well of Jawalakhel (depth 122 m) in post monsoon was 0.029 mg/L and followed by 0.032 mg/L in a deep tube well in Pulchowk (depth 219 m). The concentrations of arsenic in these areas in winter increased to 0.041 mg/L and 0.050 mg/L, respectively (Fig. 2).

Mean, median, minimum and maximum arsenic concentration for post monsoon were 0.053 mg/L, 0.048 mg/L, 0.029 mg/L and 0.090 mg/L, respectively, and for winter were 0.075 mg/L, 0.083 mg/L, 0.041 mg/L and 0.105 mg/L, respectively.

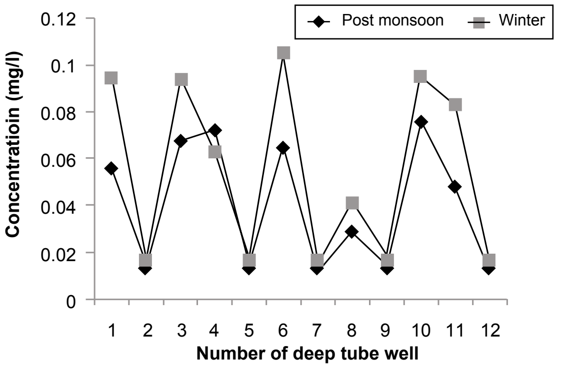

Fig. 2 Arsenic concentrations in post monsoon and winter

Arsenic concentration in 92.30% tube wells increased from post monsoon to winter and reduced in 7.7% tube wells. In most of the tube wells the arsenic concentrations measured were higher in winter (Fig. 2).

The depth of the tube wells tested arsenic ranged from 75 to 304 m. The mean and standard deviation (SD) of depth were 219.8 m and 74.8 m, respectively. It showed weak but positive correlations between arsenic concentration and depth of deep tube wells in winter (r=0.23, p=0.451). Similar results shown by the studies carried out by JICA/ENPHO (2005), Maharjan et al. (2007) and Shrestha et al. (2010). It contradicts with the situation found in the Terai where deeper wells tend to have lower concentration of arsenic. In the Terai Basin, arsenic contamination is greater in the shallow tube wells (< 20 m) than in the deep wells. However, the opposite is the case in the Kathmandu Basin, with the deep tube well water having the higher arsenic concentration up to 0.200 mg/L. The cause of higher arsenic in deep wells is not understood. However, conditions in the deep aquifers in Kathmandu Basin are more reducing (Khatiwada et al., 2002). In more than 200 m, the dilution of arsenic concentration is less significant because the percolation of monsoon water to the depth more than 200 m is limited. It is due to the contrast geochemistry of groundwater in the shallow and deep aquifers.

Arsenic concentration in 84.62% tube wells increased from post monsoon to winter and reduced in 7.7% tube wells. Higher arsenic concentration in winter compared to that of post monsoon. Arsenic concentration was not detected in one tube well. Mean, median, and maximum arsenic concentration for post monsoon were 0.037 mg/L, 0.029 mg/L, and 0.076 mg/L, respectively, and for winter were 0.051 mg/L, 0.041 mg/L and 0.105 mg/L, respectively. Arsenic concentration in 7.7% of tube wells were less than 0.01 mg/L. In most of the tube wells the arsenic concentrations measured were higher in winter (Fig. 2). It showed strong positive correlation between arsenic concentration in post monsoon and winter (r=0.94, p<0.001), which infers similar distribution of arsenic in both seasons. Arsenic concentrations were insignificantly varied between seasonal groundwater samples (Fig. 2).

In post monsoon and winter 92.31% of tube wells exceeded permissible values of World Health Organization guideline value of 0.01 mg/L for drinking water (WHO, 2008). In post monsoon 38.5% and in winter 46.2% exceeded the permissible values of Nepal Drinking Water Standard of 0.05 mg/L (GoN/MPP, 2006).

This study has confirmed the existence to arsenic in deep aquifers of Kathmandu Valley. Thus, understanding of the arsenic-release in the Kathmandu Valley is important. Two mechanisms of arsenic release are probable in the groundwater of the valley. First is the mobilization of arsenic due to the change of redox condition. Arsenic mobilizition is high in the reducing conditions (Carbonell-Barrachina et al., 1999; McArThur et al., 2004; Smedley & Kinniburgh, 2002). The groundwater displays clear redox gradient between shallow and deep aquifers as indicated by the diminishing trend of ORP downward from shallow to deeper depth. Khatiwada et al. (2002) reported negative ORP (-195 mV) in deep aquifers showing highly reduced environment. Arsenic concentrations in the sediments of Kathmandu Valley averaged 8 mg/kg (ramging 3-25 mg/kg) similar to the general level seen in the modern unconsolidated sediments, typically 5-10 mg/kg (Gurung et al., 2007; Smedley & Kinniburgh, 2002).

Though the study showed positive correlation between arsenic concentration and depth of tube wells in winter, it showed very weak positive correlations between depth of the tube wells and arsenic concentration in monsoon (r=0.055, p=0.859) and p-value suggest there is an insignificant correlation.

A geospatial analysis of arsenic was performed to attempt to identify areas in the sampled regions of increased contamination (hotspots). Geospatial analysis has become increasingly important when examining spatial trends. A GIS-based kriging technique was utilized to interpolate contamination estimates between sampling locations. The spatial distributions of maps were analyzed using kriging method. Semivariogram analysis for kriging interpolation showed that arsenic concentrations in post monsoon and winter were best fitted for exponential model. In kriging analysis, areas of color indicate areas where one would expect to see similar concentration of the element of interest. The geospatial analysis revealed that several areas of the state tend to have higher concentrations of metals in both seasons.

The geospatial trends in Kalanki, Sanepa, Jawalakhel, Balkumari and Gwarko which lies in the central ground water zone of the study area showed high arsenic concentration in the post monsoon and winter (Figs. 3, 4). Likewise, Tripureswor, New Road, Kalimati and New Baneswor also showed relatively higher concentration of arsenic. The thick layers of the Kalimati Formation in these areas with fine grained sediments would have influenced in increase of arsenic concentration. Similarly, as this aquifer is of non-rechargeable type (JICA, 1990); the deep aquifer appears to have higher arsenic concentration. The studies carried out by Fujii and Sakai (2001) have indicated that the fluvio-lacustrine sediment in the Kathmandu Valley is rich in organic matter, especially the clayey sediments of central part of the valley, which could have enhanced the arsenic mobilization. All these features demonstrate that the deep aquifers are under reduced arsenic mobilization is high in the reducing conditions though not all reducing water contains arsenic. The spatial analysis revealed that the concentration of arsenic was low in Swayambhu and Kamalpokhari which are in Tistung and Gokarn Formations, respectively (Figs. 3, 4). This may be attributed to coarse region with grained sediments in these Formations.

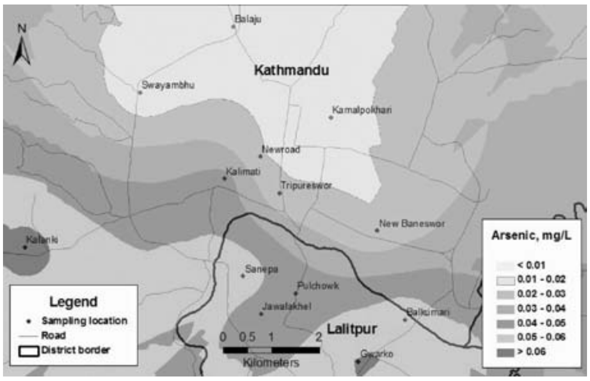

Fig. 3 Spatial distribution map of arsenic in post monsoon

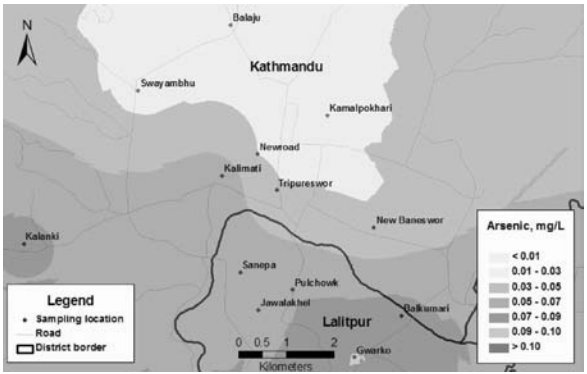

Fig. 4 Spatial distribution map of arsenic in winter

Conclusion

This study has confirmed the existence higher levels of arsenic in deep tube wells of Kathmandu Valley. The highest arsenic concentration measured in winter was 0.105 mg/L and 0.076 mg/L in post monsoon. The study showed strong positive correlation between arsenic concentration in post monsoon and winter, suggesting similar distribution of arsenic. It also showed weak but positive correlation between arsenic concentration and depth of deep tube wells in winter. GIS and geospatial analysis were used to generate distribution maps for arsenic. Kriging method was selected for interpolation, which satisfy statistically optimal and unbiased prediction. The high concentration of arsenic in some parts of study area is attributed to the groundwater geochemistry in the study area.

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