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Research Article

Spatial Variation in Arsenic Concentration in the Groundwater of Nawalparasi District, Terai Nepal

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Abstract

The spatial variability of arsenic (As) in the groundwater was studied in the three villages of Nawalparasi district, Nepal. The average concentration of As varied as low ($0.16 mgL^{-1}$) in Kasiya to high ($1.34 mgL^{-1}$) in Thulokunwar with all the tubewells exceeding WHO ($0.01 mgL^{-1}$) and NIS ($0.05 mgL^{-1}$) limits for drinking waters. The concentration of As was varied even in closely located tubewells suggesting the possibility of spatial variation due to some conditions such as latitude, longitude and depth of tubewell. The As level also varied inversely with the depth of tubewells.

Keywords: Kasiya; Panchgawa; Thulokunwar; Tubewells; Depth of Water Table; Lithology

Introduction

The water quality is the major issue not only in Nepal but also in countries across the globe. Generally, groundwater is more susceptible to arsenic (As) contamination than the surfacewater, because groundwater interacts with a numbers of different kinds of minerals in aquifer. It is know that most of the As-related health problems reported so far is associated with consumption of As-contaminated groundwater over period of time. Nowadays, As-contamination of groundwater is of increasing concern due to its high toxicity and the widespread occurrence [1]. The alarming concentrations of As have been reported in South East Asia viz. Bangladesh, Vietnam, West Bengal–India, Nepal, Cambodia, Mongolia, China, Thailand, Pakistan and Taiwan [2-7], Central and South America (Argentina, Chile, Mexico), North America (USA and Canada) [8-12] and Australia [13]. Elevated As concentrations are also reported in European countries i.e. Hungary, Romania, Italy, Greece, Spain, Finland, and Germany [1,14,15].

Groundwater As is highly variable on the local as well as regional scale. The groundwater chemistry also varies both at the spatial as well as temporal scale [16,17]. Although As concentrations vary over distances ranging from meters to kilometers, the cause of the lateral heterogeneity yet remains to be explored. Regional dependency of As contamination accounts for the geologic divisions of the area but at the smaller scales, this pattern is more random. van Geen et al [18] have reported that in the smaller village with higher resolution (6000 tube wells in a 25 km^2 area), tube wells having shallower depths are highly variable in As load, and do not follow the clear spatial pattern. It seems that the knowledge of spatial variability of As remains crucial not only for evaluating the biogeochemical-hydrological events that control groundwater concentrations of As but also for developing strategies for sustainable use of shallow groundwater that will reduce exposure to As [19].

In recent years, groundwater As-contamination in Terai region, Nepal has been the major issue [20]. Temporal variations in groundwater As-contamination of the Terai region necessitate mitigation efforts as there has been very little investigation on the spatial and temporal pattern of groundwater chemistry especially in the high-As aquifers. In the present study an attempt has been made to evaluate the spatial distribution of As-contamination in the groundwater of Nawalparasi district of southern Nepal.

Geological setting of the area

Tectonically, Nepal Himalayas can be classified into four different zones (i.e. Tethys Himalayas, Higher Himalayas, Lesser Himalayas, sub Himalayas and Terai plain) from north to south followed by Terai Plain bordering them on the south [21,22]. The Tethysian zone which lies in the northern part of western central Nepal consists of high mountain ranges crowned by cretaceous fossiliferous sediments. The higher Himalayan zone consists of crystalline rocks (schist and gneiss). Main control Thrust (MCT) marks the contact of crystalline zone to that of lesser Himalayan sedimentary pile. The contact of the crystalline with the overlying Tethys sediments is gradational. To the south of higher Himalayas, the lesser Himalaya zone which consists of meta-sediments with different grades of metamorphism. The sub-Himalayan zone, which lies to south of the lesser Himalayas and separated by MBT (Main Boundary Thrust) from it consist of sedimentary rocks containing silt, sand, shale and pebble and boulder beds. The pebbles and boulders are quartzites, sandstone, phyllites etc. These formations form the low lying hill ranges that rise from the Indo-Gangetic plain on the south. These hills are called Churia hills which is the Nepalese designation of Siwalik [22].

The Terai plain lies in the southern part of Nepal and is separated from the Churia formations by the Himalayan Frontal thrust. Nawalparasi lies in the Terai plain as the continuation of Indo-Gangetic plain and has gentle slope toward south from an elevation of 200-300m in the north to as low as 63m in the south near Indian border [21, 22]. The lithology of the Terai sedimentary basin belongs to Holocene alluvium that includes the present day alluvial deposits, channel sand and gravel deposits and outwash deposits [23].

Materials and Methods

Study area

Nawalparasi, a part of Lumbini zone (one of the 75 districts), is located in the western Terai region of southern Nepal. It lies 147 Km. west of the capital city Kathmandu, and surrounded by Chitwan district in the east, Tanahun in the north, Palpa and Rupandehi districts in the west, and the Indian state of Uttar Pradesh in the south. The present study was conducted in three villages namely Thulokunwar, Kasiya and Panchgawa of Nawalparasi district of Nepal (Figure 1) where the As-contamination of groundwater has variously been reported [20,24]. A total of 24 tubewells were selected (8 each) in Thulokunwar (T01, T02, T02, T03, T04, T05, T06, T07 and T08), Kasiya (K01, K02, K03, K04, K05, K06, K07, and K08) and Pachgawa (P01, P02, P03, P04, P05, P06, P07, and P08) for sampling of groundwater samples.

Collection of Water Samples

A total of 24 groundwater samples (250 ml) were collected from tubewells, varying in depth from 6 to 48.7m in September, 2011. Tubewells were flushed well before collecting the samples to remove the stagnant water. One set of sample was collected with 1 ml of conc. HNO_3 for metal analysis while the other set was collected without any preservative and used for analysis of major anions. The samples were stored at 4°C until analysis. Depth to water table (DWT) of the tubewells was measured by inserting a steel measuring tape in tubewell.

Physico-Chemical Analysis

Water pH and oxidation reduction potential (ORP) were measured *in-situ* using Hanna made portable kit (HI 98121 waterproof pH/ORP/Temp). The electrical conductivity (EC) was recorded using Milwaukee sharp EC tester (M111751). SO_4^{2-}, PO_4^{3-} and NO_3^- were analyzed spectrophotometerically (Systronics Visiscan 167) while HCO_3^- was analyzed titrimetrically. Water samples were digested with conc. HNO_3 following standard methods [25]. Fe, Mn, Ni, Pb and Zn were quantified by Flame Atomic Absorption Spectrometer (Perkin Elmer AAnalyst 800). Total As was analyzed using hydride generator atomic absorption spectrometer (HG-AAS). As (III) was completely reduced to As (V) by adding 10 ml each of conc. HCl and 5% (w/v) reducing solutions (KI and ascorbic acid) in 50 ml volumetric flask and incubating it at room temperature for 45 min. The samples were diluted with 1.5% HCl to the mark and were analyzed by AAS-HG. The detail protocol about As analysis by GH-AAS is described elsewhere [12].

Results and Discussion

Characteristics of Groundwater Parameters

Descriptive statistics has been used to characterize the composition of groundwater (Table 1). Maximum pH (7.60) was recorded in Kasiya followed by Panchgawa (7.44) and Thulokunwar (7.41). The slightly alkaline pH values as recorded for all the sites were also well within the limit of Nepal drinking water quality standards (NDWQS). The EC values of groundwater

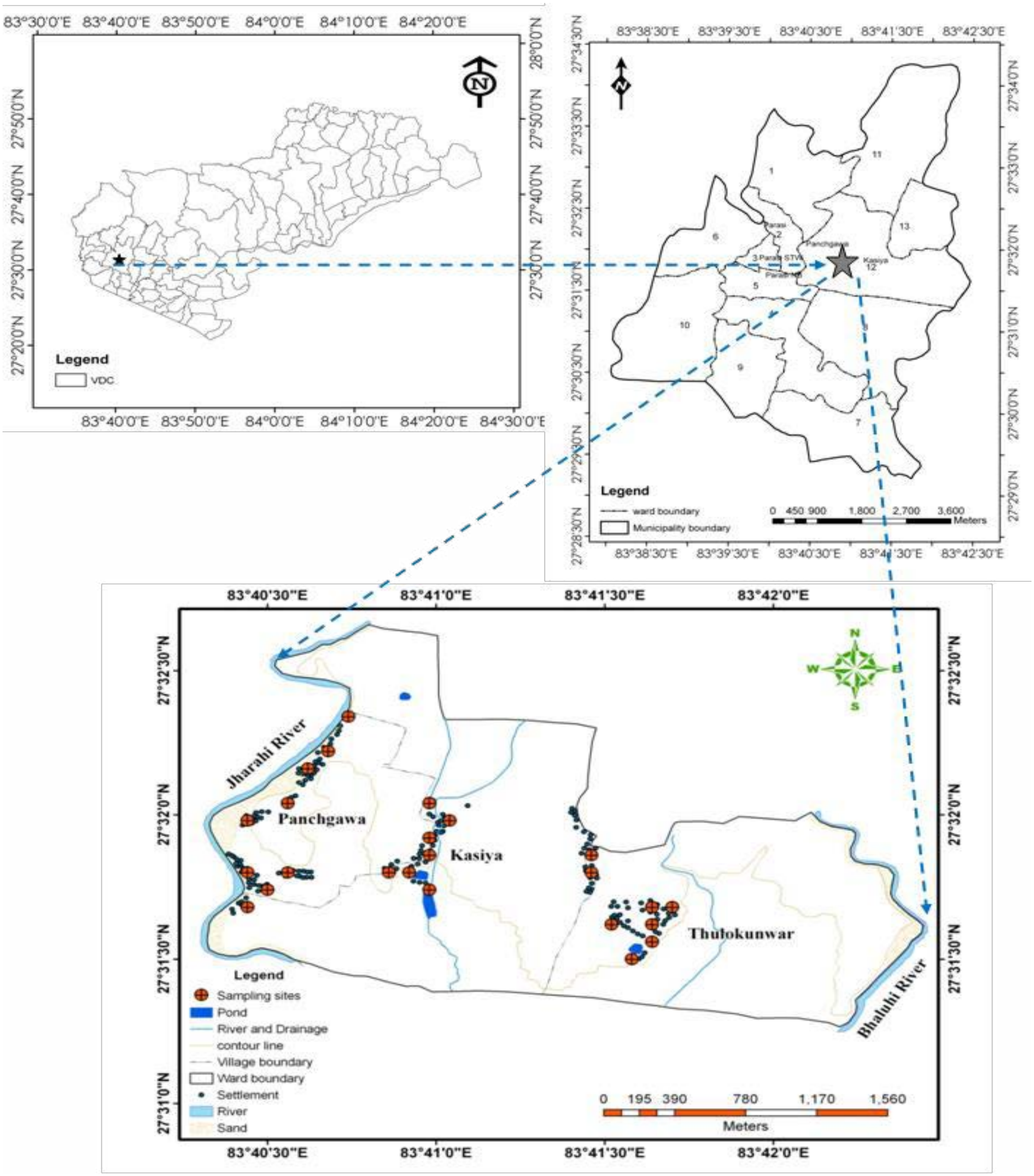

Figure 1. Map of Nawalparasi district showing study area and sampling locations.

Table 1. Descriptive statistics of groundwater quality parameters.

Variables	Unit	Drinking water quality standard*		Thulokunwar				Kasiya				Panchgawa			
		NDWQS	WHO	Mean	SD	Min.	Max	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
pH	-	6.50-8.50	6.5-8.0	7.41	0.21	7.17	7.79	7.60	0.21	7.33	7.87	7.44	0.09	7.26	7.56
EC	μScm^{-1}	1500	-	721	313	450	1438	510.4	59	449	624	485	71.4	391	571
ORP	mV	-	-	-97.0	25.5	-124	-39.0	-53.6	67.7	-99.0	97.0	-94.0	25.9	-129	-39.0
SO_4^-	mgL^{-1}	250	400	0.27	0.36	0.06	1.14	0.16	0.17	0.06	0.58	0.14	0.04	0.09	0.22
PO_4^{3-}	mgL^{-1}	-	-	0.02	0.01	0.01	0.03	0.02	0.01	0.01	0.03	0.01	0.00	0.01	0.02
HCO_3^-	mgL^{-1}	-	-	632.5	156.7	402.5	920	503.1	73.7	402.5	575	517.4	61.6	402	575
NO_3^-	mgL^{-1}	50.0	50.0	0.25	0.13	0.14	0.43	0.18	0.07	0.14	0.29	0.34	0.15	0.14	0.56
Fe	mgL^{-1}	0.3-3.0	0.30	3.71	0.24	3.46	4.14	3.54	0.09	3.41	3.64	3.67	0.09	3.55	3.79
Mn	mgL^{-1}	0.20	0.40	0.21	0.24	0.01	0.73	0.07	0.10	0.00	0.31	0.07	0.03	0.02	0.12
Ni	mgL^{-1}	-	0.07	0.08	0.01	0.06	0.09	0.06	0.01	0.06	0.10	0.06	0.01	0.05	0.07
Pb	mgL^{-1}	0.01	0.01	0.10	0.02	0.08	0.13	0.12	0.02	0.09	0.16	0.14	0.01	0.13	0.16
Zn	mgL^{-1}	3.00	-	0.08	0.02	0.05	0.10	0.09	0.04	0.06	0.18	0.13	0.12	0.06	0.38
As	mgL^{-1}	0.05	0.01	0.80	0.29	0.34	1.34	0.35	0.16	0.16	0.60	0.39	0.10	0.20	0.53

*Government of Nepal [36]; WHO [37]; ND: not detected

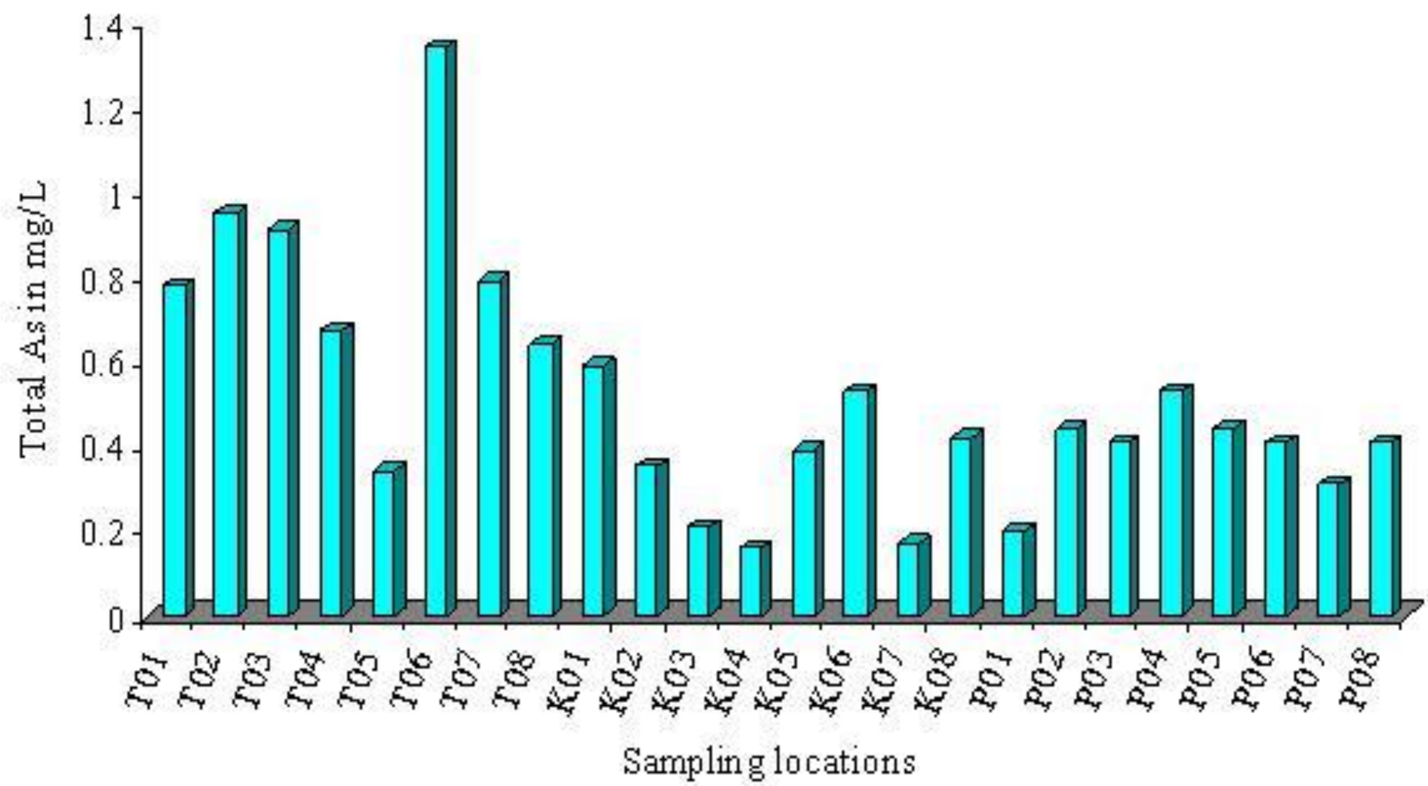

Figure 2. Location-wise concentration of total As in Nawalparasi.

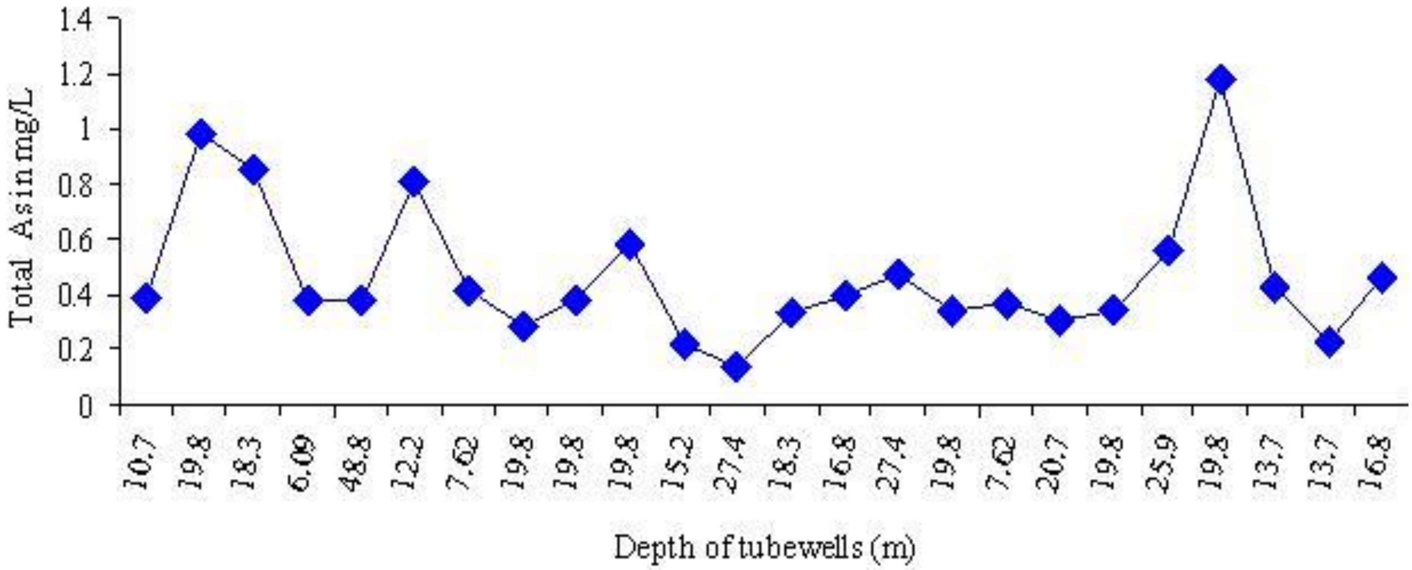

Figure 3. As concentration in tubewells of Nawalparasi by depth.

varied from 450 to 1438 µScm^{-1}, 449 to 624 µScm^{-1} and 391 to 571 µScm^{-1} in Thulokunwar, Kasiya and Panchgawa, respectively and were in compliance with the NDWQS limit of 1500 µScm^{-1}. The groundwater in this area showed low ORP values and ranged from -124 to -39 mv, -99 to 97 mv and -129 to -39 mv in Thulokunwar, Kasiya and Panchgawa, respectively. Negative ORP value in groundwater is the indication of the reducing groundwater conditions which promotes As release from aquifer sediments [26]. SO_4^{2-}, NO^{3-} and PO_4^{3-} are major constituents of groundwater, and their elevated concentration is indicative of anthropogenic pollution. The concentration of SO_4^{2-} ranged from 0.06 to 1.14 mgL^{-1}, 0.06 to 0.58 mgL^{-1} and 0.09 to 0.22 mgL^{-1} at Thulokunwar, Kasiya and Panchgawa, respectively and was well within the limit of NDWQS (250 mgL^{-1}). Low concentration of SO_4^{2-}, NO^{3-} in the groundwater of present study may be due to sulfate reduction and nitrate reduction in groundwater [27,28]. The average concentration of PO_4^{3-} was either very low or not detectable, and well within the limit of Bureau of Indian Standard (BIS) for drinking water. However, no limit is set for PO_4^{3-} by NDWQS. The SO_4^{2-}, NO_3^- and PO_4^{3-} concentration detected in groundwater of this area is consistent with previous study from Nepal [12 17,24,29,30] and other part of world [31-33].

Bicarbonate (HCO_3^-) represents major source of alkalinity in groundwater. It varied from 402.5 to 920 mgL^{-1}, 402.5 to 575 mgL^{-1} and 402 to 575 mgL^{-1} in Thulokunwar, Kasiya and Panchgawa, respectively. The concentration of Fe was maximum in Thulokunwar (3.71 mgL^{-1}) exceeding permissible limit of WHO (0.30 mgL^{-1}) in all samples and within the limit of NDWQS (3 mgL^{-1}) for Fe. Mn was very low at all the sites having its mean 0.21, 0.07 and 0.07 mgL^{-1} in Thulokunwar, Kasiya and Panchgawa, respectively. The presence of high concentration of Fe and low concentration of Mn indicates the reducing condition of the groundwater. High level of Pb was recorded at all the sites which ranged from 0.08 to 0.13 mgL^{-1}, 0.09 to 0.16 mgL^{-1} and 0.13 to 0.16 mgL^{-1} in Thulokunwar, Kasiya and Panchgawa, respectively. Whereas Ni was present in the limit of WHO, Zn was, however, very low and was below the WHO limit of drinking water.

The average As-concentration was 10 to 100 times more than the WHO limit (0.01 mgL^{-1}) and 25-30 times higher than Nepalese interim standard (NIS, 0.05 mgL^{-1}) limit for As in drinking water (Figure 2). All the tubewells analyzed under present study contained As more or less, and none of the tubewell found to be free from As. While sampling in Nawalparasi, we found that the local people are forced to drink the As-contaminated water in absence of alternate option for drinking water. They are at high risk of several As-poisoning. Hence, the Department of Water Supply and Sewerage and Ramgram municipality, who manage the water supply in the area, are also advised to supply the treated tank water (As-free) in these villages to protect the health of local residents.

Higher concentration of As was recorded in Thulokunwar and Panchgawa in the east and west side, respectively as compared to Kasiya where high As was recorded in the middle. The level of As varied from 0.16 mgL^{-1} in Kasiya to 1.34 mgL^{-1} in Thulokunwar with majority of the tubewell containing >0.01 mgL^{-1} of As, indicating that distribution pattern of As is highly heterogeneous. The As-concentration varied even within the closely located tubewells (Figure 2). The differences in mean As level may probably be due to geospatial conditions especially to latitudinal and longitudinal differences. This may also possibly be due to the vertical distribution of aquiclude such as dyke, fault or some unconformity etc. in the groundwater aquifer limiting the movement of As from one tubewell to another. Our finding is in agreement with previous study reported across the world [16, 18, 34, 35]. High level of As was detected in Thulokunwar and Panchgawa located adjacent to third grade rivers (rivers whose water source areas lie in Siwalik range) i.e. Bhaluhi and Jharahi river. The possible reason for high As content in such villages may be the sedimentary rocks of Siwalik origin brought by these third grade rivers. These rivers are much smaller in size and have insignificant or no flow during dry periods. Flash flood during monsoon results in the deposition of transported sediments in the nearby area. However, the exact reason as to why the As levels vary greatly within the closely located tubewells, is yet to be ascertained.

As Concentration of Tubewells as a Function Of Depth

The level of As changed with the tubewell depth (Figure 3). Tubewells with lesser depth (≤ 20 meter) had elevated As concentrations in contrast to those with higher depth (>20 meter) having lower As. However, both the tubewell types (with lesser or higher depth) contained As levels higher than the WHO and NIS limits of As for drinking water. Whereas maximum As (1.18 mgL^{-1}) was detected for the tubewell with the depth of 19.81m, tubewells with the depth of 27.4m, however, had the least As (0.14 mgL^{-1}). In general, the level of As varied inversely with the depth of the tubewells, suggesting that As concentration depends more or less on the tubewell depth.

As Concentration Vs Depth of Water Table

DWT gradually increased from east to west direction from Thulokunwar to Panchgawa through Kasiya. It ranged as high as 0.52m below the ground level (bgl) at Thulokunwar in the east to as low as 5.55m bgl at Panchgawa in the west. High DWT at Panchgawa village lies towards Jharahi River. Water table also increased from north (2.52m bgl) to south (4.02m bgl). The annual fluctuation of water table was low (0.34m bgl) and high (1.58m bgl) at Panchgawa and Thulokunwar, respectively. The eastern part is having the high water level fluctuation (1.23m bgl) which may be due to sand/gravel bearing aquifers of Panchgawa. The deepest DWT was recorded at Panchgawa located at an altitude of 100m (7.5m bgl) while the shallow DWT was common for Thulokunwar located at an altitude of 96m. The DWT decreased from west to east and also from south to north.

Conclusion

The spatial distribution of As showed significant variation even in closely located tubewells in the groundwater of Nawalparasi. The difference in As concentration over space may probably be due to spatial conditions such as latitude, longitude and depth of tubewells. All the tubewells contained many fold higher As than the WHO limit. However, none of the tubewells was free from As contamination, suggesting that all are unsafe and there is an urgent need to educate the residents of Nawalparasi to avoid drinking such contaminated tubewell water forthwith. The Department of Water Supply and Sewerage and Ramgram municipality, who manage the water supply in the area, are also advised to supply the treated tank water (As-free) in these three villages.

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