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Analysis of Arsenic Concentration in the Constructed Groundwater of Nepal

Case Study of the Terai Region of Nepal.

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Arsenic (As) is present naturally in the earth's crust. The high concentration of As in drinking water possesses a great threat to the health condition of people dependent on such sources. Arsenic contamination is a serious problem around the world including Nepal. The impact of arsenic contamination is prominent and severe in the southern lowland of Nepal also known as the Terai region. Though the exact reason for groundwater arsenic contamination is not known, the sediments from Siwalik and the high Himalayas can be considered as a source of As contamination in Terai. Groundwater provides potable water for about 90% of total population in this region. The arsenic contamination has degraded the health of many Nepalese people and thus also reduced the average life expectancy rate.

This thesis mainly deals with the arsenic contamination in the constructed groundwater sources (wells) in Terai Alluvial Land. The goal of this thesis is to analyse the arsenic contamination in constructed groundwater sources. The analysis was done based on the data provided by various national and international organisations such as DWSS, ENPHO and NRCS. The analysis was done to determine the relationship between various factors affecting arsenic concentration in groundwater. The factors include depth of the well, age of the well and the number of people using the well. These factors were compared with As concentration in order to establish the relation between them. Also, further analysis was done to study the population exposed to arsenic poisoning.

The analysis showed that 3 %(> 50µg/l) and 8 % (10-50µg/l) of Terai's total population are at risk of Arsenic contamination. The analysis revealed that Chitwan (with average As concentration 0.53 µg/l) is the least contaminated district, while Nawalparasi (with average As concentration 18.61 µg/l) is the most contaminated district. More than 2% of wells were contaminated with >50µg/l of As, and about 8 % of samples were contaminated with >10µg/l. As concentration was found to be more in shallow water. However, As concentration decreased with increasing depth. The result indicated that the age of the well and the As concentration are independent of each other. The result also revealed that over-exploitation directly increased the As contamination in wells. The result showed that public wells were slightly more contaminated than private wells and the wells used for school, colleges and offices were found to be more contaminated than other user types. The drinking water is not safe in most part of the Terai region; hence alternative water resources need to be identified as soon as possible. The possible mitigation techniques which are prevalent in Nepal and which every person under the threat of arsenic contamination should use are also discussed in the thesis. There is room for further analysis if enough data on pH changes, climatic factor and concentration of other elements such as Fe and Mn is provided as As concentration also depends on these factors as well.

Keywords	arsenic, arsenic contamination, Terai, well age, groundwater, over-exploitation, well depth

Contents

List of abbreviations

As	Arsenic
DWSS	Department of Water Supply and Sewerage
μg/l	Micrograms per litre
RWSSFDB	Rural Drinking Water Supply and Sanitation Fund Development Board
NRCS	Nepal Red Cross Society
UNICEF	United Nations International Children's Emergency Fund
NEWAH	Nepal Water for Health
RWSSP	Rural Water Supply and Sanitation Project
NSCC	National Sanitation Steering Committee
JRCS	Japan Red Cross Society
H_3AsO_3	Arsenic acid
CoAsS	Cobaltite
NiAs	Nicolite
$CuAs_2$	Copper Arsenate
FeOOH	Hydrous ferric oxides
WHO	World Health Organisation
NASC	National Arsenic Steering Committee
ENPHO	Environment and Public Health Organisation
PVC	PolyVinyl Chloride
KAF	Kanchana Arsenic Filters
AMU	Atomic Mass Unit
g/mol	Gram per mole
GO/NGO	Governmental Organisations/Non-Governmental Organizations

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1 Introduction

The contamination of Arsenic in groundwater is a burning issue in Southeast Asian countries like Bangladesh, India, Nepal, Myanmar and China. Earth's crust is rich in Arsenic. Under favourable conditions, As can be released to an extent that is dangerous to human health. The natural process like volcanic activity, erosion and anthropogenic activities like use of pesticides, mining, improper disposal of sewage and sludge also causes arsenic poisoning in groundwater. In Nepal, the guideline for drinking water is 50 µg/l. The drinking water exceeding this limit is toxic and can cause several health conditions such as skin lesions, cancer and keratosis. According to research, the most contaminated districts are Nawalparasi, Rautahat, Bara, Parsa, Rupandehi, Kapilvastu [1]. Approximately 0.5 million people in Terai were at risk of drinking water with a concentration of > 50 µg/l and the prevalence of arsenicosis on average was 2.6% [2]. These findings have alerted the government and the non-governmental organisations to act in controlling and maintaining the quality of drinking water in Nepal. As a result of this National Arsenic Steering Committee (NASC) was formed which collaborated with organizations like ENPHO in order to test the condition of Arsenic status in Nepal. Arsenic poisoning is a serious issue and must be addressed. Every human has basic right to safe drinking water.

2 Objective

This aim of this thesis was to analyse the concentration of Arsenic present in constructed groundwater sources (mainly dug well and suction well) in southern lowland i.e. the Terai region of Nepal, to compare the relationship between the depth of well and Arsenic contamination, to find the relation between the As concentration and the age of the well and to find the relation between the As concentration and the overexploitation of groundwater. The other goal was to determine the As contamination based on ownership type and user type. The final objective was to determine the population under the threat of Arsenic poisoning.

3 Literature Review

Many types of research have been done in the field of Arsenic poisoning throughout the world. Researchers, universities and different governmental and non-governmental organizations have been trying to establish a relationship between As concentration and factors such as well age, well depth and well exploitation. Researches have shown that As contamination is dependent on the depth of the well. The study conducted in Bengal basin suggests that arsenic is high in shallow groundwater source (<100m). Dissolved arsenic migrates downwards during deeper pumping. Hence, deep resources are contaminated with As and are destroyed [3]. It was found that the age of the well affects the As contamination threshold. Further, the proportional relationship was found between the age of the well and As concentration. The concentration of arsenic increased with the increase in the age of the well for the first ten years of existence, irrespective of threshold or region [4]. Various studies found out that the overexploitation of groundwater for different purposes like irrigation also contribute to As contamination as it induces oxidation [5].

4 Arsenic Poisoning in the World

Arsenic poisoning is an epidemic and has reached all the corners of the world. The concentration of arsenic in different countries depends on the status and natural setting of the country and many other anthropological sources such as industries, fertilizers, and pesticides. In the past, exposure to arsenic contamination was limited and reported only in a few south Asian countries.

Figure 1. Countries in world with reported Arsenic problems [6]

Recently, many countries such as Argentina, Canada, China, India, Japan, Korea, Malaysia, Mexico, Mongolia, Nepal, Taiwan, the United States, and many European countries have reported an increase in the arsenic concentration in water and aquifers as shown in Figure 1[6].

5 Arsenic Contamination and Nepal

5.1 Geographic features of Nepal

Nepal, a small nation in south east Asia, shares its boundary with two countries. Nepal is surrounded by India from three sides- south, east and west and by China on the remaining side. Nepal has no direct access to any sea. The nearest sea to Nepal is Bay of Bengal, which is at the distance of little more than 1500 km. Even with an area just a little over 147 thousand sq. km., Nepal has an astounding geographical diversity. It stretches 800 km in length and 200 km in breadth. Within this 200 km, Nepal elevates from as low as 60 m to top of the world 8,848 m. Hence, Nepal is physically divided into three physical regions namely: Mountain region, Hilly region and Terai region. Figure 2 gives a better illustration of different regions of Nepal.

Mountain region: Mountain region is the northernmost part of the country. All the high mountains of the country lie in this region. Mount Everest, the highest point on Earth, is also located in this region.

Hilly region: Hilly region lies in between Mountain region and Terai region and boasts about many beautiful hill stations such as Pokhara and Kathmandu.

Terai region: The Terai region is the southernmost part of Nepal. It has plain land with fertile soil. Most of the crops of the country are grown here. Hence, it is also called the 'granary or food-basket of the country.' [8]

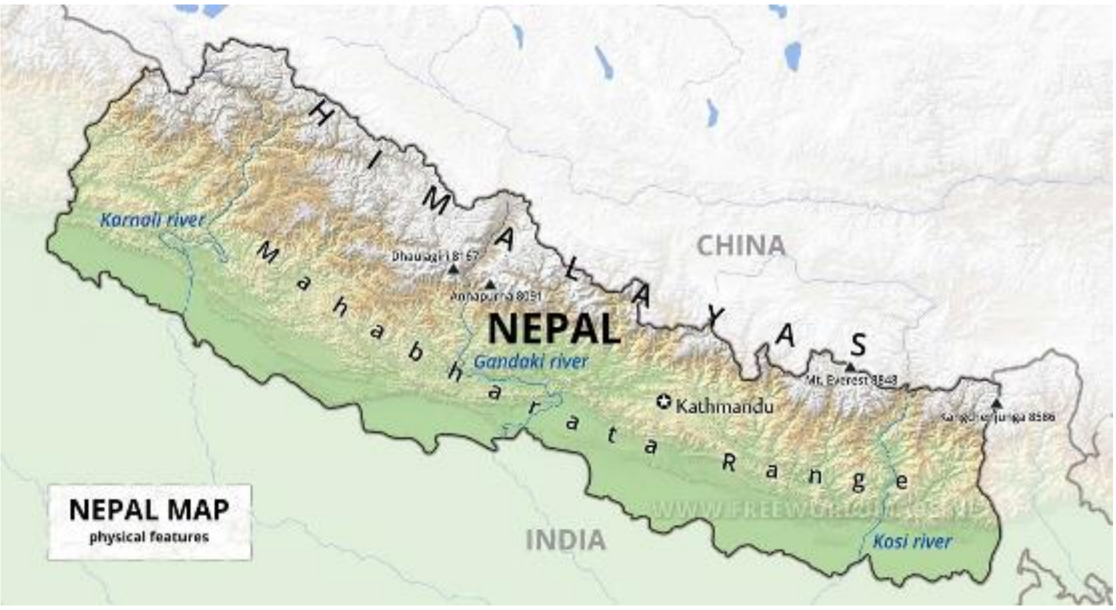


Figure 2.Map showing physical features of Nepal [7]

Nepal has 3 major river system namely the Gandaki, Karnali and Koshi. These rivers later mix with Ganges River before draining in the Bay of Bengal.

5.2 Arsenic concentration in Nepal

Arsenic contamination in groundwater became an alarming issue in Nepal when an un-expected situation arose in the neighbouring countries Bangladesh and India. People of both countries were exposed to drinking water with very high As concentration. These people's health were severely affected by As poisoning. Geographically, Terai is very similar to the affected part of both countries as they are located on the same plain [9]. Hence, the Terai region started attracting interest from all over the world.

The first official survey regarding As concentration in Nepal was done by DWSS with the assistance from WHO in the year 1999. Three districts of Terai region (Jhapa, Morang, and Sunsari) bordering with India were analysed. Out of 268 tested wells, 24 wells exceeded 10 µg/l, a value considered as the limit for As contamination by WHO. There were 2 samples showing an As concentration level beyond 50 µg/l [10]. This result led to an extensive analysis of the As contamination in constructed groundwater drinking sources throughout the Terai region of Nepal. Further, the analysis was done by NRCS and JRCS together in other 17 districts of Terai region. The results showed that districts like Nawalparasi, Rautahat, Bara, and Bardiya were highly contaminated with As concentration. [11]

6 Study Area: Terai of Nepal

Terai region is the southernmost part of Nepal that borders with India. It covers a total area of 33,998.8 km2. It covers about 23.1% of Nepal's area. The annual temperature ranges from 18.8°C to 30.1°C. The climate zone is tropical. The most fertile land in the country lies here. Thus, most of the crops are grown here. Many industries are also established here due to the abundance of raw materials produced here. [12]

Figure 3. As-affected districts analysed in this project.[13]

There are altogether 20 districts in this region of Nepal which are also shown in Figure 3. These districts are studied in this thesis. According to census 2011, nearly 13 million people live in these districts (50.27% of the total population) and groundwater provides water for drinking to more than 90% of these people. [14]. Arsenic contamination is the most widespread in this area of Nepal.

6.1 Geology of Terai region

Geologically, Bengal Delta Plain and Terai region of Nepal have similar characteristics. Terai region is a small, northern extension of Indo-Gangetic plain. The Terai plain can be further split into two parts: upper Bhabar region and lower main Terai region. These zones are tremendously different in their hydrogeological characteristics. There is a channel of natural rivers separating the two zones. The Bhabhar region is located just below Siwalik Hills [15]. It is a small enlargement of alluvial and colluvial deposit. It is composed of many ingredients such as gravel, sand, silt and pebbles. In the lower Terai region, sediments are accumulated by streams. These sediments include clay, silt, sand and gravel deposits, but the density of the composition of each material in the sediments keep changing due to altering stream channels.

Most of the large rivers in Nepal are emanated from high mountains and some from Siwalik Hills. These rivers deposit sediments and organic materials into lowlands, wetlands and swamps [16]. Sediments carried by small rivers from Siwalik Hills releases more As than the sediments carried by large rivers from high Himalayas. The precipitation during monsoon and snow-fed rivers recharge the sediments of Terai increasing the potential of groundwater resources. There are many aquifer systems in Terai Plain. The shallow aquifers (<50m) are generally unconfined while the deep aquifers (>50m) are mostly confined by layers of semi permeable clay. The plain of Terai comprises older and recent alluvium. It is reported that thin alluvial aquifers are severely contaminated by As. [9]

6.2 Sources of water

Nepal has abundance of water resources. There are 6000 rivers and rivulets that flow throughout the year. As Nepal is a landlocked country, most of the water resources are freshwater. There are different sources of drinking water available for the Nepalese depending on the geological location. Tap water is the most important and dominant source of drinking water in Mountains and Hills while tube well is the second most important source of water and dominate in the Terai. The people in Terai depend on groundwater (about 90% of Terai's population) as potable source of water. [9][14]

7 Arsenic

7.1 Nature, properties and chemistry of arsenic

Arsenic (As) is a ubiquitous element found on the earth's crust (average 2-3 mg/kg). As per the abundance, it ranks 12th in the human body, 14th in seawater and 20th in nature [18]. It is odourless and tasteless. Arsenic usually occurs in many minerals, for example, in combination with sulphur and metals, but also as a pure elemental crystal. There are four oxidation states of arsenic namely, arsine(−III), arsenic (0), arsenate(+V) and arsenite (+ III). It occurs in organic and inorganic forms. The inorganic arsenic (arsenite) is more toxic than the organic (arsenate) arsenic. The physical properties of arsenic is well pictured in Table 1.

Table 1. Properties of Arsenic [19]

Atomic number	33	Molecular weight	74.92 g/mol
Atomic symbol	As	Boiling point	Sublimes at 615 °C
Electron configuration	$[Ar]4s^2 3d^{10}4p^3$	Melting point	814°C at 36 atm
Appearance	Metallic grey	Vapor Pressure	1.0 mm Hg at 372 °C
Atomic weight	74.92 AMU	Density	5.7 g/cm^3
Crystal Structure	Rhombohedral	Phase at STP	Solid

Arsenic is a metalloid. It combines with oxygen very slowly at room temperatures. Arsenic is insoluble in water and most cold acids. However, it reacts with hot acids and forms arsenic acid (H_3AsO_3).

The reaction of arsenic with water does not occur in the absence of air. A bronze layer is formed when arsenic reacts with moist air, which later turns into a black surface. $As_2S_3 + 6 H_2O \rightarrow 2 H_3AsO_3 + 3 H_2S$ [20]

Arsenic in natural water undergoes coagulation, adsorption, oxidation and reduction reactions. Arsenic enters sediments when arsenic adsorbs to fine particles in water and precipitates hydroxides of iron and aluminium.

7.2 Source of arsenic in groundwater

Arsenic compounds are abundant in earth's crust. Arsenic is present in more than 200 minerals such as cobaltite (CoAsS) and nicolite (NiAs). Arsenic is present in igneous rock, sedimentary rock and coal as well. It is released in groundwater by natural or anthropogenic activities. The natural phenomenon like weathering of rocks and soils release arsenic in groundwater. In the areas with geothermal activity, arsenic concentration in groundwater is high. Volcanic activity releases large amount of arsenic that enters water bodies. Microbial activity also produces an organic form of arsenic, which is present in marine and terrestrial organisms such as algae, microbes, fungi and plants.

On the other hand, human practices for instance irrational use of pesticides, insecticides and fungicides containing arsenic as one of the components such as copper arsenate, $CuAs_2$ etc. eventually increases arsenic concentration in groundwater. Also, arsenic compounds are used in wood preservatives, paints, glass processing, chemical factories, semiconductors and also in medications. Besides this, mining of ores like copper, iron etc, improper dumping of slag and wastewater from copper smelters and various refineries releases arsenic in groundwater. There are so many ways arsenic is being used and released into groundwater eventually increasing the risk of arsenic contamination in water. [18][20]

7.3 Mobilization mechanism of As in groundwater

Arsenic is released in groundwater from the sediments and rock surrounding the water source. Thus, the mechanism of As release from these source plays a significant role in the concentration of As in groundwater. Arsenic in ground water is available either as reduced Arsenite (AS(III)) or oxidized arsenate. The inflation in amount of As in groundwater is observed under the certain geochemical situation. There are many theories proposed behind how As enters groundwater from sediments. The widely acknowledged four theories are [21]:

1. Oxidation of iron pyrite
2. Reductive dissolution of FeOOH (hydrous ferric oxides)
3. Anion exchange of As with phosphates from fertilizers
4. Geochemical process in sediments.

7.3.1 Oxidation of iron pyrite

Oxidation of pyrite (FeS2), releases arsenic via several reactions. The sulphide minerals containing arsenic are deposited in sediment of aquifer. In this process, FeS2 is oxidized by dissolved O2 in shallow aquifer [22]. Human interference such as overexploitation of groundwater lowers the water table below these deposits, which causes diffusion of oxygen in between the pore of sediments. The increased level of dissolved oxygen in the upper part oxidises FeS2. The oxidised FeS2 on contact with water forms a compound called pitticite, which is soft in nature and dissociates easily in water. Even the light pressure of tube wells splits the compound into different elements which permeates from the soil into the water layer. Hence, arsenic is released from groundwater via tube well.

7.3.2 Reductive dissolution of FeOOH

Arsenic is released by desorption of ferric hydroxide minerals under reducing condition [22]. Ferric hydroxide minerals are found abundantly in the aquifer sediments. In anoxic groundwater, iron reducing microbes oxidises organic carbon for metabolism which liberates free As in groundwater. Organic matter plays a crucial role in reduction and dissolution of FeOOH. This is the most accepted theory worldwide [23].

7.3.3 Anion exchange of As with the phosphates

This theory suggests that Arsenic anions absorbed in the aquifer sediments (mostly to Iron oxyhydroxides) are replaced by the competitive exchange from phosphate which is available from the fertilisers used. This makes As free and releases it in the groundwater. Simple illustration of these reactions is given below in Figure 4(b) [24].

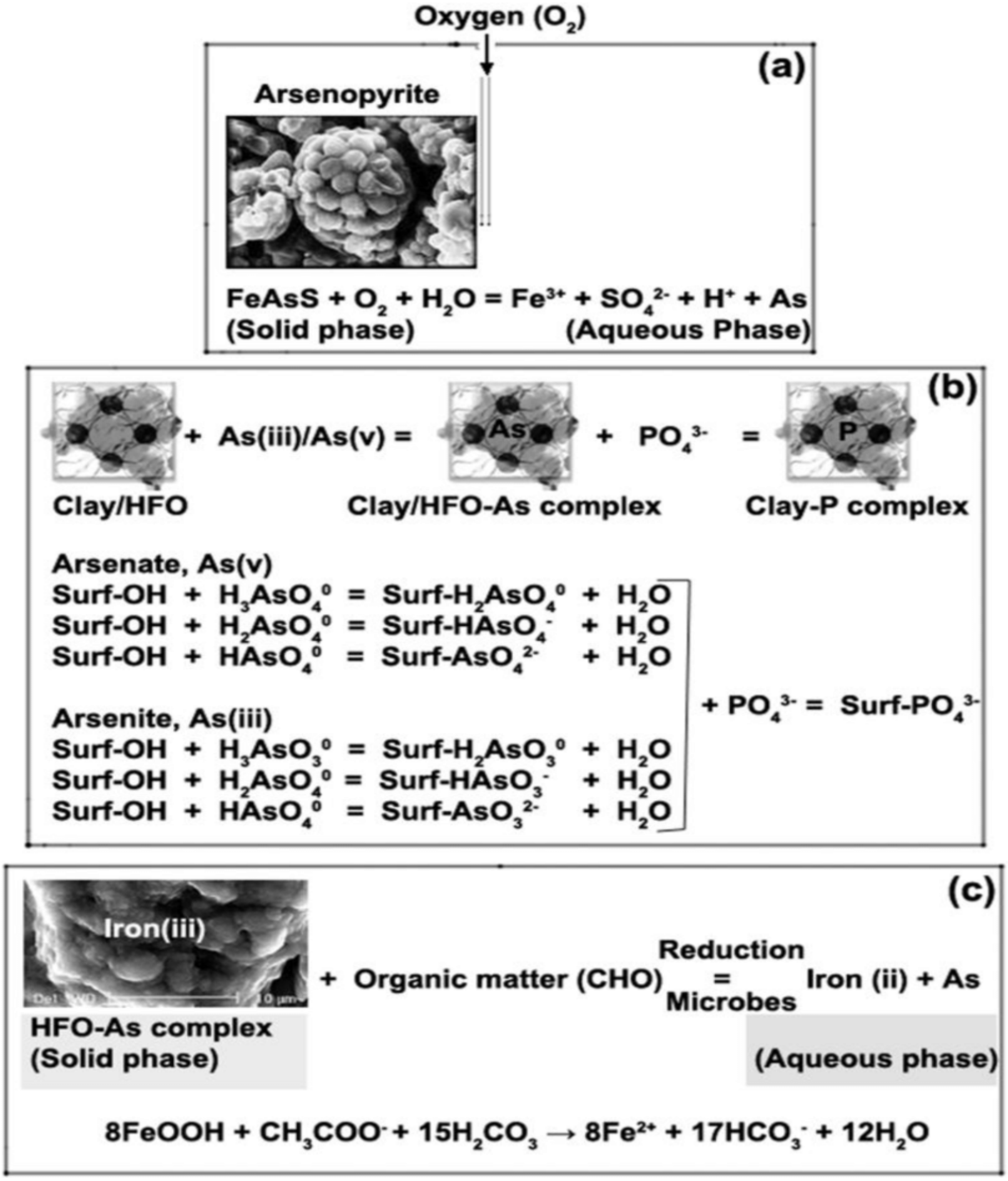


Figure 4. Schematic illustration of (a) arsenic-pyrites oxidation (b) competitive ion (phosphate) exchange (c) reductive dissolution of iron (oxy) (hydro)oxides hypotheses with possible chemical reactions. [21]

7.3.4 Self-organizing geochemical process

As is released by both oxidation and reduction in groundwater naturally. The Figure 5 gives a better illustration of this theory.

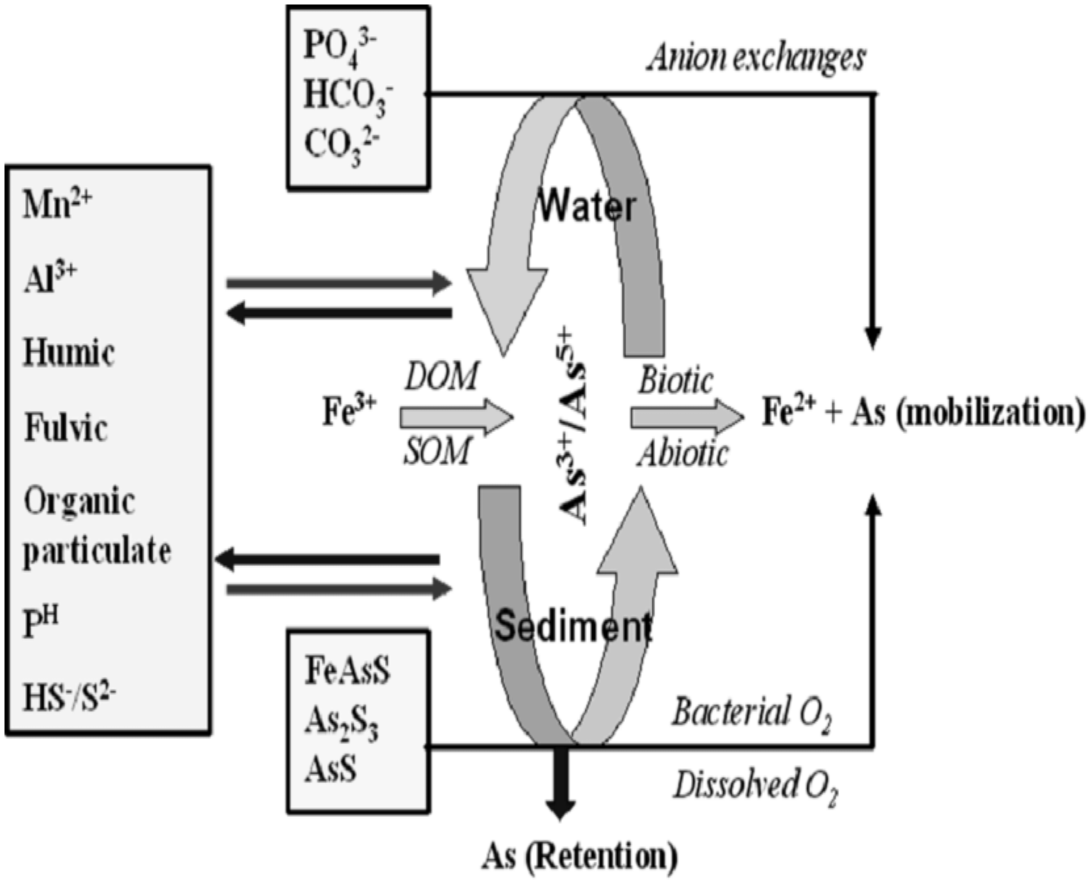


Figure 5. Geochemical process of As mobilisation in groundwater; DOM (Dissolved Organic Matter); SOM (Sedimentary Organic Matter).[21]

In case of Bengal Gangetic Plain, reductive dissolution of FeOOH is the most accepted hypothesis [25]. The oxidation of iron pyrite is a very common process and occurs more frequently and easily in groundwater, throughout the world. However, the amount of As released by oxidation of iron pyrite throughout the world is negligible compared to the amount of As released by other theories.

Arsenic is released in groundwater of Terai of Nepal naturally. The origin of As is geogenic which is further assisted by reductive dissolution of FeOOH. [26].

7.4 Guidelines of Arsenic value in drinking water

The accumulation of arsenic in lethal level in human body results in severe health conditions. Considering this, World Health Organisation (WHO) has set some guideline standards for arsenic concentration in drinking water. However, different nations have set different guideline for arsenic in drinking water as shown in Table 2.

Table 2. National standard of arsenic in drinking water in different countries [10]

Country	National Standard for As in drinking water(ppb)	Country	National Standard for As in drinking water(ppb)
Australia (1996)	7	Bangladesh (1997)	50
European Union	10	China	50
Japan (1993)	10	Nepal	50
Mongolia (1998)	10	India	50
Laos (1999)	10	Vietnam	50
USA (2001)	10	Sri Lanka	50
Canada (1999)	25	Cambodia	50
Philippines (1978)	50	Pakistan	50

The standard was set to 200 ppb, 50 ppb and 10 ppb in the year 1958, 1963 and 1993, respectively. Many countries have adopted 10 ppb as national standard while most of the developing countries have adopted 50 ppb as national standard. In Nepal the standard of 10 ppb is not feasible and it has been set to 50 ppb instead, due to lack of expertise, economic instability and technical insufficiency to maintain the standard of drinking water and to measure such a low concentration accurately.

7.5 Effects of Arsenic

Human beings are exposed to arsenic via soil, water, air and food. The inorganic As(III) arsenic is more lethal than organic As(V). The inorganic arsenic is the most significant contaminant in drinking water and is considered as carcinogen. Arsenic species found in water are shown in Table 3.

Table 3. Form of arsenic found in water [27]

Name	Abbreviation	Chemical formula
Arsenite	As^{III}	$As(OH)_3$
Arsenate	As^{V}	$AsO(OH)_3$
Monomethylarsonic acid	MMA^{V}	$CH_3AsO(OH)_2$
Monomethylarsonous acid	MMA^{III}	$CH_3As(OH)_2$
Dimethylarsinic acid	DMA^{V}	$(CH_3)_2AsO(OH)$
Dimethylarsinous acid	DMA^{III}	$(CH_3)_2AsOH$
Trimethylarsine oxide	TMAO	$(CH_3)_3AsO$

The limit of arsenic concentration permissible in drinking water is 50µg/l; however recommended concentration by WHO is 10µg/l. If it exceeds the limit, it can lead to severe health conditions in human beings. The effect is not only dependent on arsenic concentration in drinking water, but it also depends on the amount of arsenic consumed on a daily basis. Hair, nails and blood are the parts where arsenic can be found when accumulated in the human body. Arsenic is excreted via kidney and faeces. The effect of arsenic in human body is well illustrated by Figure 6.

Figure 6. Keratosis on hand (left) and Arsenic lesion on feet (right) [29]

The effects of arsenic on human health can be categorised into acute, subacute and chronic effects. The acute symptoms of arsenic poisoning are abdominal pain, vomiting, diarrhoea, cramping of muscles and death in severe cases. However, the prolonged exposure to arsenic results in thickening and discoloration of the skin, hyperkeratosis, partial paralysis, blindness, pulmonary and cardiovascular diseases. It also causes anaemia, leukopenia, and thrombocytopenia. Due to its carcinogenic effect, it leads to cancer such as skin, brain, liver, kidney and stomach. Apart from the carcinogenic effect, it has been found that there is a correlation between increased level of arsenic and spontaneous abortion and perinatal death [28].

8 Data Collection and Analysis

The data was collected from various sources in the time period between 2001 and 2007 AD. The data was collected by different authorities:

- DWSS (Department of water supply and sewerage)
- NRCS (Nepal Red Cross Society)
- NEWAH (Nepal Water for Health)
- UNICEF (United Nation International Children's Emergency Fund)
- RWSSP (Rural Water Supply and Sanitation Project)
- RWSSFDB (The Rural Water Supply and Sanitation Fund Development Board)
- Birgunj municipality
- Army

The data is very thorough and includes many details such as district, VDC, Community, well id, well type (i.e. dug well or suction tube well), well ownership, well usage, As concentration, depth used, As concentration category, and test used for analysing As concentration. The analysis was done in laboratory using different techniques. The HACH test, the biological test and the Indian field kit were some of the common techniques used to analyse As concentration in water sources.

The data was provided by a Finnish company named as Pohjavesikonsultointi Asko Vasarvuori Tmi. The data provided was analysed by using Excel.

9 Results

9.1 Arsenic concentration

A total of 689,185 samples were taken from different districts of Terai in Nepal. There were 13,266 samples with no data or As concentration mentioned as -1. The remaining samples were categorised in three different categories based on the arsenic concentration as shown in Figure 7.

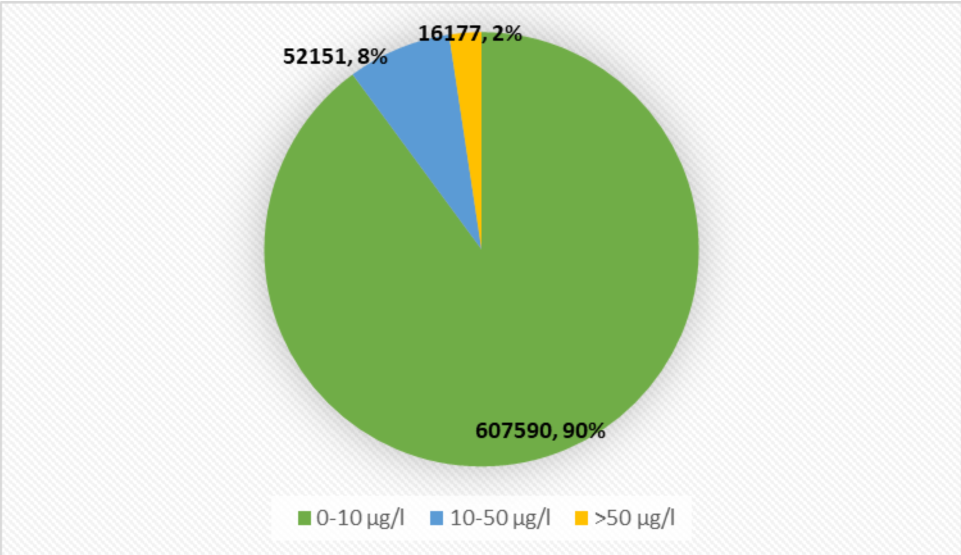


Figure 7. Overall As concentration in Terai

Out of the remaining 607,590 samples, almost 89.89% (607590 samples) had an As concentration between 0-10 µg/l. The next 7.71% of samples had As concentration between 10 to 50 µg/l. The remaining 2.39 % of water sources had an As concentration above 50 µg/l.

Table 4. Summary of district wise As concentration comparison

Districts	0-10 µg/l	10-50 µg/l	>50 µg/l	Total sample	Max As concentration (µg/l)	Average As concentration (µg/l)
Banke	748	84	11	843	270	5.12
Bara	34444	2689	1456	38589	350	4.94

Districts	0-10 µg/l	10-50 µg/l	>50 µg/l	Total sample	Max As concentration (µg/l)	Average As concentration (µg/l)
Bardiya	507	120	24	651	160	8.66
Chitwan	203	0	0	203	8	0.53
Dang	187	9	0	196	50	2.00
Dhanusha	54388	1724	419	56531	500	1.96
Jhapa	245	35	1	281	79	5.31
Kailali	74357	7009	2839	84205	770	5.09
Kanchanpur	47633	4365	1580	53578	500	4.98
Kapilvastu	36031	2508	1160	39699	1000	5.40
Mahottari	190	8	1	199	80	2.13
Morang	184	15	1	200	70	2.71
Nawalparasi	24136	3836	3704	31676	571	18.61
Parsa	26550	1598	671	28819	500	4.60
Rautahat	39351	8305	1084	48740	1007	7.75
Rupandehi	69950	2283	470	72703	500	1.94
Saptari	53070	2445	557	56072	210	2.60
Sarlahi	42905	6952	609	50466	215	5.36
Siraha	38608	5823	1172	45603	300	8.85

Districts	0-10 µg/l	10-50 µg/l	>50 µg/l	Total sample	Max As concentration (µg/l)	Average As concentration (µg/l)
Sunsari	63903	2343	418	66664	300	1.89

The exact number of tube wells and suction tube wells is still unknown in Nepal. Though Table 4 shows the 689,185 different wells and suction tube wells examined, there still might be some unregistered wells gone missing during this analysis. Nevertheless, most of the recognised water sources in these 20 districts of Nepal are mentioned in Table 4. The amount of water source examined varied from district to district. The districts with most samples was Kailali with 84205 water samples examined. The districts with least samples examined was Dang with only 196 water samples. In Rautahat, a sample was recorded with a high As concentration of 1007 µg/l. This concentration was measured in the private Suction Tube Well of a person named Bhikari Das. It was in Rajdevi VDC of Rautahat district. The data suggested that 7 people used this water source for drinking purpose. The district with highest arsenic concentration on average was Nawalparasi with an 18.61 µg/l. And the district with least arsenic concentration on average was Chitwan with 0.53 µg/l. The percent wise comparison of data is well illustrated in Figure 8.

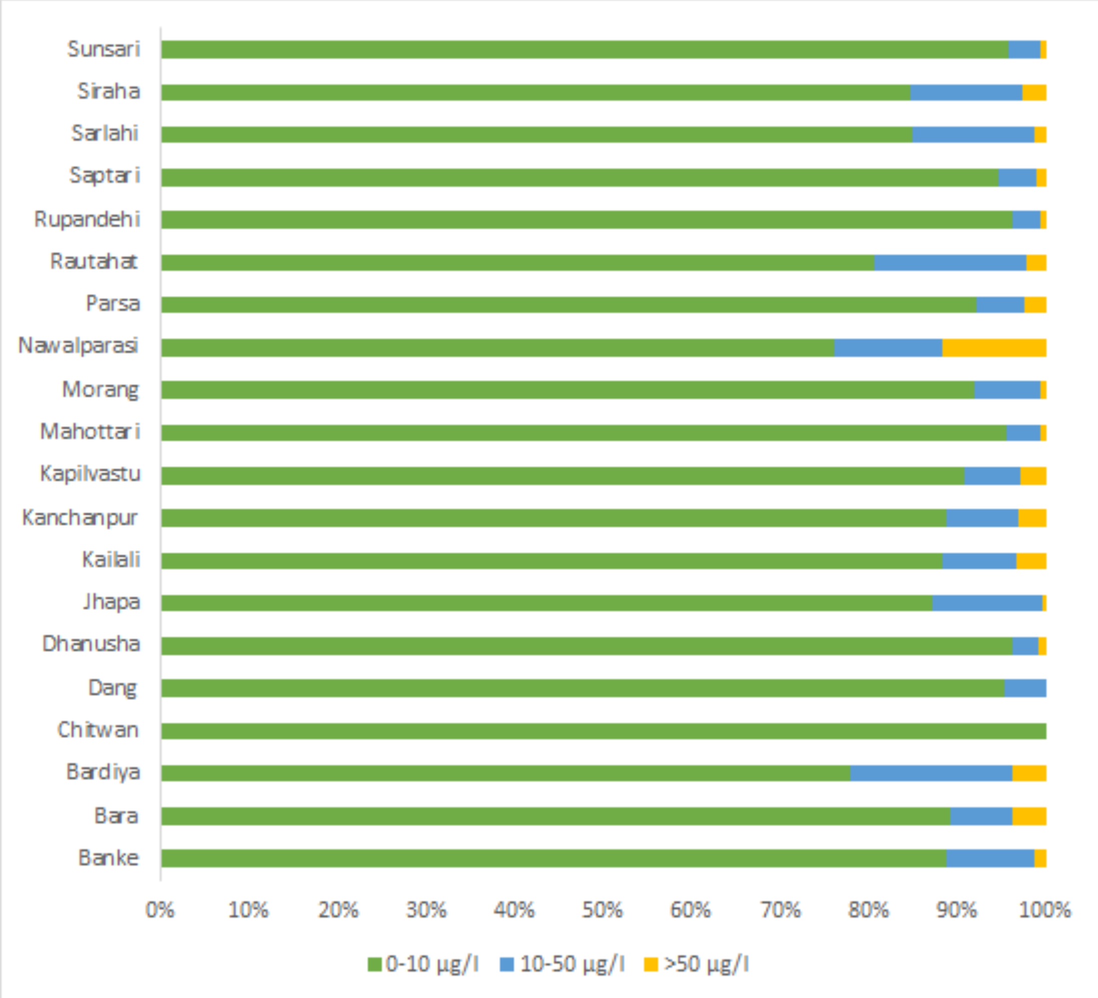


Figure 8. As concentration in analysed districts of Nepal

Figure 8 gives better idea on how contaminated water sources in different districts are. We can see from above that Nawalparasi was the most affected district. There were 31,676 wells tested in Nawalparasi. Among these tested wells, more than 11% of the water source had more than 50 µg/l while the other 12% had more than 10 µg/l. Only 76% of the total wells were under the regulation limit set by WHO (10µg/l). The other heavily contaminated (>10 µg/l) districts in descending order are Bardiya (22%), Rautahat (19%) and Siraha (15%). All the wells analysed in Chitwan districts measured less than 10 µg/l. The second least polluted district is Dang with only 4% of total samples above 10 µg/l of As concentration.

9.1.1 Nawalparasi: The largest concern

The results showed that water sources in Nawalparasi districts were the most contaminated among all the districts analysed in this thesis. Many researches indicated that As concentration is dependent on the depth of the well. So, the total water sources in Nawalparasi were divided into 5 categories based on their depth as in Table 5.

Table 5. Total samples of Nawalparasi districts divided in different depth ranges

Depths (m)	total samples	contaminated (>50 µg/l)	contaminated (10-50µg/l)	uncontaminated (0-10 µg/l)	Depth Percent (%)	Percent contaminated (%)
0-30	31038	3604	3696	23738	98.27	23.52
30-60	519	86	126	307	1.64	40.85
60-90	20	2	2	16	0.06	20
90-120	4	0	0	4	0.01	0
120+	2	0	1	1	0.01	50

From table 5, it can be seen that 23.52% of the total wells dug between 0-30 m were contaminated with As. Further, 40.85% of the wells dug between 30-60 m were contaminated with As. It can be found that 99.91% of the wells in this district were only 0-60 m deep, which indicates the presence of shallow aquifers. This could be one of the main reasons why the water sources were not free from Arsenic contamination.

9.1.2 Chitwan: the cleanest district

There were only 203 samples from constructed wells and suction tubes in this district. The depth of the well ranged from 0m to 30m. As per the researchers, the generally accepted theory is that the shallow aquifer is more contaminated with high concentration than deep aquifer which is not always true. Like in this case, even though the aquifers are in a shallow region, they are free from As contamination. Another possible reason for the water source in this district being free from As could be the geological setting of the district. The deep aquifer in this district starts as early as 20 m and ends at 120 m depth. In these depths, the sediments are mainly pebbles, boulders and cobbles dating back to Pleistocene age (2,588,000 to 11,700 years ago) [31]. These sediments are not rich in organic materials which can trap As absorbed in different forms of Iron oxides. The release of arsenic as hypothesized by McArthur [23] happens in reducing condition, by bacteria in presence of organic carbon. Hence, due to lack of organic carbon in the sediments around the groundwater of the Chitwan district, Arsenic cannot be released easily into the groundwater [31].

9.2 Relation between concentration of As and depth of Well

A graph was plotted between As concentration and well depth to see if As concentration was dependent on the depth from which water was extracted to drink. Literature review showed that As concentration was more in the shallow region (around 20-60 metres in depth) than in the deep aquifer (>60m). The contamination of As in groundwater decreased the deeper in the Earth's crust the well was located.

The graph was plotted and the following data were not included in the graph:

- Well depth denoted as -1 or below in the dataset has not been considered while making this graph.
- Well with As concentration 0 and below has not been considered while making this graph. There were 546,420 samples with As concentration mentioned as zero or below.

The graph was plotted of 142,765 samples with non-zero values which can be seen below:

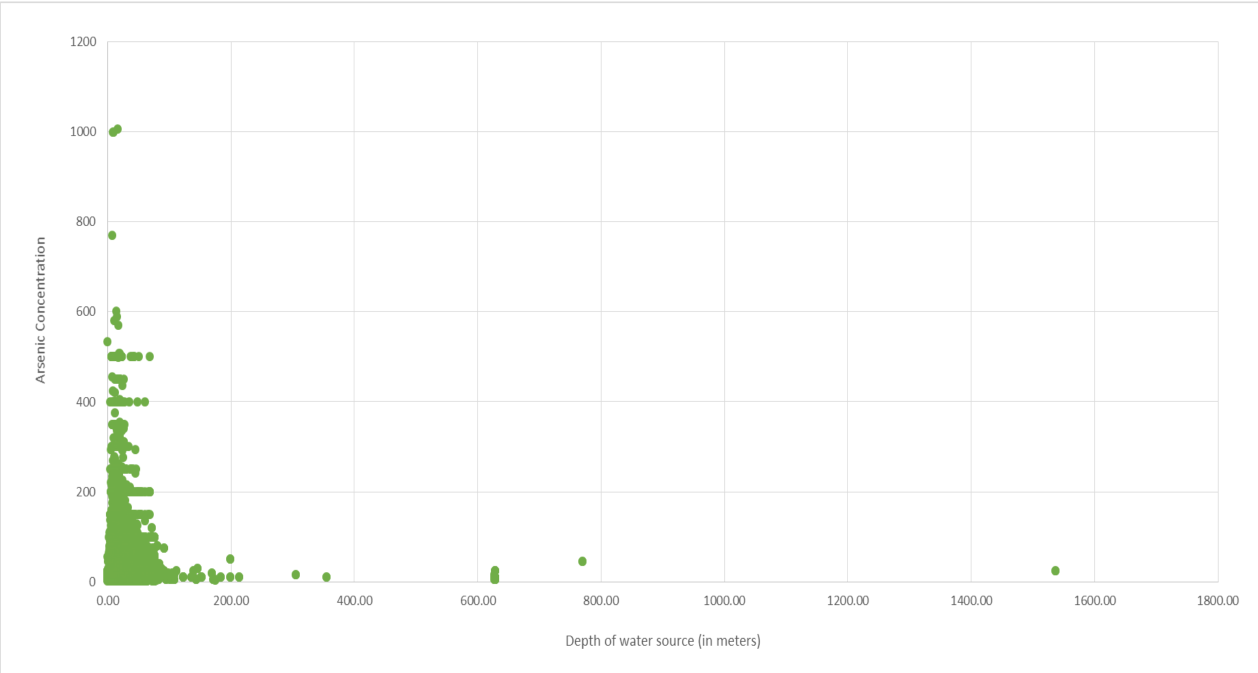


Figure 9. Plot between depth of well and their respective As concentration

Figure 9 shows that most of the wells within the depth of 0-60 meters have high Arsenic concentration. Arsenic concentration decreased as the depth of the well continued increasing to a certain depth and it started increasing again. A percentage-based graph was plotted to illustrate exactly how many samples were contaminated with As and how many were not. To define contamination, any well with As concentration more than 10 µg/l (a limit set by WHO) is termed as a contaminated water source. The graph can be seen below:

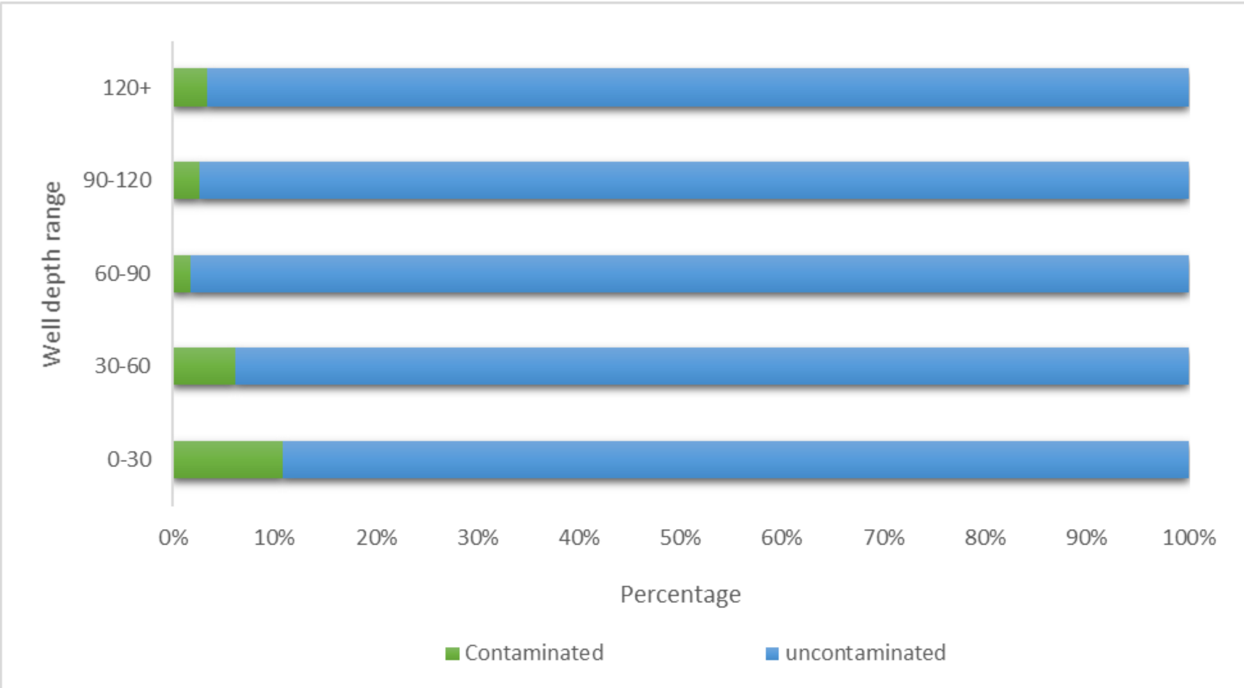


Figure 10. Percentage comparison of contamination (As > 10 µg/l) of water wells and their depths

It can be seen that the most of the As contaminated samples were in the depth range from 0-30 meters. Around 10.9% of the wells were contaminated with As and were harmful to human health and society (Appendix 1). The least contaminated wells were in the depth range from 60-90 meters in this case. Only 1.7% of the wells tested had arsenic present in them beyond the WHO limit of 10 µg/l. This meant that there was a probability that 17 out of the 1000 wells constructed in these depths range had chance of being contaminated with As concentration more than 10 µg/l.

Further, the average concentration of As in different well depths can be seen in Appendix 1. From Appendix 1, it can be seen that the average As concentration of the samples were least in depth range 90-120 m (1.2 µg/l) followed by depth range 60-90 m (1.4 µg/l) and 120+ m (1.6 µg/l). This suggested that any water source with a depth more than 60m and less than 120 m had a very low chance of having high As concentration in them.

Hence, it can be concluded that contamination of water with As is dependent on the depth of well. As contamination was at peak in the first few meters near the shallow water region and went on decreasing as the depth of well was increased.

9.3 Relation between the age of the well and the concentration of Arsenic

The graph of As concentration against well age was plotted and can be seen in Appendix 2. No conclusions could be drawn from that graph. So, a percentage wise bar graph was plotted to determine if there was any relation between the As concentration of the well and the age of the well. The well age was divided in 6 categories of 5-year interval which can be seen in Figure 11. The following data were excluded while plotting the graph:

- For the plot in Appendix 2, any well age beyond 40 years were not considered. Some of the wells were beyond 4000 years, which could not be fitted into a proper plot.
- For some wells, the age was not mentioned at all and some were mentioned -1. So, these were excluded in the graph.

Figure 11 is a percentage-wise comparison of wells by their age as it gives better illustration if there is any correlation between age of the well and As concentration.

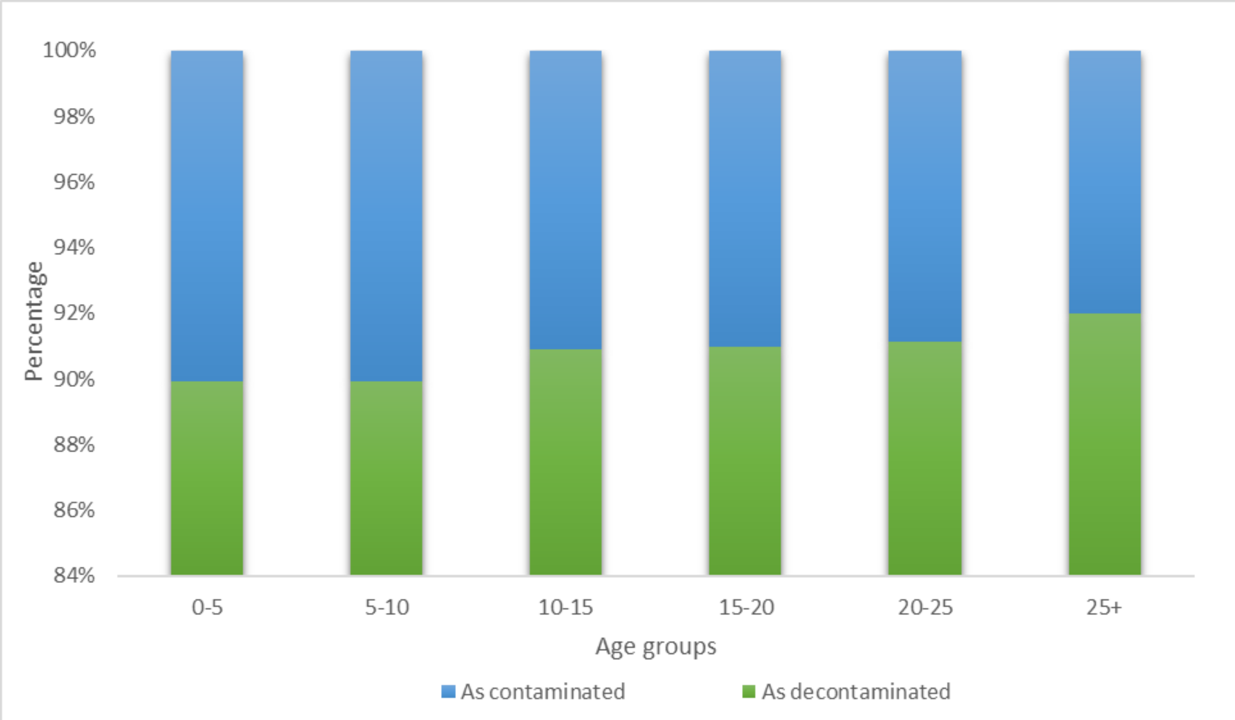


Figure 11. Percentage comparison of contamination and well age

It can be seen from the figure 11 that around 8-10% of the total samples were contaminated with As and were unsafe for drinking. The concentration of As in these wells exceeded 10 µg/l (WHO limit for safe drinking water). And this was valid to all the age groups. The average concentration of each age group was also in between 4 to 5 µg/l. This suggests that there is no relation between age of the well and As contamination in them.

9.4 As concentration and overexploitation of water resources

Overexploitation can be defined as utilising a renewable source to an extent that it results in a very low return. In this case, overexploitation of an aquifer can be defined as continuous harvesting of water from a single drinking source by a huge group of people. The total samples were divided in 5 different categories based on the number of people using it to determine if the As concentrations of the wells were dependent on the amount of people using it. There were 13,266 samples with As concentration mentioned as -1. These samples were not included in the results. Apart from that, there were samples where the number of people using the well was indicated as -1. There were 5499 wells which such a value. These were also not included in the analysis. The results of the remaining wells can be seen in Table 6:

Table 6. Population distribution affecting the As concentration

Population usage group	Total samples	Uncontaminated (<10 µg/l)	Contaminated (>10 µg/l)	Percent contaminated (%)
0-5	165746	150791	14955	9.02
6-10	314499	283883	30616	9.73
11-15	79963	71383	8580	10.73
16-20	35025	30915	4110	11.73
21-100	75249	8203	57046	12.57
100+	10206	1264	8942	12.38

Table 6 indicates that there was a slight increase in the number of samples contaminated as the number of users increased gradually. It demonstrates that overexploitation alters the As concentration in the water. A graph was plotted to further illustrate that overexploitation of an aquifer increases the As contamination in water. The graph can be seen below:

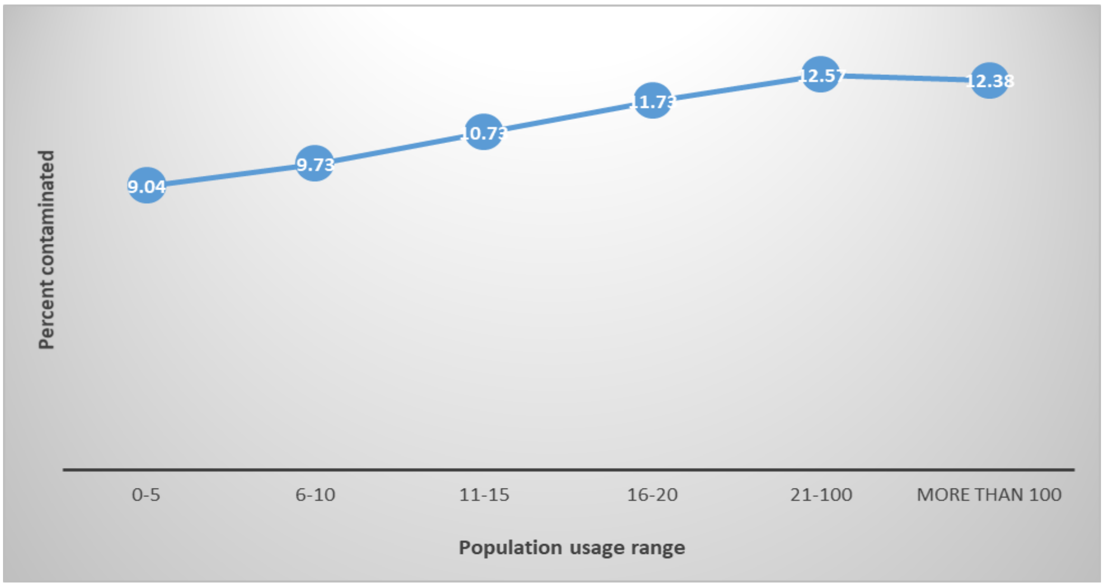


Figure 12. Percentage of Contaminated samples for different population group

Here, Figure 12 suggests that the percentage of arsenic contamination increases with the increase in population using the water source.

9.5 Ownership comparison: Public vs Private

In this analysis, private and public wells were compared to see if one of them was more contaminated than the other one. There were 317 samples whose ownership type was mentioned as -1. There were 652 samples whose ownership type was not mentioned. The total wells analyzed were 674951 which can be seen in the Table 7.

Table 7. Ownership comparison

Ownership type	Private	Public
Total samples	602759	72192
0-10 (µg/l)	542714	64021
10-50 (µg/l)	45825	6222
50+ (µg/l)	14220	1949
Percent contaminated (%)	9.96	11.32
Average As concentration (µg/l)	4.83	6.48

There were 602759 private wells and the remaining 72192 were public wells. Table 7 shows that 11.32% of the public wells were contaminated while 9.96% of private wells were contaminated. This suggests that there is 2.36% more chance of public wells being contaminated with As than private wells. Also, the average public well (6.48 µg/l) concentration was more than private wells (4.83 µg/l).

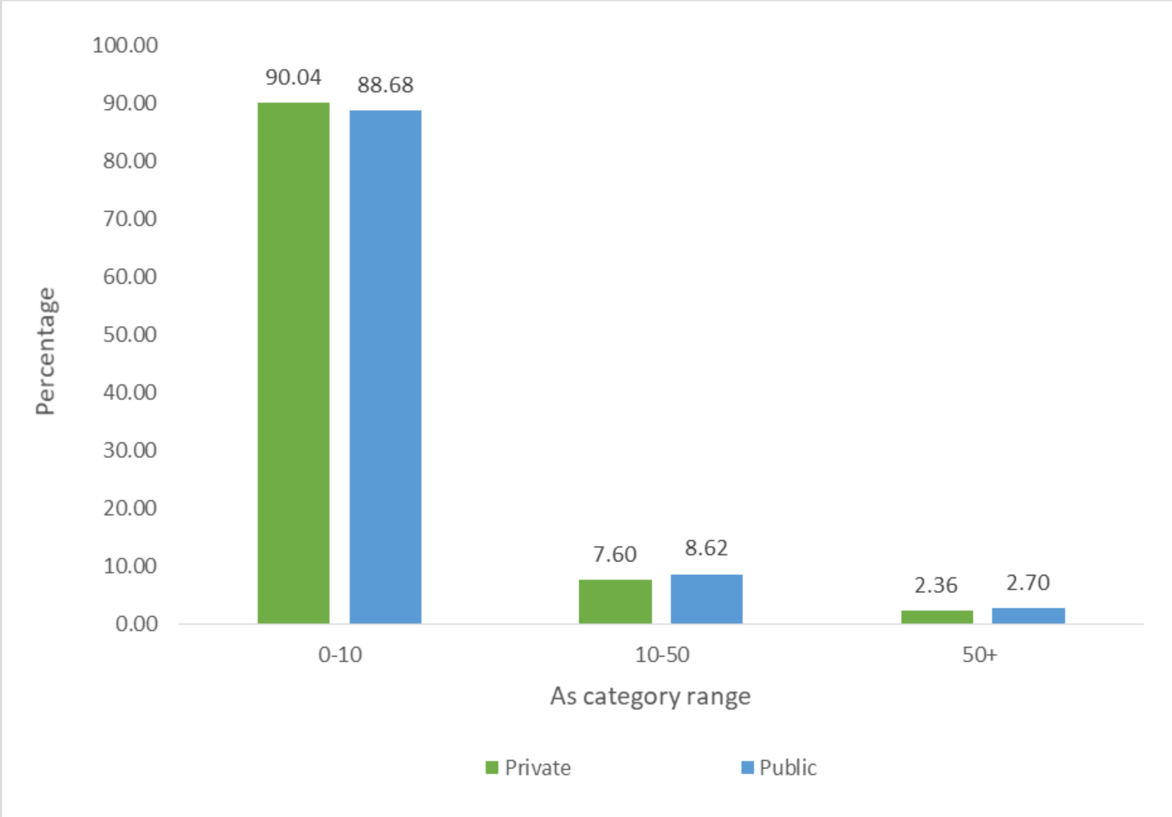


Figure 13. Ownership comparison (Public vs Private)

Figure 13 shows the percentage comparison of private wells and public wells with different As category labels. It can be seen that 90.04% of the private wells have an As concentration between 0-10 µg/l while 88.68% of the public wells have a concentration between 0-10 µg/l. Similarly, 7.6% of private wells have an As concentration between 10-50 µg/l while 8.62% of public wells have a concentration between 10-50 µg/l. Further, 2.36% of private wells have an As concentration more than 50 µg/l while 2.7% of public wells have an As concentration more than 50 µg/l. It can be concluded that public wells were more contaminated than private wells.

Table 8. Population distribution as per ownership type

Well ownership	Public	Private
Number of people	3635729	6953069
Number of people per well	50.36	11.53

Table 8 shows that there were 3,635,729 peopled dependent on public wells while another 6,953,069-people dependent on private wells. On average, around 50 people are dependent on one public well while at least 11 people are dependent on one functional private well for drinking purposes. There is a continuous use of public wells which damages groundwater quality. It has already been established in the previous section that overexploitation can lead to more As contamination in ground water. Hence, analyzing the dependence of people on an individual well suggests that these public wells might have been contaminated with As because of overexploitation.

9.6 Effects of users type and As contamination

There were 317,721 samples whose user types were not mentioned at all. There were 13266 samples whose As concentration were mentioned as -1. These data were not included in this analysis. The results can be seen in Table 9.

Table 9. Breakdown of user types and As contamination in them.

Users type	Total samples	0-10 µg/l	10-50 µg/l	>50 µg/l	Percentage of contamination (%)	Average contamination (µg/l)
Business	467	438	21	8	6.21	3.11
College	45	43	1	1	4.44	2.00
Community	20602	19525	856	221	5.23	2.41
GO/NGO	6390	606	33	0	5.16	3.30
Health Institution	160	146	14	0	8.75	3.13
Household	322434	296195	18761	7478	8.14	4.45
Not in use	27	27	0	0	0.00	0.37
Office	22	17	3	2	22.73	22.1
Religious Institutions	828	752	47	29	9.18	4.89
School	1996	1840	108	48	7.82	3.67
School/College	112	88	17	7	21.43	12.6
Unknown	10865	9595	1075	195	11.69	4.82

From the Table 9, it can be seen that most of the wells are used for household purposes. There were 322,434 wells used for household purposes. 8.14% of the total household wells were contaminated with As. There were 27 wells which were not in function. None of these nonfunctional wells had any As contamination in them. 22.73% of the total wells used in office were contaminated with As. The average contamination of wells used in offices was 22.1 µg/l. 21.43% of the total wells used in the school/college were contaminated with As. The average contamination of wells used in school/college was 12.6 µg/l. These were the most contaminated two user types. The college wells were found to be the least contaminated. Only 4.44% of the wells were contaminated with As. The average As concentration of these wells was 2.00 µg/l.

9.7 Population Affected

According to census 2011, there are more than 13 million people living in Terai region of Nepal. The data showed that 10,652,245 people consumed water from Suction tube well and Dug well. A slightly over 3 million used tap water or other source for drinking purpose.

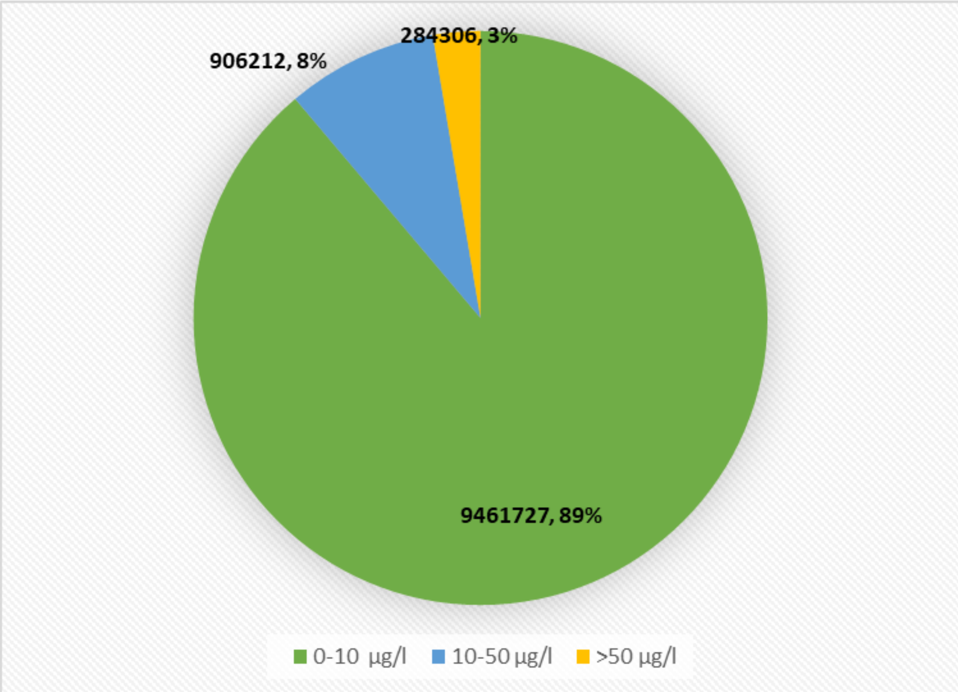


Figure 14. Population consuming water from different contaminated sources

It can be seen from Figure 14 that around 89% of people consumed water from water sources which were not contaminated with As. The remaining 11% of people were drinking water from hugely affected sources. There were 284,306 (3%) people at risk of consuming water whose As concentration was beyond 50 µg/l. These people were at huge risk of suffering from arsenicosis, skin diseases and skin cancer.

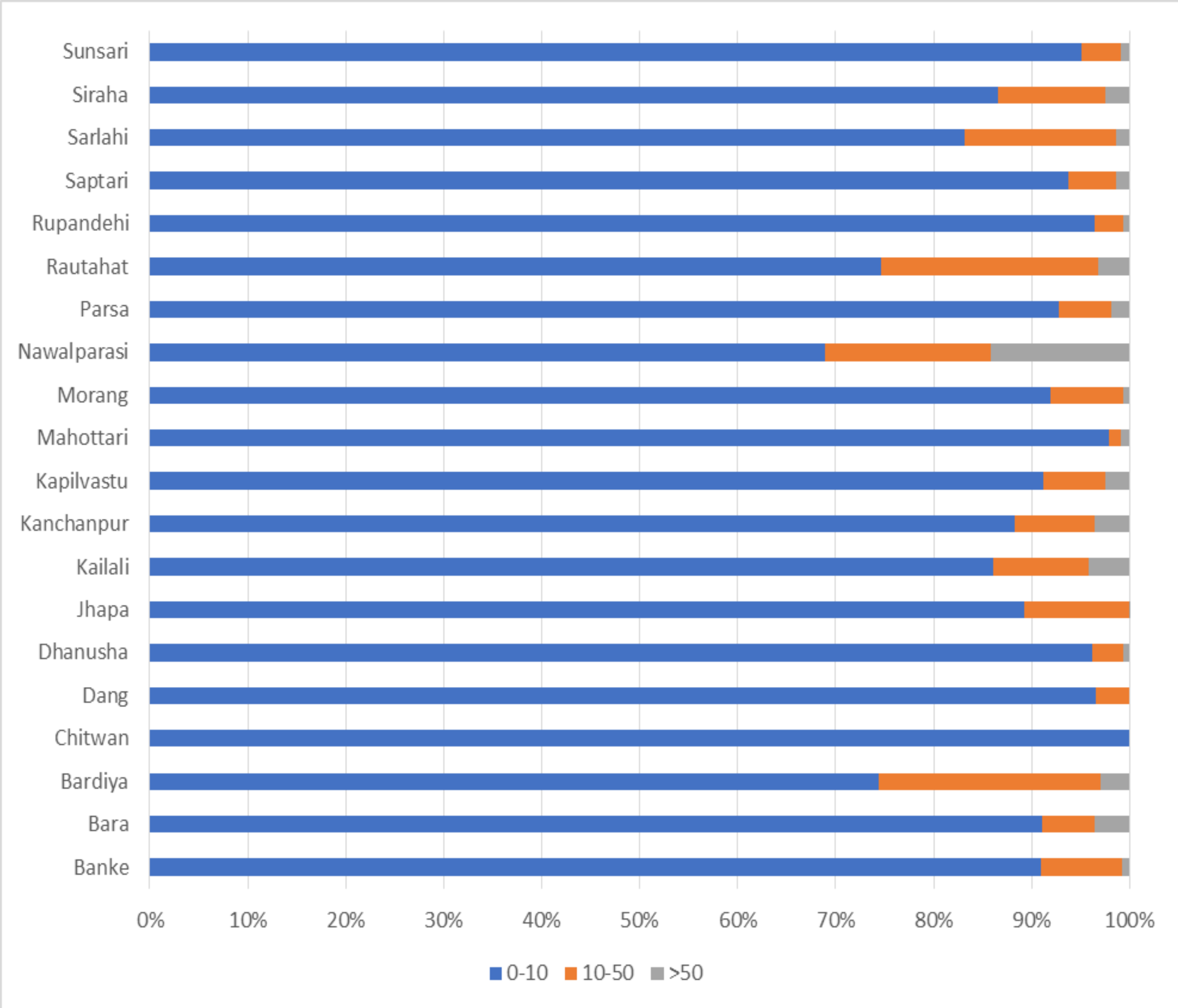


Figure 15. District wise population affected by contaminated sources

Most people were affected in Nawalparasi district as it was the district with the most polluted water source. It can be seen from the graph above that more than 30% residents of Nawalparasi districts were at risk of drinking water from contaminated sources. They were relying on water source with As contamination more than 10 µg/l. Among these 30% people, around 14% people were drinking water from water sources with As contamination more than 50 µg/l. People were in serious danger of suffering from various disease caused by higher amount of As in water. Similarly, in districts such as Bardiya and Rupandehi more than 25% population were prone to dangerous drinking water conditions. Further, more than 4% population in Kailali were exposed to very dangerous drinking water conditions (As concentration >50 µg/l) whereas in districts such as Rautahat, Bara, Bardiya and Kanchanpur, more than 3% population were prone to heavy contaminated water sources (As concentration >50 µg/l) (Appendix 4).

10 Conclusion

More than 90 % of people living in the Terai region are dependent on constructed groundwater as their primary source for drinking water. Since 1999, contamination of As in drinking water has been a major concern. Most of the wells with depths between 0-50 m have been highly contaminated with As. These wells have only reached the depth of shallow aquifer (<50 m.). However, in many other wells originating from shallow aquifers, there were no trace of As. This may be due to the geological setting of that respective place. Nevertheless, it can be concluded that As concentration decreases with the increase in depth. Further, it can be seen that wells constructed in different years are equally contaminated with As. There is no conclusive evidence to suggest that newly constructed wells are less contaminated than old wells and vice versa. In addition to that, we can see that the As concentration is also influenced by the number of people using it. More people exploiting a single water source leads to a higher As concentration. It was further proved by the analysis done between private and public wells where public wells with more users (6,953,069) was found to be more contaminated than private wells with 3,635,729 users. Hence, public wells are being overexploited and over-contaminated. Based on user types, wells used in offices, schools and colleges were the most contaminated.

This thesis includes an analysis of water wells from all the 20 districts situated in Terai region of Nepal. The district with most unsafe drinking water is Nawalparasi. And the district with safest drinking water is Chitwan. The situation in other districts is poor as well. Overall, 3% of the total wells analyzed have As concentration more than 50 μg/l, while another 8% has an As concentration between 10-50 μg/l. Only 89% of the wells have an As concentration less than 10 μg/l. Similarly, more than 1.2 million people are affected by these highly contaminated wells (>10 μg/l). They are subjected to harmful drinking water and the diseases caused by excessive As intake such as arsenicosis, skin cancer, lung cancer and others.

Research has shown that the origin of As in groundwater of Nepal is geogenic. Further, anthropogenic sources such as pesticides and fertilizers release As in soil and groundwater. Hence, intensive study of geological features and anthropogenic activities of the Terai region can assist in establishing a more reliable source of As contamination in groundwater.

11 Mitigation techniques

The possible mitigation measures for arsenic contamination can be explained as follows:

1. Construction of deeper well

Underground water drawn from shallow aquifer are always at risk of being contaminated with As. Hence, the construction of well at arsenic free depth can decrease the risk of arsenic contamination in underground water.

2. Rain water harvesting

In case of Nepal about 80% of rainfall occurs during monsoon (i.e. 4 months in a year). Rain water harvesting can be an alternative for groundwater in Terai region at least for one third of the year. However, rainwater harvesting can be used for a long term if enough research and investment is done in rain water storage for long period of time.

3. Identification and rehabilitation

The arsenic prone areas should be identified. This can be done by introducing a proper mapping of arsenic contaminated aquifers. The construction of a well should be prohibited in such areas. In case the well is identified as contaminated, the further use of the well for drinking and other purposes should be banned as soon as possible.

4. Use of different filters

Using different kind of filters can help to remove As from drinking water. Based on surveys and research, some economically viable arsenic treatment systems have been developed and practiced in many developing countries including Nepal. Some of them are explained below:

a. Gagri filters

The Gagri filter consists of three layers of earthen pots. They are placed on top of each other vertically. There are holes in the middle and top pot. The top layer is composed of a line of polyester cloth, coarse sand, iron nails and raw water. The middle layer consists of a layer of polyester cloth, fine sand, brickbats, and charcoal. The pure clean water is collected by the bottom pot. This filter could remove 95% of As. However, this filter has some drawbacks like high iron concentration in the collected water due to microorganism's growth. [30]

b. Bio-sand filters

Bio-sand filters also known as Kanchan Arsenic Filters in Nepal, is based on slow sand filtration and Fe-hydroxide adsorption principle. The process is completed in three stages: aeration, adsorption and filtration. The filter is made up of locally available products like plastics, iron nails, gravel, brick pieces, sand, and pvc pipes. In bio-sand filters, iron nails are exposed to air and water which causes the quick formation of layer of iron oxide (rust) over the nails. Excess rust is released and forms a film over sand. When contaminated water is poured, it flows past the nails and then to the sand layer, arsenic present in water gets adsorbed onto iron oxide and is trapped in the sand surface due to straining. The new iron surfaces are created, for additional arsenic adsorption. KAF also removes pathogens. Dissolved iron is removed through aeration leading to precipitation. The filtered water is then pushed out to a storage container. KAF can remove 85%-90% As. [30]

12 Recommendations

1. Blanket testing is a very important step in identifying the As contaminated wells. Such testing should be done on a regular basis for better monitoring of As concentration in different water sources, food, soil and sediments.

2. The local, national and international organizations should act jointly to resolve and assess this issue. Awareness programme should be conducted to educate people about As, its impact on human health and consequences.

3. Highly contaminated water sources should be completely sealed. The further use of such sources for drinking and irrigation purposes should be banned as well.

4. As concentration should be tested before any new well is constructed for drinking purpose. The focus should be shifted towards alternative sources of drinking water and water quality improvement. People should be encouraged to use arsenic filters to purify water.

References

[1] Shrestha, R.K., Regmi, D., and Kafle, B.P. 2014. Seasonal variation of arsenic concentration in groundwater of Nawalparasi district of Nepal. Int. J Appl. Sci. Biotechnol. 2(1): 59–63. doi:10.3126/ijasbt.v2i1.9477.

[2] Yadav, I.C., Dhuldhaj, U.P., Mohan, D., and Singh, S. 2011. Current status of groundwater arsenic and its impacts on health and mitigation measures in the Terai basin of Nepal: An overview. Environ. Rev. 19: 55–67. doi:10.1139/ a11-002.

[3] Michael, HA., and Voss, CI. (2008). Evaluation of the Sustainability of Deep Groundwater as an Arsenic-Safe Resource in the Bengal Basin. *Proceedings of the National Academy of Sciences of the United States of America, 105*(25), 8531-8536. Retrieved from http://www.jstor.org/stable/25462820

[4] (n.d.). Natural organic matter in sedimentary basins and its relation to arsenic. Retrieved April 21, 2019, from https://www.sciencedirect.com/science/article/pii/S088329270400054X).

[5] (n.d.). Participatory Governance and Inter-sector Coordination ... - CiteSeerX. Retrieved April 21, 2019, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.663.3679andrep=rep1andtype=pdf

[6] Centeno, Jose and Tseng, Chin-Hsiao and Voet, Gijsbert and Finkelman, Robert. (2007). Global Impacts Of Geogenic Arsenic: A Medical Geology Research Case. Ambio. 36. 78-81. [Accessed at 10th Feb, 2019]

[7] Freeworldmaps.net. (2019). *Nepal Physical Map*. [online] Available at: http://www.freeworldmaps.net/asia/nepal/map.html [Accessed 12 Mar. 2019].

[8] En.wikipedia.org. (2019). *Geography of Nepal*. [online] Available at: https://en.wikipedia.org/wiki/Geography_of_Nepal [Accessed 21 Feb. 2019].

[9] Barbara M. 2017. Arsenic in groundwater in the southern lowlands of Nepal and its mitigation options: a review [online]. Available at: http://www.barbara-himalaya.ch/environmental-reviews-2017.pdf [Accessed 10 Mar. 2019].

[10] Panthi S, Sharma S, Mishra A, 2006. Recent Status of Arsenic Contamination in Groundwater of Nepal - A Review [Online]. Available from: http://www.ku.edu.np/kusetjournal/second_issue/s2/Sudan.pdf [Accessed 22 April 2019].

[11] Apps.who.int. (2019). [online] Available at: https://apps.who.int/iris/bitstream/handle/10665/128871/SEA_RC54_8%20done.pdf?sequence=1andisAllowed=y [Accessed 13 Apr. 2019].

[12] En.wikipedia.org. (2019). *Terai*. [online] Available at: https://en.wikipedia.org/wiki/Terai [Accessed 2 Apr. 2019].

[13] Yadav, Ishwar and Dhuldhaj, Umesh and Mohan, Devendra and Singh, Surendra. (2011). Current status of groundwater arsenic and its impacts on health and mitigation measures in the Terai basin of Nepal: An overview. Environmental Reviews. 19. 55-67.

[14] Guillot, S., Garçon, M., Weinman, B., Gajurel, A., Tisserand, D., France-Lanord, C., et al. 2015. Origin of arsenic in Late Pleistocene to Holocene sediments in the Nawalparasi district (Terai, Nepal). Environ. Earth Sci.

[15] Kansakar, D.R. 2004. Geologic and geomorphologic characteristics of arsenic contaminated groundwater area in Terai, Nepal. In Arsenic testing and finalization of groundwater legislation project, summary project report. Edited by D.R. Kansakar. Department of Irrigation, Lalitpur, Nepal, HMG/Nepal, pp. 85–96.

[16] Sharma, R.M. 1999. Research study on possible contamination of groundwater with arsenic in Jhapa, Morang, and Sunsari districts of Eastern Terai of Nepal. Report of WHO Project, DWSS Government of Nepal.

[17] Lenntech.com. (2019). Arsenic (As) - Chemical properties, Health and Environmental effects. [online] Available at: https://www.lenntech.com/periodic/elements/as.htm [Accessed 22 Apr. 2019].

[18] Badal, M. and Kazuo, S. (2019). Arsenic round the world: a review. [online] Citeseerx.ist.psu.edu. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.530.2444andrep=rep1andtype=pdf [Accessed 22 Apr. 2019].

[19] Lenntech.com. (2019). *Arsenic (As)* - Chemical properties, Health and Environmental effects. [online] Available at: https://www.lenntech.com/periodic/elements/as.htm [Accessed 22 Apr. 2019].

[20] Lenntech.com. (2019). Arsenic (As) - Chemical properties, Health and Environmental effects. [online] Available at: https://www.lenntech.com/periodic/elements/as.htm [Accessed 22 Apr. 2019].

[21] Tareq S, Islam, SMN, Rahmam MM and Chowdhury DA. (2010). Arsenic Pollution in Groundwater of Southeast Asia: an Overview on Mobilization Process and Health Effects. Bangladesh Journal of Environmental Research,. 8. 47-67.

[22] Das, D., Samanta, G., Mandal, B.K., Chowdhury,T.R., Chanda, C.R., Chowdhury, P.P., Basu, G.K., and Chakraborti, D. (1996) Arsenic in groundwater in six districts of West Bengal, India. Environmental Geochemistry and Health, 18(1), 5 - 15.

[23] McArthur, J.M., Banerjee, D.M., Hudson-Edwards, K. A. Mishra, R. Purohit, R. Ravenscroft, P. Cronin, A., R Howarth, J., Chatterjee, A., Talukder, T., Lowry, D., Houghton, S. and K. Chadha, D. (2004) Natural organic matter in sedimentary basins and its relation to arsenic in anoxic groundwater: the example of West Bengal and its worldwide implications. Appl. Geochem. 19, 1255 - 1293.

[24] Acharyya, S.K. (2002) Arsenic contamination in groundwater affecting major parts of southern West Bengal and parts of western Chhattisgarh: source and mobilization process. Current Science, 82(6), 740 - 44.

[25] Panthi, R.S., Sharma, S., and Mishra, K.A. 2006. Recent status of arsenic contamination in groundwater of Nepal — A review. Kathmandu Univ. J. Sci. Eng.Technol. 2(1): 1–11.

[26] Pokhrel, D, Bhandari, B S and Viraraghavan, T. 2009. Arsenic contamination of groundwater in the Terai region of Nepal: an overview of health concerns and treatment options. Environ Int, 35(1): 157–161.

[27] Monographs.iarc.fr. (2019). [online] Available at: https://monographs.iarc.fr/wp-content/uploads/2018/06/mono84-6A.pdf [Accessed 22 Apr. 2019].

[28] Water, N. (2019). Health Effects of Arsenic. [Online] Ncbi.nlm.nih.gov. Available at: https://www.ncbi.nlm.nih.gov/books/NBK230891/ [Accessed 22 Apr. 2019].

[29] (wilson5@fas.harvard.edu), R. (2019). *Arsenic website project (pictures)*. [Online] Wilsonweb.physics.harvard.edu. Available at: http://wilsonweb.physics.harvard.edu/arsenic/pictures/arsenic_project_pictures2.html [Accessed 22 Apr. 2019].

[30] Shrestha, B.R., and Shrestha, K.B. 2004. Spatial distribution of arsenic concentration in groundwater in the Terai, Nepal. In Summary Project Report. Edited by D.R. Kansakar. Department of Irrigation, Lalitpur, Nepal, HMG/ Nepal, pp. 85–96.

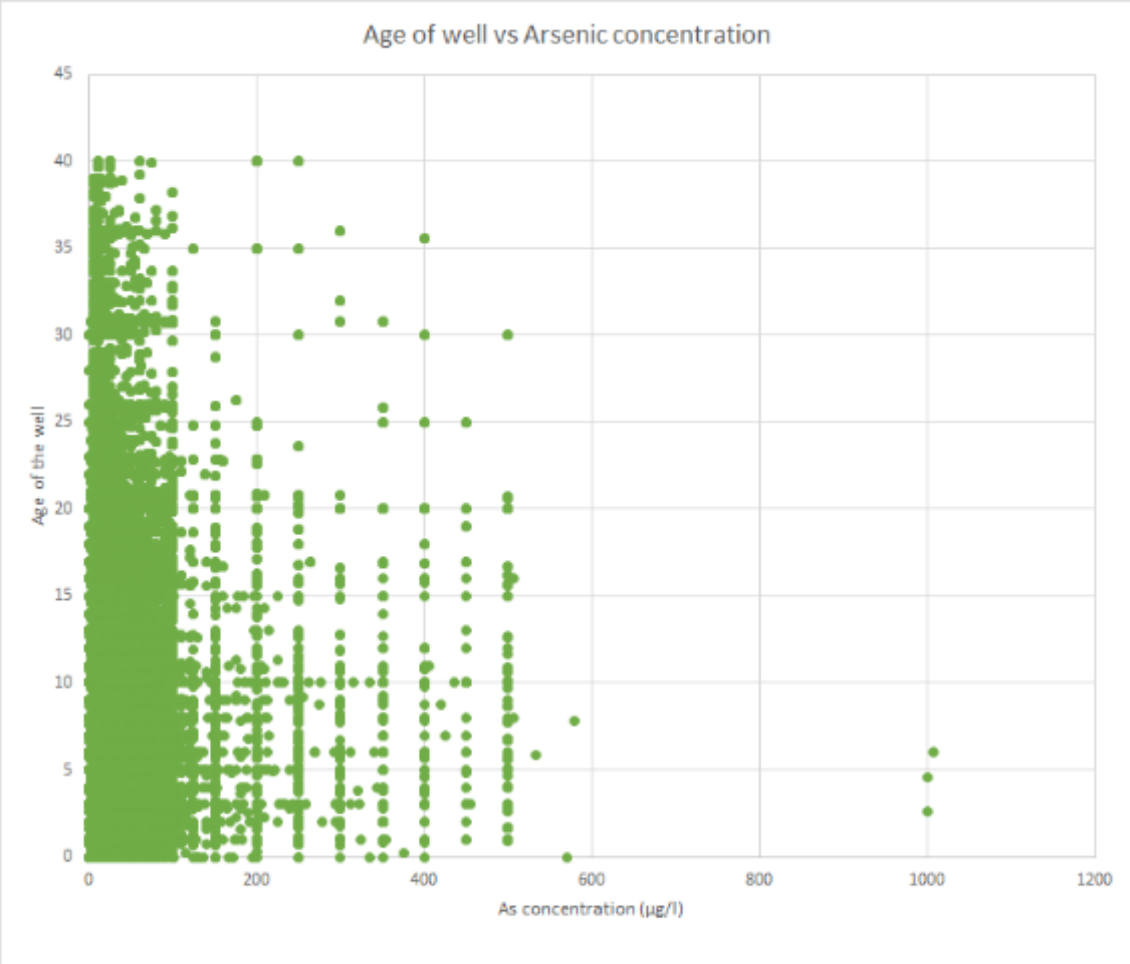
[31] Morris, B.L., Seddique, A.A., Ahmed, K.M., 2003. Response of the Dupi Tila aquifer to intensive pumping in Dhaka, Bangladesh. Hydrogeol. J. 11, 496–50

Appendix

Appendix 1 - Detailed analysis of depth of water source and As contamination

				in percentage			
Range (meters)	total samples	Contaminated samples	without As concentratior	total	uncontaminated	contaminated	average As concentration (µg/l)
0-30	574441	62332	512109	100	89.1	10.9	5.4
30-60	85967	5344	80623	100	93.8	6.2	2.9
60-90	10159	174	9985	100	98.3	1.7	1.4
90-120	312	8	304	100	97.4	2.6	1.2
120+	293	10	283	100	96.6	3.4	1.6
total	671172	67868	603304				

Appendix 2 - Plot between age of water source and As concentration



Appendix 3 - Summarised results of different Age groups of well and As contamination

age group	total	As decontaminated	10-50	>50	As contaminated	% contaminated	average concentration
0-5	225603	202830	17629	5144	22773	10.09428066	4.88
5-10	214795	193166	16723	4906	21629	10.06960125	4.92
10-15	104532	94998	7223	2311	9534	9.120652049	4.52
15-20	36058	32803	2412	843	3255	9.027122969	4.72
20-25	17259	15728	1138	393	1531	8.87073411	4.51
25+	14609	13440	857	312	1169	8.001916627	4.04
	612856						

Appendix 4 - District wise analysis of population drinking water from various contaminated sources

A	B	C	D	E	F	G	H	I	J
Districts	0-10	populatior	10-50	populatior	>50	populatior	total	total population	
Banke	748	34407	84	3121	11	292	843	37820	
Bara	34444	873399	2689	51815	1456	34221	38589	959435	
Bardiya	507	33894	120	10338	24	1368	651	45600	
Chitwan	203	6631	0	0	0	0	203	6631	
Dang	187	6426	9	227	0	0	196	6653	
Dhanusha	54388	783315	1724	26038	419	4986	56531	814339	
Jhapa	245	9665	35	1156	1	10	281	10831	
Kailali	74357	876926	7009	98743	2839	43147	84205	1018816	
Kanchanpu	47633	510611	4365	47285	1580	20518	53578	578414	
Kapilvastu	36031	650333	2508	44775	1160	17762	39699	712870	
Mahottari	190	32112	8	400	1	300	199	32812	
Morang	184	11791	15	959	1	80	200	12830	
Nawalpara	24136	308662	3836	75480	3704	63662	31676	447804	
Parsa	26550	793038	1598	46171	671	15630	28819	854839	
Rautahat	39351	616569	8305	183718	1084	26057	48740	826344	
Rupandehi	69950	973024	2283	30325	470	6171	72703	1009520	
Saptari	53070	786093	2445	40941	557	11843	56072	838877	
Sarlahi	42905	698175	6952	130143	609	11626	50466	839944	
Siraha	38608	632079	5823	79751	1172	18433	45603	730263	
Sunsari	63903	824577	2343	34826	418	8200	66664	867603	
	607590	9461727	52151	906212	16177	284306	675918	10652245	