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Review

Arsenic Contamination of Groundwater in Nepal—An Overview

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Abstract: In Nepal, arsenic (As) contamination is a major issue of current drinking water supply systems using groundwater and has recently been one of the major environmental health management issues especially in the plain region, *i.e.*, in the Terai districts, where the population density is very high. The Terai inhabitants still use hand tube and dug wells (with hand held pumps that are bored at shallow to medium depth) for their daily water requirements, including drinking water. The National Sanitation Steering Committee (NSSC), with the help of many other organizations, has completed arsenic blanket test in 25 districts of Nepal by analysing 737,009 groundwater samples. Several organizations, including academic institutions, made an effort to determine the levels of arsenic concentrations in groundwater and their consequences in Nepal. The results of the analyses on 25,058 samples tested in 20 districts, published in the status report of arsenic in Nepal (2003), demonstrated that the 23% of the samples were containing 10–50 µg/L of As, and the 8% of the samples were containing more than 50 µg/L of As. Recent status of over 737,009 samples tested, the 7.9% and 2.3% were contaminated by 10–50 µg/L and

>50 µg/L, respectively of As. The present paper examines the various techniques available for the reduction of arsenic concentrations in Nepal in combination with the main results achieved, the socio-economic status and the strategies. This paper aims to comprehensively compile all existing data sets and analyze them scientifically, by trying to suggest a common sustainable approach for identifying the As contamination in the nation, that can be easily adopted by local communities for developing a sustainable society. The paper aims also to find probable solutions to quantify and mitigate As problem without any external support. The outcome of this paper will ultimately help to identify various ways for: identify risk areas; develop awareness; adopt the World Health Organization (WHO) guideline; identify alternative safe water sources and assess their sustainability; give priorities to water supply and simple eco-friendly treatment techniques; investigate impacts of arsenic on health and agriculture; strengthen the capability of government, public, Non-governmental Organization (NGO) and research institutions.

Keywords: arsenic; arsenic contamination in groundwater of Nepal; drinking water; groundwater resources management

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1. Introduction

Arsenic (As, atomic number = 33) is a ubiquitous element, which occurs naturally in the earth's crust. It ranks 20th in natural abundance and 12th in the human body [1]. The ultimate source of As is geological in nature, human activities such as mining, the burning of fossil fuels, and pesticide application, also cause As pollution [2,3]. Arsenic exists in four oxidation states, +V (arsenate), +III (arsenite), 0 (arsenic), and −III (arsine). In addition to arsenite, arsenate, and their methylated derivatives, there are "fish arsenic" (arsenobetaine, AB and arsenocholine, AC) and arsenosugar compounds of environmental interest [4]. Both inorganic and organic forms of arsenic have been identified in water by many researches around the world [5]. Total arsenic is the sum of both particulate arsenic, which can be removed by a 0.45-micron filter, and soluble arsenic.

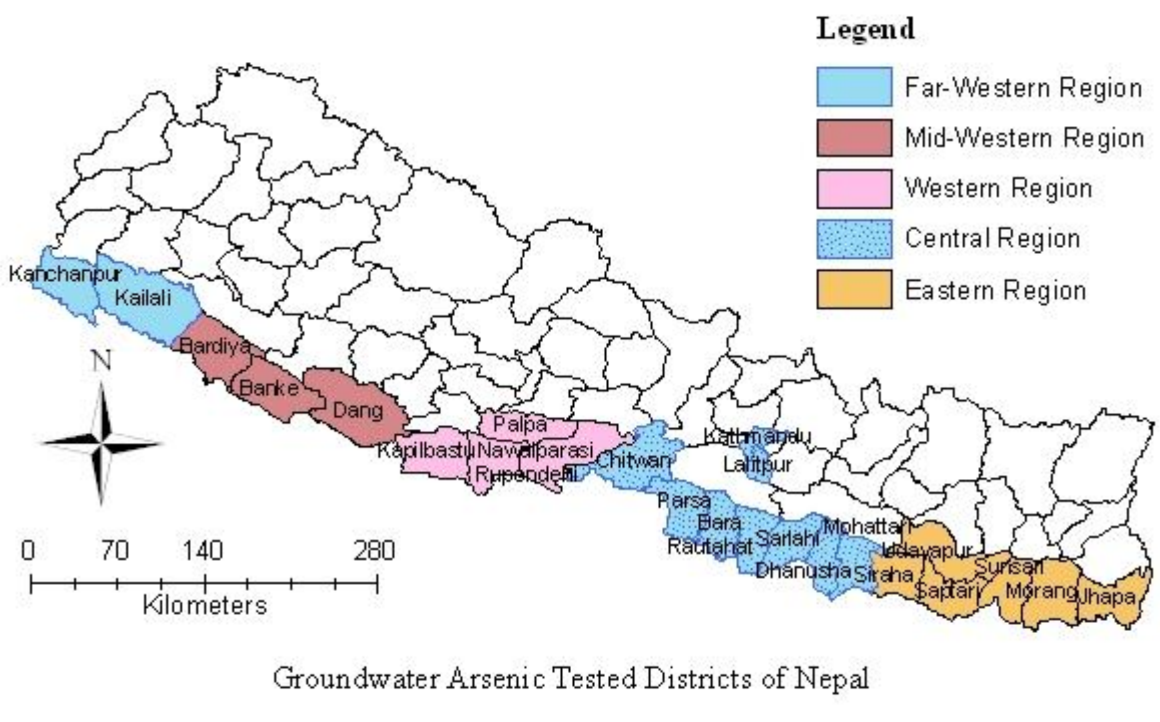
Arsenic is perhaps unique among the heavy metalloids and oxy-anion forming elements. Its sensitivity to mobilisation largely depends on the pH values typically found in groundwater (pH 6.5–8.5) under both oxidising and reducing conditions. The valency and species of inorganic arsenic are dependent on the redox conditions (E_h) and the pH of the groundwater. In general, the occurrence of the different forms of arsenic depends on the aerobic and anerobic conditions: especially arsenite, the reduced trivalent form [As (III)], is normally present in groundwater (assuming anaerobic conditions) while arsenate, the oxidised pentavalent form [As (V)], is present in surface water (assuming aerobic conditions), although the rule does not always hold true for groundwater. The ionic pentavalent [As (V)] forms of are dominating at acidic condition *i.e.*, pH > 3, and As (III) is at alkaline condition *i.e.*, pH < 9 and ionic at extremely alkaline condition *i.e.*, pH > 9. Various research study had reported that in few groundwater samples have been found to have only one form of As (III), others only As (V), while in some others both forms have been reported in the same water source [6-9].

Since ancient times, arsenic has been known as a plant and animal poison, and large oral doses (above 600 mg As L^{-1} in food or water) of inorganic arsenic can result to death [10]. Arsenic poisoning, accidental or deliberately, has been implicated in the illness and death of a number of prominent people throughout history including Francesco I de' Medici, Grand Duke of Tuscany, George III of Great Britain, Napoleon Bonaparte, Charles Francis Hall, Huo Yuan Jia and Clare Boothe Luce [11-14]. Inorganic arsenicals are proven as carcinogens in humans [4]. The toxicity of arsenic to human health ranges from skin lesions to cancer of the brain, liver, kidney, and stomach [15]. Generally inorganic arsenic species are more toxic than organic forms of arsenic present in living organisms, including humans and other animals [16,17].

2. Study Area

Nepal is a landlocked country in South Asia, located between latitudes 26°22′N to 30°27′N and longitude 80°04′E to 88°12′E, and internationally bordered by China to the north and India to the south, east and west (Figure 1). With a total land area of 147,181 km^2, the country is characterized by diverse, rugged and undulating topography, geology and in general cold climate. Nepal is predominantly mountainous, with elevations ranging from 64 m above sea level to 8,848 m at the peak of the world's highest mountain, Sagarmatha (Everest), within a span of 200 km. Approximately 6,000 rivers and rivulets, with a total drainage area of about 194,471 km^2, flow through Nepal, of which 76% of this drainage area is contained within Nepal. According to Central Bureau of Statistics (CBS) census, 2001, the total population of the country have been established as 23,151,423 (11,563,921 males and 11,587,502 females) with growth rate of 2.24% per annum in which country's urban population is 3,227,879 (14.2%) and the rural population is 19,923,544.

Figure 1. Groundwater arsenic tested districts in various developmental regions of Nepal.



3. Guideline Value for Arsenic in Drinking Water

In 1993, World Health Organization (WHO) had lowered the baseline of arsenic from 50 µg/L to 10 µg/L for "safe" limit for arsenic concentrations in drinking water, the reason for lowering the baseline limit was the widespread negative health effects on humans. The guideline value for arsenic is provisional because there is clear evidence of hazard but uncertainty about the actual risk from long term exposure to very low arsenic concentrations [18,19]. The value of 10 µg/L (microgram per litre) was set as realistic limit taking into account practical problems associated with arsenic removal to lower levels.

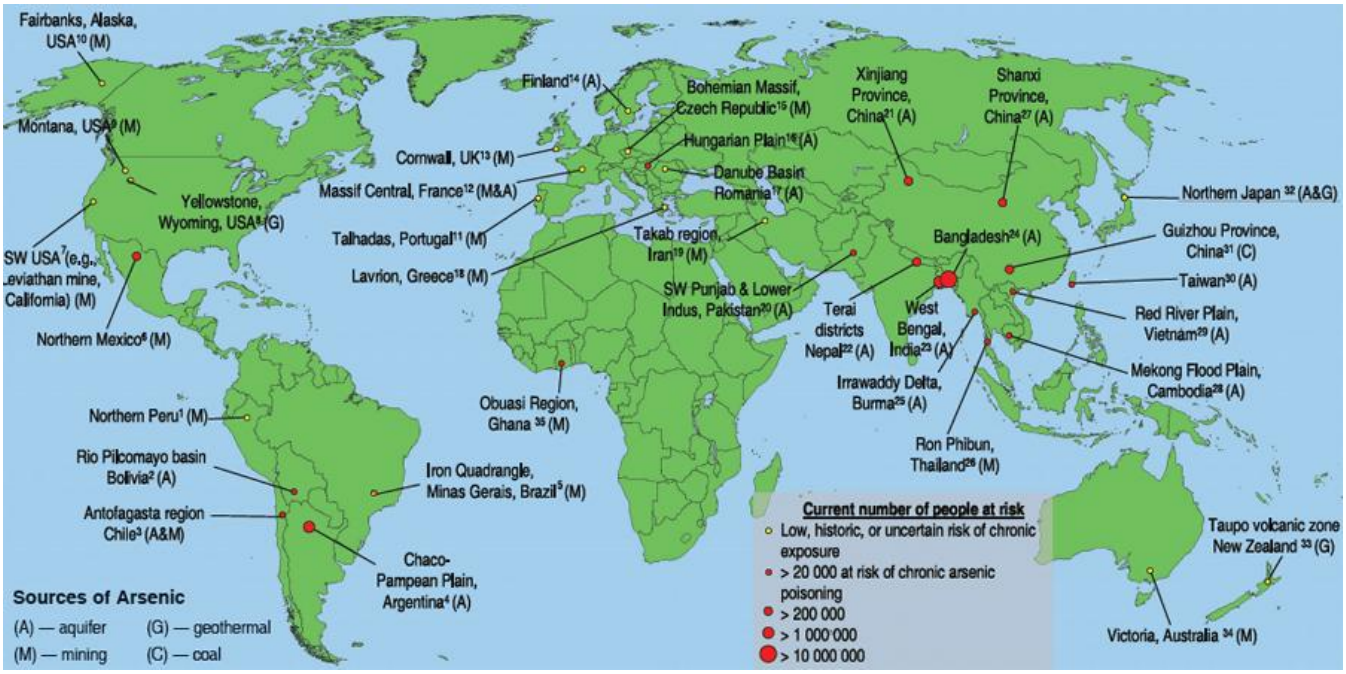
Implementation of the new WHO guideline for arsenic value of 10 µg/L in drinking water is not currently feasible for Nepal, which retains the 50 µg/L limit. Lack of expertise and knowledge of the implementation, economic consideration and technical ability to measure arsenic concentration below 50 µg/L in the field are main reason behind the national standard. The most stringent standard currently set for acceptable arsenic concentration in drinking water is implemented by Australia, which has a national standard of 7 µg/L.

4. Arsenic Challenges around the World

Arsenic is a significant contaminant and pollutant of soils and groundwater in many regions of the world. Depending upon the status and natural settings of country, exposure to arsenic has come from various natural sources such as from industrial sources or from food and beverages. Higher concentrations of arsenic in drinking water have been reported in several countries, including Argentina, Chile, Bangladesh, China, Japan, India, Mongolia, Nepal, USA, *etc.* The world's largest arsenic related health issues are the contamination of drinking water aquifers in Bangladesh and West Bengal, India, potentially affecting millions of people [20,21]. Some countries are reporting localized groundwater arsenic problems and new cases are continuing to be discovered. Many countries, particularly developing one, still use the 50 µg/L of arsenic as their national standard, because of lack of adequate test, removal and mitigation facilities for lower level arsenic concentrations due to financial support. In early days, traditional testing and analysis processes were involved but recently fully automatic water quality laboratories are installed at some government and academic institutes for routine testing and analysis of arsenic and their derivatives in water samples. It is thus possible that with the traditional testing and analysis of various water samples with lower arsenic concentration (<50 µg/L limit) might have missed [20]. High arsenic levels in groundwater are not necessarily related to area of high arsenic concentration in the soil and rocks and the reason lying behind this is that the source (sources rocks or sediments), mobility, speciation and environmental conditions [21,22].

Estimation of people at risk of arsenic poisoning is very difficult to quantify, particularly in areas where geochemical surveys are limited. These estimates are broad and are based on four criteria: (1) prevalence of current recorded cases of arsenicosis, (2) likelihood of ingested concentrations exceeding 50 µg/L, (3) number of people living in exposed areas, (4) likely ability of region to mitigate/remediate against contamination. Figure 2 is global arsenic map showing number of people at risk [23].

Figure 2. Worldwide distribution of arsenic contaminated regions, showing source of arsenic and numbers of people at risk of chronic exposure.



5. Arsenic Speciation

Arsenic speciation is the current thrust area of research and studies in the environmental and biological samples for deepening understanding of the behavior and toxicity of arsenic. Still many problems related with the arsenic speciation remain unresolved such as species instability during sampling storage and sample treatment, incomplete recovery of all species, matrix interferences, lack of appropriate certified reference method, protocols and guidelines [24].

In general arsenic speciation is transformation of arsenic species into variety of other forms and derivatives under different environmental condition such as physical, chemical and biological condition in different environment through which different arsenic species are formed. The toxicity of these forms and species varies from virtually nontoxic (e.g., biological derivatives of arsenic such as "fish arsenic" arsenobetaine (AB) and arsenocholine (AC)) to extremely toxic (e.g., arsenite) and arenosugar compounds are of environmental interest [4]. The molecular formulae of major arsenic species found in the environmental and clinical samples are listed in Table 1 [25].

The complexity of arsenic chemistry in the environment largely depends on the various oxidation states of arsenic, which exists in four oxidation states. In particular As (III) is 10 times more toxic than As (V) and 70 times more toxic than the methylated derivatives of arsenic [24]. Both organic and inorganic forms of arsenic have been determined in water around the world [26]. Several decades ago the formation of methylated arsenic species has been reviewed by Challenger (1945) [27]. There are various environmental parameters, which control and affect the arsenic speciation in the environment such as pH, redox potential (E_h), adsorption, organic matter, sulfidic waters, and others. A comprehensive review on the aquatic arsenic: toxicity, speciation, transformation, dependent of speciation on environmental parameters and remediation for arsenic have been recently done by Sharma (2009) [25]. In this review paper we had focused briefly on only the role of pH and redox potential (E_h). Both redox potential and pH impose important control on arsenic speciation in the natural environment [7]. In aqueous systems arsenic exhibits anionic behaviours in aerobic water, inorganic arsenic primarily occurs as H_3AsO_4 under oxidizing conditions, arsenic acid predominates only at extremely high E_h values and low pH (<2), within a pH range of 2 to 11 it is replaced by $H_2AsO_4^-$ and $HAsO_4^{2-}$ [24]. At low E_h values, H_3AsO_3 (arsenious acid) is the predominant inorganic arsenic species under reducing conditions, it exists at low pH and under mildly reduced conditions, but it is replaced by $H_2AsO_3^-$ as the pH increases. Only when the pH exceeds 12, the ion $HAsSO_3^{2-}$ appears. At low pH and E_h value (−250 mV) existing in the environment, and in the presence of sulfur and hydrogen sulfide, $HAsS_2$ can form arsine, arsine derivatives and arsenic metal can occur under extreme reducing conditions, but rarely if ever in the natural environment. However, these conditions are environmentally not relevant [25]; the solubility of these compounds is very limited under neutral and acidic conditions [7]. Other process such as sorption, adsorption, precipitation and biological mediation besides oxidizing versus reducing conditions playing role in distributions of inorganic arsenic in natural water has been demonstrated by Seyler and Martin (1989) [28]. The importance of biological processes affecting speciation of arsenic in natural waters has been reported by Andreae (1978) [29]. Exact arsenic speciation situation in the groundwater aquifers in Nepal is yet to be understood, which need more scientific research, cooperation from different governmental and non-governmental research organization and far most people's participation.

Table 1. Major arsenic compounds of environmental and clinical interest (modified from Sharma (2009) [25]).

Name	Formulae	Name	Formulae
Arsenite	As (III)	Monomethlyarsonic Acid	$CH_3AsO(OH)_2$, MMA^V
Arsenate	As (V)	Monomehtylarsenous Acid	$CH_3As(OH)_2$, MMA^{III}
Arsenious Acids	(H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$)	Dimethlyarsinic Acid	$(CH_3)_2AsO(OH)$, DMAV
Arsenic Acids	(H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$)	Dimethlyarsenous Acid	$(CH_3)_2AsOH$, DMA^{III}
Methylarsine	CH_3AsH_2	Trimehtlyarsinic Oxide	$(CH_3)_3AsO$, TMAO
Dimehtylarsine	$(CH_3)_2AsH$	Tetramethylarsonium Ion	$(CH_3)_4As^+$, TMA^+
Trimethylarsine	$(CH_3)_3As$	Dimethylarsonoulribtol sulfate	--
Arsenobetaine	$(CH_3)_3As^+CH_2COO^-$ (AB)	Glycerophosphorarsenocholine	--
Arsenocholine	$CH_3As^+CH_2CH_2OH$, (AC)	Glycerophosphatidylarsenocholoine	--
Dimethlyarsinoylribosides	--	Triaklylarsonioribosides	--

6. Sources of Arsenic

The geology of Nepal is a complex system, centred on the great elevation change from the top of the Himalayas to the flatlands of the Terai [30]. Geologically, the Terai region is similar to Bengal Delta Plain, and the sedimentary layers consist of Holocene thick sand and gravel deposits interlocked with alluvium flood plains carried by rivers from Siwalik Hills [31,32]. The sources of arsenic in the groundwater are geogenic. The dissolution of arsenic-bearing rocks, sediments and minerals contribute arsenic to the groundwater [33,34]. Hydrogeochemical analysis of Terai groundwater results suggested high HCO_3^- and low SO_4^{2-} concentrations, indicating possible oxidation of organic matter and reduction of sulfate. In study of Bhattacharya et al (2002), it has been seen that the total arsenic in the groundwater was between 1.7 and 404 μg/L with As (III) as the dominant species (79% to 99.9%). The concentrations of iron and manganese were high indicating that arsenic mobilization in groundwater was possibly due to desorption of As-oxyanions attached onto iron and manganese bearing minerals because of microbial action and geochemical changes [33]. An average arsenic concentration of 9 mg/L in sediments of Nawalparasi districts has been reported. Arsenic and iron oxide patterns were similar at various depths of the sediment samples. In this district, Iron oxide, titanium oxide and calcium oxide concentrations were 5%, 0.7%, and 3.9%, respectively [34]. The arsenic in these oxides might have leached due to geochemical changes and microbial action.

Organic matter and iron oxide/oxyhydroxide are carriers of arsenic that limit arsenic mobility in the groundwater of the Bengal Delta Plain [35]. The possible mechanism of arsenic release in the Nepalese Terai may be that bicarbonate ions form complexes with iron or manganese hydroxides which are abundant in the soil. Other processes may be sulfide oxidation [36]; ion displacement by phosphate [37]; microbial reductive processes [38]; and transport through the sandy aquifer [39]. An exact mechanism of arsenic mobility in sediment aquifers is yet to be understood, but the reducing condition is the key indicator of high arsenic concentration due to dissolution of arsenic-bearing minerals [40].

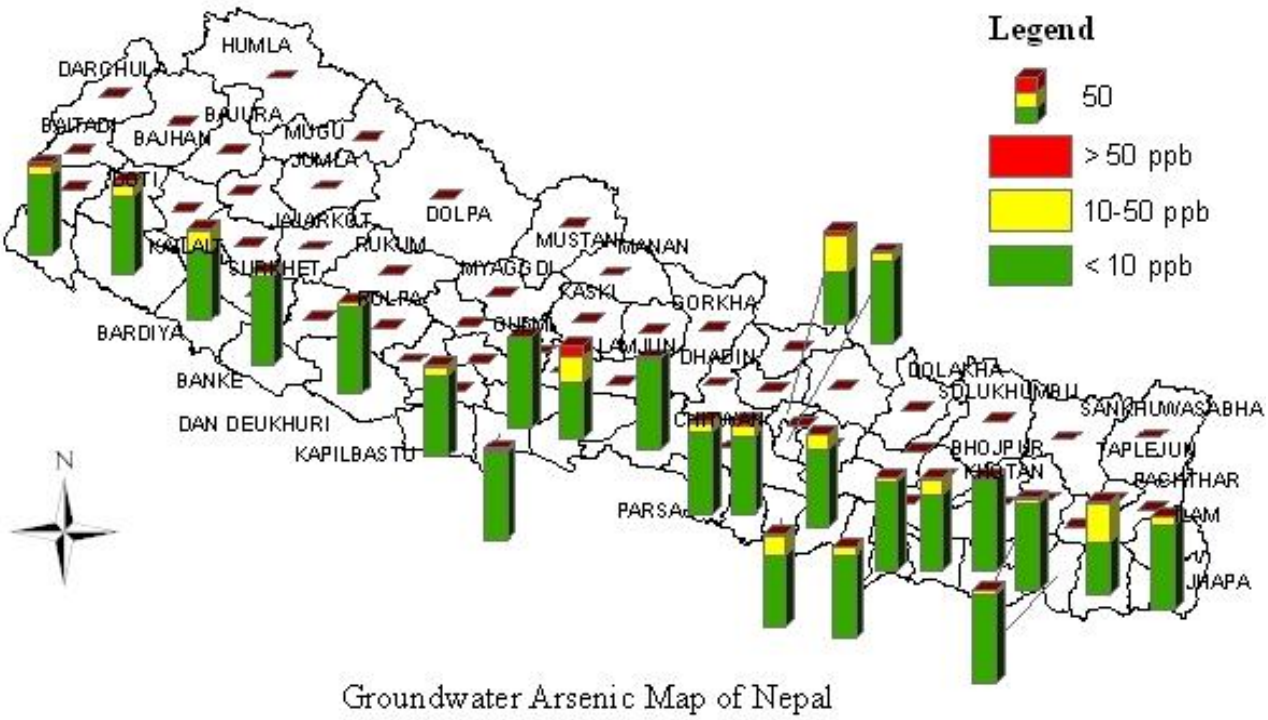
7. Testing Methods in Nepal

Several testing methods are available and have been used to measure arsenic concentration in environmental and biological samples. These tests are often helpful in determining the level of arsenic exposure in the past. These methods are either field based method or laboratory based analytical method. In field-based methods, when any metal arsenide reacts with strong acids, arsine gas is formed. Most arsenic test kits rely on the reduction of inorganic arsenic to arsine gas (AsH_3) using zinc metal and hydrochloric acid. This gas is allowed to pass through the mercury bromide ($HgBr_2$) indicator paper and the intensity of colour indicates the concentration of arsenic. Many field kits, including two Nepali kits namely ENPHO Kit and Modified AAN Kit are available in Nepal [41]. Most of the analytical laboratory based methods have same principles. The sample is simply acidified and sprayed (via a nebulizer) into argon plasma. The high temperature of the plasma atomizes and ionizes all forms of arsenic so that response does not vary by species. The Induced Coupled Plasma Mass Spectroscopy (ICPMS) using direct nebulization and high levels of chloride may interfere with the analysis due to the formation of argon chloride (ArCl) in the plasma, which has the same atomic mass as arsenic (atomic mass 75). This interference may cause the arsenic levels to be biased high by as much as 1 μg/L for each 100 mg/L of chloride present. Even if corrections are being made to the results using the chlorine isotope ratio, these values may be inaccurate at the μg/L level. Newer instruments, like Agilent 7500ce, are equipped with reaction or collision cells to eliminate this chloride interference. ICPMS with traditional sample introduction (direct nebulization) can determine total arsenic to approximately 0.2 μg/L.

8. Arsenic Distribution in Nepal

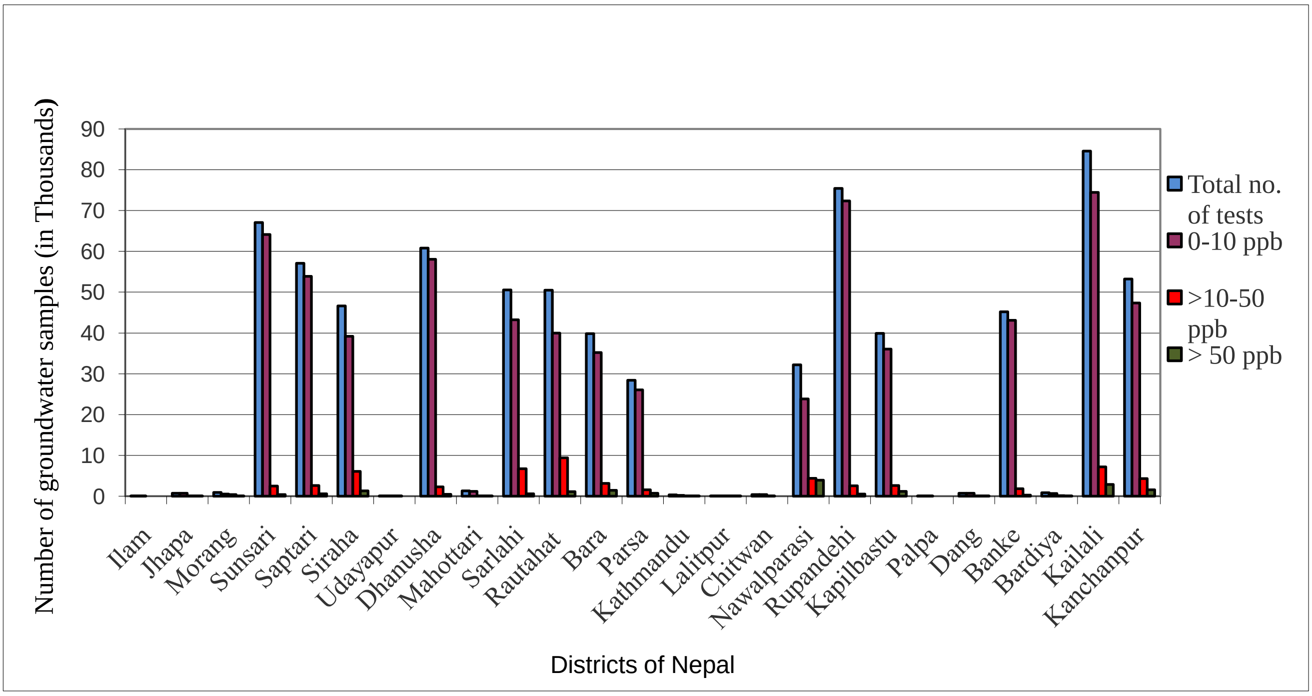
In 1999, arsenic presence in groundwater in the Terai district was brought to light for the first time during the survey conducted by WHO [42]. Figure 3 indicates the number of samples containing various concentration of arsenic in groundwater samples in 25 districts of Nepal which were studied by different organizations and individuals. In general maximum numbers of samples are having the arsenic concentration below 10 μg/L. Few samples were also reported arsenic concentration in the range of 10–50 μg/L. The southwestern to southeastern regions, located along the Indian border, proved to be severely affected arsenic, with concentration larger than 50 μg/L. Thus, this study reflects that there is alarming situation in a few areas which needs the analysis, mitigation and removal of the low level arsenic concentration from the groundwater.

Figure 3. Groundwater arsenic map of Nepal showing proportion of arsenic contaminated samples found in various districts of Nepal.



The district Iiam, Jhapa, Morang, Udayapur, Mahottari, Parsa, Kathmandu, Lalitpur, Chitwan, Palpa, Dang, and Bardiya had reported the low level of arsenic concentrations hence arsenic pollution level is low (Figure 4).

Figure 4. Arsenic (total) concentration in the samples of groundwater of different districts in Nepal.



The district such as Sunsari, Saptari, Siraha, Dhanusha, Sariahi, Rautahat, Bara, Nawalparasi, Rupandehi, Kapilbastu, Banke, Kailali and Kanchanpur had reported the varying from the degree of 10–50 μg/L and even higher than the 50 μg/L.

The districts showing the minimum arsenic pollution and concentration are in Ilam, Palpa and Chitwan, where the maximum values of As concentration in the tested samples lie in the range of 10–50 μg/L, which is higer than the WHO 1993 threshold (Figure 5). The highest arsenic concentration, >50 μg/L As, was reported at Nawalparasi but over all arsenic concentration level was less than the Morang which had 46% tested sample having 10–50 μg/L As and 2% samples having >50 μg/L As. Udaypur and Jhapa have reported around 10–50 μg/L arsenic concentrations. Other districts of Nepal had reported both types of arsenic concentration that is 10–50 μg/L As and >50 μg/L As in their tested sample.

In summary, the 89.8% of the samples of groundwater contamination by arsenic in Nepal has shown a concentration lower than 10 μg/L, 7.9% in the range 10–50 μg/L and 2.3% higher than 50 μg/L of As (Figure 6). Nevertheless, long term changes in land use practices, urbanization, industrialization, population increment and other developmental activities foreseen in the near future could easily lead to arsenic related problems. For this reason, the studied areas, which are not monitored regularly, will require a continuous and regular monitoring of the arsenic pollution to find out eventual trends. Of course, the 10.2% of tested samples showing already concentration values larger than the internationally established threshold will require critical observation procedures and more sustainable approaches for the mitigation and management of arsenic related problems.

Figure 5. Percentage of arsenic contaminated samples in various districts of Nepal.

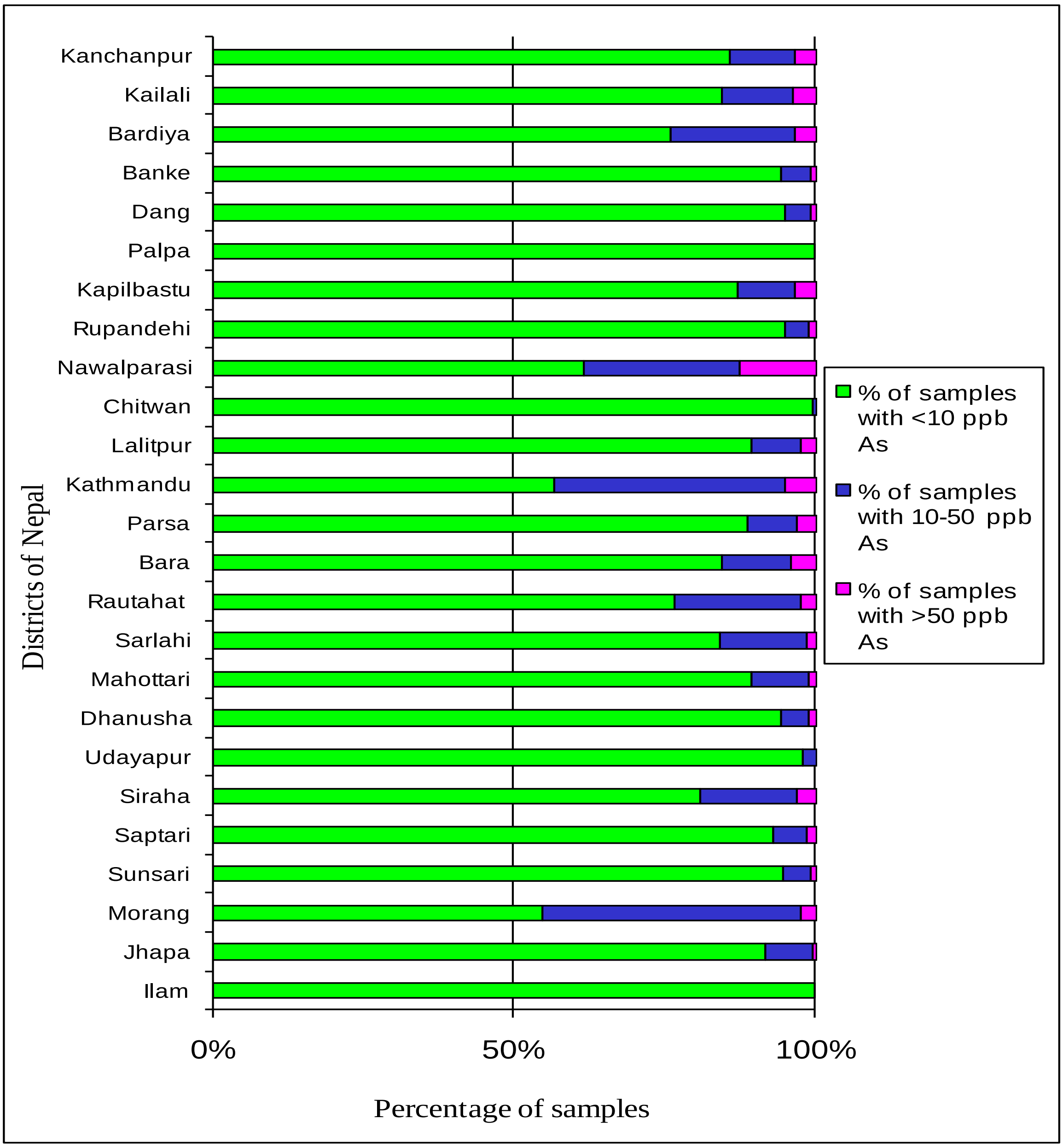
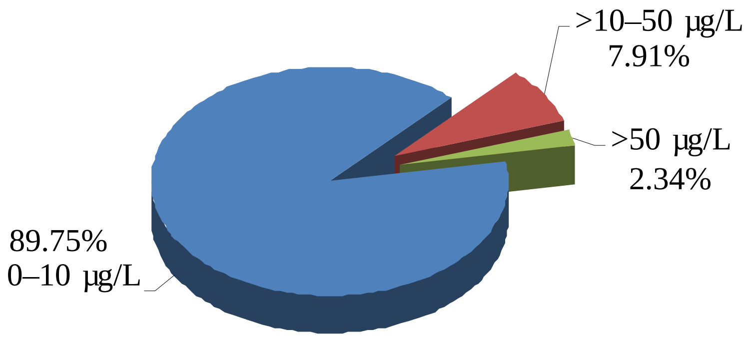


Figure 6. Overall arsenic concentration in the groundwater of Nepal.



9. Individual Research Community Wise Tested Sample Number

The statistical summary subdivided per institution or group, as well as the relative total, is reported in Table 2. The results suggest that the samples having arsenic concentration in the range 10–50 µg/L or greater than 50 µg/L require more attention for their management.

Table 2. Statistical summary of relative total groundwater arsenic contamination samples subdivided per institution or group [43].

Research Organization/ Individuals	Total no. of tests	Samples with Arsenic Concentrations		
		0–10 µg/L	>10–50 µg/L	>50 µg/L
DWSS/UNICEF/WHO	670,117	91%	7%	2%
Nepal Red Cross Society (NRCS)	42,719	79%	16%	5%
Rural Water Supply and Sanitation Support Programme (RWSSSP)/Finnish International Development Agency (FINNIDA)	3,686	86%	8%	5%
Nepal Water Supply Corporation (NWSC)	30	53%	47%	0%
Nepal Water for Health (NEWAH)	5,328	83%	14%	2%
PLAN International	6,307	59%	39%	1%
Tandukar, N.	99	60%	32%	8%
Birgunj municipality, Nepal	6,670	97%	1%	1%
Rural Water Supply and Sanitation Fund Development Board (RWSSFDB)	1,021	87%	12%	1%
Department of Irrigation, MoI, Nepal	590	83%	7%	9%
Royal Institute of Technology (KTH)	53	42%	23%	36%
Japan International Cooperation Agency (JICA)/Environment and Public Health Organization (ENPHO)	389	69%	26%	5%
Total Samples	**737,009**	**82.63%**	**7.59%**	**2.64%**

10. District Wise Expected Population Drinking Arsenic Contaminated Water

According to the population census data, CBS, the total population of Nepal was 23.15 million in 2001. Projecting this population with growth rate of 2.25%, the total population will be 28.58 million by the 2011. Out of this total population on the basis of result of the % of As contaminated samples about 2.29 million and 0.37 million of population is expected drinking water having arsenic concentration 10–50 µg/L and >50 µg/L respectively. Table 3 is statistical summary of expected number of population drinking arsenic contaminated water of 10–50 µg/L and >50 µg/L in 25 districts in Nepal which has been calculated on the basis of total number of expected residing population and the % of As contaminated samples found in the respective districts.

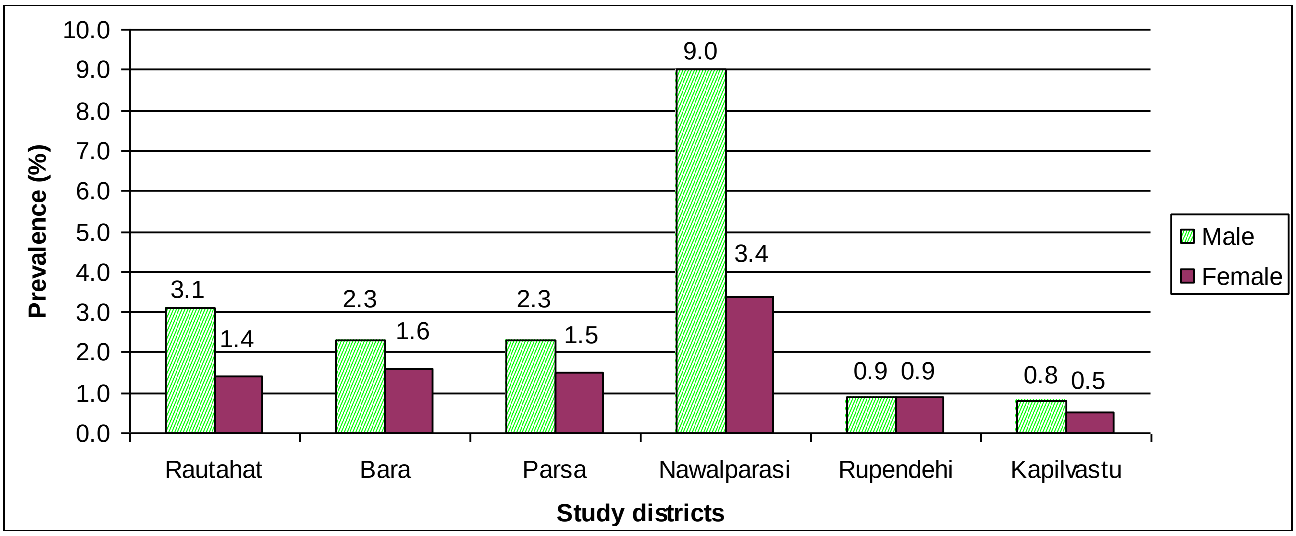
Table 3. District wise expected number of population drinking arsenic contaminated water containing 10–50 μg/L As and >50 μg/L As.

	District	**Population in 2001**	**Expected population in 2011**	**Expected population in 2011 drinking water containing 10–50 μg/L As**	**Expected population in 2011 drinking water containing >50 μg/L As**
1	Ilam	282,806	349,140	0	0
2	Jhapa	633,042	78,1527	61,832	1,014
3	Morang	843,220	1,041,003	448,500	21,985
4	Sunsari	625,633	772,380	33,792	4,790
5	Saptari	570,282	704,046	39,719	7,288
6	Siraha	569,880	703,549	112,130	19,903
7	Udayapur	287,689	355,169	6,124	0
8	Dhanusha	671,364	828,837	37,594	6,163
9	Mahottari	553,481	683,304	64,463	6,704
10	Sarlahi	635,701	784,809	113,874	9,156
11	Rautahat	559,135	690,284	144,040	15,663
12	Bara	559,135	690,284	80,297	25,766
13	Parsa	497,219	613,845	50,815	16,370
14	Kathmandu	1,081,845	1,335,600	511,916	65,433
15	Lalitpur	225,461	278,345	22,722	5,681
16	Chitwan	472,048	582,770	1,418	0
17	Nawalparasi	562,870	694,895	180,631	85,344
18	Rupandehi	708,419	874,584	35,728	5,951
19	Kapilbastu	481,976	595,027	57,468	17,784
20	Palpa	268,558	331,550	0	0
21	Dang	462,380	570,835	25,353	2,305
22	Banke	382,649	472,402	22036	2,802
23	Bardiya	382,649	472,402	97,489	14484
24	Kailali	616,697	761,348	90,802	26,026
25	Kanchanpur	377,899	466,538	51,781	13,986
	Total	**13,312,038**	**16,434,472**	**2,290,524**	**374,596**

11. Toxic Effect and Health Hazards of Arsenic Poisoning

In a health survey of Bara, Parsa and Nawalparasi district in arsenic affected households for 5,215 individuals exposed to an arsenic level greater than 50 μg/L revealed prevalence of arsenicosis related dermatosis (skin disease) in 1.3 to 5.1% of the population [44]. All patients showed symptoms of melanosis (early stages of arsenic poisoning) and keratosis (mild stages of arsenic poisoning) on the palms, trunk, and soles of the feet. Suspected arsenicosis patients were observed in Tilakpur and Thulokunuwar villages of Nawalparasi district [45]. For arsenic patient identification in Rautahat, Bara, Parsa, Nawalparasi, Rupendehi and Kapilvastu, 19,304 persons (9,545 male and 9,759 female) were examined. Out of this, 553 arsenicosis patients were identified consisting 378 male and 175 female [46]. The prevalence of arsenicosis by sex in these districts is shown in Figure 7 where as the over all prevalence by sex is 3.96% male and 1.79% female [46].

Figure 7. Prevalence of arsenicosis by sex (Adapted from Maharjan (2006) [46]).



Arsenic concentrations as high as 1,200 and 2,620 μg/L were found in the groundwater in the villages of Nawalparasi and Rupandehi respectively [43]. Arsenic in blood, urine, skin, hair, and nails are indicators of exposure level. An investigation in arsenic affected areas showed that 95% and 62% of the hair samples tested for arsenic exceeded normal (250 μg As/kg) and acute toxicity levels (1,000 μg As/kg) respectively [44]. Detailed study focused in two rural villages of Nawalparasi district: Goini and Thulo Kunwar was carried out by Ahmad et al. [47]. The groundwater arsenic concentration in Goini village ranged from 104 to 1,702 μg/L; Thulo Kunwar ranged from 4 to 972 μg/L. A recent study showed that arsenic was a part of food chain system [onion leaves (0.55 mg/kg), onion bulb (0.45 mg/kg); cauliflower (0.33 mg/kg); rice (0.18 mg/kg); brinjal (0.09 mg/kg) and potato (0.01 mg/kg) through irrigation water in the arsenic affected area in Nawalparasi district [48]. Clinical observation revealed melanosis with other manifestation in 95.6% and keratosis in 57.8% of the patients. Leucomelanosis (black and white spots on the legs and trunk) was identified in 3.3% of the population in these villages. These patients complained of bronchitis, gastroenteritis, peripheral neuropathy, gangrene of limbs, precancerous skin lesions, and cancer [47]. Further studies are necessary to determine the extent and severity of arsenicosis in all Terai districts and to estimate the overall situation on the effects of arsenic.

12. Socio-Economic Status of Arsenicosis Symptoms Patients

Arsenicosis has become a serious problem for the affected communities. The factors such as economic status, literacy and profession are playing critical role in the life of patients suffering from disease arsenicosis. Various researches had revealed that the poor, illiterate and farmer are found to be more prone to arsenic contamination. Patients of lower income group were particularly more likely to face economic problems as well as social problem. In a case study of Santpur VDC, Rautahat district, the overall prevalence of arsenicosis symptomatic patients among the risk households was found to be 15.3% (19 out of 124) with 84.21% melanosis in trunk and 15.79% keratosis in sole and palm. The highest occurrence was 22.8% (13 out of 57) in males, 29.09 percent (16 out of 55) in illiterate people, 17.50% (18 out of 103) in the poor, 51.72% (15 out of 29) in agricultural workers [49]. About half of the arsenicosis patients faced difficulty whilst receiving treatment, particularly female patients are more likely to face problem. Long waiting time for receiving treatment, discrimination in service delivery and inadequate separate facility for female patients are major problems. Moreover the financial burdens raised by the respondents seem to have emerged as significant in terms of health care access. Access to health service is particularly difficult for poor patients, as they often had to face problems like unavailability of medicines in the hospitals, travelling long distance, purchasing medicine in most cases *etc.*

13. Mitigation Approaches

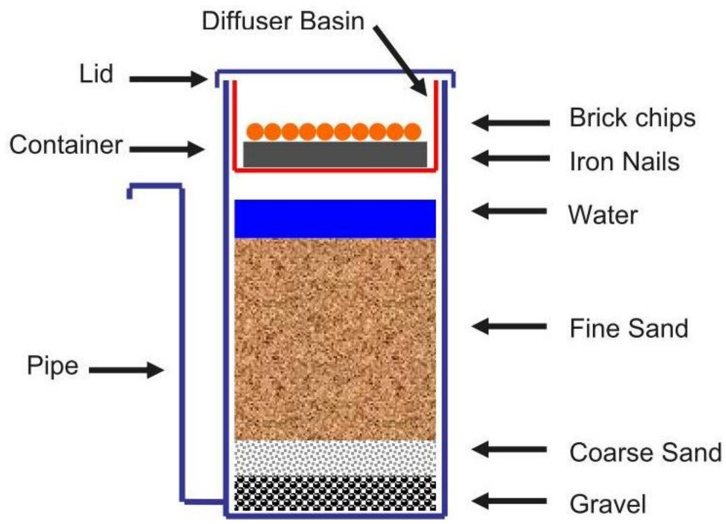
National Sanitation Steering Committee (NSSC) under the leadership of Director General of Department of Water Supply and Sewerage (DWSS), research institutions, various national and international non-government organizations were involved to test existing surface and groundwater sources to identify safe drinking water sources, provision for alternative safe water sources, effort to introduce arsenic removal technologies in the affected areas, health care and management of arsenic related conditions, and mass and interpersonal communications campaigns in districts of Nepal. These mitigation approaches are reviewed under short term and long-term basis.

13.1. Short-Term Mitigation Options Include the Following

Three-Gagri Filters and Arsenic Biosand Filter (ABF): Similar to 3-Kalsi Filter of Bangladesh, 3-Gagri filter is a water container made of copper, brass, steel, tin, and or clay pot. “The Three-Gagri Filter unit consists of three clay pots staggered vertically with a 1 cm in diameter hole in the bottom of the middle and top filters. The top and middle filters work as a reactor, and the bottom filter stores the treated water. The top filter contains the following, from bottom to top: a layer of polyester cloth, 3 kg of iron nails (3 cm depth), 2 kg of coarse sand (4 cm depth) and raw water. The middle filter contains the following from bottom to top: a layer of polyester cloth, about 50 kg of brickbats, 2 kg of fine sand (3.5 cm depth), 1 kg of charcoal (6 cm depth), 2 kg of brickbats (3 cm depth), and filtered water from the top filter” [30,50]. This filter could remove 95–99% of arsenic but there was problem with high iron in treated water and filter clogging due to bacterial growth [51]. This filter was quickly replaced by arsenic biosand filter.

Biosand filters was developed by David Manz, while he was a professor at the University of Calgary, in Calgary, Canada in the late 1990s with support of numerous organizations and individuals [52]. “The biosand filters were modified to remove arsenic and tested in Nepal jointly by the Massachusetts Institute of Technology (MIT) researchers; ENPHO, Nepal; Rural Water Supply and Sanitation Support Programme (RWSSSP), Nepal; and CAWST, Canada, based on slow sand filtration and iron hydroxide adsorption principles. The Arsenic Biosand Filter (ABF) has adapted and promoted as Kanchan Arsenic Filter (KAF) jointly by ENPHO, MIT and RWSSSP. The filter container can be constructed out of concrete or plastic. The container is about 0.9 m tall 0.3 m in diameter (Figure 8) [53]. The container is filled with layers of sieved and washed sand and gravel. There is a standing water height of 5 cm above the sand layer.

Figure 8. Cross-section through an arsenic Biosand filter which is similar to Kachan arsenic filter (Source: CAWST, 2009) [53].



The diffuser basin is filled with 5 to 6 kg of non-galvanized iron nails for arsenic removal. Arsenic from the water is rapidly adsorbed onto the rust on the iron nails. The rust and arsenic flake off the nails, and are caught in the sand filter and retained. This is a very tight bond; re-suspension of arsenic into the water, or re-mobilization of the arsenic from the waste produced from cleaning the filter has shown to be negligible. In addition, pathogens, iron and suspended material are removed from water through a combination of biological and physical processes: mechanical trapping, adsorption/attraction, predation and natural death. This filter can treat approximately 10–15 L/h of arsenic contaminated water. The filters are locally available at a cost of about 1,400 to 1,800 NRs (about US$20) per filter. Performance evaluation of the ABF revealed approximately 95% (2.5 kg of rusted iron nails in the filter) and 100% (5 kg of rusted iron nails in the filter) removal of arsenic with an influent arsenic level of 300 μg/L, while independent field studies by the researchers from Tribhuvan University, Kathmandu University, and United States Peace Corp showed 87–95+% arsenic removal rate [30,54].

13.2. Long-Term Mitigation Options Include the Following

Long-term mitigation options include:

(1) Tube wells that acquire water from deep aquifers

Groundwater from the arsenic-safe deep aquifer could be an option for safe drinking water. In a study conducted by NEWAH, some areas in the Terai region of Nepal, where safe water is available at different depth in the aquifer, have been found. However, further investigations should be carried out in this regard.

(2) Rain Water Harvesting

Of the total amount of precipitation, more than 80% of the rainfall occurs in Monsoon (June–September) in Nepal. Currently it is estimated that over 11,000 rain water harvesting systems are in use in the various districts of Nepal. About 47,000 people are getting satisfactory service by rainwater harvesting system, often in water stress areas like uphill areas in Kaski, Tanhu, Doti, *etc.* [55]. Rohini, a border village close to the highway linking the Rupandehi and Nawalparasi districts, usually receive about 2,000 mm of annual rainfall. This place is located close to the Nepalese areas showing high arsenic concentrations. Because the rainfall is essentially concentrated in just 4 months of the year, this system could constitute a viable option for one third of the year. Using low cost systems ensuring the rainwater storage, this method could be used for a longer period in the year for cooking and drinking purposes [56].

(3) Artesian and deep bore holes meant for irrigation purposes

There are numerous deep tube wells constructed by the Ministry of Irrigation (DOI) for the irrigation in some districts facing the problem of high arsenic pollution. These sources of water either directly irrigate the fields, or are stored in raised tanks. The water from these sources was found to be arsenic in the study carried by Ground Water Resources Development Board (GWRDB), Ministry of Irrigation. The users are authorized to use the water from these sources as they like, thus these sources could be utilized for drinking and not only for irrigation purposes.

(4) Rehabilitation of hand dug wells and implementation of dug well projects

Water from wells dug in a contaminated hot spot could be also contaminated. Prevention and mitigation approach including rehabilitation of dug well is necessary.

(5) Exploration of safe springs and surface sources

This could be one of the measures in the foothills of some districts. Despite the cost of the schemes needed to fetch water from far off located sources might prove relatively expensive, if seen with a long- term prospective, this might prove economical and sustainable.

(6) Identification and use of safe private wells

All the above mentioned long-term solutions are possible if the water supply program is seen from the point of view of an Integrated Water Resource Management (IWRM) principle to be applied for the whole watershed. Proper mapping of all data will determine the safe areas or aquifers. This could help in designing further usage of water, especially for drinking purposes, contributing to save enormous human and financial resources to be used for implementing new programs and mitigating the arsenic pollution [57].

14. Conclusions and Recommendations

The result of blanket testing carried out in 25 Nepalese districts on 737,009 samples of ground water showed in the 89.8% of cases arsenic concentrations lower than 10 μg/L, in the 7.9% of cases concentrations between 10 and 50 μg/L, and larger than 50 μg/L in the 2.3% of samples. These numbers indicate a serious mass poisoning, considering the severe consequences of chronic arsenic contamination caused by drinking water. The symptoms of arsenic poisoning were evident in patients exposed to elevated levels. The ingestion of arsenic can cause a variety of diseases, including skin lesions, respiratory system problems, nervous system effects, cancers of different organs, reproductive effects and even death in the worse cases. Adsorption by iron oxyhydroxide is the major mechanism for reducing in short-term the local arsenic level and removing the disease, while identification and use of safe dug wells and tube wells, exploration of safe springs and surface sources, rehabilitation of dug wells, and rain water harvesting are the possible long-term regional level arsenic pollution mitigation options.

Effective awareness measures of the causes and effects of arsenic based on in-depth analysis should be conducted on local communities in the affected areas. The tube wells and other water sources, soil and sediments, various food items needs to be monitor regularly. There is an urgent need to develop an effective national strategy for modernizing the irrigation system and improving management and performance of the surface irrigation systems in Nepal, with regard to the vulnerability of the areas with respect to arsenic contamination.

Another issue to be improved is the procedure of measurement: actually, the water samples are taken in the Terai areas and brought to the laboratories in Kathmandu valley, located several hundreds of kilometres away, with a trip often on very bumpy roads that often requires a week. In these conditions, the conservation methodology should be established and done properly.

An arsenic monitoring and mitigation program throughout the country could be effectively performed by an institution administratively and financially secured, with national and international collaborations. The arsenic groundwater monitoring program should be carried out at least twice in a year during pre-monsoon and post-monsoon period, since arsenic concentration in ground water varies seasonally. In addition, this institution should develop guidelines/regulations for installing new tube or dug wells. These guidelines should make mandatory tests prior of installing new tube wells, and also a tube well should not extract water from different aquifers, to avoid possible inter-aquifer arsenic contamination, if possible. Provision of safe water options, periodic screening of water sources for arsenic, availability of trained doctor, regular availability of medicine, doorstep treatment, follow up on severe patients are the major recommendations.

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