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Overview of Groundwater Arsenic Contamination in Nepal

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ABSTRACT

This paper provides a comprehensive overview of arsenic contamination in the groundwater of Nepal, with a particular focus on the southern Terai region. Nepal's diverse geographical landscape ranges from the high peaks of the Himalayas in the north to the flat plains of the Terai in the south, encompassing various geological zones including the Tibetan Tethys, Higher Himalaya, Lesser Himalaya, Siwaliks, and the Terai Plain. The Terai region, characterized by its flat alluvial plains, is home to over half of the population and faces significant issues related to arsenic contamination in groundwater. Residents in the mountainous and hilly regions primarily rely on surface water and natural springs for drinking, unaffected by arsenic contamination. However, in the Terai region, the reliance on groundwater sources such as tube wells and hand-pumped wells, both shallow and deep, has led to widespread arsenic contamination. Studies reviewed in this paper indicate that arsenic levels in these groundwater sources frequently exceed the WHO (World Health Organization) safety standards, raising serious public health concerns. Research by Bhusal and Poudyal revealed that detectable levels of arsenic were found in tube wells ranging from approximately 30 to 70 feet deep, indicating that shallow aquifers contain harmful levels of arsenic. This is particularly concerning in rural areas, where untreated groundwater is commonly used for domestic purposes. Conversely, urban areas have largely mitigated this issue through municipal water supply systems that provide treated deep boring water, which is generally safe from arsenic contamination. This paper aims to evaluate and analyze the extent of arsenic contamination in groundwater, its effects on human health, and the disparity between rural and urban water safety. The paper underscores effective treatment solutions and policy interventions to reduce arsenic exposure by integrating data from various studies and reports.

Additionally, the paper offers recommendations for future research and practical measures to address and mitigate the health risks associated with arsenic in drinking water in Nepal.

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Introduction

Arsenic (As), atomic number 33, is a poisonous element that naturally occurs in the earth's crust. A shiny metal found in rocks, soil, natural water, and organisms [1]. Major sources of arsenic are natural geology as well as human activities, for example, mining, burning of fossils and fuels, pesticide application, and caused by arsenic pollution. It has been found in four oxidation states in nature: arsine (-3), arsenic (0), arsenite (+3), and arsenate (+5) [2]. However, in the natural water source, mainly found in inorganic forms as oxyanions of trivalent arsenite, As (+3) or pentavalent arsenate, As (+5) and pH ranges from 5 to 9 in natural water. Predominant species are found in two-state, $H_2AsO_4^-$ lower pH and $HAsO_4^{2-}$ higher pH in Arsenate (+5) state, generally found in aerobic surface water, while H3AsO3 in Arsenite (+3) state, which is found in the anaerobic groundwater. It participates in oxidation, reduction, methylation, demethylation, and acid-base reactions without hesitation. Arsenite is stable and more mobile than arsenate in an aqueous solution when pH is greater than 7. Due to the higher stability in natural water by adsorption and precipitation processes, arsenite is difficult to remove, and a major challenge is finding out the arsenic contamination level in the water because it has no colour, no odor, and no taste, even in highly concentrated contaminated water. Also, there is no widely accepted mechanism for releasing arsenic in the water, but it is believed that it exists naturally and geologically and is related to the oxidation-reduction process of iron oxides and pyrites. According to Panthi et al., evidence supports that arsenic is released through the oxidizing or reducing desorption of iron oxides and pyrites [3]. It is believed that arsenic-rich iron oxides break down and get dissolved into the water in the context of strongly reducing the environment (Eh –110 mV to –220 mV) of groundwater in Nepal.

Study Area

Nepal is a landlocked country surrounded by China and India, located in South Asia. About 83% of the area is occupied by mountains and hills, and the remaining is a plain area called Terai, with a total land area of 147,516 km², characterized by diverse, rugged, undulating, and rough topography, a cold climate, and dominated by mountains and hills [4]. Despite having a large percentage of hilly areas, more than half of the population lives in the southern part called Terai and their major drinking water source is groundwater. Around 90% of the people living in the Terai region of Nepal depend on groundwater as their primary source of potable water [5]. Arsenic contamination has been a major issue in recent years, and many people are suffering from health problems from the continuous use of arsenic contaminated water. The Terai region contains sedimentary layers of sand and gravel deposits interlocked with flood plains carried by rivers and is extremely vulnerable to arsenic contamination. According to Shrestha, more than 200,000 shallow tube wells were installed by different government and non-government organizations in the mid-1980s, and during the mid-1990s, they were reported to be safe and free from harmful bacteria because the test was limited to iron, ammonia, nitrate, and coliform [6].

Arsenic contamination issues in drinking water came to light after the emergence of arsenic contamination in groundwater of the Bengal Delta Plain (BDP) in the neighboring Indian states of West Bengal and Bangladesh because the southern part of Nepal (Terai) lies in the same drainage basin. In 1999 and 2001, first time in Nepal, a study about arsenic contamination was conducted, and reported that 29% of tube wells had more than the WHO standard (0.01 mg/L) and approximately 0.5 million people were at risk of consuming water with arsenic concentration > 0.05 mg/L. Dangol states, arsenic in Nepal in 2011 reported that 1.73% of the tested tube wells contained more than 0.05 mg/L, the national drinking water standard in Nepal, and 7.1% of tube wells contained more than 0.01mg/L [7]. Out of 20 districts in Terai, Nawalparasi is the most arsenic-affected area in Nepal, with 11.69% of tested well-contained arsenic concentration of 0.05 mg/L.

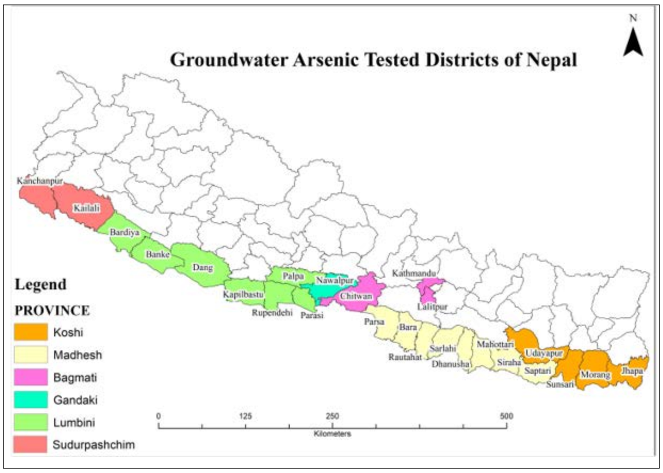

Figure 1: Groundwater Arsenic Tested Districts in Different States in Nepal

Sources of Arsenic

The geology of Nepal is quite complex, between 200 km from the north Himalayas and the south flatland Terai, there is great elevation change (59 m to 8848 m from sea level). The Terai region is plain and has sedimentary layers consisting of Holocene thick sand and gravel deposits interlocked with alluvium flood plains carried by rivers from Siwaliks hills [8]. The dissolution of these arsenic-bearing rocks, sediments, and minerals causes arsenic contamination; also, the hydrogeochemical analysis results show high bicarbonate and low sulfate concentrations and possible oxidation of organic matter and reduction of sulfate. An experiment found that some metal oxides, including iron oxide, titanium oxide, and calcium oxide, were present in the groundwater of certain districts, and due to microbial action and geochemical changes, some of the arsenic content in these oxides might have leached into the water. Thakur et al. identified the possible way to release arsenic into the water as bicarbonate ions that form complexes with iron or manganese hydroxides, which are abundant in soil [8]. The other possible ways are sulfide oxidation, ion displacement by phosphate, microbial reductive processes, and transport through the sandy aquifer.

Guidelines for Arsenic Concentration in Drinking Water in Different Places in the World

In 1958, the World Health Organization (WHO) established the first allowable arsenic concentration in drinking water at 0.2 mg/L. This standard was revised in 1963, lowering the allowable concentration to 0.05 mg/L. Further reviews led to the establishment of a stricter guideline of 0.01 mg/L in 1993, which the WHO recommended for worldwide application. Despite this, many countries adopted provisional guidelines based on national standards, and some continued to follow the 1963 WHO standard. For instance, Australia has set a high standard for arsenic concentration in drinking water, as shown in Table 1, which also includes the national standards for different countries.

Table 1: Currently Accepted National Standard for Arsenic in Drinking Water of some Countries in the World (Source: Panthi et al. [3].)

S.N.	Country Name	The National Standard for Arsenic in Drinking Water (mg/L)	Adopted Year
1	Australia	0.007	1996
2	Germany	0.01	1998
3	Japan	0.01	1993
4	EU Countries	0.01	1998
5	USA	0.01	2001
6	Canada	0.025	1999
7	Nepal	0.05	2003
8	China	0.05	NA
9	Sri Lanka	0.05	1983
10	India	0.05	NA

The Harmful Effects of Arsenic

Arsenic is a poisonous element that naturally occurs in the earth's crust. Researchers have found both organic and inorganic forms of arsenic in nature. In Nepal, Arsenic is believed to exist in the alluvial sediment deposited in the flatland Terai by rivers draining from the Himalayas. Arsenic is characterized by toxicity, and even small doses might have harmful effects on health. There are three ways of exposing arsenic to the human body: inhalation, ingestion, and dermal absorption. Inhalation occurs through respiration, digestion of contaminated water and food ingestion occurs, and dermal absorption occurs by the direct contact of an arsenic compound with the skin. The impact depends upon the duration of absorption, excretion, and retention in the body, as well as the concentration and chemical nature of the element [6]. Arsenic causes numerous health problems such as gastrointestinal and cardiac damage, affects the respiratory tract and skin of the body, and is responsible for many diseases such as skin lesions and cancer of the brain, liver, kidney, and stomach. It can also take the life of an unborn child from a pregnant woman and cause other various health problems, including weakness, headache, and burning of the eyes.

The symptoms of adverse effects of arsenic are divided into two categories: acute and chronic effects. The acute poisoning effect, also called the initial effect, means the immediate effect of a high dose of arsenic, for example, muscle pain, weakness, severe nausea, abdominal pain, and diarrhea. These symptoms show within 30 minutes after entering the body with arsenic. Other symptoms are numbness in the hands and feet, red rashes on the skin, intense thirst, decreased urine output, confusion, and hallucinations. An excess dose (60–180 mg) can lead to seizures, coma, and death [6].

The symptoms of chronic effect studies are in two stages, the initial and second stages where the initial stage can be shown in more than five years, for example, skin colour becomes black called melanosis, rough and tough called keratosis and eyes become red called conjunctivitis. Also, in some cases, bronchitis and gastroenteritis occur. In the second stage, black and white spots show on the skin called Leucomelanosis, hard nodules on the palm and soles called hyperkeratosis, swelling of the legs, and problems in the kidney and liver.

Groundwater Extraction Methods in Nepal

Groundwater is the major source of water in the Terai region. The people of the Terai region depend upon groundwater for domestic purposes such as drinking, washing, industry, and irrigation for agriculture. Apart from the Terai region, cities of the hilly region such as Kathmandu, Lalitpur, and Bhaktapur are highly dependent on groundwater resources to fulfill their daily water needs.

Dug Well

These types of wells are used in most places in Terai, especially in rural areas. It is believed that hand-dug wells have been used by humanity since ancient times. People were digging and taking things out of the well with the help of a small bucket and rope, but many were still using traditional methods for well digging. However, now the methods, equipment, materials, and standards for good construction have been developed and upgraded, which results in better protection from contamination and allows for permanent yields.

Simply dug wells are round, generally 15 to 60 feet, depending on the depth of the groundwater level and the presence of a shallow aquifer. Brick masonry is used on the ancient type of well for casing or protection of water from contamination or stability for dugs or kits, but in recent times, generally, round concrete ring use is shown in Figure 2.

Figure 2: Women are Drawing out Water from Hand-Dug wells in Nepal (Source: myrepublica.nagariknetwork.com/archive/64219/Failing-on-water)

Tube Well

These types of wells are often installed over a sedimentary layer; generally, a 2” to 4” diameter cast iron or steel pipe is driven up to 30 ft to 300 ft. Tube wells are used either for drinking or irrigation purposes in Nepal. Generally, people use a hand pump tube well for domestic purposes called a suction hand pump, as shown in Figure 3. For agriculture, an electric water pump is used to withdraw the water, and the tube diameter is often higher than the hand tube well.

Figure 3: Suction Hand Pump for Domestic Purposes

Municipal Water Supply System

This type of method is often used in the cities of the Terai zone and some valleys in Nepal. The municipal water system is a deep boring system with a depth ranging from 60 ft to 300 ft, and water is withdrawn by a powerful electric motor whose capacity varies from 10 liters per second to 30 liters per second. Generally, groundwater is extracted from the confined and unconfined aquifers by deep boring and collected in the overhead tank shown in the figure below. After the required treatment, the collected water is distributed to each household by an urban water distribution system. The capacity of the overhead tank is around 450 thousand liters, where extracted groundwater is stored for a while and distributed by various water supply systems.

Figure 4: Overhead Groundwater Collection Tank in the Terai Region

Overview of Arsenic Contamination

Until the 1970s, most people in rural areas of Terai, Nepal, were using surface water including river or stream water, ponds, natural water channels, and groundwater from dug wells without any treatment. In those times, people suffered and died from water-borne diseases, including cholera, diarrhea, and typhoid. Since the 1980s, the idea of tapping groundwater has come into practice, and many shallow tube wells have resulted in controlling water-borne diseases and reducing the number of deaths. However, it showed that there was a high concentration of as in drinking water, which was an emerging issue.

In 1999, the first-ever survey was conducted in Nepal by the WHO. It was started in the eastern part of Nepal, and sampling was done in 3 districts. Results showed that out of 268 water samples, 24 samples exceeded WHO guidelines (0.01 mg/L) and 2 samples were more than 0.05 mg/l arsenic concentration. Even after various organizations, NGOs, INGOs, and the Nepal government were involved in the sampling, it was conducted all over districts of Terai and even Kathmandu Valley because the people of Kathmandu Valley also used groundwater. Figure 5 shows the arsenic concentration in drinking water samples in the different districts of the Terai region of Nepal. It had shown most of the districts were safe from arsenic contamination or that they were using drinking water that is in WHO's guidelines (<0.01 mg/L). However, many districts of Terai, including Bara, Nawalparasi, Rautahat, Kailali, Kanchanpur, Kapilbastu, Sunsari, Siraha, Morang, and Sarlahi, reported varying degrees of 0.01–0.05 mg/L and even higher than the national standard of Nepal (0.05 mg/L).

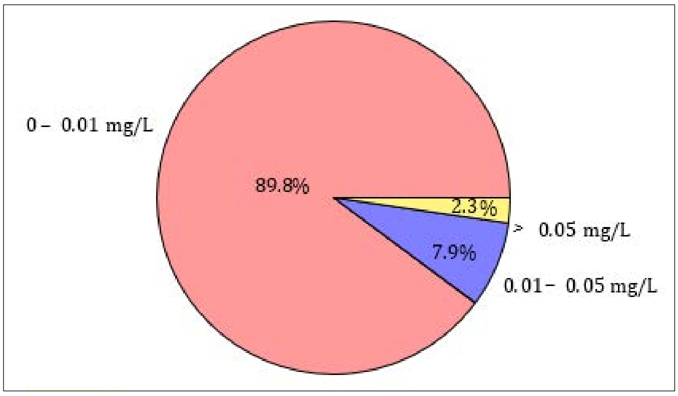

Figure 5: Overall Percentage of Arsenic Concentration on a Testing Sample of Various Districts

Overall, from the sampling, it was found that 2.3% of the sample was more than 0.05 mg/L of arsenic concentration, while 7.9% of the sample was reported to consist of 0.01 mg/L to 0.05 mg/L, and the remaining 89.8% of the sample was in WHO 1993 threshold (<0.01mg/L).

Table 2: Result of as Concentration in the Six Most Affected VDCs/ Municipality of Nawalparasi District. (Source: Panthi et al [3])

VDC/ Municipality	Total Tests	Conc.< 0.01mg/L		Conc. 0.01 - 0.05mg/L		Conc.>0.05mg/L	
		Numbers	%	Numbers	%	Numbers	%
Ramgram	729	98	13.4%	270	37.0%	459	63.0%
Pantnagar	70	6	8.6%	26	37.1%	44	62.9%
Manari	139	17	12.2%	64	46.0%	75	54.0%
Tilakpur	164	49	29.9%	105	64.0%	59	36.0%
Ramnagar	213	42	19.7%	155	72.8%	58	27.2%
Swathi	322	97	30.1%	248	77.0%	74	23.0%

After the survey, it was found that Nawalparasi district had the most severe arsenic contamination problem. Despite this, people continued using the contaminated water for drinking and other domestic purposes. Particularly, six Village Development Committees (VDCs) and Municipalities had water sources with arsenic concentrations exceeding WHO standards, posing serious health threats to both humans and livestock. The sampling and testing results of these six Village Development Committees (VDCs) and Municipalities are shown in Table 2.

Health Issues

According to Thakur et al., a health survey of most arsenic-contaminated districts such as Bara, Parsa, and Nawalparasi showed a total of 5,215 people were exposed to an arsenic level greater than 0.05 mg/L and affected by arsenicosis-related dermatosis (skin diseases) in 1.3% to 5.1% of the population, which was higher in older age groups (> 50 years) [8]. Most of the patients had shown symptoms of melanosis (early stage of arsenic poisoning) and keratosis (mild stage of arsenic poisoning) on the palms, trunk, and soles of their feet [6]. The male population suffered more than the female population, and clinical observation revealed melanosis in 95.6% and keratosis in 57.8% of patients, while leucomelanosis (black and white spots on the legs and trunk) was identified in 3.3% of the population of these districts [6]. According to the WHO's 1990 worldwide cancer incidence index, 2.79% suffered from liver cancer, 11.95 lung cancer, melanoma of the skin (0.38), bladder cancer (4.39), and kidney cancer (1.40 per 10,000 people) [9]. However, there are several causes of these cancers. There is no direct relationship between arsenic contamination and cancer, but it is believed one of the causes was arsenic contamination. The Nepal Red Cross Society (NRCS) surveyed three different districts in 2001 and 2002, and the Department of Water Supply and Sewerage System (DWSS), with UNICEF's assistance, conducted a study in Nawalparasi district in 2002. These surveys revealed that many people were affected by diseases caused by excessive arsenic in drinking water. Table 3 shows the number of people suffering from arsenicosis diseases in the two districts of Nepal in 2001 and 2002 respectively.

Table 3: Prevalence of arsenicosis in most arsenic-contaminated districts conducted by some organizations. (Source: Panthi et al. [3])

Study Conducted by	In	District	Population Surveyed	Prevalence of Arsenicosis	
NRCS	2001	Nawalparasi	855	27	3.2
NRCS	2001	Parsa	2732	50	1.8
NRCS	2002	Bara	667	9	1.3
DWSS/UNICEF	2002	Nawalparasi	961	49	5.1
Total			5215	135	2.6

Mitigation Measures
Some mitigation options can preserve the arsenic contamination in drinking water or remove the arsenic from drinking water, and they have been categorized into two groups: a short-term solution and a long-term solution. As a short-term solution, some experts have recommended some types of water filters in affected areas of Nepal. Gagri filter and Kanchan arsenic filter are used by people, and the Kanchan arsenic filter is the most used all over the Terai region of Nepal.

Kanchan Arsenic Filter
The prestigious awards at the MIT IDEAS Design Competition 2002 and so many award-winning filters were developed by researchers at the Massachusetts Institute of Technology (MIT), Environmental and Public Health Organization (ENPHO), and Rural Water Supply and Sanitation Support Program (RWSSSP) (DWSS/JICA/EN-PHO, 2016). Since the successful demonstration of the KAF implementation model in 2003, approximately 33,000 KAF have been installed in arsenic-affected areas of Nepal by several organizations and agencies. It is useful for removing arsenic, pathogens, iron, turbidity, and other contaminants as well. The principle of this filter is the combination of slow sand filtration and iron hydroxide adsorption. The function of the filter is that the non-galvanized iron nails rust quickly, forming ferric hydroxides on the iron nails' surface, which absorb the arsenic. When an arsenic ferric hydroxide particle exfoliates from the iron nails, a new iron surface is created, which provides additional arsenic absorption capacity. In addition, it removes pathogens that follow the same principle as a slow sand filter or bio-sand filter, and rusty iron nails can also remove viruses through inactivation and irreversible adsorption. Typically, it can reduce arsenic by 85% - 90%, iron by 90% - 95%, turbidity by 80% - 95%, and total coliform by 85% - 99%.

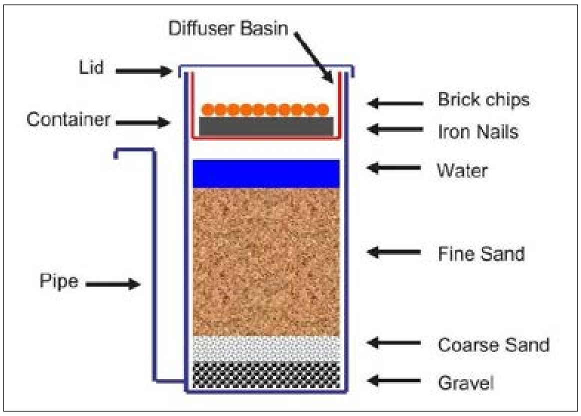

Figure 6: Cross Section of Kanchan Arsenic Filter and in use [7,8]

Some experts also recommended long-term mitigation options and suggested the use of the water from deep wells, rainwater harvesting, rehabilitation of hand-dug wells, and exploration of safe springs and surface springs.

Conclusion
Groundwater serves as the primary water source in Terai, Nepal, catering to domestic, industrial, agricultural, and irrigation needs. The prevalence of arsenic contamination is notably higher in shallow-depth tube wells. However, some shallow tube wells have arsenic concentrations below national standards, and contamination levels tend to decrease with increased well depth.

The analysis of 737,009 groundwater samples across 25 districts of Terai revealed that approximately 11% exceeded the WHO's arsenic concentration threshold, highlighting a widespread and severe public health threat. A health survey estimated that around 20,000 individuals may be affected by arsenicosis, underscoring the alarming situation of arsenic contamination in Nepal's drinking water and its detrimental impact on public health [3]. Despite awareness of the health risks associated with arsenic, many people in affected districts continue to use contaminated water for daily activities due to limited alternative sources.

Studies conducted over several years indicated dangerously high arsenic concentrations of 0.12 mg/L and 0.262 mg/L in specific Terai districts, emphasizing the acute nature of the problem. The public's reliance on such poisoned water, despite awareness, reflects the lack of viable alternatives. Following the publication of sampling data, concerted efforts by national and international organizations, supported by the Nepal government, have been crucial in addressing the crisis. Projects have been implemented to protect human health, including awareness campaigns, the prohibition of water use from visibly contaminated sources, and the introduction of alternative drinking water options.

International organizations have played a pivotal role by introducing filtration systems like KAF, aimed at removing arsenic from water sources and providing safe drinking water solutions to communities. These efforts collectively aim to mitigate the adverse effects of arsenic contamination, ensuring safer and healthier living conditions for the population of Nepal.

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Author Contribution
The author has the original idea for the paper and took overall responsibility for the study, including data collection and analysis, preparation of figures, and finalization of the manuscript.

Conflict of interest
The authors reported no potential conflict of interest.

Data availability
The data that support the findings of this study are available from the corresponding author.

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