Arsenic Concentration in Public Wells Around the Ring Road in Kathmandu Metropolitan City, Nepal

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ABSTRACT

An estimated 110 million people across South and Southeast Asia—including the Kathmandu valley and Terai region of Nepal—are susceptible to arsenic contamination. To assess the current levels of arsenic in shallow public wells (1–30m depth), this study was conducted in February 2022 with in the ring road area of Kathmandu Metropolitan City. Eleven water samples (n=11) were collected from the wells selected through simple random sampling. Arsenic concentrations were analyzed using Continuous Hydride Generation Atomic Absorption Spectrophotometry (HG-AAS). Results revealed arsenic levels below the detectable limit (<0.005 mg/L) in all samples, well within Nepal's permissible limit of 0.05 mg/L. These findings indicate no immediate arsenic-related health risk from the shallow public wells examined. However, prior research has documented significant arsenic pollution in the deep aquifers of the Kathmandu Valley, which is hydrologically distinct from the shallow groundwater sources sampled. Despite known risks of chronic arsenic exposure, including cancer, infertility, and developmental impairments, 84.61% of respondents were unaware of arsenic and its potential health impacts. This necessitates urgent public awareness and education.

Keywords: *Arsenic, Groundwater, Kathmandu valley, Health hazard, Public well.*

1. INTRODUCTION

Arsenic-laden groundwater has been a serious public health hazard worldwide for several decades. Though the most common metal pollution in freshwater is from mining industries, groundwater's primary source of arsenic (As)—a poisonous metalloid of the nitrogen family—is mostly geogenic (Rasaili et al., 2024). Arsenic is mobilized through the dissolution of arsenic-rich geological materials, particularly via oxidation of As-containing sulfides, desorption from oxide and hydroxide, and leaching of arsenic from sulfide bicarbonate (Nickson et al., 2000; Stolze et al., 2022). In groundwater systems, arsenic is typically present in inorganic form—arsenite (As(III)) or arsenate (As(V)) oxyanions. In oxygen-rich groundwater, arsenate is dominant, whereas arsenite is more likely to be found under reducing conditions. The higher toxicity of trivalent arsenic, As(III), relative to pentavalent arsenic, As (V), is associated with its greater solubility and mobility, which enhances its bioavailability and cellular uptake (Valskys et al., 2022). Given the well-established toxicity of arsenic, a significant disparity exists in the regulatory limits for arsenic in drinking water: the World Health Organization (WHO) guideline is 0.01 mg/L (WHO, 2008), while the enforceable National Drinking Water Quality Standards of Nepal (NDWQS) remain at 0.05 mg/L (NDWQS, 2022).

Globally, an estimated population of 220 million people are vulnerable to groundwater arsenic contamination, with chronic exposure affecting approximately 100 million (Podgorski & Berg, 2020). Regions of South and Southeast Asia, including Bangladesh, India and Nepal, are particularly affected. High arsenic concentration has been reported in Australia (0.005-300 mg/L), Canada (0.0015-100 mg/L), Bangladesh (0.002-4.73 mg/L), and India (0.001-3.88 mg/L) (Chaudhary et al., 2024). In West Bengal, 30 million people living in six districts covering 34,000 km^2 are affected by arsenic, and over 800,000 inhabitants from 312 villages consume arsenic-contaminated groundwater (Bhat & Bhat, 2020).

Arsenic is a significant problem in the potable water distribution system in Nepal's Terai region, as most shallow tube wells contain a high concentration of naturally occurring arsenic, exceeding the safer limit set for drinking purposes (Lamichhane & Singh, 2019; Mueller, 2020; Rasaili et al., 2024). However, groundwater serves as the principal drinking water source for 90% of the inhabitants in this region (Lamichhane & Singh, 2019; WHO & NHRC, 2009). As per reports, Rupandehi has the highest arsenic concentration (2.62 mg/L), accompanied by Nawalparsi (1.828 mg/L), Rautahat (1.007 mg/L), Kapilvastu (1 mg/L), and Parsa (0.456 mg/L) (NASC and ENPHO, 2004; Ogata & Suenaga, 2023; Rasaili et al., 2024). Epidemiological surveys in Nepal's Terai districts reveal a tiered pattern of arsenic exposure: approximately half a million residents are acutely exposed (>0.05 mg/L), while around 3.5 million (31%) experience chronic exposure within the 0.01-0.05 mg/L range. Approximately 80% of inhabitants in this region have been reported to suffer from arsenic-induced skin manifestations, with arsenicosis reported to be twice as prevalent in males as in females (Maharjan et al., 2005). In the Nawalparasi district alone, 60% of the inhabitants suffered from arsenicosis (Rasaili et al., 2024).

The arsenic-bearing quaternary sediments serve as the primary reservoir for groundwater arsenic contamination in the Kathmandu Valley (Gurung et al., 2007; Rasaili et al., 2024). Shrestha et al. (2013) reported that arsenic displays pronounced spatial variability, with significantly elevated concentrations in the Central Groundwater District (CGWD) within the Kathmandu basin. Given that groundwater is a principal water source used by 52% of households across the Kathmandu region, residents relying on the CGWD face heightened risks of arsenic-induced morbidities (Gwachha et al., 2020; Shrestha et al., 2018). The arsenic concentration and depth of groundwater have a positive correlation (Banson et al., 2020; JICA and ENPHO, 2005; Maharjan et al., 2009). Monitoring of 122 deep tube wells revealed seasonal variation in arsenic violations, with exceedance rates decreasing from 13.1% pre-monsoon to 8.2% monsoon ($p<0.05$), relative to the 0.05 mg/L NDWQS threshold (Maharjan et al., 2009). 2020 monitoring ($n=20$) revealed widespread arsenic contamination, with 76.2% of samples exceeding the WHO threshold (0.01 mg/L), and 47.6% violating the NDWQS standard (0.05 mg/L) (Gwachha et al., 2020). Longitudinal studies conducted in the Kathmandu Valley between 2002 and 2022 documented wide variability in arsenic concentrations. Reported values include 0.0738 mg/L (Khatiwada et al., 2002), 0.019 mg/L (Gurung et al., 2006), 0.100 mg/L (Bajracharya et al., 2007), 0.021 mg/L (Warner et al., 2008), 0.265 mg/L (Maharjan et al., 2009), 0.073 mg/L (Chapagain et al., 2009), 2.070 mg/L (Emerman et al., 2010), 0.143 mg/L (Shrestha et al., 2013), 2.8 mg/L (Gwachha et al., 2020), and 0.071 mg/L (Sarkar et al., 2022).

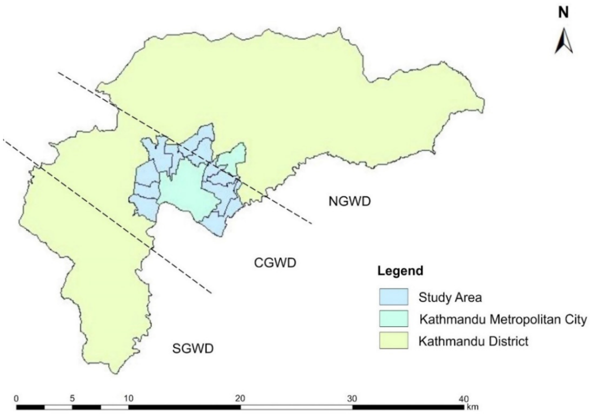
Arsenic is poisonous, and short-term exposure to arsenic causes arsenicosis—a severe environmental chemical disease—while continuous exposure causes peripheral vascular disease, diabetes mellitus, neurotoxicity, nephrotoxicity, skin lesions, Blackfoot disease, hypertension, and a high risk of different types of cancers (Mueller, 2021; Rasaili et al., 2024). Arsenic contamination also induces genotoxicity and causes the development of vascular diseases such as stroke and ischemic heart disease. The Food and Drug Administration (FDA) and the International Agency for Research on Cancer (IARC) classify arsenic as a known human carcinogen, with conclusive evidence of well-documented associations with cancers of the bladder, pulmonary system, renal organs, and hepatic tissues.

Switching shallow groundwater wells and implementing rainwater harvesting are commonly adopted mitigation strategies; however, to further minimize the health risk, the engineered treatment of arsenic-contaminated water—using methods such as reverse osmosis, ultrafiltration, distillation, or ion exchange—remains an effective and sustainable option. Various arsenic removal techniques have proven effective, including phytoremediation, coagulation-flocculation, oxidation—such as photochemical, photo-catalytic, biological, and in-situ oxidation—as well as electro-coagulation, adsorption (activated alumina,iron-based sorbent, and zero-valent iron), ion exchange, and nanoparticles and nano-engineered adsorbents have shown considerable potential (Hassan, 2023; Rasaili et al., 2024).

According to the annual report of Kathmandu Upatyaka Khanepani Limited (KUKL), only 240.02 million liters per day (MLD) of water is supplied to meet a total demand of 506 MLD, with 25.95 MLD sourced from groundwater (KUKL, 2024). Various sources, including public wells, compensate for the deficit of 265.98 MLD, and the exact data are unknown. Despite the substantial contribution of shallow aquifers to municipal water provision in the Kathmandu Valley, most hydrogeological investigations have concentrated exclusively on deeper aquifer systems. Although public wells play a critical role in Kathmandu Valley's water supply, no systematic investigation has assessed their arsenic contamination status. This study addresses this research void by (1) quantifying arsenic levels across shallow public wells and (2) evaluating associated health risks. This study establishes critical baseline data while significantly advancing understanding of arsenic contamination of groundwater and its linked public health risks in the region.

2. MATERIALS AND METHODS

2.1 Study area and sampling sources



Source: JICA, 1990

Fig 1: GIS map showing the study area within the ring road of Kathmandu Metropolitan City

This study focused on areas within the ring road of the Kathmandu Metropolitan City (27°71›72››N, 85°32›40''E), Kathmandu District, Bagmati Province, Nepal. The study area spans approximately 49.45 km² and receives an annual average precipitation of 1,742 mm (Department of Hydrology and Meteorology (DHM), 2023). While the valley's mean annual temperature (17.6°C) aligns with subtropical highland norms, its extreme precipitation seasonality (80% monsoon concentration) creates marked hydrological contrasts between wet and dry periods. The Kathmandu Metropolitan City consists of 32 administrative wards, and those located along the ring road—Kalanki, Kalimati, Dallu, Shorakhutte, Lainchour, Maharajgunj, Baluwatar, Mitrapark, Pashupati, Gausala, and Koteshowr, were included in this study.

Kathmandu Valley is categorized into three Groundwater Districts (GWD) based on hydrogeological classification: Northern Groundwater District (NGWD), Central Groundwater District (CGWD), and Southern Groundwater District (SGWD), as illustrated in Fig. 1 (JICA 1990). The NGWD and CGWD are located within Kathmandu Metropolitan City. Notably, NGWD is the valley's sole groundwater recharge zone, with aquifer replenishment occurring exclusively through precipitation.

2.2 Data collection, water sampling, and preservation

Data collection and analysis for this study were conducted exclusively during the dry season, from January and February 2022. A dual-methods strategy was implemented, incorporating both qualitative and quantitative analysis. Data sources included field surveys, laboratory analysis of water samples, a structured questionnaire survey, and Key Informant Interviews (KIIs). The questionnaire was administered to 385 well users across all sites. Arsenic awareness was evaluated through multiple questions addressing familiarity with arsenic and knowledge of its health effects; respondents answering ‘no’ to all related questions were categorized as unaware. Verbal informed consent was obtained from all participants prior to data collection. KIIs were conducted with medical professionals at Tribhuvan University Teaching Hospital, Kathmandu’s busiest public hospital. Participants for the KIIs were selected using snowball sampling, wherein each respondent referred to the next.

For water quality assessment, one shallow public well was randomly selected from each of the 11 administrative wards along the ring road, yielding 11 spatially representative samples (n=11). A 125 ml sample was collected in a high-density polyethylene (HDPE) bottle, acidified with 2 mL of concentrated hydrochloric acid (HCl), and stored in dark containers to prevent photochemical reactions. The samples were then transported to the Environment and Public Health Organization (ENPHO) in Kathmandu for arsenic analysis.

2.3 Sample analysis and calculation

The total arsenic concentration in water samples was quantified using a Continuous Hydride Generation Atomic Absorption Spectrophotometer (HG-AAS) at the ENPHO Research Laboratory. The instrument used for the analysis was the iCE 3300 AAS (Thermo Fisher Scientific, USA), which can detect arsenic in water at a minimum concentration of 0.005 mg/L. For the analysis, 50 mL of each water sample was placed in a 100 mL beaker, and then 5 mL of concentrated hydrochloric acid (HCl) was added. The solution was stirred thoroughly using a glass rod. Subsequently, 5 ml of potassium iodide (KI) solution was added, mixed well, and allowed to sit undisturbed for 30 minutes in a safe location. A blank solution was prepared using double-distilled water following the same procedure.

Following sample preparation, the arsenic concentration was measured directly using the HG-AAS system. The spectrophotometer reading (in mg/L) was then multiplied by the dilution factor to calculate the total arsenic concentration in the sample, following the standard procedure recommended by APHA, AWWA, and WEF (2017).

As (mg/L) = AAS reading (mg/L) × dilution time (df)…………………………………………..(i)

where,

As (mg/L) = Concentration of arsenic in milligrams per litre

AAS reading (mg/L) = Measured value from the Atomic Absorption Spectrometer in mg/L

df = Dilution factors used during sample preparation

3. RESULTS

Our preliminary survey identified 43 public wells distributed across 11 wards of the Kathmandu Metropolitan City, with depths varying between 1–30 meters, as indicated in Table 1.

Field assessment revealed that 23.26% of these wells were non-functional (dry), while 76.74% remained actively used by local communities. Among operational wells, six specific locations—Pepsicola, KMC (Sinamangal), Biswarup Forest (Pashupati), Nawali, Dhumbarahi, and Bohoratar— served as crucial drinking water sources for 13.95% of users. Conversely, 30.23% of wells were used exclusively for household chores. Seasonal analysis indicated significantly increased reliance on these wells for drinking and cooking purposes during dry periods.

The study documented 385 household users of these public wells, with usage patterns as follows: 36.88% for drinking, 38.18% for cooking, and 24.94% for cleaning purposes. Notably, despite this substantial dependence on groundwater resources, our survey revealed alarmingly low awareness levels, with only 15.39% of respondents demonstrating knowledge of potential arsenic contamination and its associated health risk. This disparity between usage rates and risk awareness highlights critical gaps in public health education regarding groundwater safety in urban Kathmandu.

Table 1: Details of public wells: location, longitude, latitude, depth (in meters), condition, and number of families using each well.

Ward/Location	Longitude	Latitude	Depth	Condition	No. of the family using well
Ward 14: Kalanki					
TU	85º17’29” E	27º40’54” N	3	Polluted	12
Shanti Rokka Dharmashala	85º17’54” E	27º40’54” N	9	Dry	N/A
Gangkhola**	85º17’22” E	27º41’11” N	7.5	Normal	15
Makalu	85º16’47” E	27º41’45” N	1.5	Polluted	N/A
Buddha Marg	85º17’03” E	27º41’39” N	6	Scarce	7
Gita Panchyam Marg	85º17’01” E	27º41’41” N	8.5	Scarce	5
Ward 13: Kalimati					
Dhaukhel**	85º18’08” E	27º41’56” N	3	Normal	15
Tarkeshowr	85º18’08” E	27º42’04” N	2	Polluted	N/A
Ward 15: Dallu					
Manjushree	85º17’11” E	27º42’50” N	10	Dry	N/A
Kimdol	85º17’34” E	27º42’52” N	N/A	Dry	N/A
Chamati**	85º17’43” E	27º43’01” N	2	Polluted	6
Chhauni	85º17’22” E	27º42’38” N	1	Dry	N/A
Ward 16: Shorakhutte					
Gaurishankar Temple	85º17’32” E	27º43’49” N	7	N/A	N/A
Kharibot**	85º17’34” E	27º43’53” N	3.5	Polluted	10
Bohoratar	85º17’40” E	27º44’14” N	N/A	N/A	N/A
Bohoratar Height	85º17’37” E	27º44’13” N	1.5	Normal	12
Balaju Height	85º17’50” E	27º44’04” N	1.2	Dry	N/A
NEA Balaju Station	85º17’44” E	27º43’35” N	2.5	Normal	4
Ward 32: Koteshowr					
Pepsicola**	85º21’41” E	27º41’26” N	30	Normal	15
Purano Sinamangal	85º21’24” E	27º41’15” N	9.5	Dry	N/A
Sinamangal	85º21’23” E	27º41’09” N	7	Normal	15
Jadibuti	85º21’10” E	27º40’48” N	10	Polluted	9
Ward 03: Maharajgunj					
Gajendra Basti**	85º19’58” E	27º44’13” N	6	Normal	12
Maharjan Nursery	85º19’52” E	27º43’83” N	3	Normal	35
Ward 04: Baluwatar					
Dhumbarahi A	85º20’41” E	27º43’51” N	1	Normal	45
Dhumbarahi B	85º20’41” E	27º43’51” N	0.7	Normal	
Dhumbarahi Marg	85º20’27” E	27º43’34” N	1	Normal	30
Tushaloohar Temple A	85º20’02” E	27º43’52” N	1	Normal	25
Tushaloohar Temple B	85º20’02” E	27º43’52” N	1.4	Normal	
Baluwatar A**	85º19’57” E	27º43’40” N	3	Normal	20
Baluwatar B	85º20’02” E	27º43’47” N	N/A	Dry	N/A
PanchaKanya	85º20’10” E	27º43’51” N	1.5	Polluted	N/A
Ward 07: Mitrapark					

Ganesh Temple**	85º20'41" E	27º42'58" N	6.8	Normal	10
Mirmirey	85º20'36" E	27º43'08" N	3.5	Dry	N/A
Bulbule	85º20'28" E	27º43'01" N	11	N/A	N/A
Ward 08: Pashupati					
Nawali**	85º20'33" E	27º42'40" N	9	Normal	40
Biswarup Forest	85º21'10" E	27º42'29" N	6	Normal	6
Kirateshowr	85º21'02" E	27º42'45" N	4	Normal	5
Ward 09: Gaushala					
KMC, Sinamangal**	85º21'13" E	27º41'42" N	1	Normal	25
Riverside, Sinamangal	85º20'59" E	27º41'42" N	1.7	Scarce	7
Ward 26: Lainchour					
Amrit Marg	85º18'45" E	27º42'57" N	N/A	Dry	N/A
Bhagwan Bahal	85º18'44" E	27º42'57" N	N/A	Dry	N/A
Kapurdhara**	85º18'56" E	27º43'24" N	N/A	N/A	N/A
** represents public wells selected for water sample collection using simple random sampling.					

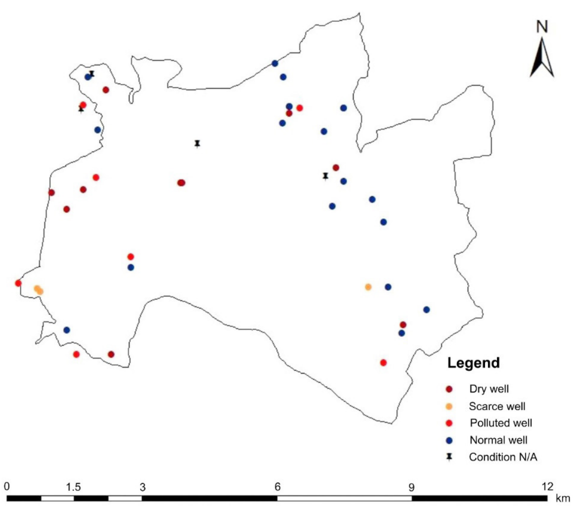


Fig 2: GIS map indicating the status of public wells in Kathmandu Metropolitan City, including conditions such as dry, scarce, and polluted wells.

3.1 Arsenic concentration in public wells

Analysis of water samples (n=11) revealed arsenic concentrations below the detection limit of 0.005 mg/L in all samples. These findings indicate an absence of arsenic pollution in the sampled wells at the time of testing.

3.2 Arsenic exposure, health impacts, and medical professionals

While no statistically significant health impacts from groundwater arsenic contamination were identified in this study, medical practitioners at TU Teaching Hospital report that approximately 5% of patients presenting with dermatological symptoms (itchy skin, sores, overnight blisters, and allergic reactions) were originate from agricultural places like Kavre palanchowk, where arsenic-containing pesticides may contribute to these clinical manifestations. Clinical experts confirm arsenic as an established public health hazard, with acute exposure (8–10 months) causing arsenic poisoning symptoms including nausea, abdominal pain, loss of appetite, diarrhoea, skin allergies, itching of the feet, abdomen, and limbs, and overnight blisters on the hands and skin. Chronic exposure is associated with severe consequences, including arsenic cancer and infertility in women and delayed physical and cognitive development in children. Additionally, chronic arsenic toxicity can impair vital organs, including the nervous system, kidneys, heart, and liver, and may manifest through damage to the skin, hair, and nails.

4. DISCUSSION

Kathmandu has experienced persistent water scarcity since the 1980s, with escalating severity in recent decades. Groundwater extraction supplies 50% of the valley's water demand, rising to 60-70% during dry periods (ICIMOD, 2007; Shrestha et al., 2023). This unsustainable reliance has led to severe aquifer depletion, with water table declining by 13-33 meters (1980-2000), 1.38-7.5 meters (2000-2008), and a projected decrease of 5.25-7.39 meters by 2050

(Lamichhane & Shakya, 2020). Over the last few decades, unprecedented groundwater extraction, coupled with inadequate recharge, exacerbated the crisis.

Our study of public wells revealed that 23.25% were completely dry, 6.98% were functionally scarce, and the remainder exhibited measurable annual decline in water levels due to uncontrolled urban expansion and minimal groundwater recharge. While groundwater is the key water source for 88% of the valley residents for bathing, only 3% utilize groundwater for drinking purposes (Shrestha et al., 2018). This stands in stark contrast to Nepal's Terai region, where approximately 90% of the population sources their potable water primarily from groundwater (WHO & NHRC, 2009; Lamichhane & Singh, 2019). Our data further delineates usage patterns among shallow public well consumers: 36.88% for drinking, 38.18% for domestic chores, and 24.94% exclusively for cleaning.

The absence of detectable arsenic in these shallow wells may be attributed to the prevalent oxidizing conditions, which immobilize arsenic through adsorption onto iron and manganese oxides. Conversely, deeper reducing aquifers, where arsenic is often reported, mobilize As(III), elucidating the disparity between shallow and deep groundwater arsenic levels. However, Shrestha et al. (2013) reported that 34% of the deep groundwater within the Kathmandu Valley surpassed the WHO threshold of 0.01 mg/L, while all shallow groundwater samples remained within acceptable limits. In contrast, Maharjan et al. (2009) identified that 11.4% of 149 shallow tube wells tested within the valley exceeded the WHO threshold, indicating localized variability. The highest recorded arsenic concentration in the valley was 2.8 mg/L (Gwachha et al., 2020).

This study is constrained by its limited sample size (n=11), single-season (dry period) sampling, and the absence of arsenic speciation. Arsenic concentrations are known to exhibit considerable spatiotemporal variability, influenced by seasonal hydrological fluctuations and geological heterogeneity. This necessitates spatiotemporally resolved monitoring designs to accurately characterize arsenic exposure risks across different seasons and hydrogeological settings.

In the Terai region, extensive testing conducted across 20 districts revealed that, out of 25,058 water samples, 23% had arsenic levels falling within the 0.01–0.05 mg/L range, and 8% exceeded 0.05 mg/L (NASC and ENPHO, 2004). Notably, 19 of these districts surpassed the NDWQS threshold. Rupandehi reported the highest arsenic concentration at 2.62 mg/L, followed by Nawalparsi (1.828 mg/L) and Rautahat (1.007 mg/L. By 2008, the blanket testing of 11,39,891 tube wells in Terai had identified 20,243 wells exceeding the NDWQS threshold, and 64,168 wells surpassing the WHO limits (WHO & NHRC, 2009).

A weak positive correlation between groundwater depth and arsenic concentration has been observed, suggesting that deeper aquifers may contain higher arsenic levels compared to shallow ones (Banson et al., 2020; JICA and ENPHO, 2005; Maharjan et al., 2009), which is consistent with the current study's findings. Despite the high literacy rate in Kathmandu, the adoption of safer water practices remains limited only 13% of residents use public wells for drinking, and merely 3.85% employ filtration systems to mitigate contamination. Furthermore, only 15.39% were found to be adequately informed and cautious regarding arsenic contamination. The discordance between high groundwater dependence and significantly low public awareness of arsenic (84.61% unaware) delineates considerable public health vulnerability. In the absence of detectable arsenic, this knowledge deficit nevertheless escalates exposure risk from coexisting contaminants and potential future deterioration of water quality. This awareness gap is likely to be more pronounced in the Terai region. Therefore, public education and targeted training initiatives play a critical role in minimizing the health risks posed by arsenic.

In the public wells of Kathmandu Metropolitan City, arsenic levels were found to be below the detectable limit, and no associated health impacts were reported. In contrast, the situation in Nepal's Terai region is significantly more severe. According to Maharjan et al. (2005), approximately 80% of the population in the Terai were diagnosed with arsenicosis. In Nawalparasi, one of the affected districts, around 60% of the population were diagnosed with the same condition (Rasaili et al., 2024). Skin disorders are among the most reported health issues following arsenic exposure.

Although awareness and capacity among healthcare professionals were minimal up to the year 2000 with limited knowledge and skills to diagnose or manage arsenic-associated health conditions (WHO & NHRC, 2009) recent reports indicate that many health workers are now equipped to treat various complications arising from arsenic exposure. Despite these advancements, no comprehensive research or large-scale surveys have been conducted in the Terai region since 2009 to evaluate the extent of arsenic contamination and the incidence of arsenicosis in Nepal.

5. RECOMMENDATIONS

To address the identified vulnerabilities and ensure long-term water safety, we propose the following measures: (1) routine monitoring of wells by establishing a credible regulatory body to track potential contamination trends, (2) implementing community-based water safety literacy initiatives for consumers, and (3) promotion of preventive strategies, including artificial ground water recharge and rainwater harvesting systems to diversify water sources.

6. CONCLUSION

This study confirms that arsenic levels in shallow public wells are below detection limits, indicating no immediate health risk from arsenic exposure. Despite this, deep aquifer contamination in the Kathmandu Valley and critically low public awareness sustains latent vulnerability. These findings underscore the need for stratified and proactive water safety, as detailed in the following recommendations.

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