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Assessing the Human Health Risks of Heavy Metal Contamination in Groundwaters: A Comparative, Multi-Regional Study

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تقييم مخاطر تلوث المياه الجوفية بالمعادن الثقيلة على صحة الإنسان: دراسة مقارنة متعددة الأقاليم

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Abstract:
Groundwater is an important source of drinking water in many rural and urban areas. This can include heavy metals from stone, industry, agriculture, mining, and plumbing. This paper compares human health hazards from arsenic, lead, cadmium, chromium, manganese, iron, and nickel in selected groundwater regions. The study used general data from Bangladesh, India, Pakistan, China and Nigeria. World Health Organization (WHO) guidelines and risk assessment methods are also used by the U.S. Environmental Protection Agency. No new field samples were taken. Therefore, this paper is a secondary data study and practical review. The results show that arsenic is the leading cause of cancer risk in South Asia. Bangladesh is facing significant exposure to arsenic in shallow wells. Pakistani studies show that arsenic levels are very high in some parts of Punjab. Under India's supervision, the national excise rates are low, but the affected areas are still prominent. China's data show that there is strong manganese and iron enrichment in the South Dongting Lake reservoir. Children had a higher risk index than adults. Nigerian data shows that there is a local abundance of lead, nickel and cadmium in Lagos' groundwater. Children are generally at higher risk because they drink more water per kilogram. The study recommends risk-based surveillance, treatment at home, safe exchange between wells, source control, and public reporting. It also supports periodic testing by ICP-MS or AAS where resources allow. The biggest limitation is that the datasets use different years and sample designs. However, this comparison shows clear public health priorities for groundwater conservation.

Keywords: Groundwater, Heavy Metals, Arsenic, Lead, Cadmium, Chromium, Hazard Ratio, Cancer Risk, Public Health, South Asia.

الملخص:
تُعدّ المياه الجوفية مصدرًا مهمًا لمياه الشرب في العديد من المناطق الريفية والحضرية. وقد تحتوي هذه المياه على معادن ثقيلة ناتجة عن التكوينات الصخرية، والأنشطة الصناعية والزراعية، والتعدين، وشبكات وأنابيب المياه. تقارن هذه الورقة البحثية المخاطر الصحية البشرية الناجمة عن وجود الزرنيخ والرصاص والكادميوم والكروم والمنغنيز والحديد والنيكل في عدد من مناطق المياه الجوفية المختارة.
اعتمدت الدراسة على بيانات عامة متاحة من بنغلاديش والهند وباكستان والصين ونيجيريا. كما استندت إلى المبادئ التوجيهية الصادرة عن منظمة الصحة العالمية(WHO) ، وإلى منهجيات تقييم المخاطر التي تستخدمها وكالة حماية البيئة

الأمريكية (U.S. EPA). ولم تُجمع عينات ميدانية جديدة؛ ومن ثمّ، تُعدّ هذه الورقة دراسة قائمة على تحليل البيانات الثانوية ومراجعة تطبيقية للأدبيات والبيانات المتاحة.
أظهرت النتائج أن الزرنيخ يُعدّ العامل الرئيس المسبب لمخاطر الإصابة بالسرطان في جنوب آسيا. وتواجه بنغلاديش مستويات مرتفعة من التعرض للزرنيخ في الآبار الضحلة. كما أظهرت الدراسات الباكستانية ارتفاعًا شديدًا في تركيزات الزرنيخ في بعض مناطق إقليم البنجاب. وفي الهند، كانت المعدلات الوطنية للتعرض منخفضة، إلا أن المناطق المتضررة ما تزال بارزة وتشكل مصدرًا للقلق.
وأظهرت البيانات الصينية وجود تراكم مرتفع للمنغنيز والحديد في خزان بحيرة دونغتينغ الجنوبية. كما تبين أن مؤشر المخاطر لدى الأطفال كان أعلى منه لدى البالغين. وأشارت البيانات النيجيرية إلى وجود تراكيز محلية مرتفعة من الرصاص والنيكل والكادميوم في المياه الجوفية بمدينة لاغوس.
وبوجه عام، يكون الأطفال أكثر عرضة للمخاطر الصحية؛ نظرًا إلى استهلاكهم كمية أكبر من المياه نسبةً إلى وزن الجسم مقارنةً بالبالغين. وتوصي الدراسة بتطبيق برامج مراقبة قائمة على مستوى المخاطر، واستخدام تقنيات معالجة المياه على مستوى المنازل، وتوفير بدائل آمنة بين الآبار، والسيطرة على مصادر التلوث، والإفصاح العلني عن نتائج الفحوصات.
كما تدعم الدراسة إجراء اختبارات دورية باستخدام مطيافية الكتلة بالبلازما المقترنة حثيًا (ICP-MS) أو مطيافية الامتصاص الذري(AAS) ، متى ما سمحت الموارد المتاحة بذلك. ويتمثل القيد الرئيس للدراسة في أن مجموعات البيانات المستخدمة تعود إلى سنوات مختلفة، كما أنها تعتمد على تصاميم وأساليب متباينة في أخذ العينات. ومع ذلك، تُظهر هذه المقارنة بوضوح أولويات الصحة العامة المتعلقة بحماية المياه الجوفية والمحافظة على سلامتها.

الكلمات المفتاحية: المياه الجوفية، المعادن الثقيلة، الزرنيخ، الرصاص، الكادميوم، الكروم، نسبة الخطر، مخاطر الإصابة بالسرطان، الصحة العامة، جنوب آسيا.

Introduction

Groundwater often appears to be clean and safe. This appearance can be misleading. Minerals can be soluble in groundwater without odor or color. People can drink such water for many years. Prolonged exposure can damage skin, kidneys, liver, blood, nerves, and child development (WHO, 2022; Lamma, 2021b).

Heavy metals do not destroy the environment. It can move between soil, water, crops, and the human body. Some minerals are required in small quantities. Others have no bio-safe role. Arsenic, cadmium, lead, and chromium are major concerns because they can cause serious damage at low levels (Balali-Mud et al., 2021; Mohammad et al., 2015b).

Groundwater contamination is not the same in every region. In delta reservoirs, arsenic can be discharged from sediments under depleting conditions. In industrial belts, you can add metal coating, smearing, battery work, mining, and landfills. In cities, old plumbing can pick up lead from the tap. Agriculture can also change the conditions of oxidation, compacting, and metal movement. These mixed sources make it difficult to assess the risk. (Lamma, 2021a)

Health risks from metal depend on quantity and exposure. It also depends on age, body weight, water intake and exposure time. A child can get more water intake than an adult. This is because the child's body weight is low. Separate pathways for adults and children are needed for risk assessments (U.S. Environmental Protection Agency, 2011; Lamma & Swamy, 2018).

The World Health Organization (WHO) sets guidelines for drinking water. These values are widely used by governments and researchers. Helps identify unsafe patterns. However, the comparison of the guidelines is only the first time. There is no risk of lifelong infection. It also does not show a complete non-cancer risk. For this reason, the risk ratio, risk index, and cancer risk framework have been included in this paper (Agency for Toxic Substances and Disease Registry, 2024).

This paper is based on real public data from five regions. Bangladesh represents the natural effects of arsenic in shallow pipe wells. Arsenic and fluoride contamination is common in Punjab, Pakistan. India is represented by national surveillance through General Sampling Expressions data. China represents recent research on the health risks of groundwater from South Dongting Lake (Lamma et al., 2018). Nigeria represents the local connectivity of urban groundwater in Lagos. These areas provide a useful comparison between hydrogeological and urban environments.O. A. Lamma & Krair, 2018)

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The goal is not to declare any one country insecure. The aim is to identify risk patterns. The sheet also shows the minerals which need immediate action. It combines pollution data with simple calculations of health risks. It then makes practical recommendations for monitoring and control. (Lamma, 2024)

Objectives and Objectives

The purpose of this paper is to evaluate the human health risks due to heavy metals in groundwater based on general data from several areas.
The first objective is to compare the quantum of selected minerals with the values of the WHO drinking water guidelines. The second objective is to examine general evidence from Bangladesh, Pakistan, India, China, and Nigeria. The third goal is to describe non-cancer practices and cancer risks in simple language. The fourth objective is to identify the minerals and groups that need the most attention. The fifth objective is to suggest practical measures to safely control groundwater use.

Materials and Methods

The study used a comparative secondary data design. No new water samples were collected. Public reports, court papers and official information were used for surveillance. This design is useful when there are already large public data sets. It also reduces costs and avoids duplication of fieldwork.
The survey focused on groundwater which is used for drinking or domestic supply. Surface water was not the main focus. The selected minerals included Arsenic, Lead, Cadmium, Chromium, Manganese, Iron Ore, and Nickel. These minerals were selected as they have been included in general groundwater studies. It also has a well-known health significance.
Data was extracted in micrograms per liter where possible. Some sources report one milligram per liter. These values were multiplied by 1000 to converted to micrograms per liter. The values of abuse were compared with the guidelines of the World Health Organization. National borders were also mentioned where the source was informed.
The public dataset is not a standard monitoring survey. Each source used its own sampling plan. It's a restriction. However, the sources provide real field evidence. Therefore, this paper compares risk patterns and not accurate national averages.

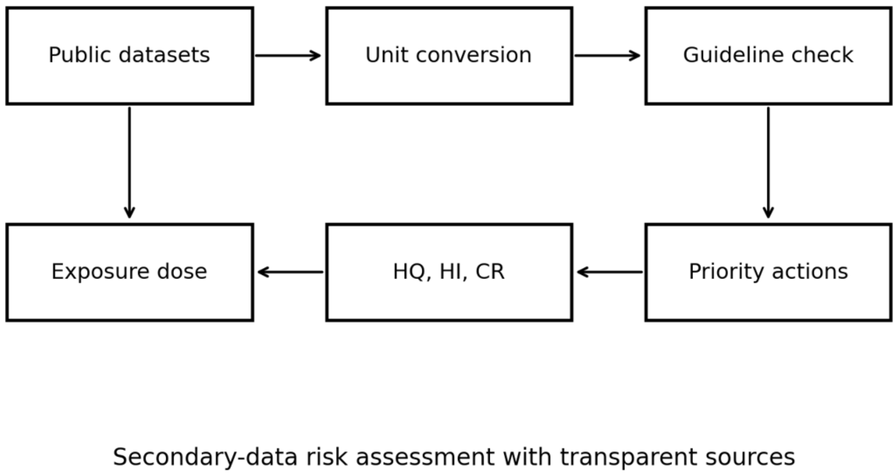

Figure 1: Workflows used in comparative health risk assessment.

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General Data Sources

Table 1 Important public data sources used in the paper.

Area	Type of Source	Metals used	Useful Data	Source of Quote
Bangladesh	BGS/DPHE Survey and Arsenic Reviews	K	Geological Survey/DPHE has reported the rate of deep and shallow rise in tubular wells.	(British Geological Survey and Department of Public Health Engineering, 2001; Ali, 2006)
India	CGWB Annual Groundwater Quality Report, 2025, via PIB	As، Pb	The CGWB Board reported sample numbers and above rates for 2024.	(Central Groundwater Council, 2025)
Pakistan	Farooq etc., Khan etc., Punjab Studies and Nowshera	As، Pb، Cd، Cr، Ni	Investigations in Punjab have reported high levels of arsenic. The Nucera study examined heavy metals.	(Farooqi et al., 2007a, 2007b; Khan etc., 2015)
China	Study of the South Dongting Lake Basin	Fe، Mn، As، Cd، Pb، Cu، Zn	In the study, 88 groundwater sites were sampled and ICP-MS was used.	(Zhang & Ren, 2025)
Nigeria	Study of Groundwater in Lagos	Pb، Ni، Cd، Cu، Cr، Zn	The study used AAS and health risk calculations.	(Yahya et al., 2020)

Guiding Values and Risk Criteria

WHO guidelines were used as key values for drinking water testing. The tentative values of both arsenic and lead are contained in the WHO guidance document of 10 µg/L. The price of cadmium is 3 µg/L. The total chromium is valued at 50 µg/L. The provisional value of the total manganese is 80 µg/L (WHO, 2022; Lamma, 2023).

The sample given above does not prove disease in a person. This indicates the need to take action. This means that the exposure should be studied less or more. As far as lead is concerned, the World Health Organization notes that there is no clear limit that protects all health effects. Children and lions are particularly susceptible to blood lead (WHO, 2022; (Mohammad et al., 2015a).

The risk factor is used for non-cancer effects. The exhibit food is divided into reference foods. Less than one value indicates a lack of interest in this path. Multiple values do not predict disease. This means that the chemical needs to be examined in more detail (Agency for Toxics and Diseases Registry, 2024; Lamma, 2020).

The risk of cancer is usually expressed as an additional lifelong possibility. A risk of $1 \times 10{-}4$ means one additional cancer case for every 10,000 people. Many risk assessments look at $1 \times 10{-}6$ to $1 \times 10{-}4$ as a management scope. This does not eliminate the need for local policy governance.

Table 2 Values of the WHO Drinking Water Guidelines used in this paper.

Metal	Symptom	Value (µg/L)	Biggest Health Concern	Basis of this paper
Arsenic	Ar	10	skin, lung, bladder and kidney cancers	WHO Interim Guidance
Cadmium	Cd	3	Damage to the kidney ducts; long biological half-life	WHO Guidelines
Bullets	.P.B	10	Neurodevelopmental effects in children; effects of blood pressure in adults	WHO Interim Guidance
Total Chromium	Cr	50	Gastrointestinal upset in Cr(VI) and possibly cancer	WHO Guidelines
Manganese	Mg	80	Nervous anxiety, especially for infants	WHO Interim Guidance

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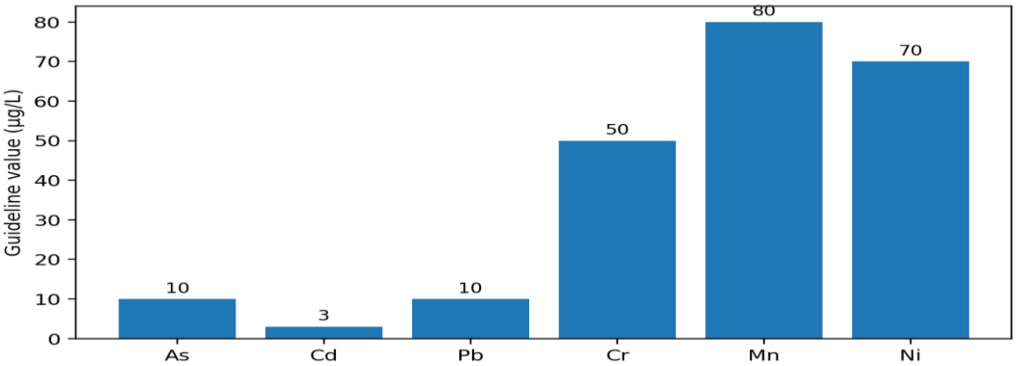

Figure 2: Values of WHO Guidelines used for Selected Minerals. Source: WHO Drinking Water Quality Guidelines, 2022.

Exposure and Risk Equation

The study uses a standard swallowing route. This route is most important for displaying drinking water. Skin exposure is not calculated here. Many minerals are absorbed more quickly than swallows. The equations are described in a simple manner below.

Chronic daily consumption, or CDI, was calculated as follows: CDI = C× IR× EF× ED/BW× AT. C is the amount of minerals in water. IR is the average daily water consumption. EF is the exposure frequency. Penis dysfunction is the duration of exposure. Heavy weight is body weight. AT is the average time.

For non-cancer risk, the risk ratio HQ = CDI/RfD was calculated. The Risk Index was calculated as the sum of the headquarters values of all metals. For cancer risk, CR = LADD × SF. LADD stands for Average Daily Dose for a Lifetime. SF stands for Mouth Tilt Factor.

The exhibition factors have been kept simple. It helps readers recreate stories. Adults are allocated 2 litres per day. One litre has been earmarked for children/day. These values follow EPA and ATSDR's long-established assumptions for drinking water testing (EPA, 2011; Agency for Toxic Substances and Disease Registry, 2023 ; Lamma & Sallam, 2018).

Table 3: Exposure Factors Used in Examination Calculations.

Parameter	Symptom	Estimate	Reason
Adult Consumption Rate	IRadult	2.0 liters per day	Default Scan Rate
Children's Meal Rates	IRchild	1.0 liters per day	Default Scan Rate
Adult Body Weight	BWadult	70 kg	Common Screening Hypothesis
The Child's Body Weight	B.W. Child	15 kg	Common Screening Hypothesis
Frequency Exposure	EF	365 days/year	Daily use of drinking water
Exhibition Duration for Adults	Ed Adult	30 years	The Assumption of Residential Screening
Exhibition Period for Children	E.D. Child	6 years	Children's Window Exhibition
Average Cancer Time	ATC	70 years × 365 days	Median age
Average Non-Cancer Time	ATnc	ED × 365 days	Duration of Average Exposure

Table 4: Toxicity values used only to illustrate this analysis.

Metal	RfD (mg/kg-day)	Oral Affinity Factor	Comment
Arsenic	0.0003	1.5	It is used for screening based on swallowing.
Cadmium	0.0005	0.38	The value of cancer varies according to the source. Use it carefully.
Chromium(VI)	0.003	0.5	The aggregate CR data can overestimate the risk of Cr(VI).
Bullets	There is no safe limit	Not used	It is better to compare the guidelines of this paper.
Manganese	0.14	Not used	Non-cancer screening only.

Practical and empirical basis

General studies have used practical methods in the laboratory. In the China study, 88 samples of groundwater were collected from reservoirs. The samples were filtered through 0.45 µm membranes. They were acidified with nitric acid. Metals were measured by ICP-MS (Zhang & Ren, 2025; O. A. Lamma, 2021c).

Atomic absorption spectroscopy was used in the Lagos study. Compare lead, nickel, cadmium, copper, chromium, and zinc to the WHO limits. It also derived the value of the average daily consumption to risk ratio (Yahya et al., 2020 Zhmool,et al., 2026).

In the study in Maharashtra, aquatic minerals were measured by ICP-MS. Topical urine samples were also collected from the selected participants. This practical design connects water quality with physical exposure indicators. Its authors report that arsenic further increased the risk of water ingestion (Mawari et al., 2022; Lamma et al., 2019; Zhmool, et al., 2026).

A practical field programme should follow suit. First, select wells based on depth, land use, and community use. Second, disinfect each well before taking the sample. Third, measurement of pH, conductivity, dissolved oxygen, and redox and reduction potential in the field. Fourth, provide filter and acidity to the mineral samples. Fifth, use ICP-MS or AAS with spaces and standards. Sixth, share the results with communities in plain language.

Results

Bangladesh: Arsenic Low-Depth Tubular Well

Bangladesh is one of the most obvious examples of the natural effects of arsenic through groundwater. In the BGS/DPHE study, 3,534 samples were tested across Bangladesh. A later review reported that 46% of the shallow pipe wells were more than 10 micrograms per liter. It also reported that 27% exceeded 50 micrograms per liter. Emission values in deep wells were low, at 5% and 1%, respectively (Ali, 2006;

This pattern shows why well depth is important. Lower substrates can release arsenic from the sediment. Deep water bodies may be safer in many places. However, deep wells are yet to be tested. Poorly constructed wells can mix water through reservoirs. Local geology can also change rapidly.

Overall health means great. The BGS/DPHE estimated that millions of people could drink more than 10 µg/L and 50 µg/L of water. Subsequent reviews found serious exposure, although mitigation reduced some risks (Chakraborty et al., 2010; Flanagan et al., 2012).

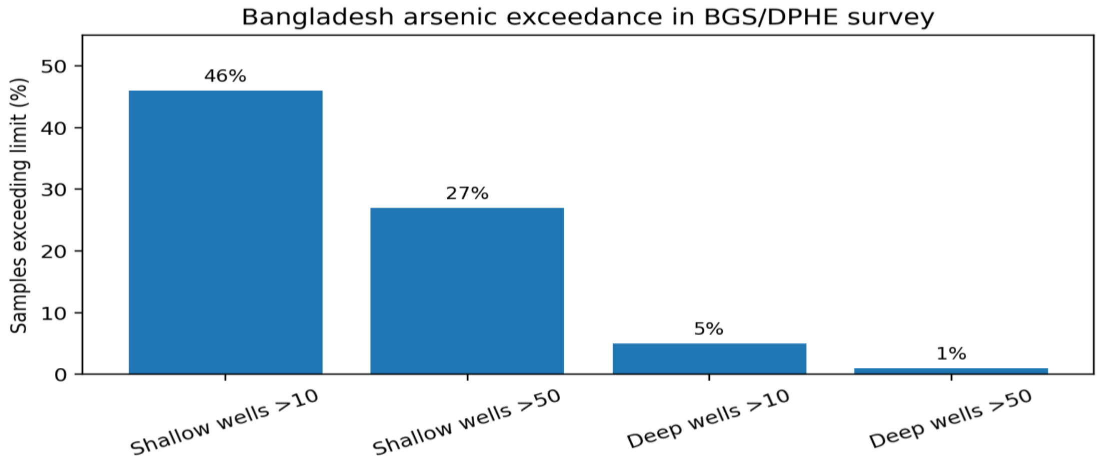

Figure 3: Arsenic abundance rate in shallow and shallow wells in Bangladesh. Source: BGS/DPHE values reported by Ali (2006).

India: Consumer Council and Monitoring of Affected Areas

India has a large national ground water monitoring system. CGWB public data shows that 3,415 arsenic detection samples were analysed in 2024. A total of 123 samples exceeded 10

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ppm. In the same version, 2,537 lead samples were reported. A total of 24 tablets were over 0.01 mg/L of lead (Central Groundwater Council, 2025; Mohammed et al., 2026).

This national average appears to be lower than the pattern of shallow wells in Bangladesh. However, they should not be considered harmless. A low national percentage can mean many unsafe wells. Local groups are more important than the national average. India has also listed partially affected areas in the form of Arsenic, Lead, Cadmium, and Chromium (Central Ground Water Board, 2020).

Empirical evidence from the One Health Risk Study in Maharashtra has been incorporated. Its authors analyzed several toxic elements of ICP-MS. They found that arsenic further increases the risk of potential ingestion. They also linked various drinking water sources to reported intestinal problems (Mawari et al., 2022; Alshebgo et al., 2026).

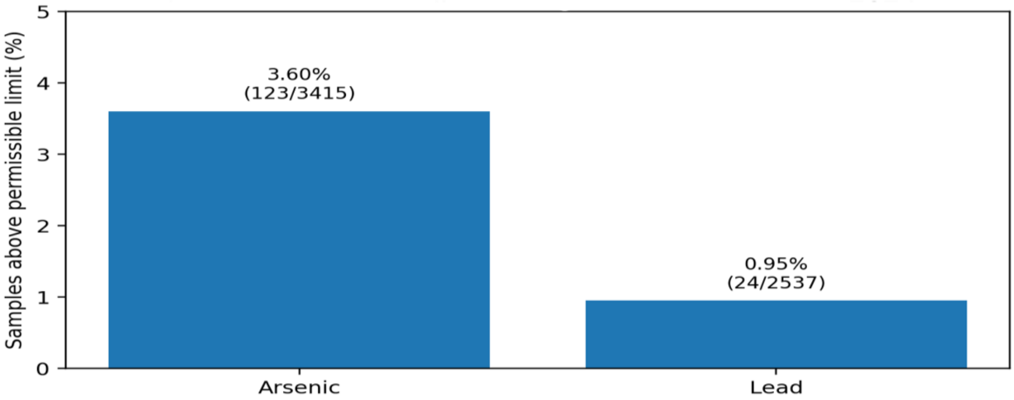

Figure 4: Override rate in CGWB Indian Arsenic and Lead Monitoring Index 2024. Source: Press Information Office, Government of India.

Pakistan: Arsenic zones and drinking water threaten in Punjab

Groundwater studies in Pakistan show locally intense arsenic problems. A study conducted in Lahore reported the amount of arsenic in fractures between 32 and 1900 micrograms per liter. All reported samples had WHO values greater than 10 µg/L (Farooqi et al., 2007a; Alfarjani et al., 2026). This range is much higher than the normal drinking water test values.

Another study in East Punjab reported severe arsenic and fluoride contamination. Link this pattern to natural hydrogeology and human activities. Sulfates, nitrates, waste, fertilizers, and industrial emissions are discussed as controls on groundwater chemistry (Farooqi et al., 2007b (Lamma et al., 2026).

A case study from Nowshera area which was related to arsenic and heavy metals in drinking water. Contamination of chromium, nickel, lead, cadmium, and arsenic has been reported. The authors used risk assessments to assess health risks (Khan et al., 2015; (Alnaass et al., 2026). These results show that Pakistan needs a common metal test. Arsenic testing alone can ignore other risks.

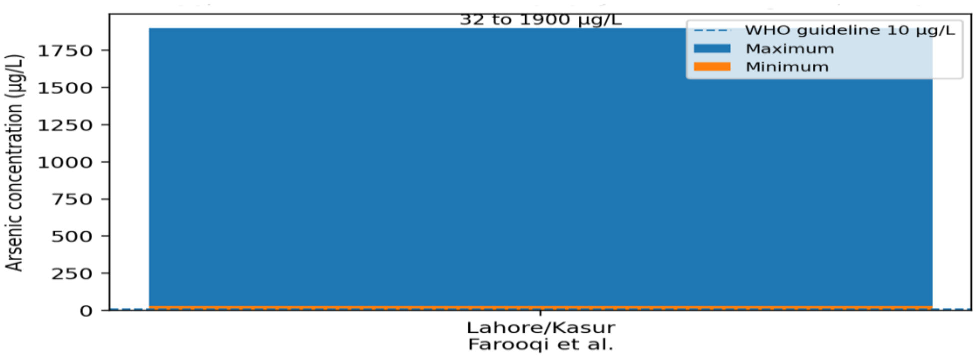

Figure 5: Arsenic range in the groundwater of Lahore and Kasur, Pakistan. Farooqi et al. (2007a), PubMed Abstract.

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China: South Dongting Lake Basin

The study of the South Dongting Lake Basin has provided recent detailed data. 88 groundwater samples were collected. They measured iron, manganese, copper, zinc, arsenic, cadmium, and lead by ICP-MS. The study found that manganese and iron are the main pollutants (Zhang and Ren, 2025 : Lamma et al., 2015).

The average consumption of manganese was 362.68 µg per L. Its maximum amount was 8312.28 µg per L. The average iron content was 318.33 µg/L. Its maximum capacity was 8984 µg/L. The maximum local energy of arsenic was 13.91 µg per L. This value was 1.39 times higher than the standard range used in the study (Zhang & Ren, 2025).

The picture of danger was also clear. The risk of total reported cancer in children was 1.82× 10−4. Arsenic further increased the risk of cancer. The overall risk index was 3.59 for adults and 6.54 for children. Manganese has been the primary risk source for non-cancer diseases (Zhang & Ren, 2025).

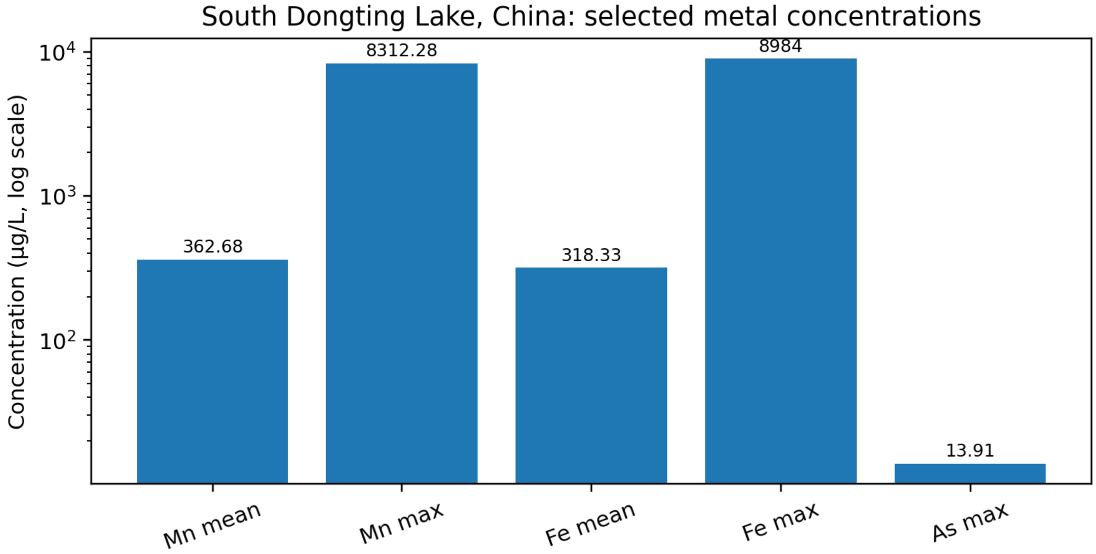

Figure 6: Quantity of selected minerals in the groundwater of Dongting Lake [Chang Ren (2025)].

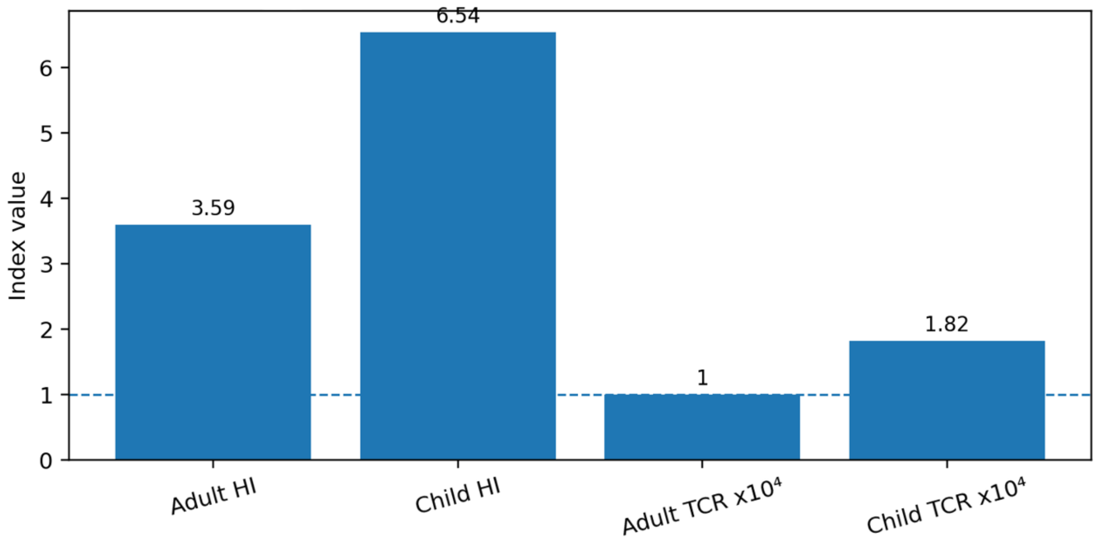

Figure 7: Reported risk and cancer indicators for South Dongting Lake. After multiplication, TCR values are shown to be 10,000 [Zhang and Ren (2025)].

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Nigeria: Lagos Groundwater

The groundwater study in Lagos focused on Iwaya, Makoko and Elaji. I checked the well water and the well water. AAS was used for lead, nickel, cadmium, copper, chromium, and zinc. Compare the results with those of the WHO (Yahya et al., 2020).

The study reported the presence of lead and nickel which was not allowed in well and well water. Maximum cadmium concentrations have also been reported in the water of the irrigation well. Copper, chromium, and zinc concentrations were within the normal range. The calculated risk indicators were less than one. However, the authors recommended treatment in high-risk areas (Yahya et al., 2020).

This result shows an important point. A hazard ratio of less than one does not mean that the water is full. It only means that his dosage is less than the selected reference dose. Minerals are still present with bacteria, salts or other contaminants. Community action must take into account all the risks together.

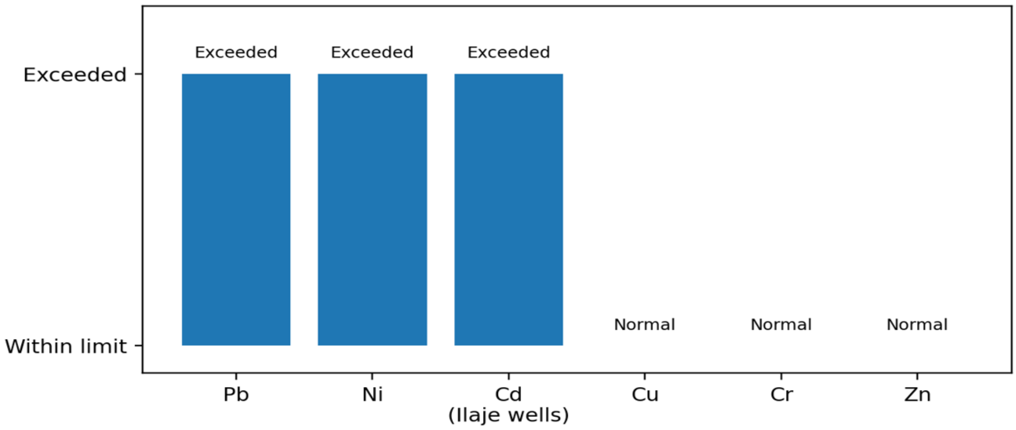

Figure 8: Compliance markers for selected minerals in Lagos groundwater [Yahya et al. (2020)].

Table 5: Comparison of results from selected public sources.

Area	The Root Problem of Metal	Key Overall Results	Meaning of Risks
Bangladesh	Arsenic	46% shallow wells >10 µg/L; 27% >50 µg/L	Chronic high arsenic exposure in shallow groundwater
India	Arsenic and Lead	123/3415 as samples; 24/2537 elliptical specimens above the border	Specific action required for domestic unsafe wells
Pakistan	Arsenic, Co-Contaminants	Lahore/Kasur study as a range of 32 to 1900 micrograms per liter	The risk of cancer is very high in hot spots
China	Hmm, inside, one.	Average weight 362.68 µg/L; baby weight 6.54	Manganese increases the risk of non-cancer infections
Nigeria	Pb، Ni، CD	Bypassed Pb and Ni; bypassed Elaje Wells CDs	Need for local treatment and monitoring

Search

The results show three different types of risks. The first type is high natural arsenic in silt aquifers. Parts of Bangladesh and Pakistan fit this pattern. The second type is a combination of industrial and urban metal inputs. Parts of India, Pakistan and Nigeria fit this pattern. The third pattern is the depletion of groundwater, which uses iron and manganese enrichment. South Dongting Lake is a clear example of this.

Arsenic is the strongest source of cancer risk in this comparison. This is because the toxicity of arsenic in small amounts of water is higher. It is also common in groundwater. Bangladesh shows the biggest problem in terms of population. In Pakistan, some specimens from Punjab

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have locally high concentrations. India showed a rate lower than the national limit in the above monitoring for 2024. However, local areas still face serious risks.
Lead is different from arsenic. Drinking water often enters from plumbing, fixtures, welding, batteries and industrial waste. The World Health Organization says the value of lead is temporary. It also indicates that it is not possible to set limits for large impacts. This means that lead control should aim for the lowest level of operation rather than just compliance (WHO, 2022).
Cadmium and chromium look more local in this comparison. It is often associated with industry, waste, electroplating, tanning, fertilizer, or mining. Total chromium is difficult to define. Chromium(VI) is much more toxic than chromium(III). Many field studies indicate total chromium. This can make cancer risk estimates uncertain.
Manganese and iron are often seen as aesthetic problems. China's data shows why this approach is so limited. Manganese posed a primary non-cancer risk in the South Dongting Lake study. Children were at higher risk than adults. This is as per the Exposure Rule. Children get more doses per kilogram of body weight.
The comparison also shows that exceeding guidelines and health risks are not the same. A metal may be higher than the standard but still has a calculated headquarters of less than one. This happened in the study of specific minerals of Lagos. This metal may be close to normal, but it raises cancer concerns throughout its life. Arsenic is the best example of this. Risk managers should use both tools.
Public data should be transmitted with caution. The national average can hide hotspots. Hotspots can also create fear if it is not clearly defined. Communities need results for their wells. They also need safer alternatives. Safe switching of wells, deep-protected wells, purified water through pipes, absorber filters, and reverse osmosis can be helpful. The choice depends on local chemistry and cost.
The treatment should match the shape of the metal. Arsenic removal often requires oxidation, coagulation, absorption, ion exchange, or membranes. Iron and manganese may require ventilation, oxidation, and filtration. Plumbing replacement and anticorrosion may be required for lead control. Removing cadmium and chromium from the source may require advanced treatments. One Home Filter can't solve every case.
Supervision should include quality control. Blank, copied cards, approved standards, and identity limits are mandatory. Without them, small differences in concentration can be misleading. It is important to record the field parameters because the redox state controls the movement of the metals. It is also important to record the depth and location of the well. These details make this data useful for the business.
Policies should be focused on the most vulnerable groups. Infants, pregnant women, and people with kidney disease may be at higher risk. Schools and health centres should be priority test points. Safe and unsafe wells should be shown in plain colours in public reports. It should also be clear what families can do immediately.

Example of Test Calculation for Arsenic

A simple calculation of arsenic shows why low profile values are important. At 10 µg/L, an adult who drinks 2 L/kg daily gains about 0.00029 mg/kg daily. If the oral RfD is 0.0003 mg/kg-day, the HQ for adults is about one. A child who drinks 1 litre daily and weighs 15 kg, gets about 0.00067 mg/kg per day. The child's residence is over two years old.
At 50 µg/L, the calculated gold rate is very high. This does not mean that the child will definitely get sick. This means that the exposure exceeds the health screening guidelines. This level of risk needs to be mitigated urgently. The same logic applies to the arsenic-rich areas of Bangladesh and Pakistan.
For cancer risk, the dosage is averaged over a lifetime. A person who has been exposed to it for decades can face serious lifelong threats. That's why arsenic has received so much

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attention in groundwater studies. Smaller quantities can be important when the exhibition lasts for several years.

Table 6: A simple example of Arsenic screening through injection pathway.

Arsenic (µg/L)	Adult Headquarters	Child Headquarters	Risk of Cancer in Adults
10	0.95	2.22	1.84E-04
50	4.76	11.11	9.18E-04
100	9.52	22.22	1.84e-03

Recommended Multi-Zone Monitoring Design

A robust field design is simple and repeatable. Each area should include rural wells, urban wells, and public supply points. It should also include deeper and shallow wells where possible. This design can showcase both natural and human sources.

Samples should be taken in dry and rainy seasons. When the groundwater flow changes, the mineral level can change. The pump can also mix water from different depths. Weather tests help reduce false confidence from a single visit.

Each sample should include field observations. The notes should include the depth of the well, type of pump, land use, and nearby drains. It should also include pH, electrical conduction, dissolved oxygen, and redox voltage. These values help explain the motion of arsenic, iron, and manganese.

Samples of dissolved metals should be filtered in the field. They should be acidified with clean nitric acid. Bottles should be washed and labeled before travelling. Reservation series models must go with each sample. These measures reduce handling errors.

In vitro analysis can use ICP-MS, ICP-OES, or nuclear absorption methods. The method chosen must meet the discovery threshold. It should be measured below the health reference value. It is important for arsenic, lead, and cadmium.

Quality control should be part of the budget. Each sampling trip requires at least one field blank. At least one copy is required for every 10 samples. It is important to use certified reference materials in the laboratory. Recovery tests should be reported with results.

The consequences of the threat should be returned to the communities. Reports should not be limited to metal names. They should be clear about what the outcome means. They should also clarify whether the water is safe to drink or not. This phase of communication is part of the work of public health.

Open data should use a common format. Each row should show location, type of well, mineral price, unit, date and method. This allows later studies to compare areas. It also allows for the construction of maps and warning systems.

Table 7 : Proposed Design for Multi-Zone Ground Water Monitoring Study.

Foot	Minimal movement	Purpose
Location Selection	Rural, urban, shallow shallow and public wells	Source Patterns Shoes
Sampling Season	Visits to dry and wet seasons	See Climate Changes
Field Records	PH, EC, DO, ORP, Depth, Land Use	Description of Metal Release
Sample Handling	Filtered and Sour Bottles	Protects the values of the dissolved metals
Laboratory Method	ICP-MS، ICP-OES، أو AAS	Detects low guidance levels
Quality Control	Blanks, Duplicates, Standards, Recovery Checks	Builds confidence in the results
Risk Reports	Comparison of HQ, HHI, TCR, and Guidelines	Converting Data into a Healthy Meaning
Public Participation	Maps, Tables, and Safe Stickers	Helps families act quickly

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How to reproduce practical work

A new researcher can reproduce the paper with the help of public data. First, download national or project-level water quality data. Then convert all the mineral values to micrograms per liter. This can avoid the mistakes of hybrid units.

Second, test each sample according to World Health Organization (WHO) guidelines. Mark each pattern below or above the guideline. This gives a clear overtaking rate for each metal. It also helps in fair comparison of regions.

Third, calculate the daily consumption of adults and children. Use the same amount, body weight, and exposure duration in different zones. This keeps the comparison transparent. Local factors can be added later.

Fourth, divide the quantity by the reference dose. It provides a measure of risk. Add the outer ratio of metals to assess the risk index. This step is useful when several metals overlap.

Fifth, calculate cancer risk only for carcinogenic minerals. Arsenic is the largest example of this thesis. Chromium (VI) may also be important. However, macro chrome data should be used with caution.

Sixth, check the results with the raw data. Too many values should be checked. These can really be hotspots. There can be errors in the unit as well. A short verification step can avoid inaccurate results.

Finally, generate data from verified data. Bar graphs can show override rates. Maps can show hotspots. Hazard charts can show the path from the source to the entrance. These figures make the paper easier to understand.

Quality and Limitations of Data

This paper has several limitations. Sources do not use a sample year. Do not use the same sample density. Some of them mention averages. Some of them mention ranges. Others reported percentages. Therefore, the paper compares patterns rather than an aggregate average.

Mineral types are not always dead. It is important for chromium and arsenic. Arsenic(III) can be more active and difficult to remove than arsenic(V). Chromium(VI) is more toxic than chromium(III). The overall values of the metal can mask these differences.

The exposures were kept simple. Domestic water use may vary depending on season, work, age, and diet. Body weight can also vary by region. Future studies should use local exposure surveys. Monte Carlo methods can better reflect uncertainty, as used in the China study (Zhang & Ren, 2025).

The study also does not measure dietary exposure. It is important for arsenic and cadmium. Crops roasted with contaminated water can increase nutrients. The full risk assessment should include drinking water, food, soil, and where possible, household dust.

Risk Management Recommendations

Groundwater conservation should start with mapping. Each well should have the location, depth, type of owner, and test result. Unsafe wells should be clearly marked. Nearby safe wells should also be marked. This helps families to change the source quickly.

Arsenic, lead, cadmium, chromium, manganese, iron and nickel should be tested together in high-risk areas. Only a metal test can miss mixed exposure. Schools, clinics and community supply wells must be tested first. These spaces serve sensitive groups.

Treatment should be chosen after testing the water. Arsenic filters can fail if iron, phosphate, or pH are not taken into account. Oxidation and filtration are often required to remove manganese. Plumbing checks are required for lead control. Industrial areas require source control before processing at home.

Public health institutions should share the findings in plain language. Reports should show whether the water is safe for drinking, cooking and infant formula. They should also take immediate action. Technical terminology should be retained in the Appendix.

Land use measures are essential for long-term control. Industrial effluent must be cleaned before discharging water. The waste dump should line up with the liner and be monitored. It is important to regulate the use of fertilizers and pesticides. Mining and smelting areas need to monitor groundwater. These measures reduce the risk in the future.

Conclusion

The paper compared heavy metal contamination in groundwater in five regions using real public data. The results show that arsenic is the biggest risk factor for cancer in hotspots in Bangladesh and Pakistan. India has a low rate of exceeding the national limit under 2024 monitoring, but the affected localized areas still need attention. Data from China show that manganese and iron can cause serious concern about non-theatrical cancer. The Lagos data shows an increase in lead, nickel and local cadmium.
Children are more at risk in most swallowing situations. This is because the dosage per kilogram is higher. Therefore, risk assessments should report child and adult outcomes separately. Comparing guidelines is helpful, but not enough. The hazard ratio, risk index, and cancer risk make public health meaningful.
The best answer is not to have the same technique everywhere. Areas require testing, source control, safe well replacement, treatment, and clear public coverage. There is already enough evidence in public datasets to take action. The upcoming work should include local exhibits, mineral variety composition, seasonal sampling and food chain exposure.

Data Availability Statement

All the data used in this paper are taken from publicly available reports, scientific articles, and official publications. Original links are included in tables, character comments, and references.

Moral Expression

Only secondary general data were used in this study. It did not include human participants, animal actions or new personal information.

References

1. Agency for Toxic Substances and Diseases Registry. (2024). Calculating risk ratios and cancer risk estimates. Centers for Disease Control and Prevention in the United States.
2. Alnaass, N. S., Ibrahim, M. B., & Hossean, K. A. (2026). Physicochemical Parameters of Drinking Water Produced by Small-Scale Desalination Plants and Their Impact on Consumer Safety in Sabratha, Libya. Libyan Open University Journal for Applied Sciences (LOUJAS), 2(1), 40-49.
3. Alnaass, N. S., Lamma, O. A., & Alhadad, A. A. (2026). Climate Change and Groundwater Contamination: A Comprehensive Review of Impacts, Challenges and Adaptation Strategies. (2026). Libyan Open University Journal of Applied Sciences (LOUJAS), 2(1), 576-590. https://doi.org/10.65422/loujas.v2i1.353
4. Alshebgo, M. A., Alshaybani, M. O., Zayed, A. M., & Lamma, O. A. (2026). Human Health Risk Assessment of Heavy Metal Contaminated Groundwater: Implications for Drinking Water Treatment and Policy Design. Libyan Open University Journal of Applied Sciences (LOUJAS), 551-566.
5. Alfarjani, N. J., Alfaydh, M. A., Alsaghair, S. O., & Lamma, O. A. (2026). Climate Change: Saline Water Leakage in Coastal Reservoirs: A Predictive Hazard Model and Adaptive Groundwater Management Framework. Libyan Journal of Health, Science, and Development (LJHSD), 128-140.
6. Agency for Toxic Substances and Diseases Registry. (2023). Guidelines for Exposure Dose for Drinking Water Use. Centers for Disease Control and Prevention in the United

States. https://www.atsdr.cdc.gov/pha-guidance/resources/ATSDR-EDG-Drinking-Water-Ingestion-508.pdf
7. Ali, M. A. (2006). Arsenic contamination in groundwater in Bangladesh. International Review of Environmental Strategies, 6(2), 329–350. https://www.iges.or.jp/en/publication_documents/pub/peer/en/1204/IRES_Vol.6-2_329.pdf
8. Bilali-Mood, M., Nasiri, K., Tahir Gorabi, Z., Khazdeer, M. R., & Sadeghi, M. (2010). (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Fruitiers in Pharmacology, 12, 643972. https://doi.org/10.3389/fphar.2021.643972
9. British Geological Survey and Department of Public Health Engineering. (2001). Arsenic Contamination of Groundwater in Bangladesh: Final Report. British Geological Survey Technical Report WC/00/19.
10. Central Groundwater Council. (2020). State-wise details of Partially Affected Areas containing certain selected contaminants in ground water in India. Ministry of Jal Shakti, Government of India https://cgwb.gov.in/sites/default/files/inline-files/districts-contamination.pdf
11. Central Groundwater Council. (2025). Annual Groundwater Quality Report 2025: Contamination of Heavy Metals in Groundwater. Ministry of Jal Shakti, Government of India https://www.pib.gov.in/PressReleasePage.aspx?PRID=2198926&lang=2&reg=3
12. Chakraborty, D., Rahman, M.M., Das, B., Moral, M.D., S., Chandramukherjee, S., Dhar, R.K., Biswas, B.K., Choudhary, U. (2010). K., Roy, S., Surif, S., Saleem, M., Rehman, M., & Qamaruzzaman, S. (2010). (2010). Arsenic Groundwater Contamination Status in Bangladesh: Report of a 14-Year Study. Water Research, 44(19), 5789–5802. https://doi.org/10.1016/j.watres.2010.06.051
13. Farooqi, A., Masouda, H., & Firdous, N. (2007a). Groundwater has been contaminated with toxic fluoride and arsenic in the areas of Lahore, Qasr, Punjab and Pakistan and is also a potential source of pollution. Environmental Pollution, 145(3), 839–849. https://doi.org/10.1016/j.envpol.2006.05.007
14. Farooqi, A., Masouda, H., Kosakabi, M., Naseem, M., & Firdous, N. (2007b). Distribution of highly contaminated arsenic and fluoride groundwater from East Punjab, Pakistan, and the role of human pollution control in the natural hydrological cycle. Journal of Geochemistry, 41(4), 213–234. https://doi.org/10.2343/geochemj.41.213
15. Flanagan, S. F., Johnston, R. B., & Cheng, Y. (2012). Arsenic in pipe well water in Bangladesh: health, economic impacts, and impacts for arsenic elimination. Bulletin of the World Health Organization, 90(11), 839–846. https://doi.org/10.2471/BLT.11.101253
16. Ibrahim, M. B., Alnaass, N. S., & Alyaseer, N. A. (2026). Assessment of Consumer Acceptance and Public Awareness of Drinking Water Quality in Tobruk, Libya: An Analytical Field Study. Libyan Journal of Health, Science, and Development (LJHSD), 34-46.
17. Khan, S., Shah, E. A., Mohammad, S., Malik, R. N., & Shah, M. T. (2015). Concentration and Risk Assessment of Arsenic and Heavy Metals in Drinking Water in Pakistan: A Case Study. Human and Environmental Hazard Assessment, 21(4), 1020–1031. https://doi.org/10.1080/10807039.2014.950925
18. Lamma, O. A. (2021). The impact of recycling in preserving the environment. IJAR, 7(11), 297-302.

19. Lamma, O. A. (2021). Groundwater problems caused by irrigation with sewage effluent. International Journal for Research in Applied Sciences and Biotechnology, 8(3), 64-70.
20. Lamma, O. A., & Swamy, A. V. V. S. (2018). Assessment of ground water quality at selected industrial areas of Guntur, AP, India. Int. J. Pure App. Biosci, 6(1), 452-460.
21. Lamma, O. A., Swamy, A. V. V. S., & Subhashini, V. (2018). Ground Water Quality In The Vicinity of Industrial Locations In Guntur, AP, India. International Journal of Engineering Science Invention, 7(1), 72-80.
22. LAMMA, O. A., & KRAIR, S. S. A. (2018). To Study The Relation Between The Environmental law and climate change. Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences, 5(4), 23-28.
23. Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality using Limnological studies of Wyra reservoir, Khammam district, Telangana, India. Int. J. Curr. Microbiol. App. Sci, 4(2), 880-895.
24. Mohammed, K. A., Beltet, A. A., Abofares, H. J., & Lamma, O. A. (2026). Assessing Groundwater Quality and Pollution Risk Using an Integrated Water Quality Index (WQI) and Spatial Mapping Approach. Libyan Open University Journal of Medical Sciences and Sustainability, 80-91.
25. Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality seasonal variations of paler reservoir, Khammam district, Telangana, India. International Journal of Current Research in Chemistry and Pharmaceutical Sciences, 2(2), 31-43.
26. Muwari, J., Kumar, N., Sarkar, S., Frank, A. L., Daga, M. K., Singh, M. M., Joshi, T. K., & Singh, I. (2022). Assessment of human health risks due to heavy metals in groundwater and surface water and the relationship of diseases to drinking water sources: a study from Maharashtra, India. Environmental Health Insights, 16, 11786302221146020. https://doi.org/10.1177/11786302221146020
27. Lamma, D. O. A. (2020). Study on groundwater analysis for drinking purpose in Mangalagiri Mandal regions, Andhra Pradesh, India. International Journal of Appl ied Research, 6(1), 148-153.
28. Lamma, O. A., & Sallam, R. M. A. (2018). Analysis of water quality of Lingala Munner Krishna district, AP, India. J. Adv. Stud. Agricult. Biol. Environ. Sci, 5(3), 22-27.
29. Lamma, O. A. (2021). Waste disposal and landfill: Potential hazards and their impact on groundwater. International Journal of Geography, Geology and Environment, 3(2), 133-141.
30. Lamma, O. A., AVVS, S., & Alhadad, A. A. M. (2019). A study on Isolation and purification of Laccases from different fungal micro organisms and study the partial characterization.
31. Nouri Salem Al-Naas, Mohamed Bashir Ibrahim, Souad Abdelhamid Issa, & Hussein Khalifa Aqeel. (2026). Physicochemical Properties of Drinking Water Produced by Small Desalination Plants and Their Impact on Consumer Safety in Sabratha, Libya. Libyan Open University Journal of Applied Sciences (LOUJAS), 40-49.
32. Lamma, O. A. (2024). Innovative Remediation Strategies for Tackling Groundwater Pollution: A Comparative Analysis. African Journal of Advanced Pure and Applied Sciences, 90-98.

33. LAMMA, O. A. (2023). Beneath the Surface: Unveiling the Silent Threat of Groundwater Contamination. Bani Waleed University Journal of Humanities and Applied Sciences, 8(5), 380-393.
34. Lamma, O. A., Alnaass, N. S., & Alhadad, A. A. (2026). Assessing Long-Term Groundwater Quality Trends Using Historical Water Quality Monitoring Data. Libyan Journal of Health, Science, and Development (LJHSD), 141-154
35. Lamma, O., Abubaker, M., & Lamma, S. (2015). Impact of reverse osmosis on purification of water. Journal of Pharmaceutical Biology, 5(2), 108-112.
36. U.S. Environmental Protection Agency. (2011). Exposure Factors Guide: 2011 Edition. National Centre for Environmental Assessment https://www.epa.gov/expobox/about-exposure-factors-handbook
37. U.S. Environmental Protection Agency. (2026). Regional Screening Levels User Guide. https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide
38. World Health Organization. (2022). Guidelines for Drinking Water Quality: 4th Edition containing 1st and 2nd Additional Materials. World Health Organization. https://www.who.int/publications/i/item/9789240045064
39. Yahya, T. O., Oladeli, E. O., Fatodo, E. A., Abdulaziz, A. and Yaldo, Y. E. (2020). Concentration and assessment of health risks of heavy metals and microscopic organisms in groundwater in Lagos, southwestern Nigeria. Journal of Advances in Environmental Health Research, 8(3), 225–233. https://doi.org/10.22102/jaehr.2020.245629.1183
40. Zhang, S. , and Ren, P. (2025). Groundwater Heavy Metal Contamination and Health Risk Assessment: A Case Study of South Dongting Lake, China. Al-Ma'a, 17(21), 3036. https://doi.org/10.3390/w17213036
41. Zhmool, H. S., Adel, A. S., Abdaslam, N. M., Abboub, A. D., Sallam, R. M., & Alhadad, A. A. (2026). Chemical Characteristics of Hospital Wastewater and Their Association with Antibiotic Resistance Patterns in Sabratha, Libya. Libyan Open University Journal of Applied Sciences (LOUJAS), 346-354.
42. Zhmool, H. S., Banana, A. A., Abboub, A. D., Mohamed, G. S., Sallam, R. M., & Alhadad, A. A. (2026). Microbiological and Physicochemical Assessment of Antibiotic-Resistant Bacteria in Hospital Wastewater: A Case Study from Sabratha Teaching Hospital, Libya. Libyan Open University Journal of Medical Sciences and Sustainability, 38-48.