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Review Paper

Presence and Dispersion of Organic and Inorganic Contaminants in Groundwater

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Abstract

This paper offers an extensive examination of studies published in the recent past and highlights the documented issues surrounding groundwater pollution, its sources, and distribution worldwide. The depletion of groundwater resources and the deteriorating overall quality present a significant cause for concern, particularly as a large human population relies on groundwater as a drinking water source. The review focuses on various factors contributing to groundwater pollution, including anthropogenic activities, hydro climatological influences, and natural processes. Special attention is given to organic contaminants such as pesticides, herbicides, and emerging pollutants, which have been found to have a substantial impact on groundwater quality. Additionally, the review covers pollution caused by inorganic pollutants like arsenic and other heavy metals, with a particular emphasis on regions experiencing a higher incidence of these contaminants in groundwater. Furthermore, the paper includes a compilation of studies that highlight the increased occurrence of waterborne illnesses resulting from fecal and microbial contamination, often caused by inadequate sanitary practices. To provide a comprehensive understanding of the global groundwater pollution problem, the review also *encompasses an examination of contaminants like fluoride and nitrate.*

Keywords

groundwater pollution, arsenic pollution, microbial pollution, organic contaminants, fluoride contamination, pharmaceutical contamination

1. Introduction

Groundwater pollution, arising from both human activities and natural processes, is a matter of significant concern (Jat Baloch, Zhang et al., 2022, Dilpazeer, Munir et al., 2023, Jat Baloch, Su et al., 2023, Li, Zhang et al., 2023). Numerous studies have extensively documented the occurrence and impact of groundwater pollution resulting from various anthropogenic activities (Jat Baloch, Talpur et al., 2020, Tariq, Mumtaz et al., 2022, Tariq, Ali et al., 2023). These include the improper discharge of industrial and municipal wastewater and the utilization of recycled wastewater for irrigation purposes (Jat Baloch and Mangi 2019, Talpur, Noonari et al., 2020, Iqbal, Su et al., 2021, Jat Baloch, Zhang et al., 2021, Jat Baloch, Zhang et al., 2023). Moreover, the mobilization of contaminants facilitated by subsurface geochemistry and seasonal changes further contributes to the pollution of groundwater resources (Jat Baloch, Zhang et al., 2022, Zhang, Chai et al., 2022, Zhang, Zhu et al., 2022, Iqbal, Su et al., 2023). While localized sources are often responsible for groundwater pollution, it is crucial to recognize that site disturbances and climatological variables can also mobilize contaminants, thereby affecting groundwater quality over wider areas. Understanding the occurrences of groundwater pollution, including their distribution, origins, volume, and frequency, necessitates a comprehensive review encompassing both anthropogenic and natural activities.

This review aims to provide a thorough analysis of the incidences of groundwater pollution worldwide. It explores the diverse sources and factors contributing to contamination, shedding light on the extent of the issue and its implications. By examining the distribution patterns of polluted groundwater, the review seeks to identify hotspots and regions that are particularly susceptible to contamination. Additionally, the review delves into the origins of groundwater pollutants, highlighting the key anthropogenic activities and natural processes responsible for their introduction into aquifers. It assesses the volume and frequency of contamination events, providing valuable insights into the temporal dynamics of groundwater pollution and the potential long-term consequences. By synthesizing a broad range of studies, this review endeavors to deepen our understanding of groundwater pollution, ultimately aiding in developing effective mitigation strategies and preserving this vital water resource for future generations.

2. Groundwater Organic Contaminants

2.1 Pharmaceutical Contamination of Groundwater

Pharmaceutical contamination is a growing concern, and it is widely believed that the use of biosolids from livestock farming activities is a significant contributor to this issue. In particular, confined animal feed operations have been identified as a long-standing source of antibiotic pollution in both surface water and groundwater. Recently, a study conducted in the "Baix Fluvià" alluvial aquifer in NE Catalonia, Spain, shed light on the extent of contamination caused by pharmaceuticals. The researchers aimed to evaluate the occurrence and fate of 53 antibiotics in an agricultural region dominated by an alluvial aquifer. By employing hydrogeological, hydrochemical, and isotopic analysis techniques, the authors were able to assess the presence and behavior of these antibiotics in the aquifer. The study revealed the presence of 11 antibiotics from various classes, including fluoroquinolones, macrolides, quinolones, and sulphonamides. These classes of antibiotics are commonly used in both human and veterinary medicine. The detection of these pharmaceutical compounds in the groundwater signifies a potential risk to the environment and human health. The maximum concentration of antibiotics found in the groundwater was reported to be 300 ng/L.

This finding suggests that the contamination levels in the alluvial aquifer were significant and noteworthy. The presence of these antibiotics in the aquifer may have adverse effects on the aquatic ecosystem and can potentially contribute to the development of antibiotic-resistant bacteria. The study underscores the importance of understanding the sources and fate of pharmaceutical contamination in agricultural regions. It highlights the need for improved management practices in confined animal feed operations to minimize antibiotic pollution. Additionally, it emphasizes the significance of monitoring and regulating the use of biosolids from livestock farming to mitigate pharmaceutical contamination and protect water resources (Boy-Roura et al., 2018).

The authors emphasized that understanding the behavior and impact of antibiotics in groundwater is crucial, and it is greatly influenced by various factors. One of the key factors they highlighted is the physicochemical interaction between antibiotics and aquifer materials, specifically referring to processes like sorption and degradation. These interactions play a significant role in determining antibiotics' fate and spatial distribution once they enter the groundwater system. Moreover, the authors emphasized that how antibiotics are released into the environment is another important factor to consider. They specifically mentioned two modes of release: pulse and constant flow. The release of antibiotics in a pulse fashion refers to sudden and intermittent discharges, while constant flow refers to a continuous and steady release. The release mode can influence antibiotic transport in groundwater, which in turn affects their distribution and concentration in the aquifer.

Besides, the authors identified the release of treated wastewater as a significant source of antibiotic pollution. Wastewater from various sources, including hospitals, households, and industrial facilities, often contains residues of pharmaceuticals, including antibiotics. When this treated wastewater is discharged into the environment, it can introduce antibiotics into the groundwater system, leading to potential contamination. To investigate the presence of pharmaceuticals, including antibiotics, downstream from onsite wastewater treatment systems in Minnesota, comprehensive experimental research was conducted. This research aimed to assess the extent of antibiotic contamination in the groundwater. The study revealed the presence of a specific antibiotic called sulfamethoxazole. The quantities of sulfamethoxazole detected in the groundwater samples ranged from 7 to 965 nanograms per liter (ng/L), indicating varying levels of contamination in different locations (Elliott, Erickson, Krall, & Adams, 2018).

The presence of antibiotics in groundwater has become a subject of extensive investigation, as numerous reports highlight its prevalence. It is a recurring concern that both surface water and groundwater sources are frequently contaminated with antibiotics originating from confined livestock feed operations. Recent studies conducted in Phitsanulok Province, Thailand, shed light on this issue by revealing the presence of various antibiotics in multiple samples, including feeds, flush water, wastewater, water supply, fresh feces, dried feces, dried sludge, and agricultural soil. The study uncovered the presence of several antibiotics across all the aforementioned samples, emphasizing the extent of the contamination. Among the antibiotics detected were lincomycin, sulfamerazine, sulfameter, sulfamethazine, ciprofloxacin, erythromycin, and trimethoprim. These findings underscore the potential risks associated with antibiotic pollution originating from swine farming systems. The presence of antibiotics in groundwater poses significant challenges for both environmental and human health. The continuous release of antibiotics into water sources can lead to the development of antibiotic-resistant bacteria, which can subsequently impact human and animal populations. Antibiotic resistance poses a global health threat, as it compromises the effectiveness of antibiotics in treating various infections and diseases. (Jarat, Sarin, Ying, Klomjek, & Rattanasut, 2018).

Therefore, it is crucial to carefully consider the potential risk to groundwater when applying manure from feedlots. An illustrative investigation examined the presence of antibiotics in groundwater resulting from the application of manure from feedlots and revealed extensive contamination of groundwater with antibiotics in such locations. Specifically, nine swine feedlots situated in North China's Beijing, Hebei, and Tianjin regions were identified as the origin of antibiotic pollution in groundwater, with concentrations of tetracyclines, fluoroquinolones, and sulphonamides reaching as high as 19.9, 11.8, and 0.3 μg/L respectively (Li, Liu, Chen, Huang, & Ren, 2018).

A comprehensive investigation was conducted to examine the prevalence of 218 organic contaminants in groundwater within the Mezquital Valley, Mexico, which hosts the world's largest untreated wastewater irrigation system. The study revealed the presence of 23 pharmaceutically active compounds, including sulfamethoxazole, N, N-diethyl-meta-toluamide, carbamazepine, the endocrine disruptor bis-2-(Ethylhexyl) phthalate, and benzoylecgonine (the primary cocaine metabolite), in groundwater samples (Lesser et al., 2018).

The researchers cautioned that although the soil acts as a filter and aids in the adsorption and degradation of these compounds, they still make their way into the groundwater. Consequently, the use of wastewater for groundwater replenishment necessitates careful consideration of potential health consequences for humans. Furthermore, a separate study conducted in the Chunga area of Lusaka, Zambia, reported the occurrence of seven antibiotics and three antiretroviral drugs in groundwater samples. The detection frequencies were found to be 11.5% for amoxicillin, 38.5% for nevirapine, and

42.3% for sulfamethoxazole across 17 shallow water wells and two boreholes. These findings highlight the presence of pharmaceutical substances in the groundwater, indicating the potential for human exposure and emphasizing the need for monitoring and addressing such contamination (Ngumba, 2018).

Although the loss of antibiotic mass due to sorption in the subsurface environment was attributed to lower detection frequency and lower concentration, the author issued a warning that there is a chance of human exposure because there is currently little to no groundwater treatment before consumption. The peri-urban community of Madimba in Lusaka, Zambia, also revealed the presence of different antibiotics in 26 groundwater samples, including samples from five borehole wells and 21 shallows (2–5 m depth) protected and unprotected wells. Antibiotics were found in 22 of the samples that were examined, with various concentrations and detection rates. Sulfamethoxazole and trimethoprim were notable examples of antibiotics that were most frequently found, with detection rates of 42% and 34.6%, respectively, with concentration levels ranging from undetectable to 660 ng/L and 140 ng/L. Other antibiotics, including amoxicillin, ciprofloxacin, and nevirapine (an antiviral medication), were also found, but at frequencies of 11.5%, 19.2%, and 38.5%, respectively, and at values of 880 ng/L, 150 ng/L, and 410 ng/L (Myllyniemi Maldonado, 2018).

The northern and southwestern regions of China have both reported the occurrence and detection of antibiotics in shallow groundwater. The identification of 35 antibiotics, including ofloxacin, lincomycin, and norfloxacin with concentrations as high as 1,199.7, 860.7, and 441.9 ng/L, is the result of widespread antibiotic discharge as well as direct and frequent interchange of shallow groundwater with the surface matrices. Some of these antibiotics, such as sulfapyridine (70%) and the antifungals norfloxacin (69%) and lincomycin (64%) were often found in the majority of shallow groundwater samples (Chen, Lang, Liu, Jin, & Yan, 2018).

There are further findings from similar research on the presence of pharmaceuticals and personal care items in the urban aquifer of Zaragoza, Spain. In contrast to prior studies, the authors concluded that heavy mining of shallow geothermal resources was to blame for groundwater pollution. The authors explained that the presence of antibiotics in the shallow unconsolidated aquifer was caused by physicochemical changes brought on by intensive geothermal resource use. These changes caused groundwater’s geothermal properties to change, which led to the persistence of micropollutants like antibiotics (García-Gil et al., 2018).

Similar research from the Xiaodian Wastewater of Irrigation Area of Northern China found 15 antibiotics in groundwater samples, with antibiotic concentrations ranging from 2.75 to 114.38 ng/L (Li, Dong, Hu, & Wang, 2018). The issue of antibiotics pollution extends to Cluj-Napoca in Romania and its surrounding areas, which are near urban sites that are susceptible to seepage from municipal solid waste landfills, urban and hospital wastewater, as well as other agricultural activities. In this context, the presence of various classes of antibiotics, including trimethoprim, macrolides, sulfonamides, β-lactams, tetracyclines, and fluoroquinolones, has been detected. These antibiotics were found at concentrations ranging from non-detectable levels to as high as 917 ng/L. This highlights the concerning contamination of the local environment with antibiotics, potentially posing risks to ecosystems and human health (Szekeres et al., 2018).

A notable finding regarding the analytical protocol used to detect antibiotics in groundwater samples reveals that, in comparison to traditional and robust liquid chromatography and mass spectrometry techniques, semi-quantitative Enzyme-Linked Immunosorbent Assay (ELISA) techniques can also deliver reliable results. Research involving the analysis of groundwater samples collected from Minnesota and Iowa employed both methods, indicating that they produced consistent results in determining the presence or absence of antibiotics in 83% of the samples. Furthermore, when specifically analyzing two target compounds, sulfamethoxazole, and carbamazepine, the results showed agreement in 76% and 80% of the samples, respectively. This comparative analysis highlights the potential of ELISA as a rapid, dependable, and cost-effective alternative to more expensive traditional spectrometry-based analytical techniques (Krall, Elliott, Erickson, & Adams, 2018).

2.2 PFCs (Perfluorinated Compounds)

The presence of perfluorinated Compounds (PFCs) has been documented in various surface water samples, while the occurrence of these compounds in groundwater has been less frequently reported. A significant study conducted across 13 cities in Jiangsu Province, China, sheds light on the vulnerability of nonindustrial areas' groundwater to PFC contamination. The analysis of 102 groundwater samples revealed total concentrations of per- and poly-fluoroalkyl substances (PFASs) ranging from 2.69 ng/L to 556 ng/L, with an average concentration of 43.1 ng/L. This study underscores the need for increased awareness and monitoring of PFC concentration (Wei et al., 2018). Groundwater samples reported a relatively high prevalence of short-chain (C4-C9) PFAS (Per- and poly-fluoroalkyl substances), ranging from 62.75% to 100%, and a low prevalence of C10-PFAS. Effects of industrial activity and seasonal variations on the occurrence of PFAS in groundwater have also been reported. Analysis of 24 shallow groundwater samples taken at the Fluorine Industrial Park in Shandong Province revealed the presence of 12 perfluoroalkyl acids, accounting for 80% of the total perfluorooctanoic acid (PFOA) detected in groundwater. occupied. The authors further stated that the highest measured PFOA concentration was 613 μg/L in the dry season and 560 μg/L in the wet season (Lu, Ma, & Zhang, 2018).

The authors of the study attributed the observed variations in PFOA (perfluorooctanoic acid) concentrations, with higher levels during the dry season compared to the wet season, to precipitation patterns. During periods of high precipitation, surface-deposited PFOAs, released from flue gas, can be swiftly transported to groundwater. Additionally, PFOA that has been adsorbed in the unsaturated zone can also rapidly reach shallow groundwater. The direct contribution of PFOA through surface water recharge accounted for 50% of the PFOAs detected, while 40% of the PFOAs in groundwater were released from adsorbed soil material.

Furthermore, the application of recycled water from municipal water resource recovery facilities for irrigation purposes has emerged as a potential source of PFCs (perfluorinated compounds) in groundwater. An analysis of twenty groundwater samples collected from Werribee South, located west of Melbourne, Australia, revealed the presence of PFAS (per- and poly-fluoroalkyl substances) in 100% of the samples. Among the PFAS compounds, perfluorooctanoic acid (PFOA) was the most frequently detected (96%), with concentrations ranging from less than 0.03 ng/L to 34 ng/L and a mean concentration of 11 ng/L (Szabo, Coggan, Robson, Currell, & Clarke, 2018).

These findings emphasize the need for careful consideration and monitoring of PFC contamination in groundwater, particularly during different seasons and in areas where recycled water is used for irrigation purposes. The presence of PFOA and other PFAS compounds in groundwater underscores the potential risks to water resources and necessitates ongoing efforts to mitigate and manage their impact.

Similarly, the occurrence of PFASs (per and poly-fluoroalkyl substances) has been reported in six Swedish counties. A comprehensive analysis was conducted on 161 groundwater samples collected from areas located near PFAS hotspots and where groundwater serves as a source of drinking water. The highest recorded concentration of total PFASs in groundwater reached 6,400 ng/L, with an average concentration of 46 ng/L. The authors attributed the elevated levels of PFASs to the groundwater's proximity to a fire training site, where aqueous film-forming foams containing PFASs are regularly used. These findings highlight the potential risks associated with PFAS contamination in groundwater, particularly in areas exposed to specific sources of PFASs such as firefighting activities. Monitoring and mitigation strategies are crucial in safeguarding drinking water resources from PFAS pollution (Gobelius et al., 2018).

2.3 Groundwater Contamination by Pesticides and Herbicides

Intensive farming operations can contaminate groundwater with various pesticides. For example, pesticide-induced groundwater contamination in Akkar, northern Lebanon, may be due to large-scale agricultural activities. We monitored 19 organochlorine (OC), 8 organophosphorus (OP), and 6 organonitrogens (ON) pesticides in 15 groundwater samples from the Akkar Plain, the second-largest agricultural region. Concentrations of 58.9, 44.6 OC, OP, and ON were shown to be present. 5.6 μg/L and 5.6 μg/L respectively. OC was detected at very high frequencies of 95-100% in these pesticides. (Chaza et al., 2018).

The authors made an additional statement, noting that the collection of groundwater samples took place during the rainy season. This timing revealed elevated levels of pesticides detected in Akkar Plain, attributable to runoff originating from the application site and subsequently leading to the contamination of groundwater. It is important to consider the implications of such findings, as they highlight the vulnerability of groundwater to pesticide pollution during periods of increased rainfall and runoff. The runoff carries the residues of pesticides from the application site, allowing them to enter the groundwater system and potentially pose risks to both environmental and human health. Understanding the dynamics of pesticide runoff and its impact on groundwater quality is crucial for implementing effective management strategies and safeguarding water resources from contamination.

3. Groundwater Inorganic Contaminants

A wide range of inorganic contaminants has been identified worldwide, frequently exceeding the recommended standards for drinking water. The presence of these inorganic pollutants in drinking water sources raises significant concerns regarding human health. Consequently, this section provides an overview of various studies that have documented the occurrence of diverse inorganic pollutants specifically in groundwater sources. These studies highlight the extensive prevalence of inorganic contaminants in groundwater, emphasizing the need for thorough monitoring and remediation efforts. Inorganic pollutants encompass a broad spectrum of substances, including heavy metals, metalloids, nitrates, sulfates, fluoride, and other chemical compounds. Their presence in groundwater sources can stem from various anthropogenic activities such as industrial operations, agricultural practices, mining, and improper waste disposal.

The documented studies not only highlight the existence of inorganic pollutants in groundwater but also delve into their concentrations, spatial distribution, and potential sources. The findings underscore the significance of ongoing research and monitoring programs to comprehend the extent of contamination, assess the associated health risks, and develop effective strategies for water treatment and management. The presence of inorganic pollutants in groundwater is a multifaceted issue that necessitates collaboration between scientists, policymakers, and water resource managers to ensure the provision of safe and clean drinking water. Continuous efforts are required to mitigate the sources of contamination, enhance monitoring systems, and implement suitable treatment technologies to safeguard groundwater resources from the harmful effects of inorganic pollutants and preserve human health.

3.1 Arsenic Contamination in Groundwater

Seasonal fluctuation and the influence of groundwater recharge on arsenic immobilization in shallow (>40 m) and deep (40 m) groundwater in the Bengal Basin aquifers of West Bengal, India, demonstrate that monsoon recharge has little impact on arsenic concentration in groundwater (Kulkarni, Mladenov, Datta, & Chatterjee, 2018). The authors determined a significant difference in arsenic concentrations between shallow tube wells with elevated levels of arsenic concentration 50-315 g/L exceeding the WHO guideline of 10 g/L and deep wells with concentrations ranging between 0.5 and 11 g/L. Similarly, a significant concentration of arsenic has been observed from the coastal Puducherry region on India’s southeast coast. Groundwater concentrations ranged from non-detect to 36.88 g/L during the pre-monsoon season and from non-detect to 28.8 g/L during the post-monsoon season, according to an analysis of 175 groundwater samples obtained during the pre-monsoon and post-monsoon seasons (Sridharan & Nathan, 2018). More than 10% of the samples from these go over the WHO drinking water criteria. Other research found no effect of the monsoon season on the level of arsenic in groundwater. The highest recorded concentrations of arsenic were 75.60 and 74.46 g/L in 72 groundwater samples from Ballia District, Uttar Pradesh, India, which reveal no change in arsenic concentration in groundwater in both pre-and post-monsoon samples (Singh & Singh, 2018).

The authors further emphasized that a significant proportion of groundwater samples, specifically 95.83%, exhibited arsenic concentrations surpassing the drinking water standards set by the World Health Organization (WHO). Another noteworthy observation pertains to seasonal variations and arsenic concentrations in groundwater within the Qaleeh Shahin Agricultural Region of Kermanshah Province, Iran. Analysis conducted on 20 groundwater samples revealed an average arsenic concentration of 6.0 ± 3.0 μg/L during the winter season, and 9.0 ± 6.0 μg/L during the summer season, with the highest detected arsenic concentration of 23 μg/L occurring in the summer (Sobhanardakani, 2018). The severity of arsenic contamination is further reported in the Ganga River basin (GRB), an expansive area encompassing significant portions of India, Bangladesh, Nepal, and Tibet. Groundwater within this region exhibits alarmingly high arsenic concentrations, reaching as high as 4,730 μg/L. Such findings underscore the urgent need for comprehensive actions to address the widespread issue of arsenic contamination, safeguard public health, and ensure access to safe drinking water sources in these affected regions (Chakraborti et al., 2018).

The effect of river proximity and river phases on arsenic concentration in groundwater found an inverse relationship between distance and arsenic concentration in groundwater. 60 groundwater samples that were collected from shallow depths of the Sutlej River alluvial plain, District Vehari, Punjab, Pakistan, revealed that 50% of the groundwater samples exceed WHO drinking water standards, with the highest recorded concentration of arsenic in groundwater with 156 g/L (Fatima, Hussain, Rasool, Xiao, & Farooqi, 2018). This study revealed that locations near rivers are more vulnerable to contamination with arsenic, with sediments deposited in the Sutlej River's alluvial plain playing a significant impact.

In addition, the Guide basin in northwest China has reported high arsenic concentrations in the deep restricted aquifer (100-300 m). Arsenic concentrations in the 97 samples collected from this location that were analyzed ranged from 9.9 to 377 g/L (on average, 109 g/L). The authors stated that the reductive dissolution of arsenic-bearing Fe (III) oxide minerals under reducing circumstances caused the mobilization of arsenic in groundwater, which explains why there is a high concentration of arsenic in deep groundwater (Wang, Guo, Xiu, Wang, & Shen, 2018).

Arsenic is frequently observed in geothermal water samples and has been reported. However, surface water may get contaminated by the high arsenic levels in these channels. A study of Thirty geothermal water samples from Tengchong, China's Rehai, and Ruidian geothermal regions reveals extremely high arsenic contents ranging from 22.1 - 1,150.3 g/L. Due to the leaching of arsenic from rock, neutral-alkaline water has a comparatively high concentration of arsenic (495 g/L on average) when compared to acidic geothermal water (77.1 g/L on average). The authors made an alert that the combination of geothermal water with shallow groundwater in the Tengchong geothermal area might lead to contamination (Jiang et al., 2018). Arsenic is often present in natural waters in relatively low quantities, with the concentration being influenced by the regional geology, hydrology, and geochemical properties of the aquifer materials (Bhattacharya et al., 1997).

Site geochemistry perhaps leads to the mobilization of arsenic in the natural environment and subsequently elevated the concentration of arsenic in groundwater. Anthropogenic activities, specifically arsenic-contaminated soils, also sometimes lead to elevated concentrations of arsenic in groundwater. Studies on shallow groundwater in Ong Phra sub-district, Suphan Buri Province, Thailand, showed concentrations from below the detection level to 14 μg/L (Tiankao & Chotpantarat, 2018). Research carried out in the Holocene alluvial aquifers of Prayagpur in southwest Bangladesh also shows the impact of site geochemistry. At this location, an analysis of fifty groundwater samples taken from tube wells screened at depths of 21 and 81 m reveals an arsenic content range of 6.05 to 590.7 g/L with an average value of 58.31 g/L (Huq, Su, Li, & Sarven, Most.S., 2018). Geochemistry affects arsenic mobilization in the lower Indus River alluvial plain in southern Sindh, Pakistan. 79 collected groundwater samples revealed a high arsenic concentration with 60% exceeding recommended drinking water standards (Naseem & McArthur, 2018). High arsenic levels were found in Khairpur Mir, an agricultural/industrial city in Sindh Province, Pakistan. The authors tested 222 groundwater samples, including 134 from hand pump wells (3-40 ft) and 88 from tube wells (80-100 ft). Most hand pump wells had arsenic concentrations above the drinking water limit, ranging from 0.24 to 315. 6 μg/L (avg. 31.8 μg/L) in dug wells and 0.6 μg/L in tube wells. 35-120.5 μg/L (avg. 10). 2 μg/L (Qasim & Ali Jakhrani, 2018).

However, the risk of Arsenic contamination in groundwater is significantly higher than in surface water such as lakes, streams, and reservoirs. Lower concentrations in rivers and lakes are most likely the result of aerobic Arsenic oxidation and subsequent attenuation by oxidic minerals, as well as surface recharge and runoff. The maximum allowable content of drinking water is 20 g/L (USEPA, updated 2001), and the WHO (1998) recommended value is 10 g/L. Natural occurrences in groundwater (>10 g/L) have been documented in various countries (Table 1).

Table 1. Arsenic Concentrations in Groundwater Arsenic-Affected Countries

Country	Arsenic source	Arsenic Concentration	References
Argentina	Shallow aquifer	100-4800	(Smedley et al., 1998) (Bundschuh et al., 2000)
Bangladesh	Well	0.5-2500	(BGS/DPHE 2001) (Kinniburgh and Smedley, 2001) (DPHE/BGS/MML 1999) (Karim 2000)
China, Inner Mongolia	Well	< 100-1860	(Luo et al., 1997) (Lianfang and Jianzhong 1994)
Chile	Well	100-1000	(Borgono et al., 1977)
India	Well	<1-1300	(Bhattacharya et al., 1997)

			(DPHE/BGS/MML 1999)
			(Mandal et al., 1996)
Vietnam	Sediment	1-3050	(Berg et al., 2001)
USA	Well	100-500	(Welch et al., 2000)
Hungary	Well	25-50	(Varsanayi et al., 1991)

3.2 Fluoride Contamination in Groundwater

The health advantages of fluoride, such as a reduction in the incidence of dental cavities and hardening of enamel as a result of drinking fluoridated water, have frequently been stated as justification for fluoridating drinking water. Fluoride levels in drinking water, on the other hand, can have negative effects on human health, such as dental and skeletal fluorosis.

Several investigations have demonstrated high fluoride concentrations in groundwater, with one recent research from Jhajjar District, Haryana, India, revealing the presence of elevated fluoride levels in 60% of the groundwater samples with concentrations ranging from 0.3 to 0.9 mg/L (Gupta & Misra, 2018). High fluoride levels in Jhajjar District were linked to salt-rich geological formations. Groundwater samples in Panipat District, Haryana, India, indicate excess fluoride in drinking water. Four groundwater samples from the area have fluoride levels ranging from 0.5 to 5. 95 mg/L avg. 1.6 mg/L (Kaur & Rishi, 2018). High fluoride concentrations in groundwater can also result from the presence of granite rock that contains fluoride-rich minerals. In Telangana, a semi-arid area of South India, large amounts of fluoride are found to occur and be distributed over all districts. To determine fluoride's geographic spread and seasonal variations, research was done. The mean fluoride content in 34 groundwater samples taken from this location was 1.13 mg/L, however, the observed range of fluoride concentration in groundwater was 0.06-4.33 mg/L (Adimalla, Li, & Qian, 2018).

The presence of geochemical factors and fluctuations in fluoride levels has also been documented. The alteration of hydro geochemistry due to mining activities has been identified as a contributing factor to elevated fluoride levels in the fluorite mining area situated in the flood plain of the River Swat, Pakistan. A total of fifty-three groundwater samples were collected, representing shallow (24–40 m depth), intermediate (46–65 m depth), and deeper (85–120 m) aquifers, and analyzed for their fluoride content. The deepest aquifer exhibited the lowest fluoride concentration, measuring 0.7 mg/L, whereas the highest concentration of 6.4 mg/L was observed in the same deep aquifer (Rashid et al., 2018). The authors additionally stated that 62.2% of the samples had fluoride levels in drinking water that were above WHO guidelines (1.5 mg/L). According to the authors, there is a concentration gradient, with fluoride concentrations being greater in shallow aquifers and lower in deeper aquifers. The samples taken from shallow, intermediate, and deeper aquifers showed depth-specific exceedances in proportions of 73 percent, 42 percent, and 17 percent, with the shallow aquifers having the highest fluoride concentrations of 6.4 mg/L. Similar findings of a study carried out in the Main Ethiopian Rift Valley region demonstrated that groundwater fluoride content and temperature are inversely related, with a higher concentration in shallow and a lower concentration in deeper aquifers (Gulta Abdurahman, & Zewdie, 2018).

The authors suggested that the higher temperature found in the shallow aquifer speeds up the process of weathering, resulting in the dissolution of CaF2. This, in turn, leads to an increased concentration of fluoride ions in the groundwater. The authors reached this conclusion by analyzing groundwater samples obtained during pumping tests at 25 wells (25–200 m depth) and by studying the lithological characteristics of the subsurface environment.

3.3 Other Heavy Metals Occurring in Groundwater

Heavy metals often enter the subsurface environment as a result of human activity. High levels of heavy metals in groundwater can pose a major health risk. For instance, intensive mining operations may mobilize heavy metals, so polluting groundwater supplies. Research showed how mining and mineral processing operations might be a source of heavy metals in the mining region of East Singhbhum, Jharkhand, India (Singh, Ramanathan, & Subramanian, 2018). The authors determined the regional extent of heavy metal pollution by analyzing 30 groundwater samples from various geological formations and land-use patterns. Twenty samples from intermediate aquifers (80-120 m) and ten samples from deep wells (130-300 m), which represent two separate aquifer systems, were taken from groundwater using hand pumps. Heavy metals include cadmium (0.01-0.08 mg/L), chromium (0.04-0.28 mg/L), nickel (0.03-0.14 mg/L), iron (0.07-4.45 mg/L), manganese (0.02-1.21 mg/L), and lead (0.08-0.42 mg/L) were found, according to the researchers. These concentrations are higher than what the WHO allows in drinking water. Lead and cadmium were found to be the two heavy metals with the highest concentrations across all sample sites. The presence of many heavy metals at extremely high levels was found in the groundwater of the Kadava River Basin in Nashik, India. The presence of various heavy metals was determined in 40 typical groundwater samples taken during the pre-monsoon seasons from various drilled and bore wells. The findings demonstrate that lead and nickel concentrations were higher than the maximum permitted value in every sample, while iron and chromium concentrations were higher in 95 percent and 92.5 percent of samples, respectively (Wagh et al., 2018).

In eastern Iran, an extensive analysis conducted over more than two years demonstrates the fluctuations in chromium concentrations and mobility brought on by drainage and mining operations (Fallahzadeh et al., 2018). In this investigation, investigators investigated for hexavalent chromium in 72 groundwater samples taken from 18 drinking water wells. Hexavalent chromium was found to have a mean concentration of 0.28–132.34 g/L, with an average of 21.306–34.68 g/L, according to the authors. The samples from three wells represented a 16.66% (or 604.791 km2) area of the 72 samples that were found to have exceeded the WHO drinking water guidelines of 50 g/L. Within two years, an area displaying chromium exceeding reached 604.7 km2, lowering the region with safe drinking water. At first, 597.36 km2 of the samples had a chromium level over the drinking water limit.

A comprehensive monitoring study in California found alarming levels of hexavalent chromium in drinking water. Of 10,642 public supply water wells, 780 exceeded the required drinking water levels of 10 g/L, with the highest documented concentration of 2.9 g/L. The authors attributed the high levels of chromium pollution to industrial activities, geological formations, land-use patterns, and metal plating industries. Variability of chromium concentrations across California is also reported due to metal plating industries, naturally occurring reducing environment, and intensive agricultural practices (Hausladen, Alexander-Ozinskas, McClain, & Fendorf, 2018).

Groundwater resources frequently contain heavy metals from numerous discarded and unused electronic instruments, batteries containing heavy metals, and general waste. It has been reported that groundwater in western Uttar Pradesh, India, contains heavy metals. Groundwater samples were taken with hand pumps from 30 to 150 feet of boring depth. subterranean level and examined for the presence of cadmium. Every one of the four areas Shahjahanpur, Bareilly, Moradabad, and Rampur in Uttar Pradesh had unnecessary presence of cadmium with mean focuses 0.06 $\pm$0.01, 0.07 $\pm$0.01, 0.06 $\pm$0.01, and 0.05 $\pm$ 0.01 mg/L, separately (Idrees et al., 2018). Cadmium is a recognized carcinogen, so the occurrence of elevated levels of cadmium in groundwater, which is used as a source of drinking water, can have enormous effects on human health. These concentration levels are higher than the WHO-recommended level of 0.003 mg/L for drinking water.

According to (Kashyap, Verma, Uniyal, & Bhardwaj, 2018), the presence of a variety of heavy metals in the groundwater that was analyzed from contaminated groundwater located close to the industrial center of northern India was recently discovered. The authors looked at 240 samples of groundwater to determine the geospatial distribution and concentrations of various heavy metals. They found that the geometric mean concentrations of aluminum, arsenic, nickel, lead, and selenium were higher than the Bureau of Indian Standards by 84%, 63%, 63%, 49%, and 41%, respectively (Wagh et al., 2018).

In other parts of India, the presence of heavy metals in groundwater samples exceeded previous estimates. For instance, Bailadila iron metal mine and its neighboring regions in Dantewada Area, Chhattisgarh, India; Heavy metals were present in a large number of groundwater samples, with lead concentrations exceeding drinking water standards in a few locations (Jareda, Mahapatra, & Dhekne, 2018).

4. Nitrogen Contamination in Groundwater

Groundwater can become polluted with nitrate if nitrogen-based fertilizer is used extensively and industrial activities are combined. As of late, a review detailed that escalated farming districts, for example, the Jinghui trench water system region in Shaanxi Territory of northwest China (addressing 1,180 km2 region) leads to the raised presence of nitrogen in the groundwater. The study of 47 groundwater samples taken from pumping wells primarily in shallow aquifers in the Loess region of the phreatic aquifer revealed that the samples exceeded drinking water standards (the national standards for acceptable limits of nitrate, nitrite, and ammonia nitrogen for drinking water are 20, 0.02, and 0.2 mg/L, respectively). For instance, the centralizations of nitrogen NO_3-N, NO_2-N, and NH_4-N (nitrate, nitrite, and smelling salts) content in half, 10%, and 2.12% of the groundwater tests went from Non recognized to 82.8, 0.15, and 3.52 mg/L separately (Zhang, Wu, & Xu, 2018). Nitrates (NO_3) are a significant contributor to water contamination. Methemoglobinemia, sometimes known as "Blue baby disorder", is a blood syndrome that is caused by nitrate (NO_3) concentrations that are too high (Niaz et al., 2022).

The researcher revealed the unreasonable concentration of nitrogen contamination primarily because of the broad farming exercises in the district. Comparable outcomes were additionally revealed from the Shenfu Mining Region (covering a 2,500 km2 area) of Shaanxi Territory, northwest China. Investigation of 76 groundwater samples from private and hand-siphoning wells showed high fixations NO_3-N, NO_2-N, and NH_4-N with normal focuses were 10.79, 0.43, and 2.16 mg/L, respectively, with the most elevated recorded centralizations of these species being 92.81, 18.87, and 116.67 mg/L (Su, Kang, Xu, & Wang, 2018). The southwestern portion of Nirmal District, which is in the northern part of the Indian state of Telangana, has been reported to have extensive agricultural activities and high levels of nitrate in groundwater samples. According to Adimalla et al., an analysis of 34 groundwater samples taken from Nirmal Province revealed a mean concentration of 36.51 mg/L of nitrate and an overall concentration ranging from 0.8 to 80 mg/L, with 26% of the groundwater samples exceeding the acceptable levels (45 mg/L) for nitrate in drinking water (Adimalla et al., 2018). According to the researchers, extensive use of nitrogen-based fertilizers and manures makes shallow aquifers in intensive agricultural fields between Vitholi Tanda and Bamangaon highly susceptible to nitrate pollution.

5. Microbial & Fecal Contamination in Groundwater

Due to the proximity of on-site sanitation facilities like pit latrines and unlined wastewater drains, shallow groundwater wells, and hand-dug wells are increasingly vulnerable to bacterial contamination. More than 70% of hand-dug wells within 10 meters of such facilities are contaminated with microorganisms, according to a comprehensive investigation of the microbial groundwater quality of hand-dug wells and boreholes in the "Dodowa" region of Ghana, E. coli bacteria were found in all groundwater samples, both in boreholes and wells that had been dug. Adenovirus was also found in 27% and 55% of the samples from hand-digged wells, respectively. According to (Lutterodt et al., 2018) 27% of the dug wells tested positive for the presence of rotavirus, but none of the samples from boreholes were found to contain the virus.

According to (Kauppinen, Pitkänen, & Miettinen, 2018) southern Finland has reported a similar incidence of a waterborne outbreak brought on by the persistent norovirus contamination of private groundwater well and the nearby onsite wastewater treatment system (OWTS), which consists of three distinct septic tanks followed by sand filters. The presence of norovirus in groundwater samples was attributed, according to the authors, to the wastewater's intrusion into the groundwater well and subsequent transport of microbes through the OWTS's sand filter, where wastewater was frequently used. Furthermore, the profundity of groundwater (2.5-3 m) which is likewise the wellspring of drinking water, and the distance between the groundwater well and the OWTS (45 m) assumed a basic part in the defilement of groundwater.

Groundwater samples taken from the Kathmandu Valley in Nepal also contain a variety of water-borne protozoa, viruses, and bacteria. Various pathogens were found in 28 groundwater samples, including 16 from nine shallow dug wells and 12 from six shallow tube wells. The concentrations of E. coli and total coliforms in shallow dug wells were consistently higher than in shallow tube wells. In addition, according to (Haramoto, 2018) all of the seven types of pathogens tested—Cryptosporidium, Giardia, human adenoviruses, noroviruses of genogroups I and II, group A rotaviruses, and Vibrio cholerae—was found in 68% of the shallow dug well water samples.

Variations in fecal indicator concentrations can be seen as a result of the influence of hydro-climatological factors like rainfall and groundwater table. There are varying concentrations of fecal indicators like E. coli and Enterococcus in the shallow and deep wells, according to a study that was done to assess the variability of fecal contamination in the groundwater of northern Thailand caused by the on-site sanitation system. Feces were found in all thirteen pairs of deep and shallow well samples (ESC and ENT >1 MPN/100 ml), with a maximum of 24,000 MPN/100 ml found in shallow wells. In comparison to deep aquifers, shallow unconfined aquifers are frequently susceptible to contamination. According to (Chuah & Ziegler, 2018), groundwater in the further wells showed pollution in just 4% and 23% of examples tried positive for E. coli and Enterococcus with the greatest centralization of 5 MPN/100 ml and 28 MPN/100 ml, separately. The creators credited the variety in waste contamination of groundwater due to numerous hydro-climatological factors, including flushing and weakening during the wet season and focus during the dry season.

The groundwater's vulnerability to feces contamination and the season's impact on sanitation are also mentioned. Groundwater used for drinking and recreation is highly contaminated by feces in sub-rural Kinshasa, Democratic Republic of the Congo. Examination of groundwater tests gathered from the shallow wells and Kokolo Waterway accounted for to be exceptionally dirtied feces in the two seasons with a fundamentally higher grouping of waste pointers during the wet season contrasted with the dry season (Kayembe et al., 2018).

Poor sanitary practices also caused feces to contaminate groundwater, and the city of Addis Ababa, Ethiopia, in sub-Saharan Africa, was found to have treated feces improperly. Examination of 27 groundwater tests collected from profound, shallow, and safeguarded wells showed far-reaching waste defilement with shallow wells showing the most elevated level of microbial specification of human waste beginning (absolute coliforms (TC), waste coliforms (FC), and Escherichia coli) contrasted with the more profound wells (Debela et al., 2018). Due to its proximity to on-site sanitation facilities, these studies demonstrate the systemic vulnerability of groundwater to fecal and microbial pollution.

6. Groundwater Contamination and Risks

Percolating leachate contamination of groundwater is a serious concern. When the landfill itself is situated on a site that has historically been contaminated, the process of determining trigger levels for monitoring the quality of groundwater is even more difficult. Based on the clustering of hydro-chemical and monitoring data, the authors came up with a protocol for dealing with such complicated landfill sites. The creators effectively executed this convention and laid out the trigger level for groundwater quality by observing a landfill site situated in northern Italy where a utilized lined landfill situated close to an old waste terminal (Stefania, Zanotti, Bonomi, Fumagalli, & Rotiroti, 2018).

Offensive perseverance pervasive nature of PFCs in groundwater has as of late raised worry about human wellbeing and ecotoxicological impacts because of the presence of PFCs in groundwater. The risk threshold for PFCs must be established immediately. In this regard, a thorough evaluation of 2,057 groundwater samples with recorded PFC measurements was used to establish the risk threshold for seven of the thirteen priority PFC in groundwater, with significance threshold concentrations ranging from 0.06 to 10.0 g/L (von der Trenck et al., 2018).

7. Conclusions

The presence and dispersion of organic and inorganic contaminants in water sheds insight into the important problem of groundwater contamination and its ramifications. Analyzing the presence and distribution of both organic and inorganic pollutants in groundwater sources was the study's main objective. The research's conclusions show that there are both organic and inorganic contaminants in groundwater, demonstrating how vulnerable this important resource is. To detect and quantify the contaminants, the study used a variety of sampling techniques and analytical methodologies, giving a thorough understanding of their distribution and potential sources.

According to the findings, the groundwater samples contained a variety of organic pollutants, such as solvents, insecticides, and petroleum hydrocarbons. These pollutants present a serious risk to the environment as well as to human health. Inorganic contaminants that can harm water quality and ecosystem health were also found in the study, including nitrates and heavy metals. The study also showed that several variables, such as hydrogeological conditions, land use patterns, and proximity to possible pollution sources, affect the dispersion of toxins in groundwater. The study emphasized how crucial it is to comprehend the underlying mechanics of contamination movement to create efficient mitigation plans and protect groundwater resources.

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