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Research Article

Liquid gold: assessing groundwater quality at the historic Kolar gold fields, Karnataka, India

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Abstract

To assess ecological sustainability and resilience, it is necessary to periodically examine various ecological properties in areas with high pollution and contaminant risks. Kolar Gold Fields (KGF) in Kolar, Karnataka, showcases one of India's most contaminated zones because of the extensive gold mining and its lingering effects. In KGF, the quality of groundwater has been severely reduced as there exist extensive mining tailings, locally referred to as cyanide dumps, which have been neglected for several preceding years without proper disposal strategies. The current approach focuses on the water pollution caused by heavy metal deposits in the KGF region. Groundwater samples were sampled from Oorgam, an abandoned region in KGF, and subsequently filtered for water quality examinations. The investigation documented concentrations of several metals, including cadmium (0.068 ± 0.0024 ppm), lead (0.288 ± 0.0016 ppm), nickel (0.058 ± 0.0047 ppm), and chromium (0.23 ± 0.0235 ppm) and have met the standard specifications in accordance with World Health Organization (WHO). Prominent pH disparity was documented amongst the experimental samples, with a detectable pH drop in the aqua-purified water in comparison to the positive control. The test results imply that the water samples collected from KGF remain unpotable for consumption or irrigation due to the persistence of high levels of heavy metal concentration. This study underscores the urgent requirement for a remedial approach to ensure water safety for drinking and irrigation in the area.

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Introduction

Water is an inevitable component imperative for sustaining life on the globe, making water quality assessment a critical global concern because of the limited and declining nature of water resources. Rapid urbanization and industrialization have escalated environmental pollution, requiring a comprehensive evaluation of the quality of groundwater concerning safe usage (Iqbal et al., 2020).

Groundwater, the chief source of water for industrial, agricultural, and drinking needs, has become increasingly vulnerable to pollution over recent years as a result of the undiscerning expulsion of industrial waste (Kumar et al., 2018). The quality of water directly impacts both environmental and public health, emphasizing the urgent need for real-time groundwater quality examinations employing various ecological attributes to elucidate the aligned risks to mankind and the environment (Barcelos et al., 2020). Water is vital for living beings, being indispensable in cell metabolism, and is also crucial for human endeavors such as manufacturing, transportation, agriculture and many more. Nevertheless, it serves one amongst the frequently mismanaged resources despite its prominence.

Groundwater acts as a critical resource for industrial, irrigation, drinking, cleaning, and bathing requirements (Sirajudeen et al., 2020). The presence of heavy metals in water resources has developed widespread ecological risks (Pidurkar et al., 2015). Heavy metals are particularly concerning as a result of their hazardous influence, even at minimal concentrations (Babuji et al., 2023). They demonstrate toxic effects on living organisms via metabolic interference and mutagenesis (Muhammad et al., 2020). Heavy metals, a substantial contributor to the deterioration of natural water bodies and underground water sources, are chiefly accumulated by industrial processes and growth.

Moreover, anthropogenic activities such as industrial production, hazardous waste disposal, agricultural runoff, and domestic sewage contribute to the deposition of heavy metals in the environment. The persistence of these metals at trace concentrations can dissolve in water as ions or compounds, resulting in water contamination. The presence of heavy metals in safe doses in the human body is essential for the proper functioning of organs, and water remains the chief medium through which these metals accumulate in the human body (Lin et al., 2022).

Given the critical effect of gold mining and tailings in the Kolar Gold Fields (KGF) on groundwater contamination contributed by heavy metals, it is essential to study these effects. Heavy metal pollution in the region of mining exists via direct expulsion from mines, wash-off from mining sites, and waste mine dumps.

The act of mining, identified by the Central Pollution Control Board (CPCB) as a red category as a result of their emission of carcinogenic pollutants, critically pollutes water resources (Worlanyo and Jiangfeng, 2021). The consumption of poor-quality drinking water leads to waterborne diseases, contributing to 80% of the world's ailments and 50% of child deaths (WHO, 2017; Madhav et al., 2020; Lin et al., 2022). Heavy metals expelled by industries demonstrate critical health risks to mankind (Chen et al., 2019).

Water quality has become a prominent challenge globally, chiefly in developing nations, where widespread contamination of groundwater and differential water sources with heavy metals, persistent organic pollutants, and waste products critically harms the environment and public health (Dharwal et al., 2022). The impact of water quality on the ecosystem and human society is serious, with multiple ripple effects on the environment (Mishra et al., 2021). Assessing water quality in Kolar is important, as uncontaminated water is a fundamental right for all individuals. The longstanding presence of mining tailings in KGF demonstrates a critical threat to the environment, water bodies, and human health.

The current work focused on examining the water quality in the Kolar Gold Fields area and elucidating its influence on the health of individuals and the environment. The water was also tested to check the presence of gold (Au), as the water samples were collected from the gold mines. But not even a trace of gold could be found in the water sample.

Materials and Methods

Area

Kolar district is located in the easternmost part of Karnataka in southern India. The district is bordered by Bangalore Rural to the west, Chikballapur district to the north, Chittoor and Annamayya districts of Andhra Pradesh to the east, and Krishnagiri district of Tamil Nadu to the south. Kolar Gold Fields, a historic mining region in this district, produced over 900 tons of gold prior its closure in 2001 as a result of high investment costs and low production. The current approach was carried out in the Kolar Gold Fields within the Kolar district of Karnataka (Table 1).

Collection of samples

To examine the quality of water, groundwater sample was collected from a borewell in Oorgam, KGF, employing a sterile 2.25 L bottle. The resultant sample was then transported to the laboratory for further examination. Moreover, a small fraction of purified water was collected in a sterile polyethylene bottle, and pre-washed with distilled water, to have comparative evaluations of changes if any.

Assessment of the samples

The resultant experimental samples were examined for the physio-chemical parameters and additionally tested for monitoring the persistence of heavy metals.

Physical parameters

The parameters such as pH and electrical conductivity (physical), were examined. The pH was measured by using a pH meter (Eutech instruments, India). The EC was measured by using an electrical conductivity meter (Hanna Instruments HI 99300).

Chemical parameters

Chemical parameters like chloride (Cl^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), sodium (Na^+), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) were tested. Calcium and sodium levels were estimated using a flame emission spectrophotometer and using calcium and sodium filters, respectively. Complexometric titration methods employing disodium ethylene diamine tetra-acetate were explored to examine the magnesium content. In complexometric determination of magnesium ion in the solution, EDTA was used as titrant and Eriochrome Black-T (Solochrome Black) as an indicator. Carbonate and bicarbonate were determined by titration method (Al Dowis et al., 2021).

Heavy metal analysis

The water samples were tested for heavy metals such as cadmium, nickel, lead, chromium and the results were analyzed with the standard values for both irrigation and drinking purposes. Heavy metals concentration in drinking water was evaluated by Atomic Absorption Spectroscopy. The water sample was obtained directly from the bore well after allowing the water to settle down for at least 5 minutes so as to stabilize the variation in electrical conductivity and temperature. The results were then matched with standard specifications.

Table 1. Illustration of water samples and sites.

Sample code	Source of collection	Site
BW	Borewell	Oorgam, KGF
PW	Purified water	Oorgam, KGF

Notes: BW = borewell water, PW = purified water, KGF = Kolar Gold Fields.

Results and Discussion

The study analyzed various physical and chemical parameters, including pH, electrical conductivity (EC), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), chloride (Cl^{-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}). The results were then compared with the World Health Organization (WHO) standards for drinking and irrigation water, as shown in Table 2. The pH of the drinking water in Kolar was found to be 5.46, indicating an acidic nature. Acidic water with a low pH is often associated with areas near mining sites, chemical disposal areas, power plants, concentrated animal feeding operations, and waste disposal sites, typically due to industrial contamination. Such water is a concern because it frequently contains significant amounts of heavy metals; in this case, the presence of heavy metals was undetectable in the purified water, though it was present in the borewell water. The acidic pH of Kolar's drinking water is a critical issue that demands urgent attention. Prolonged intake of acidic water can cause various health ailments in individuals, highlighting the requisite for immediate solutions to safeguard the safety and health of the population. According to WHO (2017), the suitable range for pH for drinking water is between 6.5 and 8.5, which makes sure that water is neither acidic nor alkaline in nature. For electrical conductivity, no specific limit is given by the WHO, but water with conductivity values above 0.75 dS/m denotes a higher concentration of dissolved solids (WHO, 2017). Chloride ranges are suitable below the recommended concentration of 250 mg/L both the water samples are under this range (WHO, 2009). Calcium and magnesium levels are also lower than typical thresholds for contributing to water hardness, which generally falls between 30-100 mg/L for both elements (WHO, 2009). The presence of mercury in Kolar borewell water is exactly at the WHO guideline limit of 0.001 mg/L, which suggests the potential for health risks if consumed over a prolonged period (WHO, 2017).

Table 2. Water quality parameters.

Parameters	Kolar drinking water (W2)	Kolar borewell water (W1)
pH	5.46	7.07
EC (dS/m)	0.06	1.69
CO_3	-	-
HCO_3	-	4.02 ± 0.060
Chloride (Cl^{-}) mg/L	1.92 ± 0.0899	8.06 ± 0.160
Calcium (Ca^{2+}) mg/L	0.427 ± 0.0201	14.26 ± 0.249
Magnesium (Mg^{2+}) mg/L	0.213 ± 0.0418	2.07 ± 0.075
Sodium (Na^{+}) mg/L	0.406 ± 0.0205	4.16 ± 0.090
Mercury (Hg) mg/L	-	0.001 ± 0.000125

The analysis of heavy metal concentrations in the borewell water (BW) sample revealed substantial contamination when compared to WHO drinking water standards (Figure 1). Cadmium (0.068 ppm) in BW exceeded the WHO recommended limit for drinking water (0.003 ppm) by approximately 22.7 times, which poses serious health risks due to cadmium's high toxicity (WHO, 2017). Furthermore, even for irrigation purposes, the cadmium concentration surpassed the permissible value of 0.01 ppm, potentially affecting soil and crop quality (WHO, 2017). Chromium level in BW (0.23 ppm) was 4.6 times higher than the drinking water guideline of 0.05 ppm and more than double the permissible level for irrigation water (0.1 ppm), indicating a significant contamination issue (WHO, 2017). Lead, with a concentration of 0.288 ppm in BW, is particularly concerning, as it exceeded the WHO limit for drinking water (0.01 ppm) by 28.8 times, posing severe health hazards, including neurotoxic effects (WHO, 2017). Though the irrigation limit for lead was much higher (5.0 ppm), its presence at high levels in the borewell water is a serious concern as it is the only water source for all the life forms there. The value of nickel in BW water (0.058 ppm) was within the permissible limit set by WHO for drinking water (0.07 ppm) and very below the irrigation water standard (0.2 ppm), which indicates that it does not pose any risk in the immediate future, but it can be fatal in the long run if it is not monitored and checked (WHO, 2017). On the other hand, purified water (PW) showed no detectable levels of these heavy metals, suggesting it is safe for both drinking and irrigation purposes. This analysis gave light on the urgent need for monitoring of BW to mitigate the risks posed by heavy metal contamination in the future.

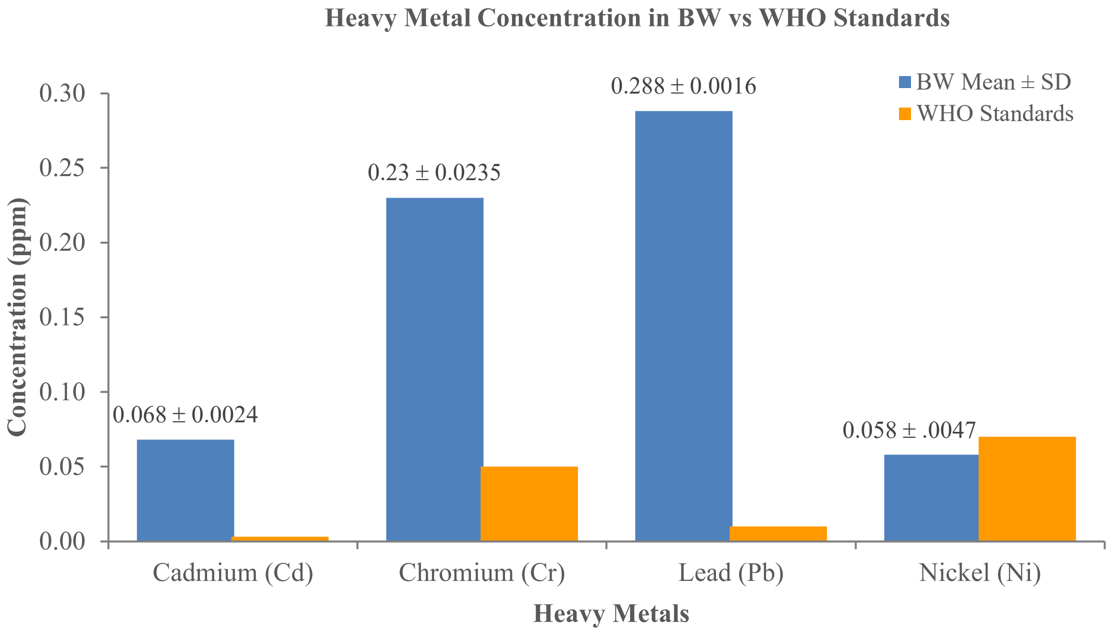

Figure 1. Concentration of heavy metals in the groundwater of Kolar area.

Purified water quality

The aqua-filtered water that was collected for the quality test showed a positive result except for the pH, electrical conductivity, and magnesium (Mg^{2+}). The results of this investigation provide an extensive assessment of the physical, chemical, and heavy metal content of water in Kolar.

pH

The pH of the drinking water in Kolar was recorded as an acidic pH of 5.46, prominently below the recommended parameter of 6.5-8.5 for drinking water (WHO, 2017). Acidic water, often linked with mining and industry, demonstrates health risks as a result of its potential for heavy metal contamination (Morrison et al., 2013). The study showed that the concentration of heavy metals in the drinking water was below detectable limits, indicating no immediate threat from toxic metals. Despite the absence of detectable heavy metals, the low pH of the drinking water is a critical concern. Extended exposure to acidic water caused to dental erosion, gastrointestinal ailments, and damage to plumbing infrastructure, elevating the likelihood of metal leaching (WHO, 2017). This result aligns with studies from mining regions where acidic water is prevalent (Mendez and Maier, 2008). The borewell water (BW) presented a pH of 7.07, which falls within the permissible range for both drinking and irrigation (WHO, 2017).

Electrical conductivity

Electrical conductivity (EC) is one of the key water quality parameters that measure the concentration of dissolved ions like salts and minerals. EC is used to detect contamination, assess ecosystem health, and determine water suitability for drinking, irrigation, and wastewater treatment. The changes in EC indicate contamination of water from agricultural runoff or industrial discharge, making it crucial for early detection of water quality issues (De Sousa et al., 2014). Checking EC is crucial for maintaining safe and sustainable water systems. The electrical conductivity (EC) of the borewell water was 1.69 dS/m, indicating moderate contamination. While this EC level is suitable for irrigation, it exceeded the ideal threshold for drinking water (Singh et al., 2019). Elevated EC levels in water can lead to soil salinization when used for irrigation, reducing agricultural productivity over time (Gupta et al., 2021).

Heavy metal contents

The water sample was tested for the presence of heavy metals such as cadmium, chromium, lead, and nickel. The water has not shown any detectable trace of these heavy metals, making it potable, but since the water has a high pH value, it makes the water unusable for consumption.

Borewell water quality

The valuation of the borewell water showed that though some parameters fell within the permissible limit, many other parameters were not under the permissible limit, making the water suitable for both drinking and irrigation purposes.

pH

One of the parameters used to assess the water quality is its pH value, and the borewell water was tested for pH. The test showed that the pH of the borewell water was 7.07, which falls under the specific standards set for both drinking and irrigation purposes (6.5-8.5).

Electrical conductivity

Electrical conductivity (EC) evaluates the potential of a solution to conduct electricity, and in alignment with standard specifications, the EC of drinking water should be zero. The tests demonstrated that the borewell water (BW) had an EC value of 1.69 dS/m, which indicates that though BW remains optimal for irrigation, it is not ideal for drinking. The findings suggest that the BW is contaminated, and continuous usage of the same for drinking purposes could result in critical health issues.

Heavy metal contents

Human health is critically influenced by toxicants, including lead, mercury, and cadmium. Advanced assessments, including atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS), presently allow precise evaluations of these metals in water samples. These techniques play an integral role in mitigating pollution sources and ensuring compliance with water safety standards (WHO standard specifications), expressing their importance in both environmental protection and public health (Gupta et al., 2021; Zhang et al., 2022). Consumption of water polluted with heavy metals results in crucial health diseases, including neurological damage, cancer, diabetes, cardiovascular diseases, and many more. The increasing deposition of metals, including lead, nickel, chromium, and cadmium, is of key concern to public health professionals (Rehman et al., 2018). Water samples were principally tested for cadmium, chromium, nickel, and lead, with significant studies on their effects. In the current approach, the water was evaluated for heavy metals like cadmium, chromium, nickel, and lead.

Cadmium

Monitoring of cadmium in water is of prime importance because this heavy metal is toxic, and its exposure may cause kidney damage, bone demineralization, and carcinogenic effects. Sources of contamination usually involve cadmium from industrial processes involving metal plating and improper waste disposal. Advanced detection techniques include AAS and ICP-MS, which will precisely monitor and control cadmium for public safety as well as the environment. During the analysis of water samples, cadmium was detected at a concentration of 0.068 ppm, which was considerably higher than the permissible limits of cadmium in drinking water of 0.003 ppm and irrigation water of 0.01 ppm (Chen et al., 2019; Singh et al., 2022). The toxic effects of cadmium can manifest even in areas of low exposure, which tend to bioaccumulate due to the very long biological half-lives of 16-30 years in human organisms and thus behave insidiously through the years. Chronic exposure to cadmium metal has been associated with lung diseases such as emphysema, asthma, bronchitis, and hypertension. Its symptoms depend on the time of exposure, age, and health status, but cadmium can cause serious respiratory injury: there is a decrease in the function of the lungs, chronic inflammation of the nasal mucous membrane, and bronchitis. Cadmium levels detected in this study were higher than the permissible limit for drinking water and irrigation water, causing great harm to the environment and human health.

Chromium

In the current investigation, the chromium concentration was recorded at 0.23 ppm, exceeding the permissible limit of 0.05 ppm for drinking water and 0.1 ppm for irrigation. The presence of chromium negatively impacts our natural resources and ecosystem. Chromium and its compounds pose serious health risks by causing DNA epigenetic alterations, resulting in heritable changes in gene expression (Iyer et al., 2023). This can lead to severe environmental and health consequences. Elevated levels of chromium can cause oxidative stress, epigenetic changes, and various health issues. Studies indicate that if chromium levels exceed the permitted limits, the water is unsuitable for both drinking and irrigation.

Lead

Lead (Pb) is recognized as the second most toxic metal, making up just 0.002% of the Earth's crust. Although naturally occurring in small amounts, lead is primarily introduced into the environment through human activities such as industry, automobiles, and batteries. In this investigation, the lead concentration was found to be 0.288 ppm, surpassing the permissible limit of 0.01 ppm for drinking water but remaining below the 5.0 ppm limit for irrigation. The presence of lead in the environment and human body can severely impact the neurological, skeletal, reproductive, hematopoietic, renal, and cardiovascular systems (Collin et al., 2022). Lead is highly toxic and contributes to numerous cases of poisoning through food. It enters the human body through absorption and biomagnification. Even trace amounts of lead can adversely affect arteries and kidneys, leading to high blood pressure and kidney damage (Kumar et al., 2020; Ren et al., 2022). The findings indicate that the water is suitable for irrigation purposes but not for drinking.

Nickel

The pollution of water through nickel is a critical environmental issue due to massive usage in industries such as electroplating, stainless steel manufacturing, and mining. Continuous examination of the presence of nickel levels in water remains crucial, as exposure to high concentrations of the same results in numerous health issues. Nickel can penetrate drinking water via industrial remnants, leaching from plumbing systems, and atmospheric fallout. Once ingested, it can deposit in human tissues, causing critical effects like skin irritation, respiratory ailments, and, in critical cases, cancer, especially with long-term exposure (ATSDR, 2005; Genchi et al., 2020). The World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA) have set maximum recommended limits for nickel in drinking water at 0.07 mg/L and 0.1 mg/L, respectively, to avoid these health risks (WHO, 2017; EPA, 2022). These regulations showcase the relevance of evaluating water quality for nickel, chiefly in regions near industrial activities, to safeguard public health and the environment. In the present approach, the nickel concentration evaluated was 0.058 ppm, which is within the permissible range for drinking water (0.07 ppm) and irrigation water (0.20 ppm). Nickel, a naturally occurring element in the Earth's crust, exists in natural waters as a divalent cation with a pH range of 5-9, resulting in trace levels existing in food, water, and soil. Higher nickel levels in the body can lead to serious health problems, including hypertension and ailments to brain tissue (Kumar et al., 2021; Zamora-Ledezma et al., 2021). In this study, heavy metal examinations of borewell water demonstrated that, aside from nickel, other heavy metals exceeded the recommended levels, making the water unfit for drinking. For irrigation purposes, the cadmium and chromium concentrations also surpassed the standard recommended limits.

Conclusion

The research on groundwater quality assessment in Kolar Gold Fields (KGF) highlights critical environmental and public health issues that lead to the persistence of hazardous heavy metals like cadmium, chromium, and lead, which exceed WHO limits. These contaminants render the water unsafe for drinking and irrigation, showing critical risks to local communities and agriculture. Cadmium exposure can lead to kidney ailments, leading to neurological issues, and chromium to carcinogenic effects, raising the potential for bioaccumulation in crops and entry into the food chain. The analysis also revealed altered physical and chemical properties, such as low pH and high electrical conductivity (EC), which are indicative of industrial pollution from unaddressed mining tailings. Acidic water elevates heavy metal leaching compounding contamination issues, while high EC levels further reduce the suitability of the water for irrigation, threatening long-term soil health.

The results underscore an immediate requisite for remedial action, including water purification technologies, regular monitoring, and rehabilitation of mining waste. Without intervention, these issues could result in public health crises and further ecological degradation. The case of KGF is a broader reflection of the global environmental influence of mining activities, emphasizing the requisite for sustainable approaches and the restoration of contaminated areas to preserve natural resources and human health.

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