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# Spatial and Temporal Evaluation of the Heavy Metal Lead in the Soil and Ground Water of Abandoned Gold Mining Sites Using ICP-0ES and AES-A Critical Study

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**KEYWORDS**

Soil pollution, Ground water pollution, Lead, ICP-OES, ICP-AES

**ABSTRACT:**

**INTRODUCTION-** Kolar Gold Fields, a town in the state of Karnataka, India, had the second deepest mine in the world when it was fully functional. The mining company at KGF has produced 40 tonnes of tailings, comprising of various heavy metals, which causes detrimental effects on biotic and abiotic components.

**Method-**The study has a bifold objectives, firstly to determine the concentration of lead (Pb) in the soil and ground water within the vicinity of a historical gold mine region located in the Kolar Gold fields (KGF), Karnataka. The study employed Thermo Scientific's Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) and ICP-AES using Iteva software. Four soil and ground water samples were collected from the selected study sites (A, B, C and D) and examined between January - December 2023.

**RESULTS-** The highest level of lead that can be present in the soil is 98 mg/kg (WHO 2008). The highest average lead content in the soil samples during January-December 2023 analyzed from Champion was 120.83 mg/kg, followed by site A, D, and B respectively. The maximum permissible limit of lead in groundwater is 0.05 mg/L (USEPA 2009). The ground water analysis revealed that the ground water was highly contaminated with lead (0.863 mg/L) in site C (Champion). The average lead content is found to be 0.559 mg/L, at sites B, A and D is 0.323 mg/L, B, 0.277 mg/L 0.161 mg/L respectively. The pH and electrical conductivity of all the water samples were within the permissible limits, but hardness of the ground water was two times higher than the permissible limit in the sample site D (Balghat).

**CONCLUSIONS-**Site C had the highest lead content in both soil and ground water, almost 1.2 times higher in soil and in ground water it was 17 times higher than permissible limits.

## 1. INTRODUCTION:

There have been momentous global environmental emissions of hazardous chemicals as a result of growing urbanization and industry [1, 2]. While some of these poisons are naturally occurring, human causes, particularly mining operations, have significantly accelerated their growth. Despite having a sizable positive social and economic impact on a country, it is difficult to ignore the mining's long-term detrimental consequences on the public health and the [3]. Over the past few decades, urbanization has rapidly increased due to the tremendous expansion in the human population. Due to the fact that untreated wastewater discharge pollutes water bodies and promotes diseases related to water, the correct management of the enormous amount of urban wastewater is an international challenge the [4].

The town of Kolar Gold Fields, often known as K.G.F., is located in the Bangarpet taluk of the Kolar district in the Indian state of Karnataka. In order to take over the mining operations of the mines situated at latitude 12° 53'12" N and longitude 78°15'03" E, at the southernmost point of a short schist strip of the township, KGF, whose residents are primarily the families of gold mine workers, the Government of India established the public company (Bharat Gold Mines Limited), or BGML. For more than a century, underground gold mining has been practiced at KGF. 65 kilometers of tunnel construction have been used to mine gold to a depth of 3 kilometers below the surface, and 40 million tons of mill tailings have accumulated the [5].

Metallurgical extraction must first break the crystallographic connections in order to extract the required element or compound from the ore source the [6].This process creates a considerable amount of waste in the case of gold mining, when practically all of the ore obtained is discarded the [7].

After the valuable ore has been extracted during the mining process, the leftover finely powdered rock and water are known as tailings. There are significant amounts of tailings that have been discarded in the open in many nations where environmental restrictions are not effectively implemented. Tailings particles have a similar chemical and physical makeup to similar river sand and mud the [8].

Tailings, a by-product of gold extraction that is heavily polluted with heavy metals, are the main product (HM) the [9, 10].These metals seep out into the environment uncontrollably when they come into touch with water or are dispersed by the wind the [11].

The quality of both surface and groundwater is significantly impacted by surface impacts like tailings and rock dumps. The process of using cyanide to extract gold from ore, also contributes to global warming, hydrogen cyanide emissions, and the creation of vast number of tailings, which might be a source of heavy metals (HMs) the [12].

The aforementioned factors are only a few of the many sources of tailing characteristics. Sediments from mines frequently resemble a particular type of river sand or silt in terms of their physical and chemical characteristics. The geochemistry, makeup, and mineralogy of the ore, as well as the procedures used to extract different commercial goods, all influence the specific features of tailings. Chemically, gold tailings are highly salinized, include just 6% pyrite, and contain very little organic stuff. According to sources, the pH of Iran's tailings was 7.35, that of South Africa's was 3.25-6.28, and that of India was 3.48-8.12 the [13].

Heavy metal soil pollution is caused in the regions with gold mining activities primarily due to the extraction of ores from soil and rocks and due to unscientific methods of dumping the leftover tailings around residential places. Heavy metals may endanger humans, animals, plants, and the ecosystem through various channels the [14, 15, 16].These include direct consumption, plant absorption, food chains, ingesting polluted water, and changes to the pH, opacity, color, all of which affect soil quality the [17].

Even though heavy metals are only found in trace concentrations in water sources, they are exceedingly dangerous and pose serious health hazards to both people and other species the [18, 19 ].When humans consume toxic metals in excess, it can cause serious stomach pain, extreme vomiting, and deteriorating liver abnormalities. Lead poisoning from drinking water has been linked to horrible long-term effects, such as learning issues, nervous system damage, and children's growth being stunted the [20].

Gradually the heavy metals present in soil tends to get washed off from tailings present in high altitude during monsoon season and seeps into groundwater, lakes, and pond water. The HMs which are present in pond water tend to invariably affect the metabolism and growth of the fish. Fishes containing impermissible levels of heavy metals when consumed by animals in higher tropic levels get affected resulting in various complications. The study attempted to demonstrate that heavy metal concentrations in Channa punctatus from sewage-fed aquaculture ponds in India constitute a health threat to locals. The majority of the fish samples examined contained dangerously high amounts of heavy metals, putting the local population at risk if they consumed too much fish [21].

Over the course of a century, various companies mined gold. Low gold production and unprofitability forced its closure in 2001 the [22]. Heavy metal pollution comes from mining. Mining contaminates soil, generating environmental hazards. Samples contained heavy metals in soil and water the [23].Heavy metals can cause cancer, organ damage, stunted growth, and death the [24].Heavy metal removal from soils requires remediation. He concluded that rainwater penetration contaminates groundwater, which contaminates the soil. Heavy metal harms plants, animals, and humans. Thus, it is vital to assess soil contamination and offer remedial actions to improve soil quality and reduce contamination.

In the majority of the world's accessible freshwater reservoirs, groundwater makes up 99 percent of the planet's liquid freshwater supply. Since it can be pumped, groundwater often becomes the main source of water in areas where there are no other permanent water supplies. Currently, groundwater is the source of over 50% of all drinking water, 40% of all agricultural water, and 35% of all industrial the [25].

The main contributors to heavy metal contamination have been lead (Pb), chromium (Cr), mercury (Hg), and cadmium (Cd). The presence of these metals has caused a number of issues for plant life in the beautiful surroundings. In growing plants, cadmium causes leaf chlorosis, or inadequate chlorophyll. Plants that contain excessive levels of lead and mercury have experienced a decrease in photosynthesis and root development. Chromium is not biodegradable and significantly reduces the dry weight of seedlings. They enter the food chain and accumulate at various trophic levels, which have an adverse influence on the growth of plants the [26].The immune system is altered by cadmium, and proliferative prostatic lesions and lung adenocarcinoma are more common. Overexposure to blood lead can lower a child's intellectual capacity, damage their endocrine, skeletal, and immune systems, and induce hypertension. In adults, it also impairs cardiac and renal function. Chromium has been connected to respiratory system tumors and cancer the [27].Groundwater contamination from rainwater infiltration eventually contaminates soil the [22]. Heavy metal harms plants, animals, and humans. Thus, it is vital to assess pollution and offer remedial strategies to improve groundwater quality and reduce contamination. Six water samples from bore wells (BWs) were chosen at random from the mining and residential regions of KGF. To evaluate the presence of heavy metals in the KGF, samples of bore well (BW) water were taken all throughout the research area. Six samples of well water were examined in the lab. Heavy elements like copper (Cu), nickel (Ni), and arsenic (As) were discovered in the water during the preliminary research.

## 2.**OBJECTIVES**

To assess and evaluate the quantity of heavy metals lead in the soil and ground water of mining vicinity in the Kolar Gold Fields.

## 3.METHODS

### COLLECTION OF SOIL SAMPLES:

### 3.1 General methodology:

During this research work, the general methodology was devised based on spatiotemporal factors like place and time. So, the four places selected based on the minimal distance from the abandoned gold mining sites were Oorgaum, Tenants, Champion, and Balghat and named A, B, C, and D which are located 50,100, 200 and 300 meters from the mining sites respectively.

The four sampling seasons were

Season 1-January, February, and March Season 2-April, May, and June

Season 3- July, August, and September Season 4-October, November, and December

Four sample locations were used for the sampling, which took place between January and December 2023 (gold ore tailings). Every month, one sample was taken from each location, resulting in four samples that were examined. The presence of certain heavy metals, such as Cd, Cr, and Pb was determined by sampling the area throughout the four distinct seasons. After removing contaminants from the surface, soil samples were collected from 10 to 20 cm below the surface and put in self-locking polythene bags. The sample preparation procedures for the spectrochemical determination of the total recoverable elements were finished in accordance with U.S. Environmental Protection Agency requirements the [28].

### 3.2 Sample preparation:

To calculate the total recoverable analytes in soil samples, the sample was well mixed, a piece of it was placed on the tared weighing dish, the sample was weighed, and the weight was recorded in order to ascertain the total recoverable analytes in solid samples. The dry material was mashed in a mortar and pestle and sieved using a 5-mesh propylene sieve to obtain homogeneity. All of the acids and chemicals utilised in this research were ultra-purity grade, and Rankem Compounds provided the chemicals for measurement. Thermo Scientific's ICP-OES (Inductively Coupled Plasma- Optical Emission Spectroscopy) was used in conjunction with Iteva software to evaluate the samples.

### 3.3 Sample digestion and analysis:

As reagents, Rankem chemicals' pure analytical grade acids with a 32 percent HCl content and a 70 percent $HNO_3$ content (both purchased from Sigma-Aldrich India) were employed. Concentrated $HNO_3$ and HCl acids were combined in a 1:3 ratio to create aqua-regia. In a 250 mL conical glass flask, one gramme of each reference material or dry powdered soil was combined with 28 mL of aqua-regia. The reactants were gently mixed in the flask before it was heated on a hot plate for five hours, reaching a temperature of 120°C. The dissolved samples were filtered into 100 mL HDPE bottles after cooling down using filter paper that had been wetted with 3 percent $HNO_3$ acid for ICP-OES analysis. All glassware used to prepare samples was cleaned before use by immersing it in an acid solution containing 10 percent v/v $HNO_3$ for 24 hours. This was done before giving the glassware a final rinse with deionized distilled water. Thermo Fischer, ICP-OES, and iCAP 6300 were used to perform chemical analyses at the ARML in Bangalore, India, and ITEVA software was used to interpret the results.

## 4. RESULTS AND DISCUSSION

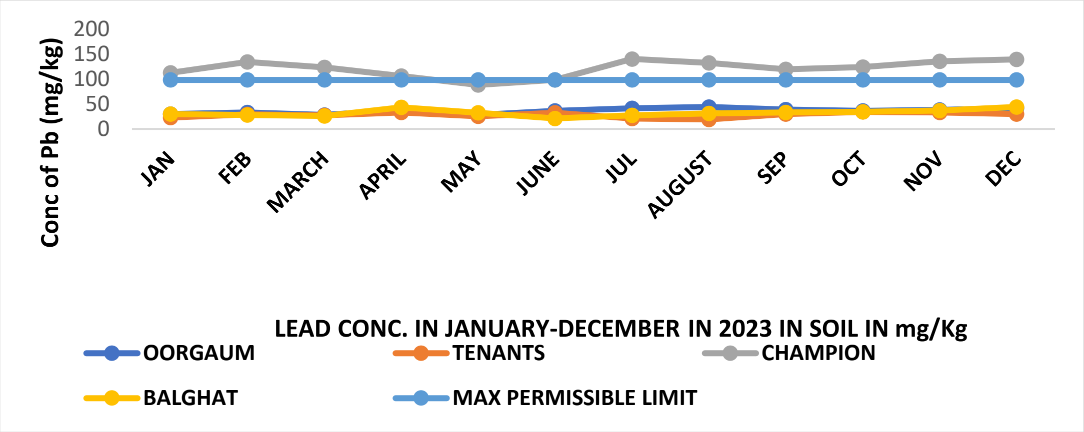
### 4.1 Lead concentration in soil

Lead, as a heavy metal, is known for its stability. In both animals and humans, it acts as a neurotoxin. The soil may contain trace quantities of lead. One of the most pervasive and deadly forms of pollution in the world is lead (Pb) pollution.

**Table 1: Assessment of Lead in the soil (mg/kg) in various sampling sites during January-December 2023**

| SAMPLING SITE | MAXIMUM PERMISSBLE LIMIT | HIGHEST | LOWEST | AVERAGE |
|---|---|---|---|---|
| **OORGAUM (A)** | 98 | 44 | 28 | 36.08 |
| **TENANTS (B)** | | 34 | 19 | 28.00 |
| **CHAMPION (C)** | | 140 | 88 | 120.83 |
| **BALGHAT (D)** | | 44 | 21 | 32.17 |

The highest level of lead that can be present in the soil is 98 mg/kg. In site (C) Champion, the amount of lead (Pb) is 140 mg/kg, which is almost 1.2 times the upper limit set by the [29] as permissible limits. The highest average lead content in the soil samples during January-December 2023 analyzed from Champion was 120.83 mg/kg, followed by 36.08 mg/kg at site A, 32.17 mg/kg at site D, and 28.00 mg/kg at site B. Tenants' soil contamination in season 3 was (19 mg/kg) as the lowest concentration through the campaign. When assessed season-wise in all sample sites the average concentrations season-wise was, season 4 at 60.45 mg/kg, followed by season 3 at 56.3 mg/kg, season 1 had 51.9 mg/kg, and the lowest amount observed during season 2 at 48.3 mg/kg.



**Graph 1: Assessment of Lead in the soil (mg/kg) in various sampling sites during January-December 2023**

Sites A (Oorgaum), B (Tenants), and D (Balghat) all have lead levels in their soil that are below the legal limit. Only site C (Champion) shows higher lead values in the soil sample than the permissible limits. The lead concentrations in the soil samples are slightly rising from season to season. Initial concentrations tend to be lowest during season 1, with subsequent concentrations gradually rising throughout the year.

**Table 2: Correlation of lead concentration in Soil in various seasons**

| Seasons during 2023 | | Correlation | Sig. |
|---|---|---|---|
| 1 | Season 1 & 2 | 1.000 | .000 |
| 2 | Season 1 & 3 | .993 | .007 |
| 3 | Season 1 & 4 | .999 | .001 |

According to Table 2, there is a positive and significant correlation between lead pollution in the soil during seasons 1 (January–March) and 2 ($r = 1.00$, $p< 0.05$). There is also evidence of a statistically significant association concerning lead pollution in soil, with values of ($r = 0.993$, $p< 0.05$) and ($r = 0.999$, $p< 0.05$), respectively, for Seasons 3 and 4.

**Table 3: Comparison of Lead concentration in Soil in various seasons**

| | **Paired Differences** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **95% Confidence Interval of the Difference** | | | | |
| **Seasons** | **Mean** | **Std. Deviation** | **Std. Error Mean** | **Lower** | **Upper** | **t** | **df** | **P-value** |
| 1-2 | 3.58333 | 14.72306 | 7.36153 | -19.84434 | 27.01101 | .487 | 3 | .660 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1-3 | -4.41667 | 6.08809 | 3.04404 | -14.10417 | 5.27084 | -1.451 | 3 | .243 |
| 1-4 | -8.58333 | 1.91243 | .95622 | -11.62644 | -5.54022 | -8.976 | 3 | .003 |

**Table 3.** displays the results of a statistical analysis comparing lead concentrations in the soil across different seasons. The results show that there is a statistically significant difference between the lead concentrations in the soil between seasons 1 (January–March) and 4 (October–December) with a p-value of 0.003. We cannot statistically report a difference in lead levels between seasons 1 (January–March) and 2 (April–June) and seasons 1 (January–March) and 3 (July-September) since the p-value is greater than 0.05.

### 4.2 Effect of gold ore tailings on the groundwater during January-December 2023

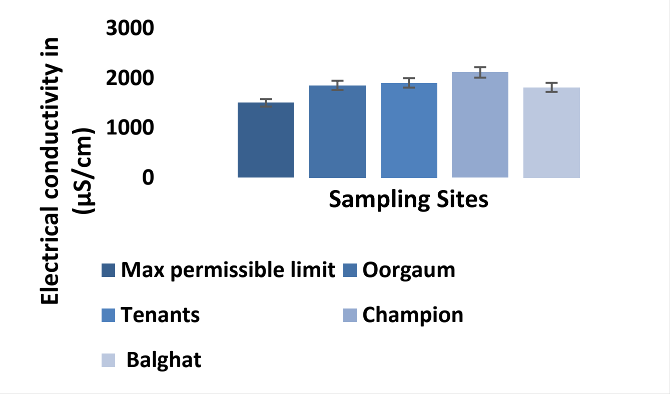
### 4.3 Assessment of pH in bore well water

An indicator of many geochemical equilibrium or solubility calculations, pH is widely recognized as a critical ecological component. Most aquatic creatures have adapted to a specific pH level and cannot survive if that level suddenly changes, making pH a crucial element in any body of water.

**Table 4: Average concentration of pH in groundwater in sampling sites 2023**

| Sites | pH |
|---|---|
| Max permissible limit | 6.5-8.5 |
| Oorgaum | 6.8 |
| Tenants | 7.1 |
| Champion | 7.4 |
| Balghat | 6.6 |

The limit pH value for drinking water is specified as 6.5 to 8.5. Sampling site Balghat has the lowest pH value i.e., 6.6 and Champoin's pH value is the highest among all the sample sites (7.4) followed by Tenants and Oorgaum with the pH values 7.1 and 6.8 respectively.



**Graph 2: Average Electrical conductivity in groundwater in sampling sites in 2023.**

### 4.4 Assessment of Hardness in groundwater

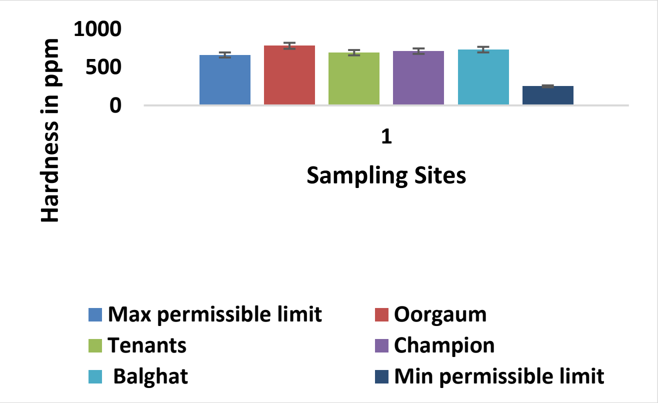
The levels of calcium and magnesium, and to a lesser extent iron, are what determine the hardness of water. Water hardness is expressed as the amount of calcium carbonate ($CaCO_3$) in milligrams per liter (mg/L) by adding the calcium and magnesium concentrations together. The weathering of limestone, sedimentary rock, and calcium-bearing minerals gives most groundwater its hardness. Chemical and mining wastewater, as well as the overuse of lime as a soil amendment in agricultural regions, can all contribute locally to groundwater hardness.

**Table 5: Average concentration of Hardness in groundwater in various sampling sites in 2023**

| Sampling Sites | Hardness in ppm |
|---|---|
| Max permissible limit | 250-660 |
| Oorgaum | 780 |
| Tenants | 690 |

| | |
|---|---|
| Champion | 710 |
| Balghat | 730 |

The optimum range of hardness in drinking water is 250 ppm to 660 ppm. All the other sampling site's borewell water's hardness is much higher than the permissible limits. The highest water hardness is seen in the Oorgaum borewell water sample, followed by sites D, C, and B.



**Graph 3: Average Hardness in groundwater in sampling sites in 2023.**

**Table 6: Concentration of Cadmium in groundwater in mg/L in sampling sites during January-December 2023**

| SAMPLING SITE | MAXIMUM PERMISSBLE LIMIT | HIGHEST | LOWEST | AVERAGE |
|---|---|---|---|---|
| **OORGAUM (A)** | 0.01 | 0.015 | 0.013 | 0.014 |
| **TENANTS (B)** | | 0.005 | 0.003 | 0.004 |
| **CHAMPION (C)** | | 0.349 | 0.157 | 0.228 |
| **BALGHAT (D)** | | 0.070 | 0.050 | 0.060 |

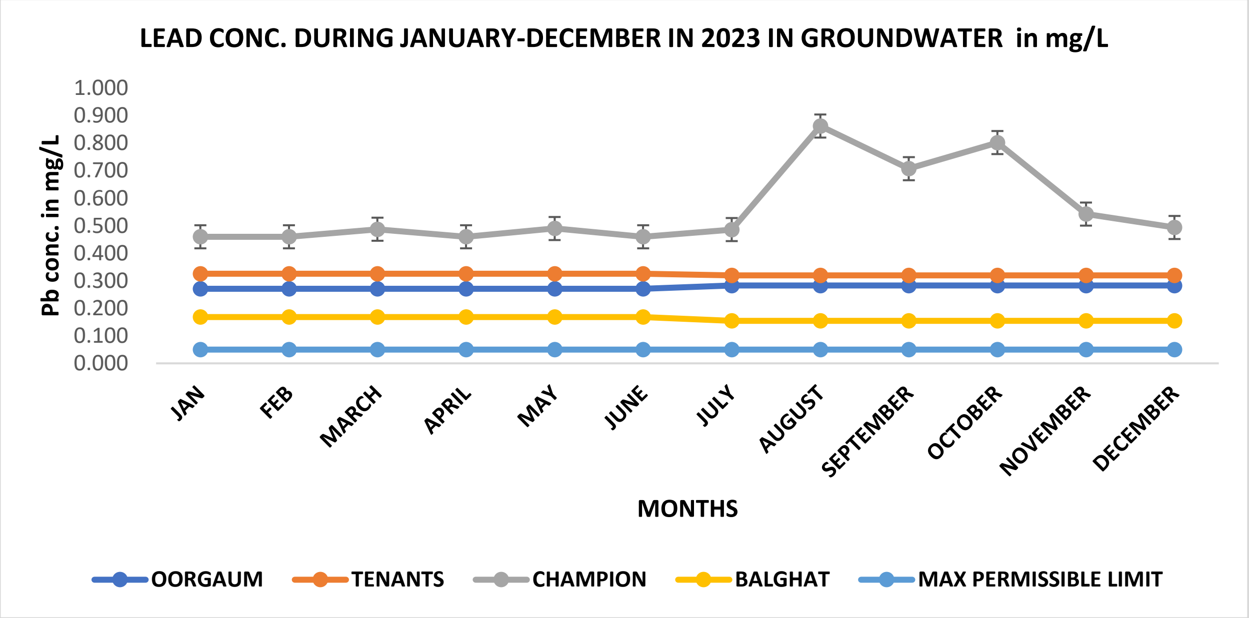
### 4.5 Lead concentration in groundwater

The environment contains naturally occurring lead, a hazardous element. Often used in household items, although its content in the environment may have been raised by human activity; it is released into the atmosphere through vehicle exhaust. Pipe corrosion is a major source of this substance in drinking water. Children under the age of six are particularly vulnerable to the adverse health effects of lead exposure, even from relatively modest exposure levels. hemoglobin production is disrupted; blood pressure is raised; kidneys are damaged.

**Table 7: Concentration of Lead in groundwater in mg/L in sampling sites during January-December 2023**

| SAMPLING SITE | MAXIMUM PERMISSBLE LIMIT | HIGHEST | LOWEST | AVERAGE |
|---|---|---|---|---|
| **OORGAUM (A)** | 0.05 | 0.283 | 0.271 | 0.277 |
| **TENANTS (B)** | 0.05 | 0.326 | 0.320 | 0.323 |
| **CHAMPION (C)** | 0.05 | 0.863 | 0.460 | 0.559 |
| **BALGHAT (D)** | 0.05 | 0.168 | 0.155 | 0.161 |

The highest level of lead that can be present in groundwater is 0.05 mg/L. Sampling site C Champion is highly contaminated with lead. In Champion, the content is 0.863 mg/L, which is much higher than the upper limit set by the WHO (2004) for safe consumption. The average lead content in the groundwater samples taken from Champion was 0.559 mg/L, followed by 0.323 mg/L at site B, 0.277 mg/L at site A, and 0.161 mg/L at site D. Balghat's groundwater contamination in season 3 and 4 (0.155 mg/L) was lowest.



**Graph 4: Concentration of Lead in groundwater in mg/L in sampling sites during January-December 2023**

Sites A (Oorgaum), C, and D (all shown on the graph 4) all have lead levels in their groundwater that are above the legal limit. Only site B shows constant lead values in the groundwater sample. The lead concentrations in the groundwater samples are slightly rising from season to season. Initial concentrations tend to be lowest during season 1, with subsequent concentrations gradually rising throughout the year.

**Table 8: Correlation of lead concentration in groundwater in various seasons**

| Seasons during 2014 | | Correlation | Sig. |
|---|---|---|---|
| 1 | Season 1 & Season 2 | 1.000 | .000 |
| 2 | Season 1 & Season 3 | .972 | .028 |
| 3 | Season 1 & Season 4 | .983 | .017 |

According to **Table 8**, there is a positive and significant correlation between lead pollution in groundwater during seasons 1 (January–March) and 2 ($r = 1.00$, $p < 0.05$). There is also evidence of a statistically significant association concerning lead pollution in groundwater, with values of ($r = 0.972$, $p < 0.05$) and ($r = 0.983$, $p < 0.05$), respectively, for Seasons 3 and 4.

**Table 9: Comparison of Lead concentration in Groundwater in various Seasons**

| Seasons | Paired Differences | | | | | t | df | P-value |
|---|---|---|---|---|---|---|---|---|
| | | | | 95% Confidence Interval of the Difference | | | | |
| | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | | | |
| 1 – 2 | -.000208 | .000417 | .000208 | -.000871 | .000455 | -1.000 | 3 | .391 |
| 1 – 3 | -.052125 | .109947 | .054974 | -.227075 | .122825 | -.948 | 3 | .413 |
| 1 - 4 | -.034000 | .073957 | .036979 | -.151683 | .083683 | -.919 | 3 | .426 |

**In table 9**, there was a statistically non-significant average difference between lead levels in the groundwater during season1 (Jan-Mar) & season 2 (Apr-Jun), season 1 (Jan-Mar) & season 3 (Jul-Sept) and season 1 (Jan-Mar) & season 4 (Oct-Dec) since the p-value >0.05.

## 5. DISCUSSION

The permissible pH value for drinking water is specified as 6.5 to 8.5. Sampling site Balghat has the lowest pH value i.e. 6.6 and Champion's pH value is the highest among all the sample sites (7.4) followed by Tenants and Oorgaum with the pH values 7.1 and 6.8 respectively. In a similar study in Singapore, the [30],the pH value of water was observed as 7.8±0.4. In a similar study in Kuwait, the pH value of water was observed in the range 7.33–7.45, justifying our results.

The highest EC in borewell water is observed in Champion (2110 µS/cm), followed by Tenants, Oorgaum, and Balghat with the values 1900 µS/cm, 1850 µS/cm, and 1810 µS/cm respectively. In a similar study in Palestine the [31] demonstrated the EC value of water was observed in the range of 473–1406, justifying our obtained results. In contrast, a study in Wondo Genet, the [32].reported the EC value of water was observed as 192.14 µS/cm.

All the other sampling site's borewell water's hardness is much higher than the permissible limits. Hardness is almost 2 times higher than the control water hardness. The highest water hardness is seen in the Oorgaum borewell water sample, followed by sites D, C, and B. In a similar study in Europe, the [33].reported the hardness value of water was observed as 60 ppm. In a similar study in Sri Lanka, the [34].reported the hardness of groundwater as 385 ppm.

When assessed for lead in soil, sample site (C) Champion, contained 140 mg/kg of Pb, which is almost 1.2 times the upper limit set by the WHO (2008) as permissible limits. The highest average lead content in the soil samples during January-December 2023 analyzed from Champion was 120.83 mg/kg, followed by 36.08 mg/kg at site A, 32.17 mg/kg at site D, and 28.00 mg/kg at site B. Tenants' soil contamination in season 3 was (19 mg/kg) as the lowest concentration through the campaign. A similar study done in Karnataka the [35] found the lead content in soils from 30 mg kg−1 in Kiradalli Tanda village soil.

Sampling site C Champion is highly contaminated with lead. In Champion, the content is 0.863 mg/L, which is much higher than the upper limit set by the [29].for safe consumption. The average lead content in the groundwater samples taken from Champion was 0.559 mg/L, followed by 0.323 mg/L at site B, 0.277 mg/L at site A, and 0.161 mg/L at site D. Balghat's groundwater contamination in season 3 and 4 (0.155 mg/L) was lowest. In a similar study in Taiwan, it was found that the lead values were found in the range 0.001-0.019 mg/L. the [36].validated that in Iran, the lead concentration was found to be in the range of 1-4.23 mg/L.

**CONFLICTS OF INTEREST**: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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