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Exploring Health Hazards from Toxic Elements in Well Water Samples Within Prism steel rolling mill, Ikirun, Osun State, Nigeria

[1]Ishola, A.D., [1]Oyeleke, G. O.,[2] Lawal, R. T., [2]Olakunle, T. P.

[1]Chemistry Department,
University of Ilesa,

[2]Biological Science Department,
University of Ilesa

Email: ishow538@gmail.com

Abstract

The Prism steel rolling mill, Ikirun, Osun State may contaminate well water, the area's main potable water source. This necessitated assessment of physical and chemical properties and possibly hazardous elements in well water samples. Standard methods and Atomic Absorption Spectrometry (AAS) were used to analyze physicochemical status and Potentially Toxic Element concentrations (Cd, Cr, Ni, Pb, Zn) in ten well water samples. Physicochemical parameters ranged as follows: pH 6.64-7.38, temperature 27.2-29.2°C, Total Dissolved Solids (TDS) 0.99-1.60 mg L^{-1}, Dissolved Oxygen (DO) 1.05-1.65 mg L^{-1}. Heavy metal concentrations decreased in order Cd > Ni > Zn > Cr, with ranges: Cd 0.04-0.31 mg L^{-1}, Cr 0.09-0.67 mg L^{-1}, Zn ND-0.04 mg L^{-1}, Ni ND-0.16 mg L^{-1}. Pb was below detection limits. Non-carcinogenic risk assessment indicated potential adverse health effects and unacceptable risks for local inhabitants from well water consumption. However, carcinogenic risk assessment showed no cancer risk.

Keywords: Waste Contamination, Heavy Metals, Human Health Hazard, well water Contamination.

INTRODUCTION

According to the World Health Organization, having access to safe drinking water is crucial for both national security and public health in 2008. However, as a result of growing demand brought on by urbanization and population growth, this resource is becoming scarce. Inadequate management of water resources can also lead to the proliferation of diseases carried by water, accounting for 6.3% of global fatalities (WHO, 2008; Manetu and Karanja, 2021). 2.4 billion people lack access to sufficient sanitation facilities, and despite efforts to accomplish the global development targets, 9% of the global population still does not have access to clean drinking water.(Hutton and Chase, 2016). Thus, it is essential for societal advancement and well-being to guarantee universal access to clean water (Emenike *et al.*, 2017).

Among the Earth's renewable resources, well water stands out as one of the most crucial and widely available. It represents about 98% of the planet's freshwater and is distributed relatively evenly across the world (Scanlon *et al.*, 2023). Approximately one-third of the global population, or nearly two billion people, relies on well water. Each year, about 20% of global water usage (600-700 km^3) is drawn from well water sources, primarily from shallow aquifers.

Author for Correspondence

In Nigeria, both urban and rural communities heavily depend on well water as a vital source of clean drinking water (Oluwaseyi *et al.,* 2020). The lack of reliable municipal water systems in rural areas has further increased reliance on well water resources for everyday use.
Environmental contamination can originate from various anthropogenic activities such as mining, industrial production, municipal consumption and refuse. These discharges significantly pollute the soil, which in turn contaminates both surface and well water through leaching or filtration. This poses serious health and environmental risks to local populations and aquatic ecosystems.

According to Oyeleke and Okparaocha (2016), heavy metals like Cd, Cr, Pb, Ni, and Zn are naturally present in emissions. Numerous studies (Ogunlaja *et al., 2019*; Ogunlaja *et al.*, 2018; Ite *et al.*, 2018) have linked the release of pollutants from a steel company to elevated concentrations of hazardous heavy metals in well water. Because of this, it poses a risk to the local population's health and the environment, especially when using well water sources. Consequently, it is essential to look into the well water's elemental composition.

Contamination of well water is one of the most important environmental issues of our time. Heavy metals are among the many contaminants that have an adverse effect on water resources, but they are especially concerning because they are highly toxic, even at low concentrations (Ali *et al., 2019*; Vardhan *et al.,* 2019; Wendling, 2018; Masindi and Muedi, 2018).

Two multivariate statistical techniques—principal component analysis (PCA) and cluster analysis (CA)—are employed in this investigation. The overall objective was to compare and examine the risks associated with consuming well water sources from Prism Steel Rolling Mill in Ikirun, Osun State, and to learn more about the hazards posed by toxic trace elements. Additionally, we assessed the possible health hazards connected with consuming this water as well as the everyday human exposure to harmful substances from local well water sources.

MATERIALS AND METHODS

2.1. Description of the Study Area

This study was conducted in Ikirun, Ifelodun Local Government Area of Osun State, (as shown in Figure 1) is positioned between longitude 7.917°N and latitude 4.667°E. It covers an area of 948 km^2 and has a population of 125,200 (NPC, 2006).

Sample Collection and Preparation

Ten samples of well water were gathered using a straightforward random selection process from specific wells situated within the study area of Prism steel rolling mill. The samples were placed in tightly sealed 1-liter plastic bottles and kept refrigerated until they were ready for analysis.

Chemical Analysis and Quality Control

A portable, calibrated mercury-in-glass thermometer and a pH meter with a glass electrode were used to quickly measure the temperature and pH. Total hardness (TH) was determined using the complexometric method. Alkalinity was assessed via titration, while a membrane probe (Tutron WA-2015) calibrated with suitable calibration solutions was used to detect conductivity, total dissolved solids (TDS), and dissolved oxygen (DO).

Figure.1: Map Showing the Study Area

All obtained physicochemical results were compared with the permissible limits established by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) standards (NSDWQ, 2007; WHO, 2011).

The heavy metals analysis involved digesting measured volumes of water samples with analytical grade nitric acid (HNO_3). After digestion, the samples were filtered into 25 ml standard flasks, topped up with deionized water, and stored in polyethylene bottles (pre-cleaned with nitric acid) in a refrigerator until instrumental analysis could be conducted.

An atomic absorption spectrometer (Schimazo model 2380) was utilized to analyze the water extracts for specific metals: Cd, Cr, Pb, Zn, and Ni. With each element's improved experimental parameters, detection limits were established to yield a 98% confidence level with three standard deviations. Trace detection and higher sensitivity settings were used in all measurements to find concentrations in the sub-ppb range for the elements under study.

The researchers conducted blank analyses and performed duplicate analyses on all samples, using the average of the results for their final data set.

Statistical Analysis

To investigate the possible sources of different metals from these aquifers, the concentrations of heavy metals in this study were analyzed using Pearson’s correlation matrix. All statistical analyses were performed using the Statistical Package for the Social Sciences, (PASW version 24, IBM Corporation, Cornell, NY, USA).

Elemental Analysis

Health Risk Assessments

The chronic health hazard associated with the consumption of water from these groundwater sources was assessed. The daily human exposure assessment to heavy metals through the ingestion pathway was evaluated using the lifetime average daily dose (LADD), as adopted by USEPA (2005). In this study, the human exposure risk was estimated according to the modified equation from USEPA by Kavcar *et al.,* (2009) and Belkhiria *et al.,* (2017). The chronic risk was determined using chronic daily intake (CDI) and hazard quotient (HQ) index.

$$\mathrm{CDI} = (C \times \mathrm{DI}) / (\mathrm{BW}) \ldots\ldots (1)$$

Where CDI is the human exposure risk through ingestion pathway (mg/kg-day)$^{-1}$, C is the concentration of heavy metal in drinking water in mg L^{-1}, DI average daily intake rate (2.0 L/day-person)$^{-1}$ and BW is the body weight (15 kg and 72 kg for child and adult respectively). The non-carcinogenic hazard was evaluated by the hazard quotient (HQ) by equation 2.

$$\mathrm{HQ} = \mathrm{CDI} / \mathrm{RfD} \ldots\ldots (2)$$

Where RfD is the oral reference dose (mg/kg-day)$^{-1}$ for individual heavy metal (Table 1) that humans can be exposed to, and for this study were obtained from USEPA. HQ is calculated for each heavy metal and the sum of HQ of all metals is used to determine the non-carcinogenic risk, hazard index (HI). If $\mathrm{HQ} < 1$, it is considered safe for human health, $1 < \mathrm{HQ} \leq 5$ is low risk, $5 < \mathrm{HQ} \leq 10$ is medium risk and $\mathrm{HQ} > 10$ is regarded as high risk.

Table 1: Oral reference dose (RfD) and oral slope factor (SF) toxicity responses to heavy metals

Metals	Oral RfD^{a} (mg/kg-day)$^{-1}$	Oral SF^{b} (mg/kg-day)$^{-1}$
Cd	5.0×10^{-4}	3.8×10^{-1}
Cr	3.0×10^{-3}	5.0×10^{-1}
Pb	3.6×10^{-3}	9.0×10^{-3}
Zn	3.0×10^{-1}	ND
Ni	2.0×10^{-2}	1.7

^{a}US EPA IRIS (2011), ^{b}USEPA (2015) and ND - not determined

Additionally, the study evaluated the risk of cancer. The pollutant intake and a toxicity index called the slope factor (SF) (see Table 1) are used in this risk characterization to determine the possible cancer risk. The incremental likelihood of a person acquiring cancer during their lifetime as a result of exposure to a possible carcinogen was used to assess the cancer risk

(Equation 3).

$$\text{Target Carcinogenic Risk (TCR)} = \mathrm{SF} \times \mathrm{CDI} \ldots\ldots (3)$$

Where the slope factor (SF) converts the chronic daily intake (CDI) to the incremental risk of individual developing cancer.

RESULTS AND DISCUSSION

Elemental Analysis

By comparing experimental and certified values ($p < 0.05$) using water Certified Reference Materials (CRM), the analytical procedure's accuracy and precision were validated (Table 2). The range of recoveries was 99.8% to 101%.

Table 2: Certified Reference Materials (CRM) are used to validate analytical methods.

Certified Reference Materials	Elements	Measured (μg g^{-1})	Certified (μg g^{-1})	Recovery (%)
Water GBW08608	Cd	0.104 ± 0.002	0.104 ± 0.002	100.0
	Cr	0.509 ± 0.05	0.51 ± 0.01	99.8
	Cu	1.029 ± 0.01	1.03 ± 0.01	99.9
	Ni	0.516 ± 0.003	0.517 ± 0.006	99.8
	Pb	1.04 ± 0.08	1.03 ± 0.02	101.0
	Zn	5.14 ± 0.01	5.15 ± 0.05	99.8

*Values mean ± standard deviation, n = 3, 95% confidence interval

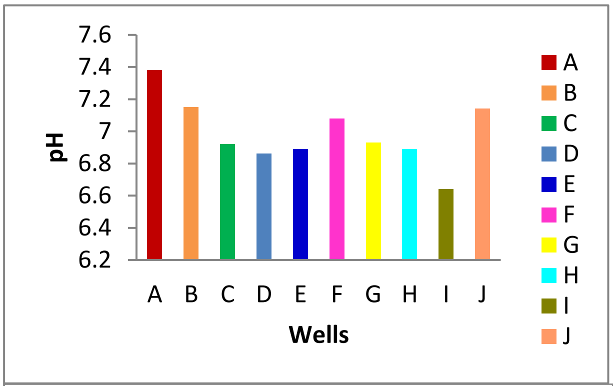
Physico-Chemical Parameters

The results of the physicochemical examination performed on well water samples are summarized in Table 3. As shown in Figure 3, the pH values ranged from 6.64 to 7.38, indicating that the samples are primarily neutral and comply with WHO and NDWQS standards. A pH of less than 6.5 can make well water caustic and soft, which could lead to an increase in the quantities of harmful metals.

Table 3: Samples of well water's physico-chemical status

Well	pH	DO (mg L^{-1})	Temp (^{0}C)	Cond. (μs cm^{-1})	TDS (mg L^{-1})	TH (mg L^{-1})	Alk. (mg L^{-1})
A	7.38 ± 0.3^{a}	1.35 ± 0.1^{a}	29.2 ± 0.3^{a}	0.512 ± 0.02^{a}	1.20 ± 0.01^{a}	128 ± 2.1^{a}	0.17 ± 0.01^{a}
B	7.15 ± 0.7^{a}	1.4 ± 0.1^{a}	27.9 ± 1.6^{a}	0.515 ± 0.01^{a}	0.99 ± 0.02^{a}	118 ± 2.8^{a}	0.12 ± 0.01^{a}
C	6.92 ± 0.5^{a}	1.6 ± 0.1^{a}	28.0 ± 1.4^{a}	0.876 ± 0.01^{ab}	1.20 ± 0.01^{a}	**151** ± 5.0^{ab}	0.07 ± 0.01^{ab}
D	6.86 ± 0.4^{a}	1.45 ± 0.1^{a}	27.4 ± 2.3^{a}	0.647 ± 0.01^{a}	1.60 ± 0.02^{a}	54 ± 5.1^{c}	0.08 ± 0.02^{ab}
E	6.89 ± 0.8^{a}	1.55 ± 0.1^{a}	27.7 ± 1.9^{a}	1.139 ± 0.01^{b}	1.20 ± 0.01^{a}	81 ± 3.5^{c}	0.17 ± 0.01^{a}
F	7.08 ± 0.8^{a}	1.05 ± 0.1^{ab}	27.6 ± 1.9^{a}	0.361 ± 0.01^{a}	1.40 ± 0.02^{a}	59 ± 2.1^{c}	0.10 ± 0.01^{a}
G	6.93 ± 0.7^{a}	1.55 ± 0.1^{a}	27.2 ± 2.6^{a}	0.816 ± 0.01^{b}	1.60 ± 0.01^{a}	69 ± 7.1^{c}	0.10 ± 0.01^{a}
H	6.89 ± 0.5^{a}	1.55 ± 0.1^{a}	27.8 ± 1.7^{a}	0.477 ± 0.01^{a}	1.0 ± 0.01^{a}	25 ± 3.5^{d}	0.11 ± 0.01^{a}
I	6.64 ± 0.5^{a}	1.65 ± 0.1^{a}	28.0 ± 1.4^{a}	0.933 ± 0.01^{ab}	1.40 ± 0.02^{a}	44 ± 5.7^{c}	0.18 ± 0.01^{a}
J	7.14 ± 0.9^{a}	1.7 ± 0.1^{a}	27.7 ± 1.8^{a}	0.618 ± 0.01^{a}	1.40 ± 0.01^{a}	46 ± 2.8^{c}	0.07 ± 0.02^{ab}
NSDWQ	6.50-8.50	N/S	N/S	1000	500	N/S	N/S
WHO	6.50-8.50	6.0	N/S	25.0	500	100-150	<120

Figure 3 illustrates the distribution of dissolved oxygen (DO), which falls between 1.05 and 1.65 mg L^{-1} and is within WHO guidelines, as well as the little temperature variance in wells A through J between 27.2 and 29.2°C. Significant variance was seen in the conductivity measurements between the wells, with a range of 0.361 to 1.139 μs cm^{-1}. With a small range of 0.99 to 1.60 mg L^{-1}, all total dissolved solids (TDS) were within the allowable limit of 1000 mg L^{-1}. Total Hardness (TH) values in the samples varied significantly, ranging from 25 to 151 mg L^{-1}. While most TH measurements were within allowable ranges, Well C revealed TH levels at 154 mg L^{-1}, significantly above the limit. There were natural salts present in the water because to its alkalinity, which ranged from 0.07 to 0.17 mg L^{-1}. The bulk of physicochemical features had mean values that were not statistically significantly different ($p > 0.05$), with the exception of TH (Table 3), suggesting a common source origin. Although Well C's physicochemical characteristics were marginally elevated (ranging from 147 to 154 mg L^{-1}, with a mean of 151 ± 5.0 mg L^{-1}), they nonetheless met the WHO and NSDWQ drinking water criteria. You can therefore probably drink water from these wells without worrying about health risks.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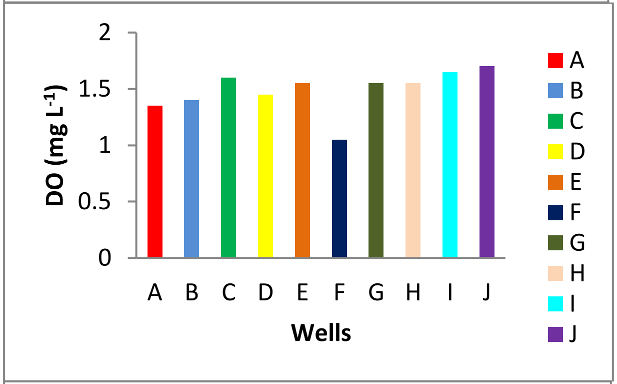
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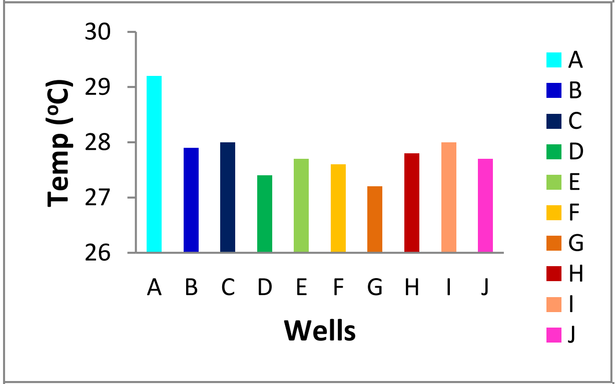
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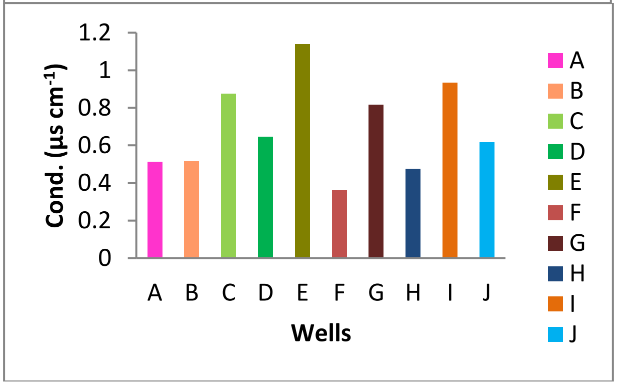
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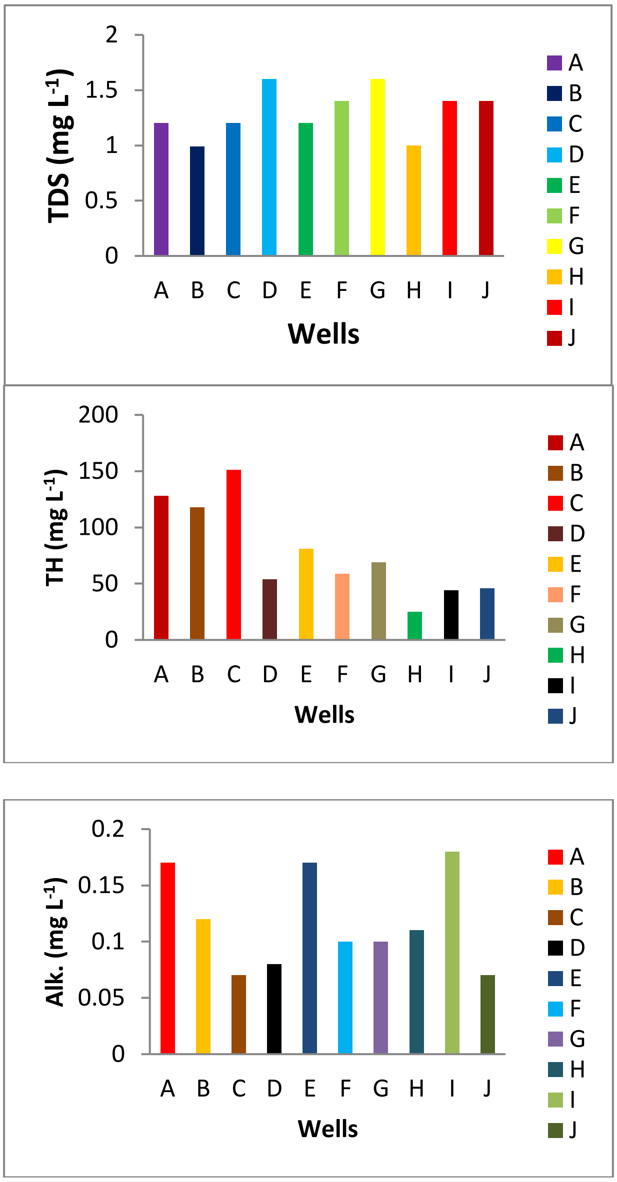

Figure 3: Distribution of Physicochemical Parameters in Studied well water Samples

The variables that are measured include temperature, electrical conductivity, alkalinity, total hardness, total dissolved solute, and dissolved oxygen. All values are displayed as (mean ± SD) n = 3. N/S = Not specified, Nigerian Standard for Drinking Water Quality, 2007; World Health Organization, 2011. Several superscript letters inside the columns represent the mean separations using Tukey's post-hoc testing at the 5% level.

Table 4 displays the levels of Cd, Cr, Ni and Zn in well water samples. The heavy metals found in the well water are listed below in decreasing order of concentration: Zn > Cr > Cd > Ni. The undetectable range for zinc and nickel levels was 0.04 mg L^{-1} and 0.16 mg L^{-1}, respectively. Lead was not present in any of the samples.

Except for E, F, and I, 70% of the well water samples had Cd levels higher than the 0.005 mg L-1 WHO recommended drinking water limit. In a similar vein, 50% of the samples had Ni levels higher than the WHO threshold. Drinking water from these sources may cause certain heavy metals to progressively build up in the body. Increased Ni levels have been connected to a variety of tumors in animals who live close to steel firms, and research indicates that Cd buildup in the kidneys may affect their ability to function.

Due to Pb concentrations falling below the detection limit, they were not included in Table 4.

Table 4: Comparison of Well Sample Heavy Metal Concentrations with WHO Guidelines

	Ni	Zn	Cr	Cd
A	0.02 ± 0.01^{a}	ND	ND	**0.18** ± 0.01^{a}
B	ND	0.01 ± 0.005^{a}	0.03 ± 0.001^{a}	**0.12** ± 0.01^{a}
C	**0.08** ± 0.02^{b}	0.01 ± 0.001^{a}	ND	**0.13** ± 0.001^{a}
D	ND	ND	ND	**0.08** ± 0.001^{a}
E	0.02 ± 0.01^{a}	0.04 ± 0.01^{a}	0.02 ± 0.001^{a}	ND
F	0.01 ± 0.006^{a}	ND	ND	ND
G	**0.11** ± 0.02^{b}	0.04 ± 0.01^{a}	ND	**0.09** ± 0.002^{a}
H	**0.15** ± 0.05^{b}	ND	0.01 ± 0.005^{a}	**0.1** ± 0.01^{a}
I	**0.16** ± 0.01^{b}	ND	ND	ND
J	**0.06** ± 0.02$^{a\ b}$	ND	0.01 ± 0.005^{a}	**0.17** ± 0.01^{a}
WHO	0.02	5.00	0.05	0.005

Values are in mg L^{-1} (Mean ± SD) and WHO (2017).

Human Health Risk Assessment

Hazard Quotient (HQ)

Heavy metal contamination of well water is a major problem since it poses a hazard to public health and the environment in both rural and urban regions. As a result, it is critical to evaluate the possible health concerns connected to drinking water from possibly contaminated wells.

Estimates of non-carcinogenic risk (HQ) for Cd, Cr, Ni, Pb, and Zn in two age groups are shown in Table 5. With the exception of wells E, F, and I, most well water samples for Cd had HQ values >1, but the majority of heavy metals for both adults and children had HQ values < 1. This suggests an intolerable risk to non-cancerous health, particularly in youngsters. The greatest Cd HQ levels were found in Well A, at 48.0 for adults and 10.0 for children.

The Hazard Index (HI) identified Cd as the primary contaminant in well samples, contributing 97% of the HI for children. For adults, Cd and Ni were the main contaminants, accounting for 46.9% and 52.4% of the HI, respectively. Similar findings have been reported in water sources near steel company-contaminated areas.

These results raise the possibility that drinking well water from the area could expose locals to heavy metals, with children being especially at risk due to physiological variations. For all age groups and water sources, the HI values were greater than 1, indicating an intolerable risk of non-carcinogenic health impacts for the local populace. Table 5 shows the total toxic risk (HI) and the non-carcinogenic risk (HQ) from the health index.

Group	**HQ**	Ni	Zn	Cr	Cd	**HI**
Child	A	0.1	0	0	48.0	**48.1**
	B	0	0.004	1.3	32.0	**33.3**
	C	0.5	0.004	0	34.7	**35.2**
	D	0	0	0	21.3	**21.3**
	E	0.1	0.02	0.9	0	1.0
	F	0.1	0	0	0	0.1
	G	0.7	0.02	0	24.0	**24.8**
	H	1.0	0	0.4	26.7	**28.1**
	I	1.1	0	0	0	1.1
	J	0.4	0	0.4	45.3	**46.2**
Adult	A	0.03	0	0	10.0	**10.0**
	B	0	0.001	0.3	6.7	**7.0**
	C	0.1	0.001	0	7.2	**7.3**
	D	0	0	0	4.4	**4.4**
	E	0.03	0.004	0.185	0	0.2
	F	0.01	0	0	0	0.01
	G	0.2	0.004	0	5	**5.2**
	H	0.2	0	0.093	5.6	**5.9**
	I	53.3	0	0	0	**53.3**
	J	0.1	0	0.1	9.4	**9.6**

Table 6 presents the Total Cancer Risk (TCR) values for Ni, Cr, and Cd, ranging from 0 to 18.2 for children and 0 to 90 for adults. The order of TCR values differed between children (Cd > Ni > Cr) and adults (Ni > Cd > Cr).

Both adults and children exceeded the USEPA's recommended safe limit for cancer risk (1 × 10-4) based on these elemental TCR values, indicating a potential cancer risk from exposure to these elements. The cumulative risk (∑TCR) suggests that adults face a higher cancer risk compared to children.

In children, Cd was the primary contributor to total carcinogenic risks at 91.1%, followed by Ni (7.2%) and Cr (1.6%). Conversely, in adults, Ni was the predominant contributor at 83.1%, followed by Cd (16.6%) and Cr (0.3%).

Table 6: Elements in Well Water Samples and Their Target Carcinogenic Risk (TCR)

Age range	Risk of cancer (TCR)				∑TCR
		Ni	Cr	Cd	
Child	A	0.23	0	18.2	18.4
	B	0	0.67	12.2	12.9
	C	0.91	0	13.2	14.1
	D	0	0	8.11	8.11
	E	0.23	0.44	0	0.67
	F	0.11	0	0	0.11
	G	1.25	0	9.12	10.4
	H	1.7	0.22	10.1	12.0
	I	1.81	0	0	1.81
	J	0.68	0.22	17.2	18.1
Adult	A	0.05	0	3.8	3.85
	B	0	0.14	2.53	2.67
	C	0.19	0	2.74	2.93
	D	0	0	1.69	1.69
	E	0.05	0.09	0	0.14
	F	0.02	0	0	0.02
	G	0.26	0	1.9	2.16
	H	0.35	0.05	2.11	2.51
	I	90.7	0	0	90.7
	J	0.14	0.05	3.59	3.78

A-J-Well water

CONCLUSION

The amounts of the heavy metals under investigation in samples of well water in the Prism steel rolling mill region were as follows: Cd > Ni > Zn > Cr > Pb. Significantly elevated amounts of Cd and Ni, which are frequently linked to steel companies, were found in the study, indicating a possible pollution risk that could be causing heavy metal contamination in nearby well water.

The study's health risk assessment data, which focused on well water use, showed that there was an intolerable non-carcinogenic health risk for the local population. These results highlight the significance of educating and alerting the local populations surrounding the Prism steel rolling mill about the safety of drinking well water. Such educational programs could lessen the risk of harmful health consequences from consuming possibly tainted well water.

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