

FULL PAPER

Assessment of Trace Elements, Heavy Metals, and Physicochemical Parameters in Drinking Water Sources from Jebel Mun, Western Darfur, Sudan

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Abstract

This study investigated the physicochemical characteristics and the presence of trace and heavy metals in drinking water sources from the Jebel Mun area, Elgeneina, and Western Sudan. Physicochemical characteristics, such as pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS), were measured using a Hach model HQ40d multimeter. The results revealed that the pH levels in water samples ranged from 6.50 to 7.80. All the samples achieved were within the limits as per Sudanese Standard and Metrology (SSMO) and WHO guidelines (6.50 to 8.50). The EC level ranged from 201.0 to 1235 $\mu\text{S}/\text{cm}$. Overall, samples meet the European Union standard (EU) 2500 $\mu\text{S}/\text{cm}$ at 20°C. TDS levels ranged from 134.7 to 827.5 mg/L; all samples were within the permissible recommended limits as per SSMO, which is 1000 mg/L. Metals were analyzed by using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES -PQ 9000). The result was compared against the Sudanese Standard Metrology Organization (SSMO), the Environmental Protection Agency (EPA), the Agency for Toxic Substances and Disease Registry (ATSDR), the European Union (EU), and the World Health Organization (WHO)—the concentration of lithium within the acceptable limits in all samples, according to Wānghammar 2017. Limit as 0.65 to 3.10 mg/L. All heavy metals, including copper, molybdenum, nickel, zinc, selenium, and chromium, were within acceptable WHO and SSMO limits. No arsenic or antimony was detected. Iron exceeded limits in 11 sites, cadmium in 9 sites, manganese in 4 sites, and barium in 2 sites. Lead surpassed permissible levels in three sites per SSMO and WHO. Concentrations of detected heavy metals are downward in the following order: $\text{Cd} > \text{Fe} > \text{Al} > \text{Mn} > \text{Se} > \text{Mo} > \text{Ba} > \text{Pb}$.

Keywords: trace elements; concentration; pollution; metal toxicity.

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Introduction

Heavy metals are the leading cause of soil and water contamination. The increasing levels of heavy metals in the natural environment have raised serious concerns, despite water being an essential natural resource. Heavy metals are often classified as periodic table elements with a density of more than 4 to 5 g/cm³. Metals like copper, selenium, and zinc play a crucial role as trace elements in the human body's metabolic processes. However, when they are present in excessive amounts, they can become poisonous. Arsenic, cadmium, chromium, lead, and molybdenum directly harm the human body, potentially leading to acute or chronic disorders (Akeel, 2013; Sherene, 2010; Hassaan et al., 2016). The majority of

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naturally present drinking water substances consist of inorganic and organic compounds. Exposure to the mentioned chemicals through contaminated drinking water can have significant health consequences. The World Health Organization (WHO, 2011) and a 2007 study by Terrence Thompson et al. support this information. The primary origins of heavy metals include igneous or sedimentary rock, weathering, soil erosion, and interactions between water and rock. The occurrence of heavy metals is contingent upon the geological composition, climatic conditions, and weather patterns (Cluj-Napoca, 2015). Anthropogenic sources encompass various activities, such as home sewage, industrial wastewater, mining, the use of advanced agricultural chemicals (including fertilizers, insecticides, fungicides, and herbicides), and urbanization development (Paul, 2016; Kang et al., 2018; Asaduzzaman, 2017). Extended exposure to heavy metals in potable water can compromise the functionality of the nervous system, lungs, kidneys, and liver. Furthermore, it may stem from vascular complications, dermatological imperfections, and reproductive disorders. Research conducted by Chaitali V. Mohod (2013), Jaishankar et al. (2014), and Cobbina et al. 2015) indicates that exposure to specific elements, such as arsenic, barium, cadmium, chromium, mercury, molybdenum, nickel, and lead, is associated with an increased risk of developing cancer.

2. Experimental Procedures

2.1. Description of the study zone

Jebel Mun is situated in the northeastern area of Elgeneina in western Darfur, Sudan. It is roughly 100 km away from Elgeneina. Jebel Mun is located at the international boundary between Sudan and Chad. In the late 1970s, aerial geological studies revealed the presence of an area with a high radiation background. The presence of intrusive rocks, such as granite and syenite, primarily defines the area's geological composition. These rocks are notable for their association with ring dikes and dike swarms, as well as the presence of Nubian sandstone sediment (A.K.S. et al., 2002).

Methodology for a project

This study evaluated the criteria for drinking water quality in eleven rural locations, including both surface and subsurface water sources, in 2018. The chemical characteristics include lithium, sodium, magnesium, phosphorus, and potassium. The study aimed to discover heavy and trace metals, including aluminum, vanadium, chromium, copper, molybdenum, nickel, selenium, zinc, arsenic, antimony, cadmium, manganese, and barium. These metals were compared to the SSMO and WHO standards.

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2.2. Collection of samples

The samples were collected from surface and subsurface water sources at various locations in the Jebel Mun region. We collected all samples using high-density polyethylene bottles with a capacity of 1000 ml. To prepare the water samples for elemental analysis, we rinsed each container twice with distilled water and then treated them with two milliliters of strong nitric acid 75%. According to EPA Procedure 200.07, it is necessary to test and quantify the pH of the water immediately before adding acid to ensure an accurate evaluation of the sample. According to the EPA (2001a), we measured and documented the site's pH, EC, and TDS, which can be stored for up to six months before analysis.

2.3 Analytical methodology

Before measuring the physicochemical parameters of pH, EC, and TDS, the pH model of the Wagtech portable meter was adjusted using standards for buffer solutions with pH values of 4, 7, and 10. And the EC multi-meter model Hach-HQ40d. The Hach multi-meter was calibrated using a sodium chloride standard of 1413 $\mu\text{S}/\text{cm}$. The Electrical Conductivity (EC) and Total dissolved solids were measured in the field. (TDS), was calculated from EC ($\text{TDS} \approx k \cdot \text{EC}$, where $k \sim 0.7$ based on values). Results for the samples were recorded in the field before the samples were acidified. The ICP-OES model PQ 9000 was used to analyze 21 elements from each sample. Every water sample underwent filtration using Watt man filter paper 45 milmicron before being put into a 100-ml volumetric flask. The Euro-Normal standard reference material was utilized. The argon carrier gas transported the fine mist created by atomizing the water sample solutions to the plasma torch. The grating spectrometer disperses the spectra and measures the concentrations of the line spectra at exact wavelength starting the elements listed are 670.784, 279.079, 214.914, 766.491, 315.887, 308.215, 292.402, 205.552, 257.610, 259.940, 231.604, 324.754, 213.856, 193.759, 196.090, 203.844, 226.502, 206.833, 493.409 and 220.353nm, for lithium, sodium, magnesium, phosphorus, potassium, calcium aluminum, vanadium, chromium, manganese, iron, nickel, copper, zinc, arsenic, selenium, molybdenum, cadmium, antimony, barium and lead. Ultimately, the computer system is responsible for processing and regulating the photocurrents generated by the photosensitive device. This data is based on the 2015 US EPA 200.7 standard. The following section introduces the configuration of samples and the instrument's working settings.

Sample introduction setup

Instrument: ICP OES Plasma Quanta 9000 – Analytic Jena

Normal mode (ml/min): 1.00

Wash time (s): 15

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Sample Pump Flow: 1.0 mL/min

Pump Tubing: tube diameter (mm): 0.762mm-black/black

Instrument operating conditions

Argon gas: (99.99 purity or more)

Auxiliary Gas (L/min): 0.5

Plasma Power (W): 1200

Plasma Gas (L/min): 12.00

Flow rate: 0.5 L/min

Nebulizer: pneumatic

Spray Chamber: cyclonic glass 3 channels peristaltic pump

Torch Injector Diameter: 2.5 mm.

Quality Control Sample (QCS)

The quality control for Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) in water samples typically aims for recovery rates between 75% and 85%. This range is crucial for ensuring the accuracy and reliability of analytical results. Several studies highlight methods and conditions that can effectively achieve these recovery rates. A solution of technical analysts at established concentrations is utilised to strengthen a small amount of LRB or sample matrix. The QCS is derived from a source outside of the testing facility and is distinct from the origin of calibration standards. It is used to test the functionality of a laboratory or instrument. (EPA, 2007).

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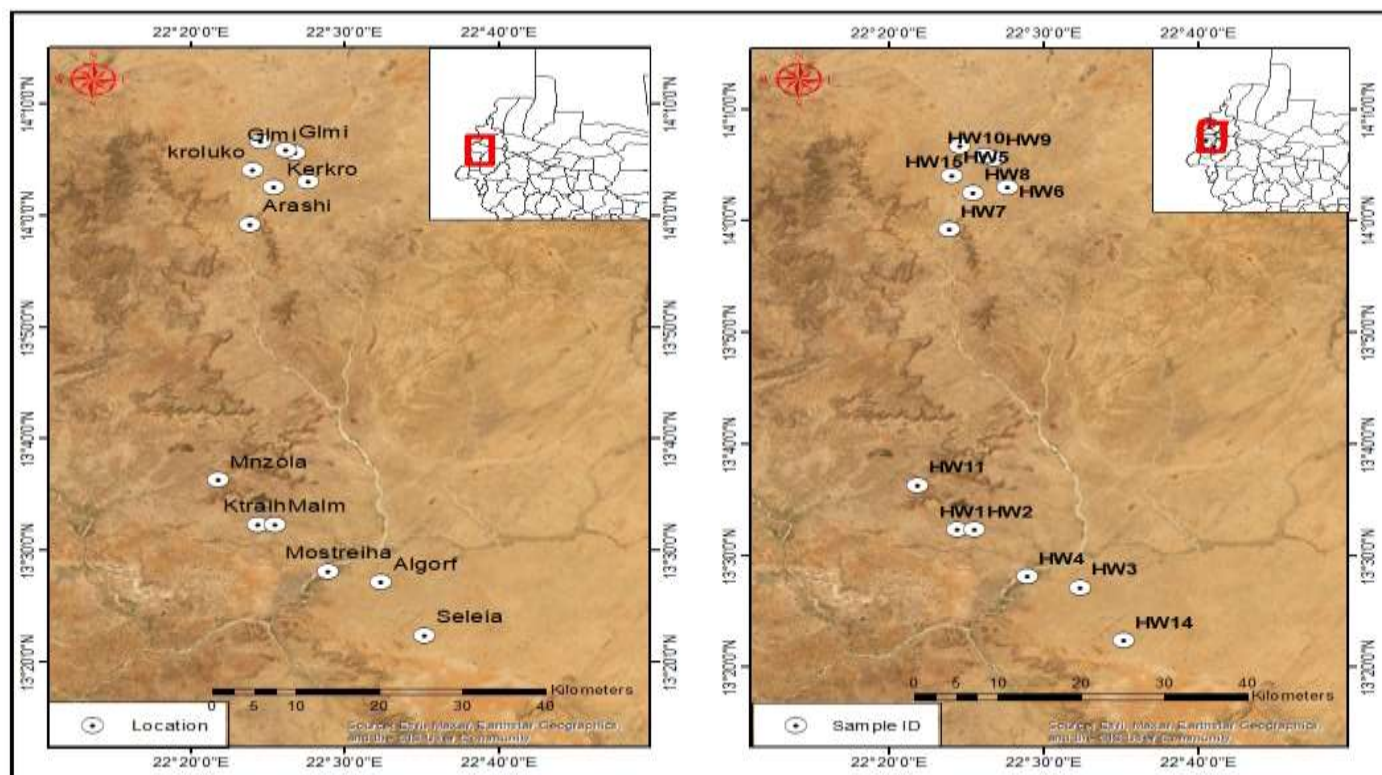
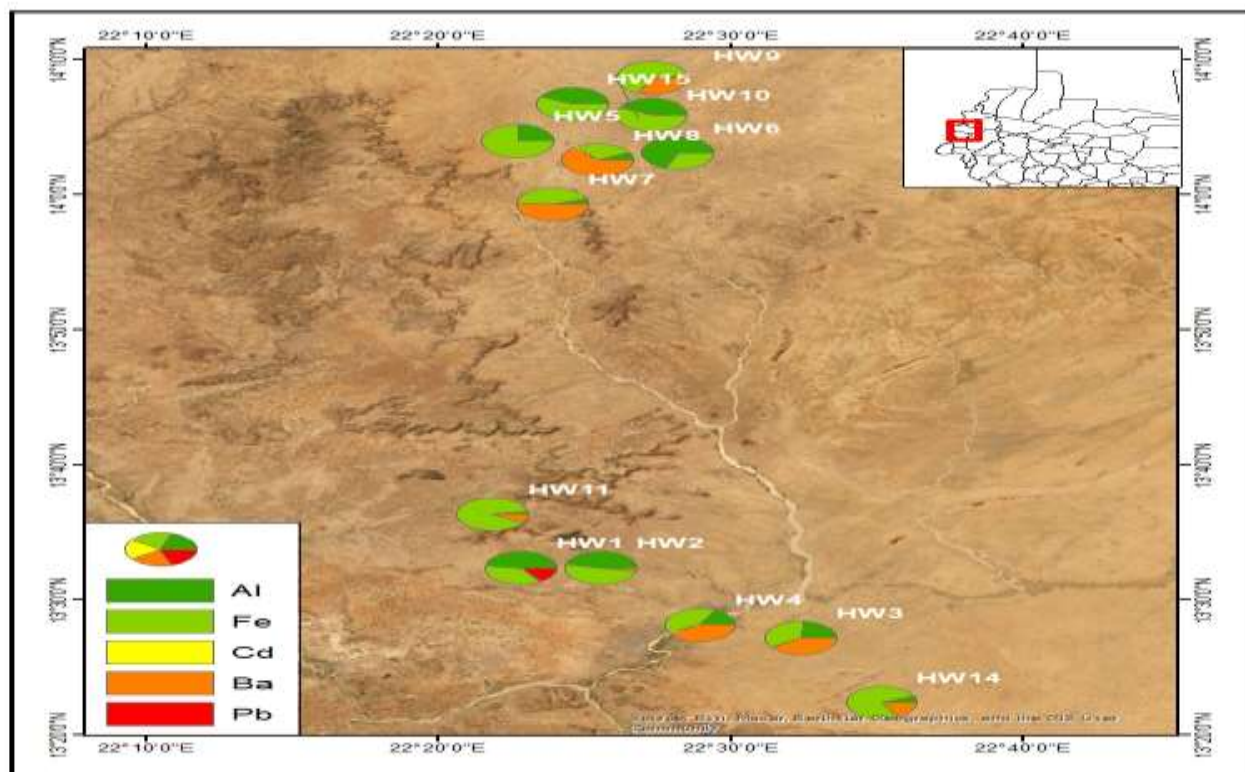


Figure 1: Location of Jebel Mun Area ARGIS map and sampling sites



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Figure 2: map sampology of relative abundance of trace and heavy metals in studied areas.



Figure 3: Hydrogeology google map of valleys in Jebel Mum area.

3 Results and Dissection

3.1 Overview of Physicochemical Parameters

The physicochemical properties of underground water, including pH, EC, and TDS, were determined on-site, and the findings are presented in Table 1. The pH level is a crucial chemical parameter for aquatic species since any alterations in pH can significantly impact the properties of water chemistry (Ojija, 2015). Consequently, an elevated pH level in drinking water renders it unpalatable to the consumer. The pH readings of the water samples ranged from 6.50 to 7.80, indicating that all samples fell within the acceptable limits set by SSMO and WHO, which are between 6.50 and 8.50. Conductivity is crucial in assessing water quality since it indicates variations in inorganic solids. It is particularly valuable for identifying issues related to scaling. The electrical conductivity (EC) of all water samples ranged from 201.0 to 1235 $\mu\text{S}/\text{cm}$, which is below the European Commission (EC) norm of 2500 $\mu\text{S}/\text{cm}$ at 20°C (WHO-EU, 2017). When the TDS levels in drinking water exceed 500 mg/L, it becomes highly unpalatable to consumers. It can have adverse health effects on individuals with conditions such as severe hypertension, diabetes, and renal dialysis (V Mood and Dhote, 2013). The TDS level in the entire water samples ranged from 134.7 to 827.5 mg/L Based on the Sudanese Standard and Metrology

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Organization (SSMO), it was found that all the obtained samples had concentrations lower than their 1000 mg/L limit. All the samples are within the recommended bounds.

Table 1: Level of some physicochemical characteristics for drinking water samples from Jebel Mun

Sample ID	Water Source and Location		Geographic position		Physical properties		
Sample ID	Water Sor	Location	N	E	pH	EC	TDS
HW1	OHDW	Ktraih	13.53.426	22.40.309	6.5	239	160.1
HW2	OHDW	Malm	13.53.426	22.40.823	6.8	207	183.7
HW3	OHDW	Algorf	13.45.957	22.50.863	6.8	207	183.7
HW4	ODW	Mostreiha	13.46.498	22.49.004	7.30	633	224.1
HW5	SP	Kroluko	14.07.142	22.40.652	7.2	833	558.1
HW6	OHDW	Kerkro	14.05.084	22.44.376	7.4	922	617.7
HW7	H.P	Arashi	14.0.142	22.40.652	7.1	832	557.4
HW8	H.P	Kerkro2	14.05.119	22.44.380	7.3	997	668
HW9	H.P	Gimi	14.09.368	22.44.675	7.2	1235	827.5
HW10	H.P	Gimi	14.09.405	22.44.675	6.5	588	394
HW11	OHDW	Mnzola	14.07.936	22.44.726	7.5	320	214.4
HW12	H.P	Shaitan	NR	NR	7.8	660	442.2
HW13	H.P	Shaitan	NR	NR	7.2	1235	827.5
HW14	H.P	Seleia	13.59.972	22.37.169	7.5	712	477
HW15	ODW	Seleia Valley	13.58.934	22.37.398	7.7	201	134.7
HW16	H.P	Falco	14.10.807	22.41.651	7.2	715	479.1
MIN		-	-	-	6.5	201	141
MAX					7.8	1235	865
MEAN					7.18	349	459
WHO Standard and EU					6.5-8.5	2500	500
SSMO					6.5-8.5	NGVS	1000
EPA					6.5-8.5	NGVS	500

Note:
 Water sor : Water sources
 NR: Not Recorded
 OHDW: Open Hand Dug Well, ODW= Open Dug Well, SP=Submersible Pump
 HP : Hand Pump. = Hand Pump
 WHO = World Health Organization,
 SSMO = Sudanese's Standard and Metrology, NGVS = Not Guideline Value Set
 Fig : Figures

3.2 Parameters for assessing the quality of water in terms of its chemical composition.

Chemical water quality parameters are often assessed by comparing the chemical properties of a water sample with established water quality objectives or guidelines (Al-Obaidy, 2015). The chemical water quality characteristics include lithium, sodium, calcium, magnesium, phosphorus, and potassium, as indicated in Table 2.

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Li

Several ecological studies have examined the correlation between concentrations of lithium in public drinking water and the rate of suicide (Klinger, 2015). The United States reports that the daily intake of lithium varies from 650 to 3100 µg (Wänghammar, 2017). Convert these results to milligram per liter (mg/L), ranging from 0.65 to 3.1 mg/L. Lithium was detected in all samples at levels ranging from 0.001 to 0.199 mg/L. According to the daily intake, all the samples are lower than the values.

Na

Sodium is seen as detrimental to individuals with heart disease and high blood pressure, as stated by (SH Mohamed, 2014). The research region had a salt content ranging from 0.646 to 8.055 mg/L. All samples indicated that the sodium concentration fell below the acceptable limits set by SSMO and WHO, which are 250 mg/L and 200 mg/L for drinking water, respectively.

Mg

Various minerals in groundwater contain magnesium, one of the most prevalent elements in the Earth's crust (Hall, 2016). According to the WHO guidelines for drinking water, the highest allowable amount of magnesium is 50 mg/L (Duruibe, J. O., Ogwuegbu, M. O., & Egwurugwu, 2007). Magnesium contents in the water specimens ranged from 4.220 to 44.32 mg/L, which was below the permitted level.

P

Natural sources of phosphorus are mainly the weathering of phosphorus-bearing rocks and the decomposition of organic matter. The EU acceptable limit for phosphorus is 5 mg/L (Chapman, 1996). The concentrations of phosphorus ranged from 0.002 to 8813 mg/L; however, the high range of phosphorus found in the study area is attributed to the weathering conditions of the geological formation. Additionally, the high phosphorus levels could be attributed to the use of fertilizers; the highest value in the study was recorded at 8813 mg/L in sample ID (HW6). All samples exceeded the limit of 5 mg/L of the EU standard except sample ID (HW1). However, we suggest that high concentrations of phosphorus pollution, resulting from fertilizer leaching into soil and water bodies during rainfall and irrigation, contribute to elevated levels in groundwater wells, in addition to intensive agricultural activity in the southern zone. In Table 2. Figure 4 illustrates the concentration of phosphorus in water samples in comparison to the EU standard.

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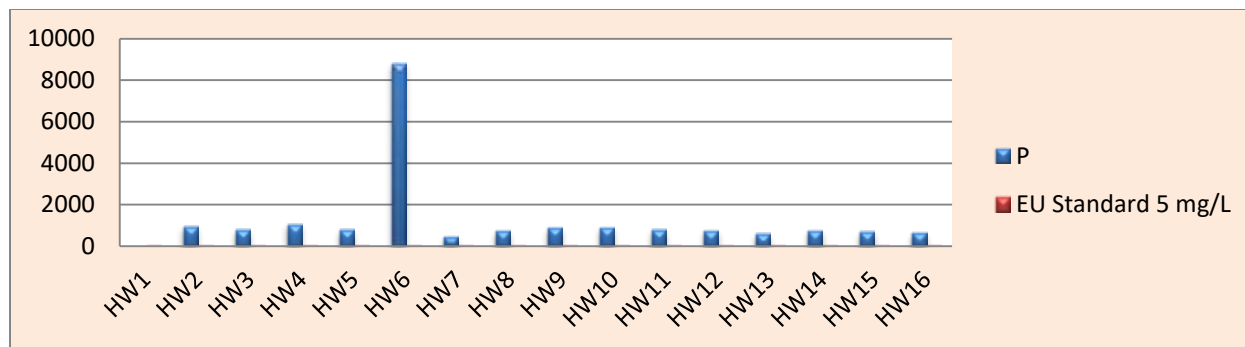


Fig 4: level of phosphorus in water samples compared to EU standard.

K

Feldspar, some micas, and clay-based minerals provide the principal natural sources of potassium in groundwater (Venkateswarlu, 2014). The potassium concentrations in the water samples range from 1.10 to 37 mg/L. The EU has suggested a maximum limit of 12 mg/L/L. The maximum concentration, 37 mg/L, was observed in sample ID (HW10).

Ca

Calcium is a vital component of human metabolism. Calcium is a crucial component in forming skeletal structures, such as bones and teeth, in animals. Compared to other metals beneficial for biological purposes, the allowable threshold for this metal is relatively elevated. It is set at 50 mg/L in drinking water (Duruibe, J.O., Ogwuegbu, et al., 2007). The calcium ion concentration in water. Exhibiting site are (HW1, HW2, HW3, HW5, HW6, HW7, HW8, HW9, HW10, HW13, HW14, HW16)

Table2. Chemical water quality parameter's concentrations (mg/L)

Sample ID	Location	Water .S	Elements concentration mg/L					
			Li	Na	Mg	P	K	Ca
HW1	Ktraih	OHDW	0.128	4.710	19.39	0.002	2.057	71.08
HW2	Malm	OHDW	0.004	2.731	15.17	961.2	4.6530	51.20
HW3	Algorf	OHDW	0.013	4.710	12.36	788.3	2.765	52.60
HW4	Mostreiha	ODW	0.002	4.731	11.10	1067	2.429	47.59
HW5	Arashi	SP	0.038	4.461	35.26	781.3	2.131	84.40
HW6	Kroluko	OHDW	0.041	3.666	32.65	8813	3.440	76.50
HW7	Kerkro	HP	0.139	5.032	20.17	457.9	1.850	73.99
HW8	Kerkro	HP	0.028	3.047	31.08	739.5	4.242	64.41
HW9	Glmi	HP	0.001	8.055	44.32	903.5	4.199	110.2
HW10	Glmi	HP	0.006	2.914	37.19	911.7	37.75	126.6

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HW11	Mnzola	OHDW	0.199	4.614	28.35	790.5	1.996	102.1
HW12	Shaitan	HP	0.003	1.395	6.516	744.0	7.540	24.15
HW13	Shaitan	HP	0.096	6.037	35.16	599.7	2.948	104.4
HW14	Seliea Loc	HP	0.067	4.120	19.88	743.9	2.281	64.51
HW15	Seliea Val	ODW	0.002	0.646	4.220	694.2	7.305	16.9
HW16	Falko	HP	0.005	2.399	26.28	652.4	2.499	72.84
Min			0.001	0.646	4.220	0.002	1.850	16.90
Max			0.199	8.055	44.32	8813	37.75	126.6
Aver			0.051	3.954	23.69	1228	5.630	71.47
S.D			0.061	1.792	11.88	2037	8.745	29.91
WHO								
EU								
EPA								
SSMO								
ATSDR								

ATSDR= Agency for Toxic Substances and Disease Registry, EU = European Union, EPA =Environmental Protection Agency, SSMO=Sudanese 'Standard and Metrology organization , NGVS = No Guideline Value set,

Locality, Seleia vall =
Source water Type
(Open Hand Dug Well (OHDW), Hand Pump (HP))

Table 3: level of Trace and heavy metals in drinking water samples from Jebel Mun areas (mg/L)

S.ID	Al	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Pb
HW1	0.167	0.041	0.001	0.011	0.126	0.001	0.001	0.078	0.002	0.004	0.010	0.001	0.002	0.004	0.052
HW2	4.117	0.049	0.039	1.125	4.538	0.009	0.477	0.278	0.002	0.023	0.001	0.001	0.002	0.271	0.002
HW3	0.101	0.035	0.030	0.072	0.149	0.001	0.391	0.220	0.002	0.016	0.001	0.005	0.001	0.169	0.001
HW4	0.063	0.045	0.040	0.073	0.134	0.001	0.558	0.300	0.002	0.002	0.001	0.007	0.003	0.139	0.001
HW5	0.127	0.086	0.027	0.007	0.394	0.001	0.407	0.452	0.001	0.005	0.004	0.005	0.001	0.004	0.003
HW6	0.879	0.086	0.027	0.001	0.395	0.001	0.407	0.452	0.002	0.006	0.004	0.005	0.003	0.005	0.003
HW7	0.037	0.001	0.014	0.010	0.269	0.002	0.211	0.266	0.003	0.004	0.007	0.003	0.001	0.101	0.002
HW8	0.034	0.101	0.025	0.002	0.118	0.001	0.399	0.227	0.001	0.003	0.002	0.005	0.004	0.317	0.001
HW9	0.088	0.110	0.001	0.001	2.355	0.005	0.507	1.344	0.001	0.008	0.005	0.007	0.003	0.273	0.004
HW10	3.207	0.111	0.034	1.799	4.3090	0.005	0.460	0.290	0.002	0.008	0.003	0.006	0.003	1.126	0.006
HW11	0.145	0.006	0.028	0.022	4.012	0.001	0.428	0.423	0.003	0.002	0.006	0.005	0.002	0.001	0.001
HW12	0.709	0.024	0.026	1.192	9.972	0.006	0.415	0.235	0.003	0.001	0.001	0.004	0.001	0.392	0.002
HW13	0.035	0.078	0.021	0.022	0.693	0.001	0.337	0.683	0.001	0.003	0.010	0.004	0.001	0.133	0.001
HW14	0.041	0.001	0.026	0.025	0.466	0.000	0.451	0.526	0.001	0.001	0.001	0.005	0.001	0.001	0.000
HW15	0.512	0.015	0.024	0.676	0.693	0.002	0.413	0.201	0.001	0.001	0.001	0.004	0.001	0.107	0.007
HW16	0.043	0.063	0.022	0.060	0.495	0.001	0.410	0.309	0.000	0.002	0.002	0.005	0.000	0.002	0.001
Min	0.034	0.001	0.001	0.001	0.118	0.001	0.001	0.078	0.000	0.001	0.001	0.001	0.000	0.001	0.000
Max	4.117	0.111	0.04	1.799	9.972	0.009	0.558	1.344	0.003	0.023	0.010	0.010	0.004	1.126	0.052
SD	1.179	0.037	0.011	0.546	2.612	0.002	0.124	0.284	0.001	0.006	0.003	0.002	0.001	0.271	0.012
Ave	0.644	0.053	0.024	0.319	1.820	0.003	0.392	0.393	0.002	0.006	0.004	0.005	0.002	0.190	0.005
WHO	0.10	NGV	0.05	0.40	0.30	0.07	2.00	2.00	0.01	0.04	0.01	0.003	0.02	0.70	0.01
EU	0.20	NGVS	0.05	0.05	0.20	0.02	0.002	NGVS	0.01	0.01	0.005	0.005	NGVS	NGVS	0.01
EPA	0.2	0.002	0.1	0.05	0.30	NGV	1.00	5.0	0.01	0.05	0.04	0.005	0.006	2.00	0.01
SSMO	0.13	NGV	0.04	0.50	0.30	0.05	1.50	3.00	0.007	0.007	0.05	0.003	0.013	0.50	0.007

References guideline (WHO 2017). (EPA 2015),(WHO 2006),(EPA 2018) (SSMO 2008).

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3.3 Heavy metals

Al

Aluminum is present in groundwater as Al^{3+} ions (National Headquarters & Laboratory, 2013). The aluminum levels in the entire water samples ranged from 0.034 to 4.117 mg/L. However, five sites were found to be elevated above the EPA and EU limits of 0.20 mg/L. The elements exhibiting exceedances at locations HW2, HW6, HW10, HW12, and HW15 were recorded as 4.117, 0.879, 3.207, 0.709, and 0.512 mg/L, respectively. It can be seen in Fig. 5 below that these concentrations are compared to the EPA and EU guidelines.

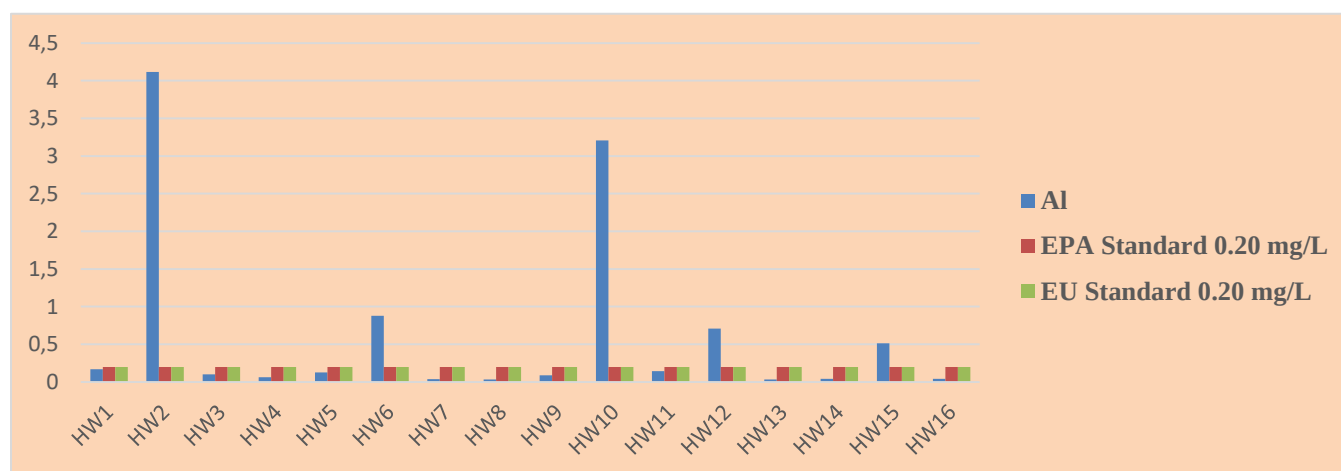


Figure5: Absorption of aluminum (Al) in water samples compared to WHO and EU guideline (0.20 mg/L).

V

Vanadium's valence state and solubility determine its toxicity. People widely regard pentavalent vanadium, specifically in the form of vanadate, as the most poisonous kind. The trivalent and divalent versions exhibit lower toxicity, as stated by the EPA in 2006. The Agency for Toxic Substances and Disease Registry (ATSDR) has proposed that vanadium can impact the health of fauna and humans. They recommended conducting sub-chronic and chronic toxicity tests to compare the effects of different oxidation states of vanadium under similar testing conditions. (ATSDR, 2012). The level of vanadium concentrations ranged from 0.001 to 0.111 mg/L. We observed a high concentration site in Glim HW10, which was 0.111 mg/L. However, the intake ranges by ATSDR are 0.22 mg/L.

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Cr

Chromium is extensively dispersed throughout the Earth's crust. It is typically present in hexavalent or oxidative states ranging from (+2 to +6). Soil and rocks typically contain modest quantities of chromium, primarily in the trivalent state (Batayneh, 2012). The results obtained for chromium varied concentrations, ranging from 0.001 to 0.040 mg/L. A high concentration was observed in sample HW4, which was 0.040 mg/L. All the samples meet the WHO limit of 0.05 mg/L. The respective limits set by these organizations are 0.04, 0.05, and 0.10 mg/L. As shown in Fig. 6, a chart of chromium concentrations is compared to the WHO limit.

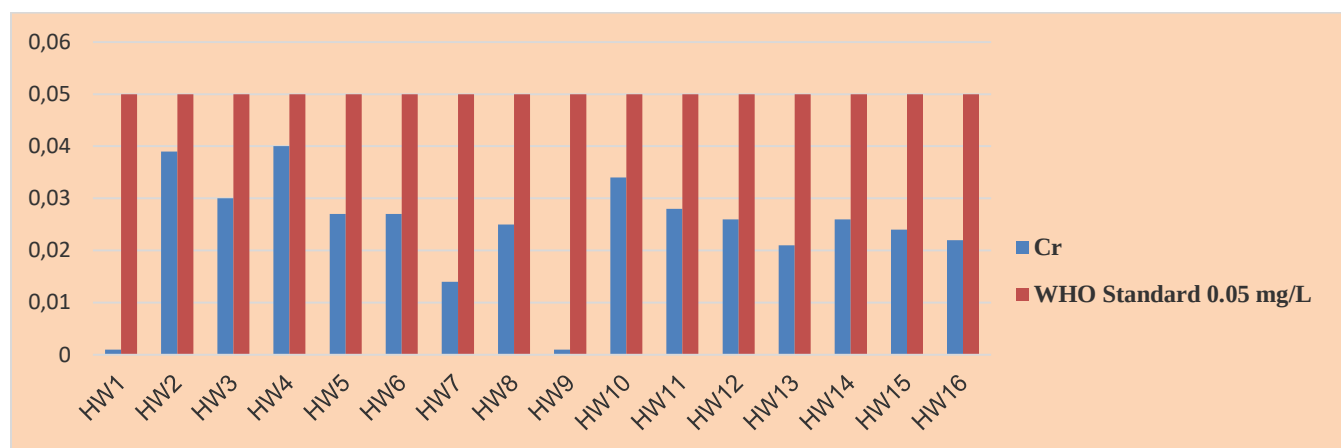


Fig 6 : Chromium level concentrations in water sample

Mn

Manganese is a vital mineral for human and animal health. However, when present in high quantities in water, it can lead to water contamination and cause neurological symptoms. In the amounts often found in water, manganese mostly has aesthetic effects rather than hazardous consequences (S. Holmes, 1996). The water samples gathered in the study area demonstrated manganese concentrations of 0.001 to 1.799 mg/L. It has been noted that the four locations represented by HW2, HW10, HW10, and HW15 are recorded at 1.125, 1.799, 1.192, and 0.676 mg/L, respectively. Have values above the allowable limits set by WHO and SSMO, which are 0.40 and 0.50 mg/L, respectively. The drinking water in the research location showed high amounts of iron and manganese, which could be problematic. The geological composition of the region likely contributes to this. Figure 7 displays the manganese levels in the water samples.

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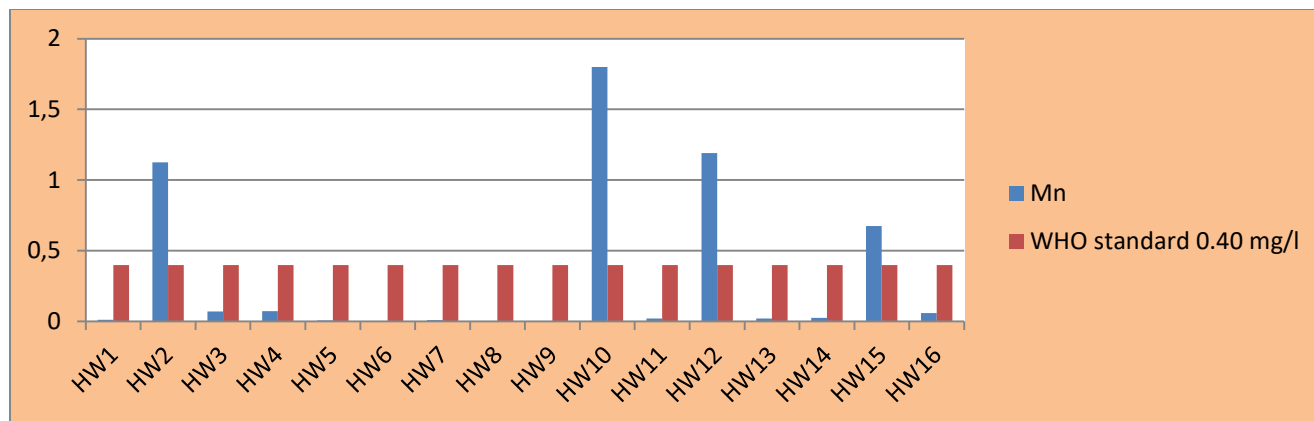


Fig7: Manganese concentration compared to WHO and SSMO guideline

Fe

Iron is predominantly present in groundwater as a result of substantial accumulations in the soil. The redox state of the water regulates the chemistry of naturally existing iron, releasing it into the water under reducing conditions. Soil leaching introduces iron into surface waters, while interactions between water and rocks result in its input into subsurface waters (Sorlini et al., 2013). The current study examined iron levels ranging from 0.118 to 9.972 mg/L. Regarding the eleven samples analyzed, it was determined that the results fell within the acceptable range set by SSMO, WHO, and EPA, which is 0 (mg/L) .. On the other hand, five locations showed values that surpassed the limit, with 0.3 mg/L, which are HW2, HW9, HW10, HW11, and HW12, where 4.583, 2.355, 4.309, 4.012, and 9.972 were recorded, respectively. Figure 8 displays the iron levels in the water samples

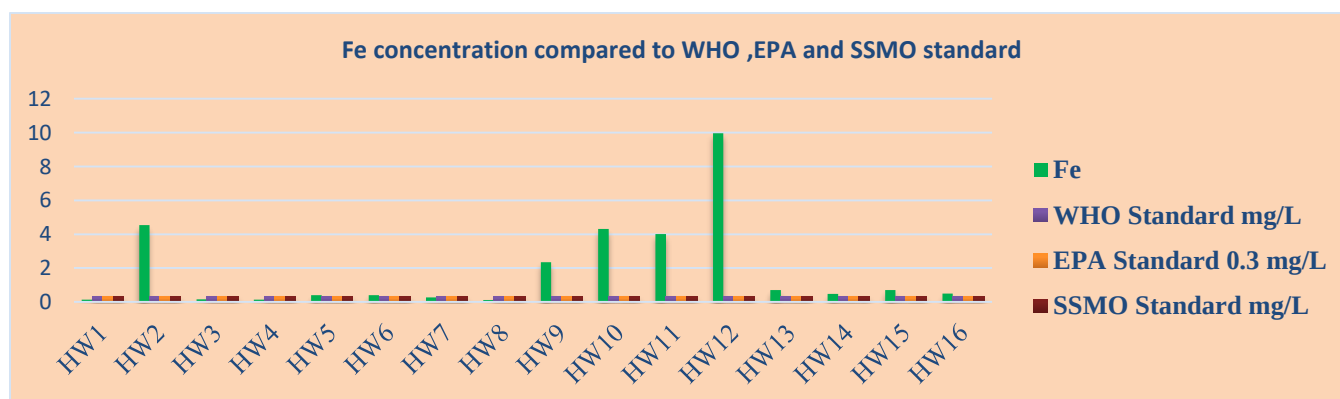


Fig 8: iron concentration in water samples compared to WHO, EPA and SSMO standard.

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Ni

Certain waters contain nickel due to the dissolution of rocks containing nickel ore. Additionally, it enters the environment through human activities, including the burning of fossil fuels, metal mining, car emissions, smelting, disposal of domestic, municipal, or industrial wastes, and fertilizer application (Rathor et al., 2014). The nickel concentration was confined (0.001 to 0.009 mg/L). High values were detected in sampling IDs (HW2), specifically 0.009 mg/L. This concentration falls below the permitted limits set by SSMO and WHO, corresponding to 0.014 mg/L and 0.07 mg/L. This can be seen in Fig. 9: the level of nickel in water samples.

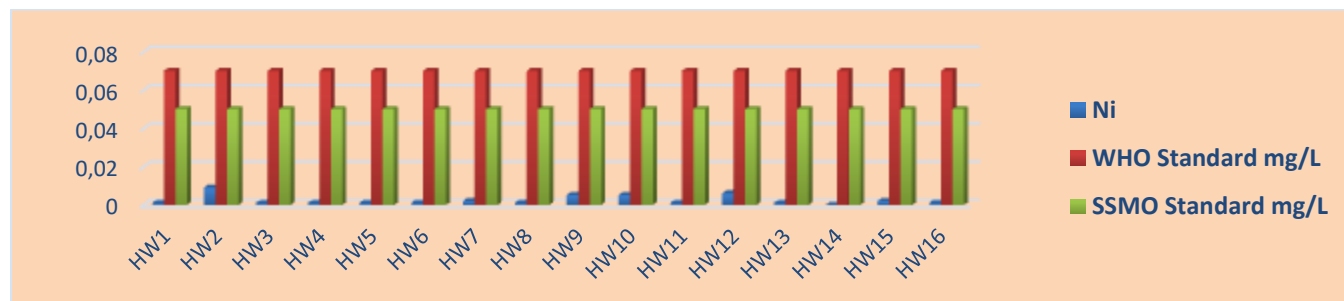
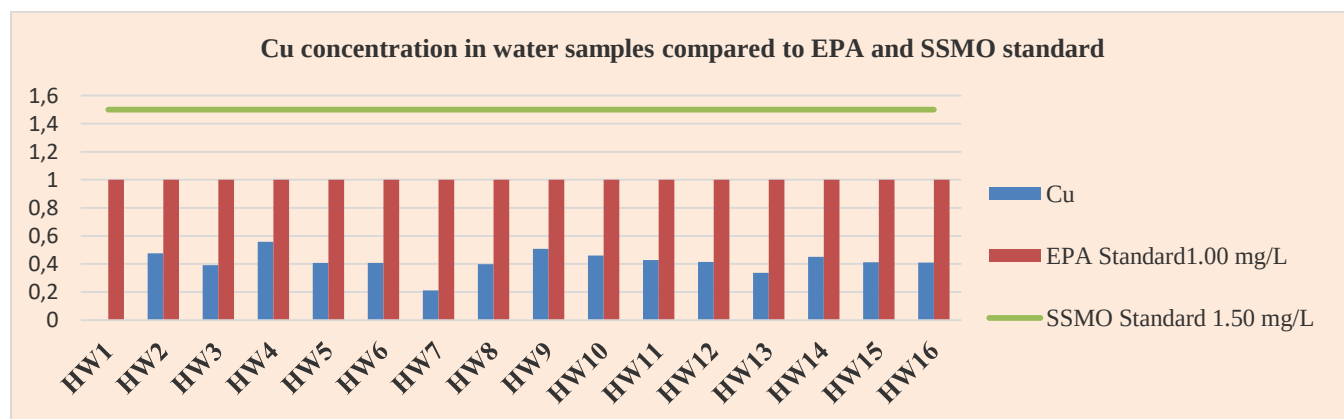


Fig 9: Nickel concentration in water samples compared to WHO and SSMO standard.

Cu

Copper is typically present in drinking water due to the use of copper pipes, industrial waste, or the addition of substances intended to regulate algae growth. An excessive amount of copper in drinking water may serve as a source of contamination, resulting in the development of chronic anemia (Paul, 2016; Mebrahtu & Zerabruk, 2011). The highest copper concentrations recorded in all the areas under study were measured at 0.558 mg/L, which is below the recommended guideline of 1.50 mg/L set by the SSMO and the standard, as well as the 1.00 mg/L set by the Environmental Protection Agency (EPA). Figure 10: Display of copper in water samples.



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Fig 10: Copper concentration in water samples compared to EPA and SSMO standard.

Zn

Zinc is a crucial trace element involved in the physiological and metabolic processes of several species. However, excessive amounts of zinc can be hazardous to humans (Ruqia Nazir, Muslim Khan, Muhammad Masab, et al, 2015). Zinc concentrations ranged from 0.078 to 1.344 mg/L, which is below the recommended limits set by SSMO (3.0 mg/L) and WHO (2.0 mg/L).

As

Arsenic in aquatic ecosystems can originate from various sources, such as nonferrous mining, animal feed additives, glass and porcelain production, herbicides, insecticides, timber preservatives, and other human activities, as documented by Jan et al. (2015). The arsenic levels in all samples ranged from 0.000 to 0.003 mg/L. All samples were lower than the limits set by SSMO, EPA, and EU guidelines, which are 0.007, 0.01, and 0.01 mg/L, respectively.

Se

Selenium is frequently located in the Earth's crust, typically associated with sulfur minerals (WHO, 2008). The results showed selenium concentrations ranging from 0.001 to 0.023 mg/L. The highest selenium levels were observed in Sample IDs HW2 and HW3, at 0.023 and 0.016 mg/L, respectively. These amounts consistently exceeded the EU permissible limit of 0.01 mg/L (Show Fig 11: concentrations of selenium in water samples).

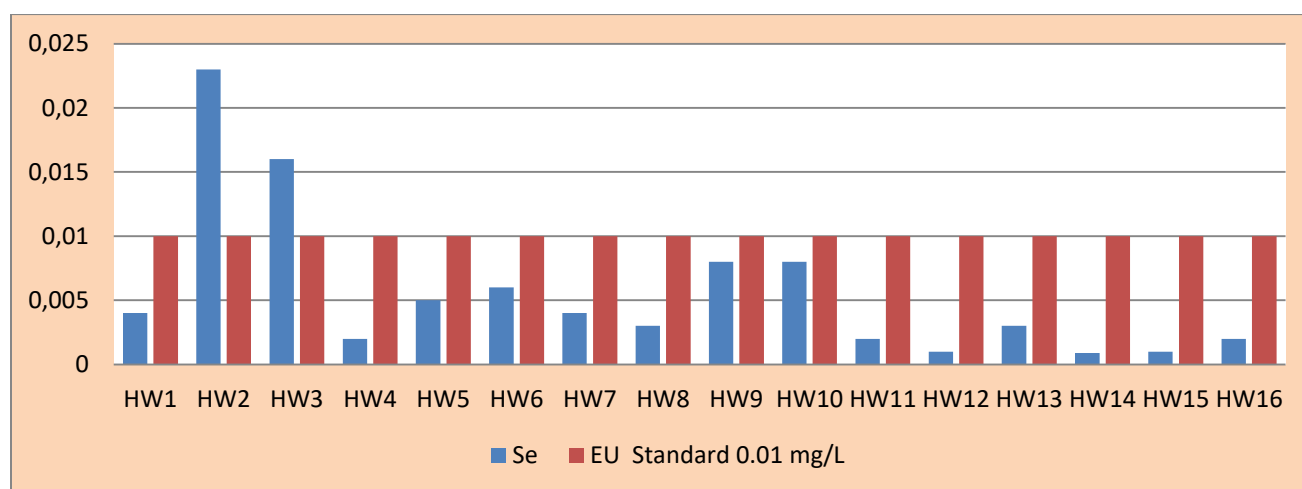


Fig11 : Selenium concentration in water samples compared to EU.

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Mo

The level of molybdenum in water sources utilized for public supply is typically relatively low, and human harm from this metal is extremely rare (EPA, 2001). The presence of molybdenum was revealed at concentrations of 0.001 to 0.010 mg/L in samples HW1 and HW13. These concentrations were consistently 0.010 mg/L, which exceeded the limit recommended by SSMO as 0.007 mg/L. In contrast, sample ID HW7 was found to have amounts measured that were satisfactory compared to the limit. As shown in Fig. 12, molybdenum is compared to the SSMO standard.

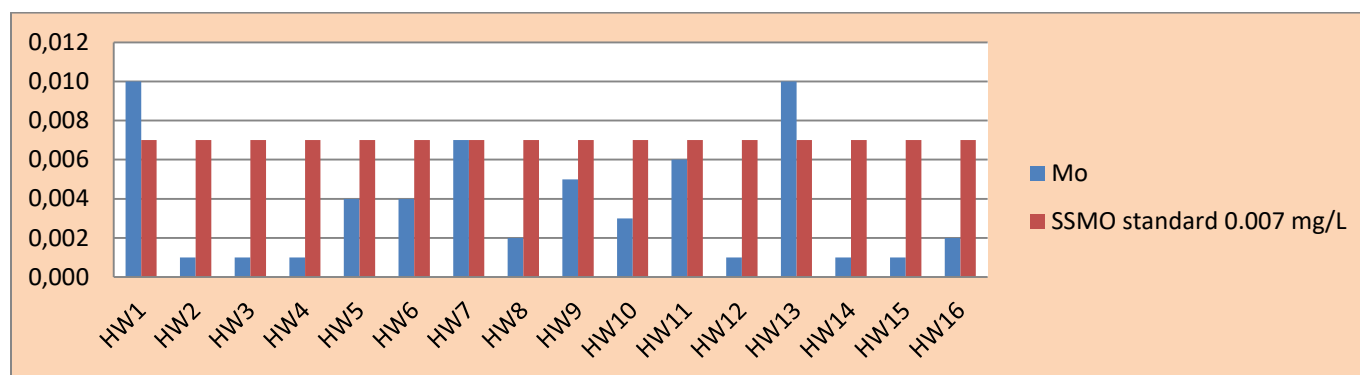


Fig 12: Molybdenum concentration in water samples compared to SSMO standard.

Cd

Surface waters often exhibit enhanced geochemical mobility of Cd, leading to an increase in Cd content when the pH of lake water decreases (Wuana & Okieimen, 2011). Impurities in zinc, found in galvanized pipes, solders, metal fittings, and phosphate fertilizers, lead to the primary cause of cadmium contamination in food and water. It is a pollutant in water bodies (Elhamili et al., 2016; Paul, 2016). The fourteenth sample exceeds the WHO and SSMO norms' acceptable limits of 0.003 mg/L, aligning with the regional standard set by SSMO. Represented samples are HW2, HW3, HW4, HW5, HW6, HW8, HW9, HW10, HW11, HW12, HW13, HW14, HW15, and HW16. Increase of cadmium in the area under studies we suggest weathering of cadmium rich rocks because the mountain areas often contain mineral deposits such as zinc, lead, and copper ores, which naturally include cadmium, apart from that rain can leach cadmium into surface and ground water also volcanic active zones volcanic emission can release a cadmium into the atmospheres which later settle into soil and water. Figure13 displays the cadmium levels in the water samples.

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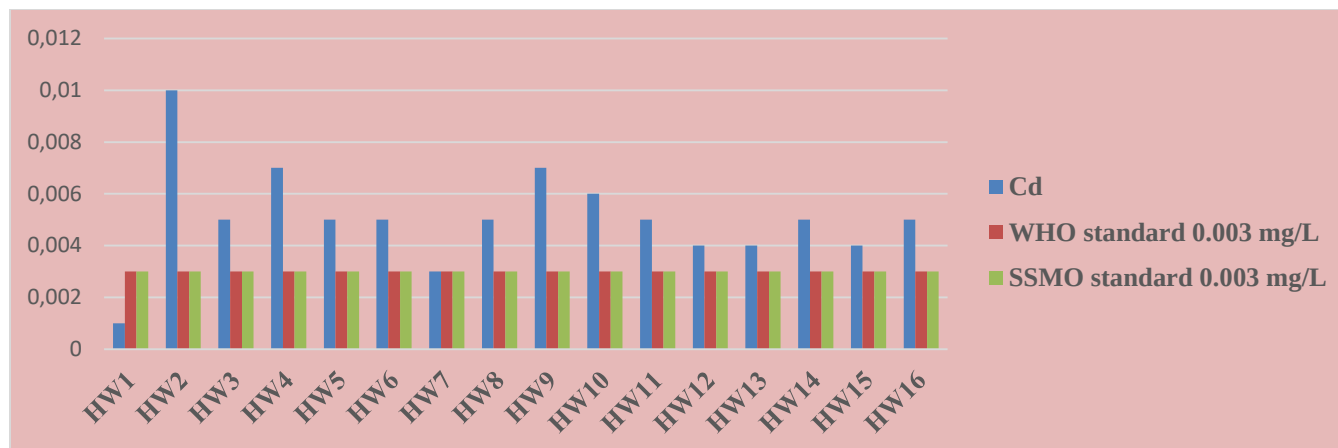


Fig 13: Cadmium concentration in water samples compared WHO and SSMO standard.

Sb

Antimony, in its elemental state, can create exceptionally durable alloys when combined with copper, lead, and tin. Antimony materials possess several medicinal applications. Initially, experts suggested antimony as a potential lead substitute in troops. However, no proof suggests that it has a noteworthy impact on the concentration of antimony in drinking water (WHO, 2006). Antimony recorded 0.001 to 0.004 mg/L. All water samples showed antimony contents below the permissible detection limit, as per the WHO, at 0.02 mg/L.

Barium

Several ores naturally contain barium, and erosion and dissolution processes discharge these ores into groundwater. Barite (barium sulfate) and barium carbonate are the most prevalent barium ores. Both volcanic and sedimentary rocks contain small amounts of barium as a trace element. Many industrial applications utilize barium compounds (EPA, 2006; WHO, 2011). The highest concentration of barium observed in this study ranged from 0.001 to 1.126 mg/L. It has been noted that the sample IDs (HW10) taken near the mountain surpassed the allowable restrictions set by SSMO and WHO, which are 0.05 and 0.70 mg/L, respectively. Figure 14 displays the barium levels in the water samples.

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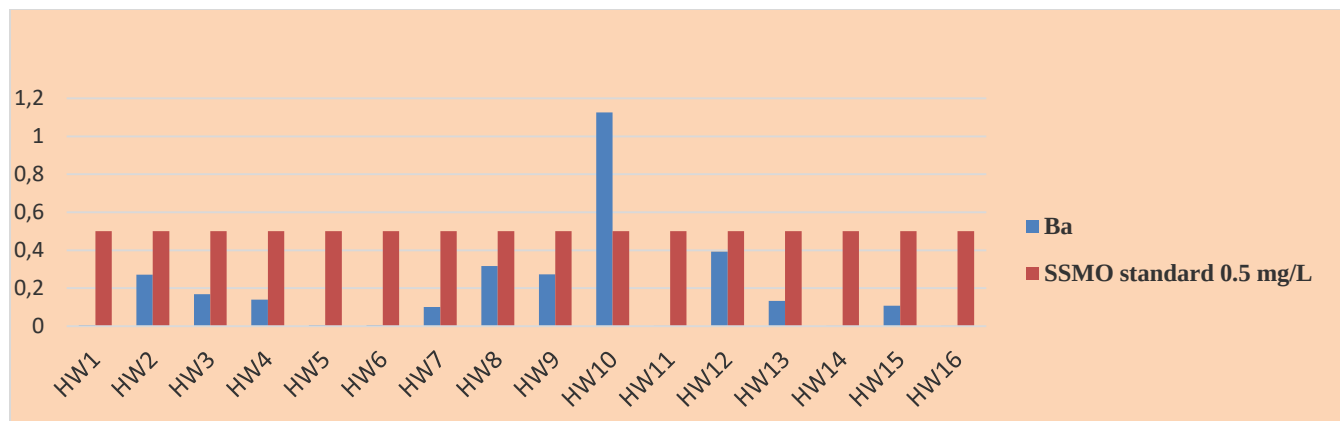


Fig14: Barium concentration in water samples compared to SSMO standard.

Pb

Lead is a prevalent heavy metal that acts as a metabolic toxin, inhibiting enzymes when present in amounts exceeding the recommended limit. It can also impair neural connections and induce circulatory and brain abnormalities. Additionally, lead has biochemical effects that interfere with hemoglobin production, leading to hematological damage (Saha, 2016). The sample with ID HW1 exhibited the highest concentration of lead, at 0.052 mg/L, which exceeds the acceptable limits established by the WHO and the EPA limit of 0.01 mg/L. A high concentration of Pb refers to anthropogenic activities; however, this open-hand dug well can be a contaminated site located in a valley. Figure 15 displays the level of lead.

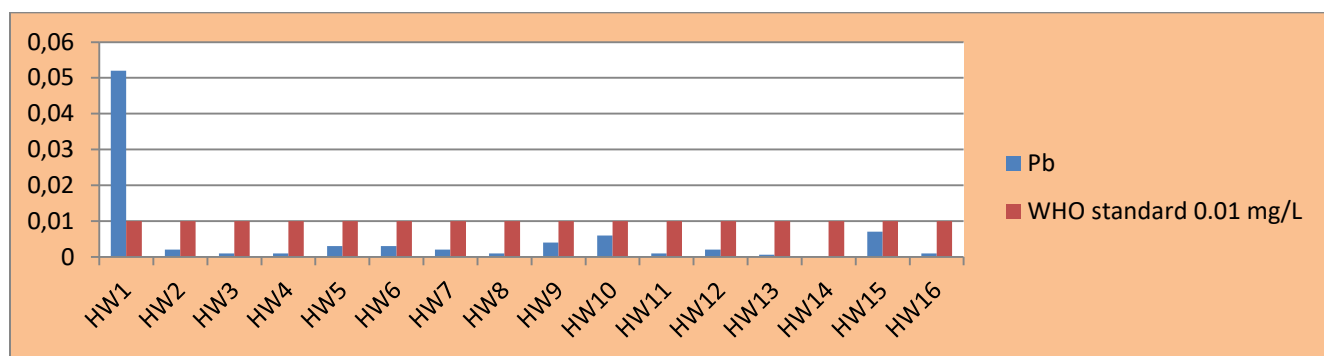


Fig15: Concentration of lead in water samples compared to WHO and EPA guideline (0.01 mg/L).

Table 5. Pearson correlation coefficient between heavy metals in water samples

	Al	V	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Pb
Al	1.000														
V	0.217	1.000													
Cr	0.463	-0.067	1.000												

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Mn	0.809	0.107	0.408	1.000											
Fe	0.456	-0.087	0.199	0.706	1.000										
Ni	0.789	0.166	0.156	0.748	0.724	1.000									
Cu	0.241	0.227	0.624	0.246	0.245	0.271	1.000								
Zn	-0.175	0.406	-0.393	-0.262	-0.014	0.112	0.368	1.000							
As	0.200	-0.435	0.140	0.266	0.499	0.271	-0.190	-0.303	1.000						
Se	0.673	0.184	0.267	0.304	0.111	0.597	0.144	0.005	0.125	1.000					
Mo	-0.263	0.088	-0.638	-0.360	-0.222	-0.248	-0.696	0.209	0.132	-0.197	1.000				
Cd	0.603	0.293	0.570	0.322	0.225	0.583	0.796	0.305	-0.105	0.616	-0.542	1.000			
Sb	0.227	0.543	0.066	0.076	-0.016	0.147	0.216	0.168	0.142	0.117	-0.018	0.314	1.000		
Ba	0.620	0.450	0.252	0.813	0.474	0.547	0.260	-0.032	0.165	0.230	-0.201	0.277	0.394	1.000	
Pb	-0.047	-0.042	-0.565	-0.062	-0.145	-0.093	-0.791	-0.276	0.088	-0.062	0.517	-0.547	0.070	-0.102	1.000

Note: correlation coefficients (r= values)

Table 5 summarizes the Pearson correlation coefficient pertaining to heavy metals. Correlation analysis showed a strong positive relationship between [r = 0.0813 to r = 0.624] was Ba-Mn (r = 0.813), Cd-Cu (r = 0.796), Ni-Mn (r = 0.748), Ni-Fe (r = 0.724), Fe-Mn (r = 0.706), Se-Al (r = 0.673), Cd-Al (r=0.603) and Cu-Cr (r = 0.624). Moderately correlation was found to be [r = 0.583 to 0.406] were Cd-Ni (r = 0.583), Cd- Cr (r = 0.570), Ba-Ni- (r = 0.547), Sb-V (r = 0.543), Pb –Mo (r =0.517), Zn-V (r = 0.406). Weak correlation [r = 0.474 to 0.256] was Ba-Fe (r = 0.474), Mn– Cr (r = 0.408), Zn-Cu (r = 0.368), Ba-Cd (r = 0.277), Ba-Cu (r = 0.260), Ba-Cr (r = 0.252), Cu-V (r = 0.227), Mo-Zn (r = 0.209) and Ni-Cr (r = 0.156).

Statistical Analyses.

The data collected for this study underwent general descriptive statistical analysis. They were presented as the Min =Minimum, Max = Maximum, and Ave=Average values alongside the correlation coefficient related to the variable metals.

Conclusion

Metal contamination in drinking water remains a significant health concern in many parts of the world. Physico-Chemical, heavy, and trace metal levels. Excessive levels of heavy metals may have several immediate and long-term adverse health impacts on people. Results revealed that we measured three physicochemical characteristics of drinking water (pH, EC, and TDS) in 16 samples. All study sites found the pH and EC to be within the permissible limits (6.50-8.50 and 2500 μ S/cm, respectively), and all obtained samples fell below the SSMO limits of 1000 mg/l. However, six of the sixteen samples exceeded the WHO's recommended limits of 500 mg/l. We found that the concentrations of four out of the six elements of the water quality parameters (Li, Na, Mg, P, K, and Ca) were within the permissible

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limits. We found that the concentrations of lithium, sodium, and magnesium were lower than the parameters set by the EPA, the EU, and the WHO. In contrast, the phosphorus concentration in 15 sites exceeded the EU's limit. Additionally, one site exhibited potassium levels that surpassed the recommended levels. We found calcium concentrations exceeding 50 mg/l in 13 sites. 50 mg/l. These concentrations differ as follows: $P > Ca > K > Mg > Na > Li$. The data indicated fluctuations in the levels of heavy metals in drinking water samples.

(As and Sb) In all samples, the level of detection was low, while Se, Zn, Mo, Ni, Cr, and Cu were found within acceptable limits according to the WHO (2017). Furthermore, the results showed that Fe, Cd, Al, Mn, Pb, and Ba exceeded the permissible limits set by SSMO and WHO. The arithmetical study revealed the median amounts of heavy metals in the following order: starting with the highest one ($Fe > Al > Zn > Cu > Mn > Ba > V > Cr > Se > Pb > Cd > Mo > Ni > Sb > As$) respectively. Each analyzed sample contained one or two of the previous heavy metals.

Recommendations:

This study suggests that future use of ICP-MS for hydrological isotope research is warranted. The study aims to encompass a broader spectrum of heavy metals and trace elements. Heavy metals are found in very high levels in the study area due to the granitic and syenite rock types and the impact of human activities, such as farming, in the farthest southeast of Jebel Mun. Therefore, we highly recommend conducting a food safety assessment. We also recommend introducing water treatment techniques such as reverse osmosis (RO), ion exchange, and aeration to reduce the current levels of heavy metals. Finally, we recommend conducting additional studies to monitor heavy metals and using more validation analysis, specifically phosphors, by AAS. The study highlights the importance of implementing stringent administrative measures to protect and sustainably manage drinking water sources, including both surface and underground water, in the Jebel Mun locality

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