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Non-cancer Health Risk Assessment of Heavy Metals in Groundwater of Qassim Region in Saudi Arabia

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ABSTRACT. In Qassim Region of Saudi Arabia, the groundwater water has been affected due to presence of naturally occurring salts, radionuclides, and heavy metals. Municipalities are providing safe water to the community after efficient treatment processes in urban settings. While in villages and farms outside the cities' boundaries, the population is using untreated water supplies for drinking and bathing drawn from private wells, thus is exposed to possible health risks. In present research, health risk assessment has been carried out for possible non-carcinogenic and carcinogenic hazards of naturally occurring heavy metals in groundwater. Quantitative risk assessment is performed for the population living outside the boundary of Buraydah's water supply system. Data of thirty-seven groundwater samples, analyzed for eighteen heavy metals, was obtained from the municipality. In 8% of the samples, Manganese (Mn) concentration was higher than WHO drinking water quality guidelines while the levels of remaining metals were found lower than the guideline values. In few samples, Sb, Cu, Mo, Se, Ag, and TI, were found in very low concentrations which shows that these metals are not the elements of importance. Study results show that the population is exposed to *'medium'* level of non-carcinogenic risk (i.e., $HI_{ING} > 1.0$) through oral ingestion. Mn, V, Cr, and Ar are the main contributors to non-carcinogenic risk and should be given importance in subsequent investigations for health risk assessment in the study area. Non-carcinogenic risk due to dermal exposure is found to be 'low' with $HI_{DER} < 1.0$.

Key Words: Human health risk assessment; Non-carcinogenic risk; Heavy metals; Iron and Manganese; Groundwater; Water quality in Saudi Arabia.

1. Introduction

Municipalities and Water Directorates around the Kingdom of Saudi Arabia (KSA) are facing challenges due to population growth and associated increase in residential, industrial, agricultural water demands [1]. Around 81% of the total water supply is being utilized to meet agricultural requirements in the country [2]. Limited available groundwater has been affected with naturally occurring total dissolved solids (TDS), radionuclides, and heavy metals [3]. Municipalities are spending extensive resources for supplying safe drinking water to the citizens by removing these natural occurring pollutants through modern treatment processes [4].

Extracted water has been adequately treated to meet Saudi Arabian drinking water quality standards. The extracted water is being treated through sand filtration or ultra-filtration for removal of primarily Iron (Fe) and Manganese (Mn), Reverse Osmosis (RO) to reduce TDS, followed by chlorination practice to ensure safe bacteriological quality up till the consumer end. According to the World Health Organization (WHO), TDS levels less than 600mg/L represents good water quality and if these levels exceed 1000 mg/L, the water is considered to be unpalatable [5]. Irrespective of taste, there are no health based guidelines reported by the WHO. On average the TDS levels varies between 600 mg/L and 1000 mg/L in the groundwater of Buraydah, Qassim, KSA [1, 4]. Municipalities provide safe drinking water to urban population while the people living in farms and small villages located in the proximity of the city are exposed to untreated water for drinking and bathing. Consequently, the population in these areas is exposed to these salts and heavy metals through oral and dermal routes.

Some of these metals are essential to maintain human health [5]. However, chronic health hazard assessment is required to ensure that the population has not been adversely affected by the long-term exposure to heavy metals present in source water. In Saudi Arabia, studies have been conducted in the past to monitor the presence of heavy metals in groundwater due to natural and anthropogenic activities [6,7]. Zabin et al. (2008) performed non-cancer risk assessment due to presence of manganese, chromium and zinc in ground water of Al-Baha region, Saudi Arabia. They identified chronic (non-carcinogenic) adverse impacts on human health through oral and dermal routes to the population exposed to direct consumption of well water in the area [8]. However, no such study has been performed in Qassim Region, so far. Therefore, the primary objective of this research is to conduct non-carcinogenic risk assessment of heavy metals present in groundwater of Qassim Region, Saudi Arabia. A case of the city of Buraydah is investigated in present study.

2. Methods

2.1 Study Area

The study area, shown in Figure (1), is the city of Buraydah in Qassim Province of Saudi Arabia. The municipality of Buraydah extracts groundwater to meet residential, commercial, and industrial requirements of the city's residents (see boundaries of urban setting in Figure (1)). The main source of water in the study area is Saq aquifer where the groundwater is entrapped in Paleozoic and Mesozoic sedimentary rock formations [9]. Groundwater is contaminated due to presence of naturally occurring high total dissolved solids (TDS), radionuclides, and heavy metals (HMs) in sub-surface hydrogeology [1,10]. Qassim region is famous due to its fertile soil and large agricultural land. Consequently, around the city of Buraydah, there are several rural setting where untreated water is being used for domestic and agricultural uses. The population living in green area (see outside urban boundaries in Figure (1)) uses untreated water extracted through private wells in their lands. Non-carcinogenic risk assessment is performed for the population living in this green area.

Fig. (1). Study area showing boundaries of City of Buraydah and green area showing human settlements with population exposed to heavy metals

2.2 Groundwater Quality Monitoring

The groundwater quality data of thirty-seven (37) samples obtained from groundwater wells was collected from the Municipality of Buraydah. The samples were collected, stored and transported according to the standard methods. Later, the samples were analyzed for eighteen (18) heavy metals using Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) in the laboratory. All of these 18 metals were defined as metals of primary interest by the United States Environmental Protection Agency (USEPA) [11]. Each of these heavy metals in concentrations higher than the given standards in drinking water supplies may cause health related issues. Heavy metals along with their health-based guideline values and a brief toxicological review, as per WHO [5], are presented in Table (1).

2.3 Human Health Risk Assessment

Human health risk assessment is primarily categorized into cancer risk assessment and non-cancer risk assessment. Concentrations of naturally existing heavy metals in groundwater vary geographically based on type of sub-surface hydrogeology [11]. Human health risk assessment process, shown in Figure (2), consists of four main steps, including, i) hazard identification – determine if the chemical under study associated to a specific health effect, ii) dose - response assessment – determine the relationships between exposure duration and the specific health impact's probability of occurrence, iii) exposure assessment – estimate the total exposure (i.e., concentration in environmental groundwater) based on body's uptake of the chemical of concern through oral, inhalation, and dermal routes, and iv) risk characterization – the information of the first three steps is interpreted through quantitatively comparing exposure concentrations with the health based guidelines to assess the magnitude of human health risk. Here, only the necessary information is provided. Details can be seen in USEPA's Risk Characterization Handbook [12].

In Figure (2), the first step for human health risk assessment is hazard identification. Hazard identification is the process to determine whether an exposure to a chemical can increase the probability of a particular health effect. This step has been essentially carried out in the last column of Table (1). It can be seen in Table (1) and the references provided, that all of the metals of primary interest have some potential to effect human health if exist in concentrations higher than the permissible levels.

Table (1). Summary of heavy metals, guideline values, and toxicology [5]

No.	**Heavy Metal**	**Symbol**	**Guideline values (ppb)**		**Toxicological review / Health impacts**
			WHO	KSA[g]	
1	Arsenic	Ar	10	50	Hyper- and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers, and peripheral vascular disease. Effected cardiovascular system of children.
2	Antimony	Sb	20	10	Limited evidence for the carcinogenicity of certain compounds through inhalation. No indication for carcinogenicity through oral route.

No.	Heavy Metal	Symbol	Guideline values (ppb)		Toxicological review / Health impacts
			WHO	KSA[g]	
3	Barium	Ba	700	700	No evidence for carcinogenicity or mutagenicity. Some potential to cause hypertension in humans.
4	Beryllium	Be	-	1	Unlikely to occur in drinking-water
5	Boron	B	2400	500	Boron compounds (boric acid and borax) are not genotoxic. Long-term animal studies revealed no evidence of tumour growth.
6	Cadmium	Cd	3	5	Carcinogenic through inhalation route. Carcinogenicity through oral route and genotoxicity is non evident. Kidney has been identified as the main target organ.
7	Chromium	Cr	50	50	Only Cr (VI) has been classified in Group 1- human carcinogen. Cr (III) has been classified in Group 3- non-carcinogen to humans.
8	Copper	Cu	2000	1000	Effects on the gastrointestinal tract. Long-term effects of copper on sensitive populations, e.g., carriers of the gene for Wilson disease, are uncertain to date.
9	Iron	Fe	2000[a]	1000	Animal studies revealed that toxic doses of Fe may lead to depression, rapid and shallow respiration, coma, convulsions, respiratory failure, and cardiac arrest. For humans, minimum daily requirement for Fe range between 10 and 50 mg/day. This range depends on age, sex,

No.	Heavy Metal	Symbol	Guideline values (ppb)		Toxicological review / Health impacts
			WHO	KSA[g]	
					physiological status, and iron bioavailability. [b]
10	Lithium	Li	-	-	Li might reduce the risk of suicide in men. [c]
11	Manganese	Mn	400 [a]	100	Neurological effects from inhalation. Extended exposure to very high levels of Mn may lead to adverse neurological effects. However, several studies showed absence of adverse effects on human health from drinking water.
12	Molybdenum	Mo	70 [a]	70	Estimated requirement for adults is 0.1–0.3 mg/day. Carcinogenicity of Mo through oral route has not be reported so far.
13	Selenium	Se	40	10	No evidence of clinical or biochemical toxicity of Se has been reported.
14	Silver	Ag	10 [a]	100	Effect of overdose, more than 10 g in lifetime, of Ag can cause Argyria, i.e., discoloration of skin and hair.
15	Strontium	Sr	-	-	Although, Sr is not highly toxic, concentration higher than 1500 ppb can affect bone formation. [d]
16	Thallium	TI	-	-	Health effects due to exposure to smaller amounts of TI even for longer periods have not been reported. [e]
17	Vanadium	V	-	-	Naturally present V in water is not harmful to human health. Large amounts of V reported minor stomach cramps. [f]
18	Zinc	Zn	3000 [a]	5000	No risk of cancer or cardiovascular diseases. Consuming higher than 500 mg of Zn may lead to acute toxicity, i.e., vomiting. [b]

[a] health based guidelines based on upper range values of intakes assuming 2L/ day consumption by a 60 kg adult [5]
[b] WHO [20] [c] Liaugaudaite et al. [21] [d] Water Technology [22] [e] ATSDR [23]
[f] Hawaii State Department of Health [24] [g] Regional guidelines obtained from water directorate of Buraydah

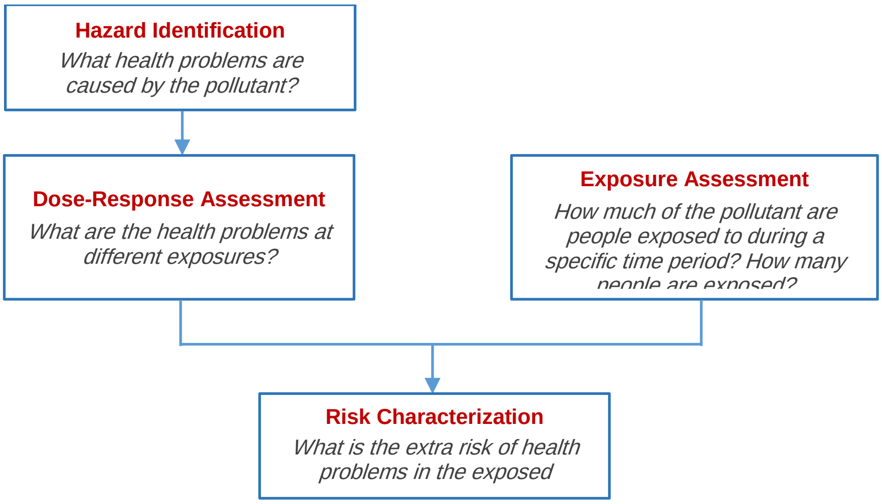

Fig. (2). Human health risk assessment framework [12]

Second step is dose-response assessment where the response increases with an increase in dose. At a certain dose, the responses can be observed either in a small fraction of the population or at a low probability rate. Both of these factors vary with certain influencing factors, such as type of pollutants, individuals, and the routes of exposure, etc. [12]. Reference dose is an outcome of dose-response assessment.

In third step, exposure assessment establishes the relationship between exposure's magnitude and the possibility of the concerned health effects [11]. Exposure assessment was done to assess the duration, frequency, pathways, routes of exposure, and possible consequences of the 18 selected heavy metals.

Heavy metals can enter into the bodies of exposed population through oral ingestion and dermal contact [13]. Therefore, Chronic Daily Intake (CDI) of groundwater, with naturally occurring heavy metals, is calculated with the help of the following equation 1 [14]:

$$CDI = \frac{C_{MW} \times I_R}{B_W} \quad \ldots (1)$$

where *CDI* is calculates in terms of □*g/Kg.day*, C_{MW} is the monitored heavy metals' concentration in groundwater; I_R is the rate of water ingestion per day, and B_W is the average body weight in Kg.

Exposure due to oral ingestion was calculated using the following formulae (equation 2) developed by the USEPA [15]:

$$Exp_{ING} = \frac{C_{Water} \times IR \times EF \times ED}{BW \times AT} \qquad \dots (2)$$

where ExpING is the exposure dose of heavy metals through ingestion (□g/kg.day), Cwater is the concentration of heavy metals in groundwater (□g/L), IR is the rate of ingestion L/d), EF is the exposure frequency (days/year), ED is the exposure duration over average life time (years), BW is the average body weight (kg), and AT is the average time during average 70 years of life time (days).

Exposure due to dermal contact was calculate using the following (equation 3) relationship USEPA [15]:

$$Exp_{DERM} = \frac{C_{Water} \times SA \times K_p \times ET \times EF \times ED \times CF}{BW \times AT} \qquad \dots (3)$$

where SA is the area of skin exposed to groundwater containing heavy metals (cm2), Kp is the coefficient of dermal permeability (cm/h), ET is the time of dermal exposure (hrs/day), and CF is unit conversion factor (L/cm2). Standard values of all the risk factors, to calculate ExpING and ExpDERM, recommended by USEPA for non-cancer risk assessment are listed in Table (2). Permeability coefficients and reference doses for all the heavy metals are provided in Table (3). Reference doses for Lithium have not be reported Integrated Risk Information System (IRIS) and hence was excluded from risk assessment in present study USEPA [16].

Reference doses, expressed as mg/kg/day, are estimated in terms of “daily exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime” [16]. Hazard Quotient (HQ) for oral exposure (HQING) was calculated for non-carcinogenic health risk of selected metals using the following relationship (equation 4a) USEPA [17,18]:

$$HQ_{ING} = \frac{Exp_{ING}}{RD_{ING}} \qquad \dots \qquad (4a)$$

where HQING is a unit less number while RDING is the corresponding reference dose of the heavy metal (□g/kg.day).

Similarly, the hazard quotient for dermal exposure (HQDERM) was calculated for non-carcinogenic health risk of selected metals using the following relationship (equation 4b) USEPA [17]:

$$HQ_{DERM} = \frac{Exp_{DERM}}{RD_{DERM}} \qquad \dots \qquad (4b)$$

where HQDERM is a unit-less number while RDDERM is the corresponding reference dose for dermal exposure to the heavy metal (□g/kg.day).

Table (2). Values of risk parameters for non-cancer risk assessment of heavy metals (Source: USEPA 2004)

Risk parameter	**Abbreviation**	**Units**	**Recommended value**
Average exposure time[1]	*AT*	hours/day	10,950
Body weight	*BW*	kg	70
Dermal permeability coefficient	*Kp*	cm/hour	0.2
Exposure duration	*ED*	year	30
Exposure frequency	*EF*	day/year	365
Exposure time during bathing	*ET*	hours/day	0.58
Exposed skin area	*SA*	cm^2	28,000
Ingestion rate	*IR*	Liter/day	2.2
Unit conversion factor	*CF*	L/cm^3	0.001

[1]*AT = EF x ED*

Subsequently, hazard indices can be calculated (using equations 5a and 5b) by aggregating the estimated values of HQING and HQDERM for all the heavy metals in groundwater being investigated USEPA [17].

$$HI_{ING} = \sum_{i=1}^{n}(HQ_{ING})_n \quad \dots (5a)$$

$$HI_{DERM} = \sum_{i=1}^{n}(HQ_{DERM})_n \quad \dots (5b)$$

where HIING and HIDERM are the hazard indices for oral ingestion and dermal exposures and n is the number of heavy metals.

Finally, risk characterization is carried out by integrating the information obtained from above steps of risk assessment to make an overall conclusion for establishing the need for further studies and for facilitating the decision-making process [12].

Table (3). Permeability coefficients, reference doses, and slope factors (Source: IRIS [16])

No.	**Heavy metal**	**Symbol**	***Kp* (cm/hour)**	**RD_{ING} (□g/kg.day)**	**RD_{DER} (□g/kg.day)**
1	Arsenic	Ar	1.0×10^{-3}	0.3	0.285
2	Antimony	Sb	-	0.4	0.00006
3	Barium	Ba	-	200	-
4	Berylium	Be	-	2	-
5	Boron	B	-	200	-
6	Cadmium	Cd	1.0×10^{-3}	0.5	0.025
7	Chromium	Cr	2.0×10^{-3}	3	0.075
8	Copper	Cu	1.0×10^{-3}	40	8
Table (3). continued					
No.	**Heavy metal**	**Symbol**	***Kp* (cm/hour)**	**RD_{ING} (□g/kg.day)**	**RD_{DER} (□g/kg.day)**
9	Iron	Fe	1.0×10^{-3}	700	140
10	Lithium	Li	1.0×10^{-3}	-	-
11	Manganese	Mn	1.0×10^{-3}	24	0.96
12	Molybdenum	Mo	-	5	-
13	Selenium	Se	1.0×10^{-3}	5	2.75
14	Silver	Ag	-	5	-
15	Strontium	Sr	-	600	-
16	Thallium	TI	-	0.8	-
17	Vanadium	V	-	9	-
18	Zinc	Zn	6.0×10^{-4}	300	60

Note: Unavailable values are due to inadequate studies or insufficient evidence of non-carcinogenicity, and non-carcinogenic effect.

3. Results and Discussions

The results of laboratory analysis showing minimum, mean, maximum, standard deviation, and coefficient of variations for all the heavy metals are presented in Table (4). It can be seen in the table that the mean values for all the heavy metals are less than both the WHO guidelines and regional water quality standards obtained from the Water Directorate of Buraydah (WDoB). Manganese (Mn) is an exception with the maximum value of 534 ppb which is higher than the WHO guideline value of 400 ppb. However, the whisker plot for Mn shown in Figure (2.a) reveals that almost 75% (third quartile) of the values were found less than 400 ppb. It can also be observed that Mn concentration was found to be higher than regional guidelines value of 100 ppb for most the cases. Regional guidelines were established based on the possible impacts of Mn on sanitary ware, laundry, and subsequent treatment processes [4,5]. The whisker plot for Strontium (Sr) is shown separately in Figure (2.b) due to larger observed values than the remaining metals. Table (1) shows that no health based guidelines were recommend either in WHO guidelines or the KSA drinking water quality standards. USEPA [19] recommends a lifetime health advisory of 4000 ppb for Sr in drinking water. This value was based on some evidence that higher concentration of Sr can increase the density of bones in human body.

Non-carcinogenic human health risk assessment (based on average concentrations of heavy metals) was carried out using equations (1) to (4) and the summary of results is presented in Table (5). Reference doses (RD) recommended by IRIS (2019) were used for estimating HQING and HQDER. Other risk factors in the equations, including AT, BW, Kp, ED, EF, ET, SA, IR, and CF, listed in Table (2) were used in risk assessment. For estimating average exposure time (AT = ED x 365), ED value of 30 was used for calculating RDING for non-carcinogenic risk. Subsequently, HIING and HIDER, estimated using equation (5), were found to be 1.27 and 0.31. As per USEPA (1989), values of hazard quotients and hazard indices higher than 1.0 direct towards a potential human health risk associated to non-carcinogenic elements. Heavy metals can be ordered in descending order based on the calculated values of HQING as: Manganese (Mn)> Vanadium (V) > Chromium (Cr) > Arsenic (Ar) > Strontium (Sr) > Boron (B) > Barium (Ba) > Cadmium (Cd) > Selenium (Se) > Zinc (Zn) > Antimony (Sb) > Beryllium (Be) > Thallium (TI) > Silver (Ag) > Copper (Cu) > Molybdenum (Mo) > Iron (Fe). HQING values of heavy metals in lower order, after Ar, are less than 0.1 and thus show negligible contribution to the overall HIING.

Table (4). Summary of heavy metals concentrations (ppb) in the groundwater of study area

No	Heavy Metal	Symbol	Guideline values (ppb)		Minimum	Maximum	Mean	Standard Deviation (SD)	Coefficient of Variation (CV)
			WHO[a]	KSA					
1	Arsenic	Ar	10	50	0	4.18	1.326	1.494	1.126
2	Antimony	Sb	20	10	0	0.65	0.018	0.108	6.000
3	Barium	Ba	700	700	48.71	308.16	155.7	86.83	0.558
4	Berylium	Be	-	1	0	0.7	0.070	0.139	1.990
5	Boron	B	2400	500	34.95	287.57	174.25	51.414	0.295
6	Cadmium	Cd	3	5	0	0.51	0.201	0.179	0.890
7	Chromium	Cr	50	50	3.18	35.87	27.22	5.619	0.206
8	Copper	Cu	2000	1000	0	15.6	0.910	3.304	3.632
9	Iron	Fe	2000	1000	0	58.7	7.89	16.205	2.053
10	Lithium	Li	-	-	0.32	114.05	46.32	29.045	0.627
11	Manganese	Mn	400	100	0	534.17	277.81	131.638	0.474
12	Molybdenum	Mo	70	70	0	0.97	0.103	0.232	2.247
13	Selenium	Se	40	10	0	5.19	1.094	1.724	1.575

No	Heavy Metal	Symbol	Guideline values (ppb)		Minimum	Maximum	Mean	Standard Deviation (SD)	Coefficient of Variation (CV)
			WHO[a]	KSA					
14	Silver	Ag	10	100	0	3.38	0.140	0.620	4.436
15	Strontium	Sr	-	-	506	3369.3	1084.8	585.5	0.540
16	Thallium	TI	-	-	0	0.47	0.026	0.109	4.182
17	Vanadium	V	-	-	32.53	188.74	97.84	30.478	0.312
18	Zinc	Zn	3000	5000	0	299.05	59.94	54.619	0.911

[a] World health Organization (WHO) [5]

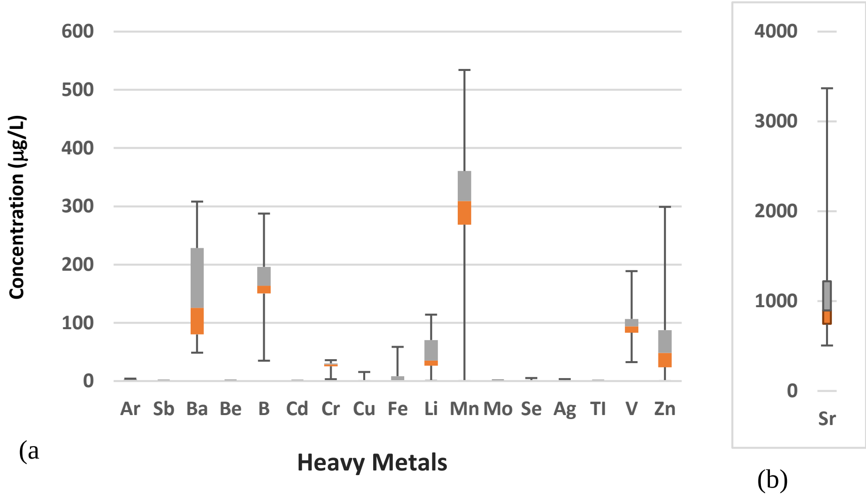

Fig. (2). Whisker plots showing minimum, median, maximum, 25% quartile and 75% quartile values for all the metals, a) all other heavy metals, b) Strontium

Table (5) Non-carcinogenic human health risk assessment results

No	Heavy Metal	Symbol	C_{water}		Kp	Exp_{ING}	Exp_{DER}	RD_{ING}	RD_{ING}	HQ_{ING}	HQ_{DER}
			ppb	ppm	(cm/hour)	□g/kg.day	□g/kg.day	□g/kg.day	□g/kg.day		
1	Arsenic	Ar	1.33	0.001	0.001	0.0417	0.000308	0.3	0.285	0.1389	0.0011
2	Antimony	Sb	0.02	0.00002	0.001	0.0006	0.000004	0.4	0.00006	0.0014	0.06982
3	Barium	Ba	155.66	0.156	-	4.8923	-	200	-	0.0245	-
4	Beryllium	Be	0.07	0.0001	-	0.0022	-	2	-	0.0011	-
5	Boron	B	174.25	0.174	-	5.4764	-	200	-	0.0274	-
6	Cadmium	Cd	0.20	0.0002	0.001	0.0063	0.000047	0.5	0.025	0.0126	0.00182
7	Chromium	Cr	27.22	0.027	0.002	0.8555	0.012631	3	0.075	0.2852	0.16841
8	Copper	Cu	0.91	0.001	0.001	0.0286	0.000211	40	8	0.0007	2.64E-05
9	Iron	Fe	7.89	0.008	0.001	0.2481	0.001831	700	140	0.0004	1.31E-05
10	Lithium[1]	Li	46.32	0.046	0.001	1.4559	0.010747	-	-	-	-
11	Manganese	Mn	277.81	0.278	0.001	8.7311	0.064452	24	0.96	0.3638	0.06714
12	Molybdenum	Mo	0.10	0.0001	-	0.0032	-	5	-	0.0006	-
13	Selenium	Se	1.09	0.001	0.001	0.0344	0.000254	5	2.75	0.0069	9.23E-05
14	Silver	Ag	0.14	0.0001	-	0.0044	-	5	-	0.0009	-
15	Strontium	Sr	1084.80	1.085	-	34.0938	-	600	-	0.0568	-
16	Thallium	TI	0.03	0.00003	-	0.0008	-	0.8	-	0.0010	-
17	Vanadium	V	97.84	0.098	-	3.0749	-	9	-	0.3417	-
18	Zinc	Zn	59.94	0.060	0.0006	1.8837	0.008343	300	60	0.0063	0.00014

[1] reference doses are not available

Manganese (Mn) was found the highest-order contributor to non-carcinogenic health impacts with the highest HQING value of 0.364. IRIS (2019) reported

'Medium' confidence on reported value of RDING. Average concentration of Mn was found to be around 0.28 mg/L which is less than the WHO health-based guideline value of 0.4 mg/L. However, in 8 % of the thirty seven samples, Mn was found in concentrations higher than 0.4 mg/L. The heavy metal ordered at second place is Vanadium, IRIS (2019) has reported 'Low' confidence on its RDING presented in Table (5). As per the toxicological review presented in Table (2), naturally occurring Vanadium (V) is not harmful to human health in low doses (as monitored in the study area, i.e., 0.1 mg/L). IRIS also documented 'Low' confidence on RDING of Chromium which is the third highly contributing metal to HIING. Although, health impacts of Cr have been reported in literature (IRIS 2019, WHO 2011), also see Table (1), its concentration is less than the health-based standards of 50 ppb in the study area. Arsenic is the fourth highly contributing metal in Table (5) with an average concentration of 1.33 ppb. The highest concentration of Ar in the thirst seven groundwater samples was found to be 4.18 ppb (data not shown) which is much lower than the health-based guideline value of 10 ppb as recommend by the WHO. However, a total value of HIING > 1.0 indicates that the ground water needs to be further investigated to establish non-carcinogenic exposure in the study area.

The estimated hazard quotients for dermal exposure (HQDER) are also listed in Table (5) for different heavy metals. Non-carcinogenic health risk through dermal exposure was calculated only for the metals with reported dermal permeability coefficients (Kp) and reference doses (RDDERM). Heavy metals are ordered in descending order based on the calculated values of HQDER as: Chromium (Cr) > Antimony (Sb) > Manganese (Mn) > Cadmium (Cd) > Arsenic (Ar) > Zinc (Zn) > Selenium (Se) > Copper (Cu) > Iron (Fe). It can be observed from the last column of Table (5) that HQDER for all the heavy metals are very low, i.e., less than 0.1, excluding Cu. Moreover, the total calculated value of HIDER was found to be 0.31 (i.e., sum of last column), which is less than 1.0, shows that there are no significant health impacts due to dermal exposure in the study area. However, these results contain different types of uncertainties associated to limited data, measurement errors, human errors, and exposure durations. Future studies are recommended for detailed human health risk assessment in Qassim Region for effective decision-making.

4. Conclusions and Recommendations

Thirty seven samples obtained from groundwater in Buraydah City (Qassim, KSA) were analyzed for heavy metals. Only in 8% of the samples, Manganese (Mn) concentration was found to be higher than WHO drinking water quality guidelines. The concentrations of all the remaining (17) heavy metals were found to be less than WHO guidelines.

Chronic health hazard assessment is recommended for water sources contaminated with naturally occurring heavy metals. Very low concentrations of some of the heavy metals, including Antimony (Sb), Copper (Cu), Molybdenum (Mo), Selenium (Se), Silver (Ag), and Thallium (TI) were found in very few samples. Therefore, these are not the elements of higher importance.

Based on the human health risk assessment results, it can be stated that the population in the study using untreated water is exposed to 'medium' level of non-carcinogenic risk (i.e., HIING > 1.0) through oral ingestion. Primary contributors to Hazard Index for ingestion (HIING) are Manganese (Mn), Vanadium (V), Chromium (Cr), and Arsenic (Ar), thus should be given importance in subsequent investigations for human health risk assessment in Qassim Region. However, non-carcinogenic risk due to dermal exposure is 'low', i.e., HQDER < 1.0.

The results of the present study are based on limited number of groundwater samples, it is recommend that further investigations should be conducted for detailed human health risk assessment. Future studies should include careful identification of exposed population and type of people exposed, e.g., males, females, and children.

5. Acknowledgements

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6. References

[1] Haider, H., Al-Salamah, I.S. and Ghumman, A.R., "Development of Groundwater Quality Index using Fuzzy-based Multicriteria Analysis for Buraydah, Qassim, Saudi Arabia", Arabian Journal for Science and Engineering, Vol. 42, No.9, (2017), pp. 4033-4051.

[2] Zaidi, F.K., Nazzal, Y., Ahmed, I., Naeem, M., "Identification of potential artificial groundwater recharge zones in northwest Saudi Arabia using GIS and Boolean logic", Journal of African Earth Sciences, Vol. 111, (2015), pp,156-169.

[3] Bamousa, A.O., El Maghraby, M., "Groundwater characterization and quality assessment, and sources of pollution in Madinah, Saudi Arabia", Arab Journal of Geoscience, Vol. 9, (2016), pp. 536.

[4] Haider, H., "Performance Assessment Framework for Groundwater Treatment Plants in Arid Environments: A Case of Buraydah, Saudi Arabia", Environmental Monitoring and Assessment, Vol. 189, No. 11, (2017), pp. 544.

[5] WHO, "Guidelines for Drinking Water Quality, Fourth Edition", WHO Press, World Health Organization, Geneva, Switzerland. (2011), pp 228.

[6] Al-Hobaib, A.S., Al-Jaseem Q.K., Baioumy H.M., Ahmed A.H., "Heavy metals concentrations and usability of groundwater at Mahd Adh Dhahab gold mine, Saudi Arabia Arab", Arabian Journal of Geosciences, Vol 6 (2013), pp 259–270.

[7] Assubaie F.N., "Assessment of the levels of some heavy metals in water in Alahsa Oasis farms, Saudi Arabia, with analysis by atomic absorption spectrophotometry", Arabian Journal of Chemistry, Vol 8, No 2 (2015), pp 240-245.

[8] Zabin, S.A., Foaad, M.A., Al-Ghamdi A.Y., "Non-Carcinogenic Risk Assessment of Heavy Metals and Fluoride in Some Water Wells in the Al-Baha Region,

Saudi Arabia" Human and Ecological Risk Assessment, Vol 14 No 6, (2008), pp 1306-1317.

[9] Ahmed, I., Nazzal, Y., Zaidi, F.K., Al-Arifi, N.S.N., Ghrefat, H., Naeem, M., "Hydrogeological vulnerability and pollution risk mapping of groundwater in the Saq and overlying aquifers using the DRASTIC model and GIS techniques", Environmental Earth Sciences, Vol 74, No 2 (2015) pp 1303-1318.

[10] Al-Salamah, I.S., Ghazaw, Y.M., Ghumman, A.R., "Groundwater modeling of Saq aquifer Buraydah Al Qassim for better water management strategies", Environmental Monitoring and Assessment, Vol 173 (2011) pp 851– 860.

[11] USEPA, "Dermal Exposure Assessment: A Summary of EPA Approaches" United States Environmental Protection Agency, Washington DC, USA. (2007), EPA 600/R-07/040F.

[12] USEPA, "Risk Characterization – Science Policy Council Handbook", United States Environmental Protection Agency, Office of Research and Development, Washington DC, USA (2000) EPA 100-B-00-002.

[13] Wu B, Zhang Y, Zhang X, Cheng S, "Health risk from exposure of organic pollutants through drinking water consumption in Nanjing, China", Bulletin of Environmental Contamination and Toxicology, Vol 84 (2010) pp 46-50.

[14] Masok, F.B., Masiteng, P.L., Mavunda, R.D., Maleka, P.P., "Health Effects Due to Radionuclides Content of Solid Minerals within Port of Richards Bay", South Africa. International Journal of Environmental Research and Public Health 13 (2016) pp1180.

[15] USEPA, "Risk Assessment Guidelines for Superfund, Vol 1, Human Health Evaluation Manual, Part A (interim Final), Office of Emergency and Remedial Response, Washington DC, USA. (1989) EPA/540/1-89/002.

[16] IRIS, Integrated Risk Information System, United States Environmental Protection Agency, < https://www.epa.gov/iris> cited in January 2019.

[17] USEPA, "2011 Exposure Factors Handbook", United States Environmental Protection Agency. Washington DC, USA, (2012) EPA/600/R-09/052F.

[18] Iqbal, J., Shah M.H., "Health Risk Assessment of Metals in Surface Water from freshwater source lakes, Pakistan", Human and Ecological Risk Assessment, Vol 19 (2013), pp 1530-1543.

[19] DSPS, "Strontium in Drinking Water, Human Health Hazards", Wisconsin Department of Safety and Professional Services, Department of Health Services, Division of Public Health, Wisconsin, USA (2015).

[20] WHO, "Guidelines for drinking-water quality, Health criteria and other supporting information". Volume 2, World Health Organization, Geneva, (1996).

[21] Liaugaudaite, V., Mickuviene, N., Raskauskiene, N., Naginiene, R., Sherc, L., Lithium levels in the public drinking water supply and risk of suicide: A

pilot study, Journal of Trace Elements in Medicine and Biology, Vol 43 (2017) pp197-201.

[22] Water Technology, Contaminant of the month: Strontium revisited. Retrieved from < https://www.watertechonline.com/contaminant-of-the-month-strontium-revisited/> on 12th January 2019.

[23] ATSDR, Toxicological profile for thallium. Atlanta, Agency for Toxic Substances and Disease Registry, GA: U.S. Department of Health and Human Services, Public Health Service (1992).

[24] Hawaii State Department of Health, Vanadium is naturally occurring in Hawaii's drinking water and not considered to be harmful at the levels present, Statement regarding vanadium in drinking water (2014).

تقييم المخاطر الصحية غير السرطانية للمعادن الثقيلة في المياه الجوفية لمنطقة القصيم بالمملكة العربية السعودية

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ملخص البحث. في منطقة القصيم بالمملكة العربية السعودية ، تأثرت المياه الجوفية بسبب وجود أملاح طبيعية ، نويدات مشعة ، ومعادن ثقيلة. تقوم البلديات بتوفير المياه المأمونة للمجتمع بعد عمليات المعالجة الفعالة في المناطق الحضرية. بينما في القرى والمزارع خارج حدود المدن ، يستخدم السكان إمدادات المياه غير المعالجة للشرب والاستحمام من الآبار الخاصة ، وبالتالي يتعرضون لمخاطر صحية محتملة. في البحث الحالي ، تم إجراء تقييم للمخاطر الصحية فيما يتعلق بالمخاطر المحتملة غير المسرطنة والمسرطنة الناتجة عن وجود الفلزات الثقيلة بشكل طبيعي في المياه الجوفية. تم إجراء تقييم كمي للمخاطر بالنسبة للسكان الذين يعيشون خارج حدود نظام الإمداد بالمياه في بريدة. تم تحليل ثمانية عشر معدن ثقيل ببيانات سبعة وثلاثين عينة من المياه الجوفية. في ٨ ٪ من العينات ، كان تركيز المنغنيز (Mn) أعلى من إرشادات منظمة الصحة العالمية بشأن جودة مياه الشرب بينما وجدت مستويات المعادن المتبقية أقل من القيم الإرشادية. في عينات قليلة ، تم العثور على Sb و Cu و Mo و Se و Ag و TI بتركيزات منخفضة جدًا مما يدل على أن وجود هذه المعادن غير ملموس. تظهر نتائج الدراسة أن السكان يتعرضون لمستوى "متوسط" من المخاطر غير المسببة للسرطان (HIING> 1.0) عن طريق الفم.

Mn .و V و Cr و Ar هم المساهمون الرئيسيون في المخاطر غير المسببة للسرطان وينبغي إيلاء أهمية في الدراسات المستقبلية لتقييم المخاطر الصحية في منطقة الدراسة. وجد ان الخطر غير المسرطن بسبب تعرض للجلد لهذه المعادن "منخفض" مع HIDER <1.0.