

Assessment of the bacteriological quality and the health risk of heavy metals (non-carcinogenic and carcinogenic) of Household drinking water in Zabid City /Yemen

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Abstract:

The objective of this work is to assess the bacteriological quality and its safety to the public and evaluate the health risks of exposure to heavy metals in household drinking water (HDW) in Zabid City, Yemen. Samples were collected, and chemical and microbiological analyses were carried out according to the standard methods suggested by the American Public Health Association . The microbiological results of this work showed that 63% of samples were found positive for fecal coliform (*E. coli*). Other contaminating bacteria besides *E. coli* were identified and confirmed by biochemical tests. The concentrations of F-, NO₃, Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al, and Ba were under the permissible limits set by WHO and local standards. The results of the health risk assessment illustrated that the Hazard Index (HI) values in 96% of the samples exceeded the safe limit of HI < 1.0, indicating that there is a potential health risk (non-carcinogenic) due to the consumption of drinking water in Zabid City. The Cancer Risk values of Cr and Cd in all HDWs were within the safe limit (10⁻⁴), but the CR values of Ni were higher than the safe limit (10⁻⁴) in 83% of samples, indicating that Ni had a chance of cancer risk. Treating water before drinking by boiling or chlorination to avoid microbiological pollution was recommended.

Key words: Health risk assessment, Bacteriological quality, Drinking water, Zabid City, Yemen.

الملخص:

يهدف هذا البحث إلى تقييم الجودة البكتريولوجية وسلامتها على الجمهور، وتقييم المخاطر الصحية الناجمة عن التعرض للمعادن الثقيلة في مياه الشرب المنزلية في مدينة زبيد، اليمن. جُمعت العينات، وأُجريت عليها تحاليل كيميائية وميكروبيولوجية وفقًا للطرق القياسية التي اقترحتها الجمعية الأمريكية للصحة العامة. أظهرت النتائج الميكروبيولوجية لهذا العمل وجود بكتيريا القولون البرازية (الإشريكية القولونية) في 63% من العينات. كما تم تحديد بكتيريا ملوثة أخرى إلى جانب الإشريكية القولونية، وتأكيدها بالتحليل الكيميائي الحيوي. وكانت تركيزات F-، NO₃، Cu، Zn، Cd، Cr، Mn، Co، Ni، Fe، Al، و Ba أقل من الحدود المسموح بها التي وضعتها منظمة الصحة العالمية والمعايير المحلية. أظهرت نتائج تقييم المخاطر الصحية أن قيم مؤشر الخطر (HI) في 96% من العينات تجاوزت الحد الآمن البالغ HI < 1.0، مما يشير إلى وجود خطر صحي محتمل (غير مسرطن) نتيجة استهلاك مياه الشرب في مدينة زبيد. كانت قيم خطر الإصابة بالسرطان للكروم والكادميوم في جميع العينات ضمن الحد الآمن (10⁻⁴)، بينما كانت قيم مؤشر الخطر للنكل أعلى من الحد الآمن (10⁻⁴) في 83% من العينات، مما يدل على أن النكل لديه فرصة لخطر الإصابة بالسرطان. لذا نوصي بمعالجة المياه قبل الشرب بالغليان أو الكلورة لتجنب التلوث الميكروبيولوجي.

الكلمات المفتاحية: تقييم المخاطر الصحية، الجودة البكتريولوجية، مياه الشرب، مدينة زبيد، اليمن.

1. Introduction

Frequent outbreaks of water-borne infections in both rural and urban areas of developing countries serve as a warning that water quality is becoming a serious issue. It is estimated that 842,000 people die from diarrheal disease each year as a result of water borne illnesses, which continue to pose a serious health threat in many regions of the world. (Chalchisa, et al: 2017,p1) According to World Health Organization each year 3.4 million people, mostly children, die from water borne diseases. According to United Nations Children's Fund assessment, 4000 children die each day as a result of contaminated water(Pandey, et al:p2). Bacterial contamination could happen at the source, during distribution, during transit, or as a result of improper domestic handling, hygiene, and sanitation procedures (Ondieki,et al:2021,p2). Health risk assessment of heavy metals is usually carried out to evaluation the total exposure to heavy metals among the people in a particular area. Risk assessment of pollutants in humans is based on a mechanistic assumption that such chemicals may either be carcinogenic or non-carcinogenic (Mohammadi, et al: 2019,p1644). The interruption of drinking water supply in Zabeid city from the starting the military conflict hindered the distribution of water to the city's residents, which resulted in the use of storage tanks Water is obtained from unsafe water tanks. Water stored in an unsanitary manner may be contaminated and can cause waterborne diseases. The current work aimed to evaluated bacterial household drinking water quality and health risk assessment of F^- , NO_3^- and selected heavy metals in Zabid city, Yemen.

2. Methodology

2.1 Study area

Zabeid City is located in the southern of Al Hudaydah Governorate in Yemen between latitude (14 11' 41" E) and longitude (43 18' 56" N) in the southern part of the Tehama coastal plain figure (1) and figure (2).



Figure (1): Map of study area



Figure (2): Image satellite map of study area

2.2 Sample collection

Thirty household drinking water samples (HDWS) were collected in the month of December , 2021 from four residential zones from the city of Zabid(Aleali , Aljamie, Almujanbidh and Aljuz). HDWS were collected in 1L sterile glass container for microbiological analysis and 500ml clean polyethylene bottles for heavy metals analysis after being washed using dilute hydrochloric acid and distilled water in the laboratory, and then it is washed several times with the water sample from which the water sample will be collected. All samples were numbered, saved and refrigerated at temperature of 4°C to preserve the cations and the microorganism before transported to the Laboratory for analyses at the Laboratories of Al jarrahi Institute of Health Sciences and the Hydrochemistry in the Department of applied Geology and Environment at the Faculty of sciences at the Jordon University.

2.3 Sample Analysis

For Total Coliforms and fecal coliform were used the Standard Methods for the Examination of Water and Wastewater adapted from the American Public Health Association 1999 based on the Most Probable Number (MPN) technique (APHA:1999,p1786)

The Most Probable Number (MPN):

Presumptive test

Presumptive test was performed by a method of most probable number (MPN). Following strict aseptic procedures, the sample was shaken vigorously. MacConkey broth was used (for total coliform bacteria), inoculation each with 5ml of sample and 5ml of the medium with inverted Durham tubes were incubated at 37°C for 48 hours and examined for acid and gas production. Acid production was determined by colour change of the broth from reddish purple to yellow and gas production was checked for by entrapment of gas in the Durham tube

Confirmatory test of bacteria :Confirmatory test of bacteria was carried out by streaking a loopful of broth from a positive tube in presumptive test onto MacConkey agar plate for pure colonies. The plates were incubated at 37°C for 24-48 hours. Colonies developing on MacConkey agar medium were further identified as faecal coliforms.

Characterization of isolates:

The macroscopic examination for colonies morphology and microscopic examination through Gram staining and biochemical tests (KIA Medium, urease, citrate, indole, Oxidase, and Motility) were used in identifying all isolates(Cheesbrough, Monica: 2006p62).

Flam atomic absorption spectroscopy (FAAS) model AA analyst 200 from Perkin-Elmer company was used as instrumental detection system using hollow cathode lamps.10 cm air-acetylene burner was used for the determination of the metals ion. A Perkin-Elmer Model analyst 200 is a double-beam atomic absorption spectrometer for flame and mercury/hydride analysis. All prepared sample solution was analyzed to determine concentration of F, Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al and Ba. Blank solution was also measured before the sample analysis using the same conditions.

2.4 Health Risk Assessment

The health risk assessment classified as a carcinogen or non-carcinogen and using two indicators: Hazard Quotient(HQ) and Hazard Index(HI) as proposed by US Environmental Protection Agency (USEPA) (Malek &Jari: 2021, p4). In current study, health risk due to ingestion content of heavy metal of household drinking water samples at Zabid city was detected. Equations (1-3) were applied to assessment the non-carcinogen health risk. First the Chronic Daily Intake(CDI) of individual heavy metal was determined based on equation (1) as following:

$$CDI = \frac{CM \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

Where:

CM (mg/L): Concentration of heavy metals in water,

IR: Drinking water ingestion rate ((L/day),

EF: The exposure frequency (Days/year),

ED: The exposure duration (year),

BW: Body weight (kg).

AT: The average resident time (days/year). The input parameters for the estimation of CDI through oral ingestion absorption are summarized in **Table (1)**.

Table(1): The input parameters for the estimation of CDI through oral ingestion absorption.			
Symbol	Description	Unit	Value
Cw	Heavy metal concentration	mg /l	-
IR	Ingestion rate of water	l/day	2.5
EF	Exposure frequency	Days/year	250
ED	Exposure duration	Years	50
BW	Body weight	Kg	55
AT	Averag time	Days	14600
Note: (Dhar, et al: 2020,p240)			

After that the Hazard Quotient(HQ) and Hazard Index were determined by equations(2) &(3)

$$HQ = \frac{CDI}{RfD} \quad (2)$$

Where:

Rfd is reference dose (in mg/kg day) for the metal.

$$HI = \sum_{i=1}^n HQ \quad (3)$$

If the $HI < 1$ means the non-carcinogenic risk is acceptable, while $HI > 1$ indicates the risk is beyond the acceptable level (Luvhimbi, et al: 2022,p5).

The cancer risks(CR) is defined as the likelihood that an individual will develop any type of cancer from lifetime exposure to carcinogenic risk (Seleem, et al: 2021,p6). The Carcinogenic health risk of HDWS was determined based on equation(4).

$$CR = CDI \times SF \quad (4)$$

Where:

SF is the slope factor (mg/kg/day).

Table (2) displays the values of oral reference dose (Rfd) and slope factor (SF).

Table(2): The values of oral reference dose(Rfd) and slope factor(SF).												
	F	NO ₃	Cu	Zn	Cd	Cr	Fe	Mn	Co	Ni	Al	Br
Rfd(mg/kg-day)	0.06	1.6	0.04	0.3	0.0005	0.003	0.7	0.024	0.0003	0.02	1.0	0.2
SF (mg/kg-day)	-	-	-	-	0.38	0.5	-	-	-	1.7	-	-

Note: (Malek &Jari: 2021, p4)

3. Results and Discussions

3.1 Microbiological Content

The total coliform group is considered a primary indicator for the presence bacteria and pathogenesis in drinking water (Saleh and Al-sallami:2022,P109). The World Health Organization(WHO) and Yemen's Ministry of Water and Environment (YMWE) recommended that the absence of total coliform in public drinking water supplies. As illustrated from **Table (3)** all of the HDWS were contaminated with lactose fermentation positive bacteria which were determined by color the formation of gas in the Derhum tube after 24 hours of incubation at 37°C.

According the probability tables, the sixteen of the household drinking water Samples (53.33%) (10,1,11,12,21,22,3,14,16,18,19,20,25,26,29,28) showed maximum counts of positive results for each of the 5 test tubes by observing the formation of gas resulting ≥ 18 MPN/100 ml of sample. samples (2 and 4) showed lowest count as 2 MPN/100 mL of sample. Nineteen (63%) out of 30 water samples were found positive for faecal coliform (*E. coli*). This results surpassed the safe limits of WHO and YMWE Which, that means dangerous indicator of the water pollution.

To demonstrate the full profile of microbial contamination of the (HDWS), other contaminating bacteria besides *Escherichia coli* were identified and confirmed by biochemical determination (**Table 4**). *Klebsiella P Pneumoniae*, *Enterobacter aerogenes*, *Proteus mirabilis*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Salmonella Typhimurium* and *Salomonella Typhi* were identified after conducting the biochemical tests. *Proteus mirabilis* and *Klebsiella P Pneumoniae* were found to be the prominent microorganisms in seven (23%) and six (20%) samples respectively. *Proteus vulgaris* and *Enterobacter aerogenes* were detected in five & six samples respectively. *Pseudomonas aeruginosa* was found in three samples (sample no 1,12 and 27). *Salomonella Typhi* was detected in two samples (sample no 17 & 19). *Salmonella Typhimurium* was found (only in sample no 16). The deterioration of water quality might be due to storing of water, no cleaning drinking water tank periodical, not disinfection the drinking water by boiling or using chlorine and lacking awareness of water polluted water. Previous studies reported that the both unsafe water piped and storing of water attributed to water pollution(Chalchisa, et al:2017,p3) .The results of

microbiological quality in present study agree with previous study such as: according to (Saleh, et al:2017a,P14)the results of groundwater of rural areas for Zabid directorate in Al Hudaydah governorate showed that the total coliform test were positive in all groundwater samples and the E. Coli presences in 95% of studied samples. According to (Saleh & Al-Sallami: 2022,p110) the tests of total coliform and E. Coli were positive in 75% and 15% of ground water in Tuban delta. Similar study by(Bekele and Teka.:2023,p4) in slum households of Hawassa City, Ethiopia found that the tests of total coliform and E. coli were positive in (46.7%) and (31.7%) of studied sampled respectively. According to (Bin Hameed, et al: 2019,p188) the results of microbiological quality in Mukalla City in Hadhramout governorate indicated that the bacterial contamination of drinking water was recorded in 8 schools by Escherichia coli 33%, coliforms of Proteus spp 25%, Citrobacter spp 17% and Staphylococcus spp 25%. The results of drinking water in Kisii Town, Kenya by (Ondieki, et al:2021,p4) recorded that 39.3% of the samples were contaminated with total coliforms and 17.5% with E. coli. According to (Hung, et al:2020,p5) 9.7% and 7.8% of studied samples were contaminated by Coliform and/or E. Coli respectively.

Table (3): The results of microbiological content household drinking water				
Sample	Zone	Total Coliform	MPN/100ml	E. Coli
1	Almujanbidh	Positive	2	+
2		Positive	3	+
3		Positive	6	+
4		Positive	7	+
5		Positive	9	+
6		Positive	16	+
7		Positive	>18	+
8	Aleali	Positive	>18	+
9		Positive	>18	-
10		Positive	>18	-
11		Positive	6	+
12		Positive	>18	+
13		Positive	>18	-
14		Positive	16	+
15		Positive	7	+
16	Aljuz	Positive	>18	-
17		Positive	>18	+
18		Positive	9	-
19		Positive	>18	+
20		Positive	16	-
21		Positive	>18	+
22		Positive	>18	-
23		Positive	>18	+
24	Aljamie	Positive	2	-
25		Positive	9	+
26		Positive	>18	+
27		Positive	>18	+
28		Positive	16	+
29		Positive	>18	-
30		Positive	>18	+

Table (4): Species of bacterial Isolates in household drinking water drinking water samples										
Species	Percentage %	KIA Medium				Urease	Citrate Test	Indole Test	Oxidase test	Motility
		Slope	Butt	H2S	Gas					
Proteus vulgaris	17	R	Y	+	+	+	+	-	-	+
Pseudomonas aeruginosa	10	R	R	-	-	-	+	-	-	+
Salmonella Typhimurium	3	R	Y	+	-	-	+	-	-	+
Salomonella Typhi	7	R	Y	+	-	-	-	-	-	+
Proteus mirabilis	23	R	Y	+	+	+	+	-	-	+
Enterobacter aerogenes	20	Y	Y	-	+	-	+	-	-	+
Klebsiella P Pneumoniae	20	Y	Y	-	+	+	+	-	-	-

3.2 Fluoride, Nitrate and heavy metals concentration in HDWS:

Table (5) presents Descriptive Data of Fluoride, Nitrate and heavy metals in the HDWS in zabied city. The mean concentration of (F^- , NO_3^- , Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al & Ba) were 0.69, 24.51, 0.00313, 0.00313, 0.00156, 0.00253, 0.00346, 0.00153, 0.00293, 0.00613, 0.00293 & 0.127) respectively. As well as the range concentration were (0.38-1.07) for F, (15.14- 32.5) for NO_3^- , (0.001-0.005) for Cu, (0.001-0.006) for Zn, (0.001-0.005) for Cd, (0.001-0.002) for Cr, (0.004-0.009) for Fe, (0.001- 0.006) for Mn, (0.001-0.005) for Co, (0.001- 0.005) for Ni, (0.001-0.005) for Al, and (0.090-0.328) for Ba , The order of the mean concentration of (F^- , NO_3^- , Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al & Ba) in HDWS from four residential zones representing the city Zabid (Aleali, Aljamie, Almujaanbidh, and Aljuz) were as followes : $NO_3^- > F^- > Ba > Fe > Mn > Zn = Cu > Ni = Al > Cr > Cd > Co$. It should be noted that the concentrations of none of these heavy metals (Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al & Ba) and (F- & NO_3) were within the permissible limit by World Health Organization (WHO: 2011,p468) and local standards (Yemen, 1999:p4) The heavy metals can contaminate household drinking; water via nature sources through groundwater movement and surface water seepage and run-off or through anthropogenic sources that come from drinking water transport tanks or bad practices of storage of this water at houses. The health risks of heavy metals to the public due to their toxicity, persistence, and bio accumulative nature (Luvhimbi, et al :2022,p14). The results of this study agree with those obtained in drinking water by (Luvhimbi ,et al2022:p14; ; Yeboah ,et al:2022p162; Rahmanian,et al: 2015p6).On Other hand , The Fluoride, Nitrate and heavy metals concentration in present study were less than same heavy metals in other published international and local studies such as: (Saleh, et al:2020,p155; Mahmoud, et a:2018,p7; Alanazi, et al:2021,p8)

The content of heavy metals in the present study differs in a very small range. This variation may be due to the distribution system, pipe age, and tank age, in addition to air particulate that is deposited in opened tanks of houses.

Table(5): Descriptive data of heavy metals in household drinking water						
Metal	Concentration mg/l					
	Mean	Max	Min	Median	WHO (2011)	YMWE (1999)
F ⁻	0.69	1.07	0.38	0.635	1.5	0.5-1.5
NO ₃ ⁻	24.51	32.53	15.14	27.165	50	10-50
Cu	0.00313	0.005	0.001	0.003	2.00	0.5-1
Zn	0.00313	0.006	0.001	0.003	3.00	5-15
Cd	0.00156	0.002	0.001	0.002	0.003	0.005
Cr	0.00253	0.005	0.001	0.0025	0.05	0.05
Fe	0.00613	0.009	0.004	0.006	0.3	0.3-1.0
Mn	0.00346	0.006	0.001	0.003	0.4	0.1-0.2
Co	0.00153	0.002	0.001	0.002	0.05	-
Ni	0.00293	0.005	0.001	0.003	0.07	0.01-0.02
Al	0.00293	0.005	0.001	0.003	0.4	0.2-0.3
Ba	0.127	0.328	0.009	0.110	1.3	0.5-1.0

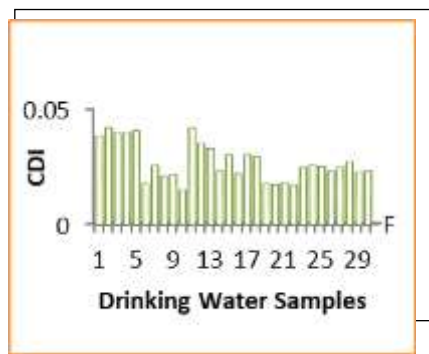
3.3 Health Risk Assessment

3.3.1 Non-carcinogenic health risk assessment:

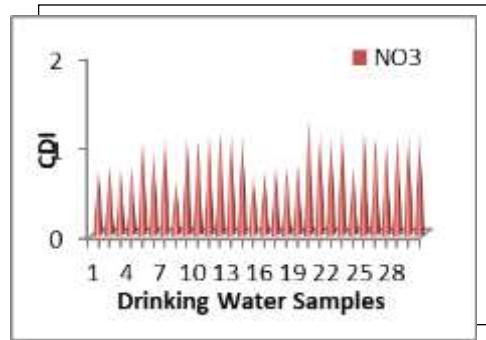
The descriptive statistical of Hazard quotient (HQ) values of individual heavy metals due to consumption of drinking water illustrated in **Table(6)**. The ratio of the CDI and oral reference dose (RfD) of the corresponding heavy metals is called the Hazard quotient (HQ). The mean values of Hazard quotient (HQ) of (F⁻, NO₃⁻, Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al and Ba) were 0.44754, 0.596372, 0.003048, 0.000406, 0.121939, 0.0328628, 0.005621, 0.198907, 0.005708, 0.003409, 0.000112, and 0.024146 respectively. The range of HQ values were (0.246472-0.694012) for F⁻, (0.3868248-0.791222) for NO₃⁻, (0.000973-0.004865) for Cu, (0.000129-0.000778) for Zn, (0.077833-0.155666) for Cd, (0.012972-0.064860) for Cr, (0.000277-0.001667) for Mn, (0.129722-0.259444) for Co, (0.000222-0.000500) for Fe, (3.89166E-05-0.000194) for Al and (0.017512-0.063823) for Ba as shown in **figures 3 to 6**. The results of HQ of individual heavy metals due to consumption of drinking water illustrated that the HQ values of F⁻, NO₃⁻, Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al and Ba were within the safe limit (HQ < 1) Which, that means there is **no potential health risk (non-carcinogenic) associated with the water consumption through ingestion in study area**. The obtained results of HQ of current study agree with the results of HQ of ground water in Radaa City according to (Meftah, et al:2023,p4). which reported that the HQ mean value of Cr, Ni, Mn, Fe and Zn were 0.007337, 0.0243, 0.0245, 0.01736 and 0.0035 respectively. And according to (Dhar, et al :2020, p244) which found that the mean values of HQ of Zn, Cu, Fe and Mn were 0.003, 0.012, 0.012 and 0.017 respectively. Similar observation according to (Luvhimbi, et al:2022, p32) in Thulamela municipality, Limpopo Province, South Africa, which the mean values of HQ were (4.87E-03) for Cu, (2.32E-03) for Zn, (7.68E-04) for Fe, (9.63E-04) for Mn, (3.47E-05) for Co, (3.42E-04) for Ni, and (2.02E-04) for Al. Moreover, a pervious study by (Seleem, et al :2021,p5) reported that the mean of HQ values of Fe, Mn, Cd and Ni were 0.01, 0.29, 0.39 and 0.09 respectively. The results of HQ were higher than the results of present study. In addition, Other published studies reported that the Hazard quotient (HQ) of individual heavy metals due to consumption of drinking water

were within the safe limit ($HQ < 1$) according to (Li, et al.:2018p8; Mahmoud, et al.:2018p11; Maleki & Jari:2021p9 ; and Niknejad, et al: 2023,p6).

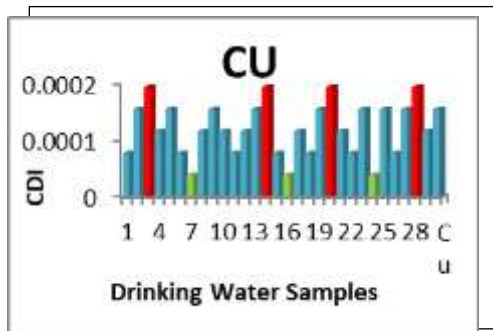
Table(6): The Descriptive statistics of CDI and HQ for individual Fluoride , Nitrate and selected heavy metal in (HDWS)			
Elements		CDI	HQ
F	Mean	0.026852	0.44754
	Max	0.041641	0.694012
	Min	0.014788	0.246472
NO ₃	Mean	0.954195	0.596372
	Max	1.265956	0.791222
	Min	0.589197	0.368248
Cu	Mean	0.000121	0.003048
	Max	0.000194	0.004865
	Min	3.89166E-05	0.000973
Zn	Mean	0.000121	0.000406
	Max	0.000233	0.000778
	Min	3.89166E-05	0.000129
Cd	Mean	6.09693E-05	0.121939
	Max	7.78331E-05	0.155666
	Min	3.89166E-05	0.077833
Cr	Mean	9.85886E-05	0.032862
	Max	0.000194	0.064860
	Min	3.89166E-05	0.012972
Mn	Mean	0.000134	0.000963
	Max	0.000233	0.001667
	Min	3.89166E-05	0.000277
Co	Mean	5.96721E-05	0.198907
	Max	7.78331E-05	0.259444
	Min	3.89166E-05	0.129722
Ni	Mean	0.000114	0.005708
	Max	0.000194	0.009729
	Min	3.89166E-05	0.001946
Fe	Mean	0.000238	0.000340
	Max	0.000350	0.000500
	Min	0.000155	0.000222
Al	Mean	0.000112	0.000112
	Max	0.000194	0.000194
	Min	3.89166E-05	3.89166E-05
Ba	Mean	0.004944	0.024719
	Max	0.012765	0.063823
	Min	0.003502	0.017512



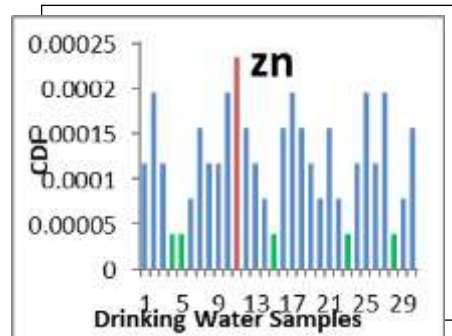
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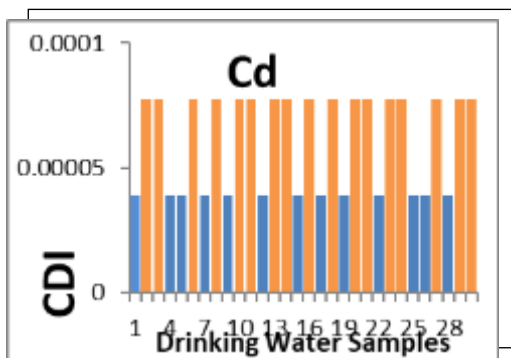
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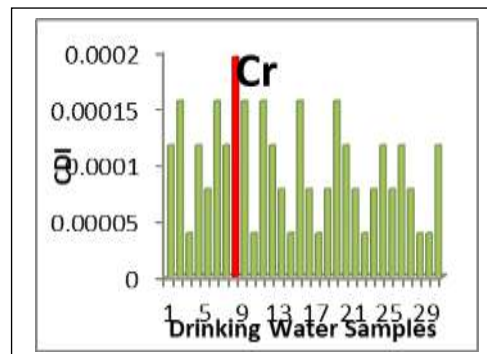
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(d)

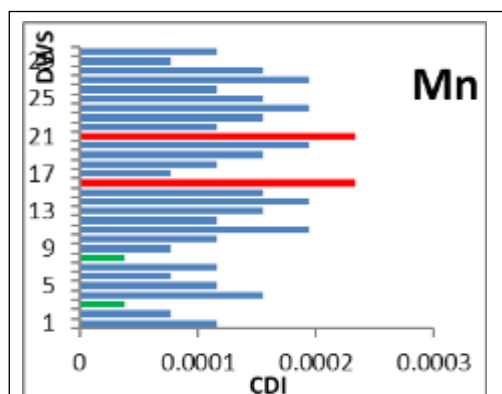


(e)

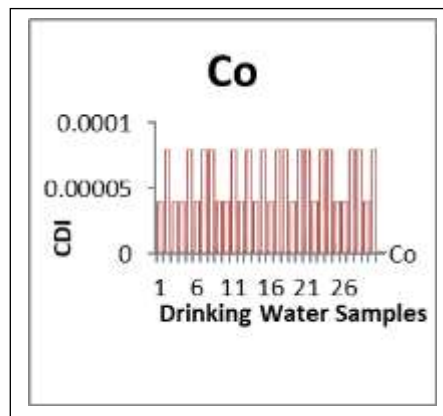


(f)

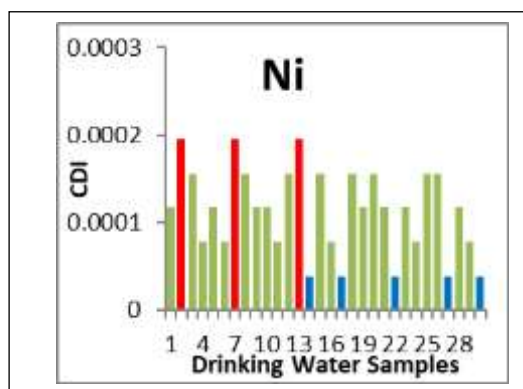
Figures(3): The CDI of F,NO₃ and studied heavy metals (a-f).



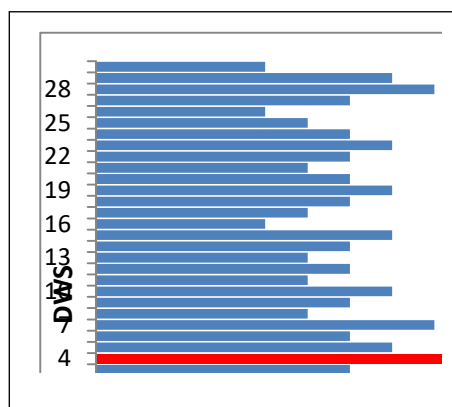
g



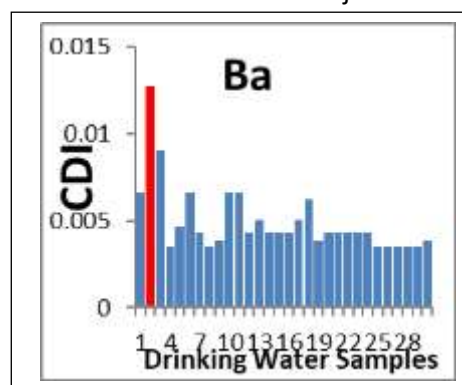
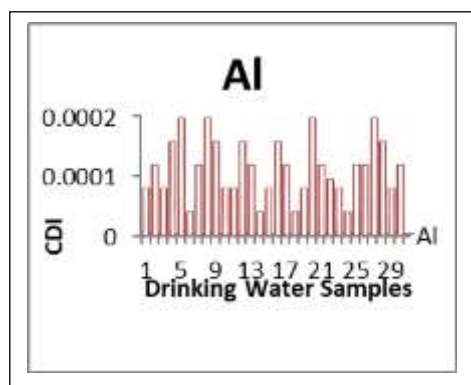
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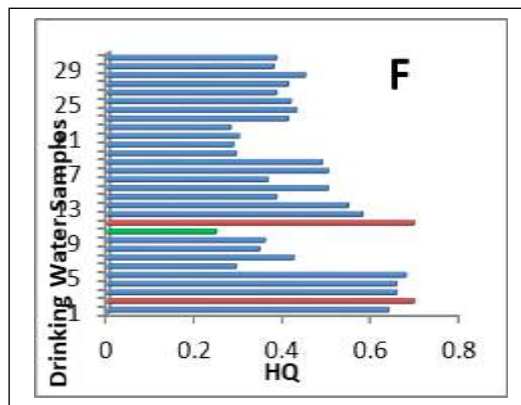
i



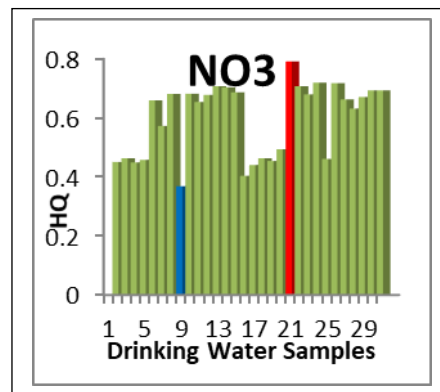
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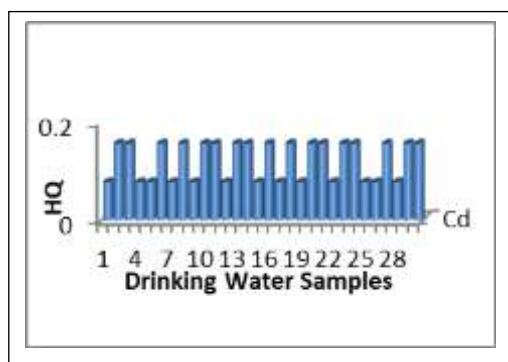
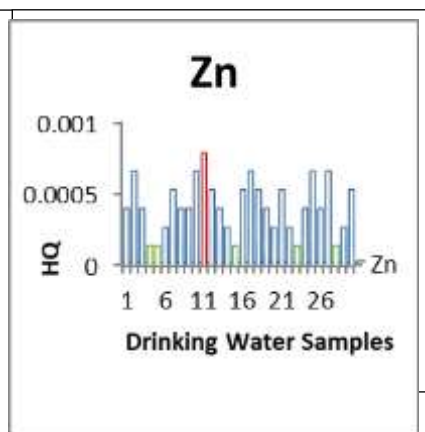
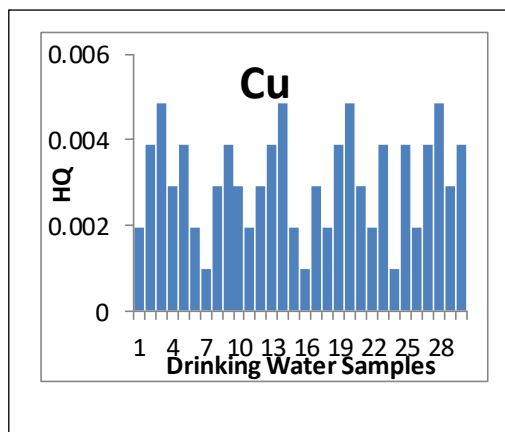
Figures(4): The CDI of studied heavy metals (g-l)



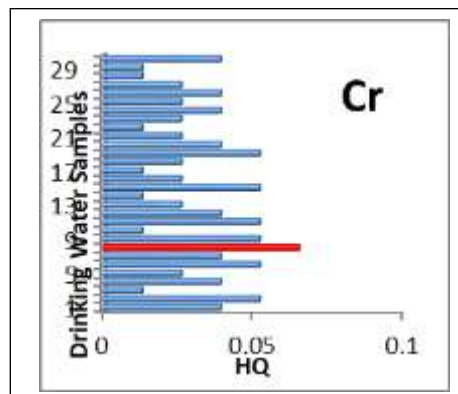
a



b

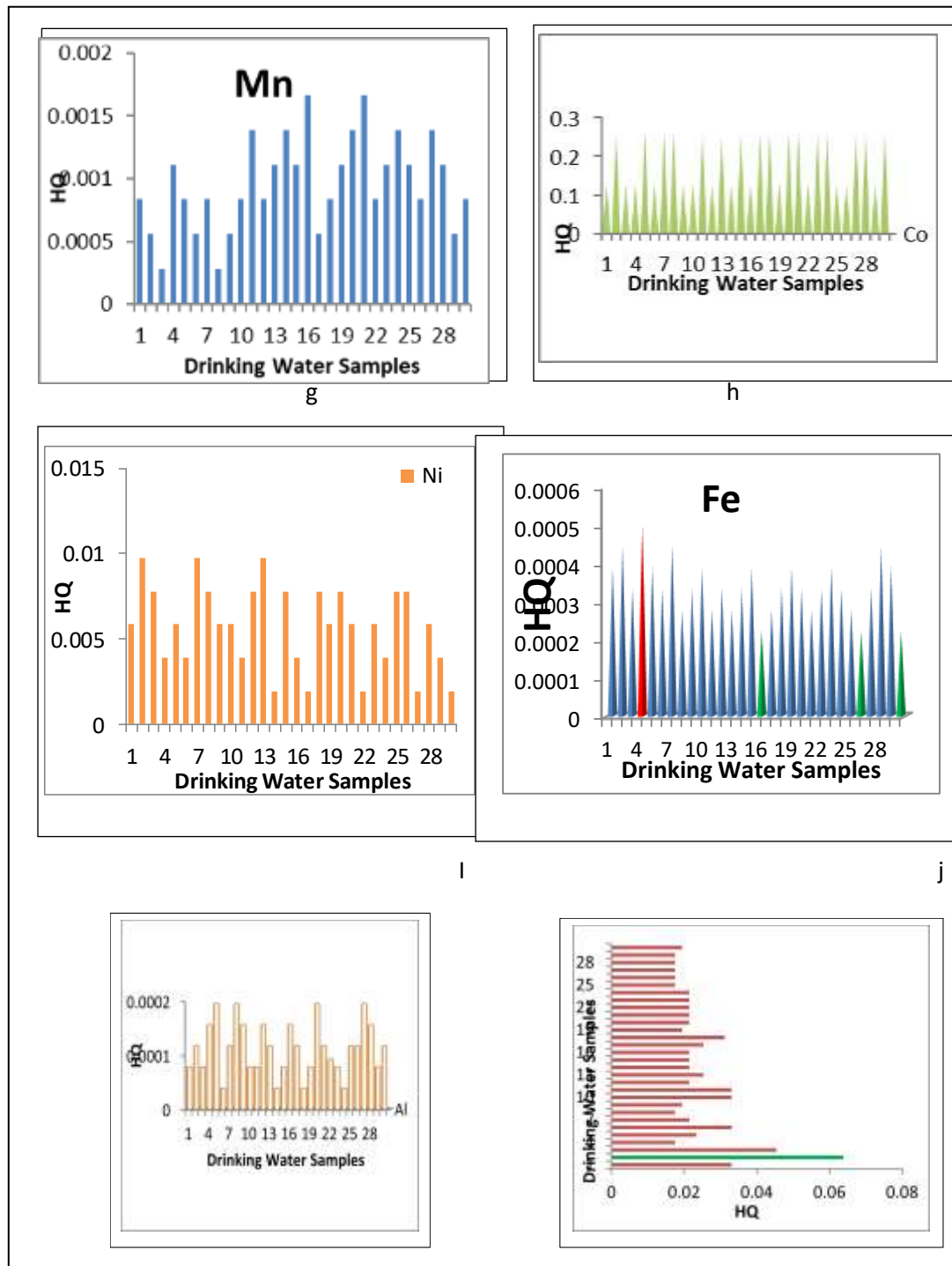


e



f

Figures(5): The HQ of F,NO₃ and studied heavy metals (a-f)



Figures(6): The HQ of studied heavy metals (g-l).

Hazard Index (HI)

To assessment the total potential health risk posed by more than one heavy metal, the Hazard Index (HI) was used. Hazard Index (HI) is the sum of the Hazard quotient (HQ) of all the investigated heavy metals in sampled house. If the value of HI is less than 1.0, the individual is safe from non-carcinogenic health risks (Seleem, et al: 2021,p6). **Figure (7)** shows that the Hazard Index(HI) of (NO_3^- & F^-) and selected heavy metals in sampled houses. The range of HI values were from (0.841952 to 1.901867) with the mean value of (1.416583). The HI values in (96%) of the sampled houses were exceeded the recommended threshold risk limit of $\text{HI} < 1.0$ which is a matter of health concern. **There is potential health risk (non-carcinogenic) from (NO_3^- & F^-) and selected heavy metals concentration due to the consumption of drinking water in Zabid city.** This results due to that the high temperatures in study area and humidity with strong exposure to sunlight, increased the need for daily water consumption. The result of Hazard Index(HI) of present study was a lot less than the result of HI in Assiut City (mean value: 376) according to (Seleem, et al: 2021,p5). A pervious study of drinking water in Khorramabad, Iran, The mean value of HI of drinking water were 0.0033 according to (Mohammadi, et al:2019,p1648) it was less than the result obtained of present study. Other study in Kurdistan, Iran rural water supplies, the mean values of HI were 0.7, 0.83 and 1.67 for men, women and children respectively (Maleki & Jari:2021,p9).

Based on the following categories:

Risk category 1: Negligible risk, where the HI or HQ are < 0.1

_ Risk category 2: Low risk, where the HI or HQ are > 0.1 but < 1.0

_ Risk category 3: Moderate risk, where the HI or HQ are > 1.0 but < 4.0

_ Risk category 4: High risk, where the HI or HQ are > 4.0 (Mahmoud, et al., 2018).

The HI Values of household drinking water categorized at **moderate risk** ($\text{HI} > 1$ but < 4.0).

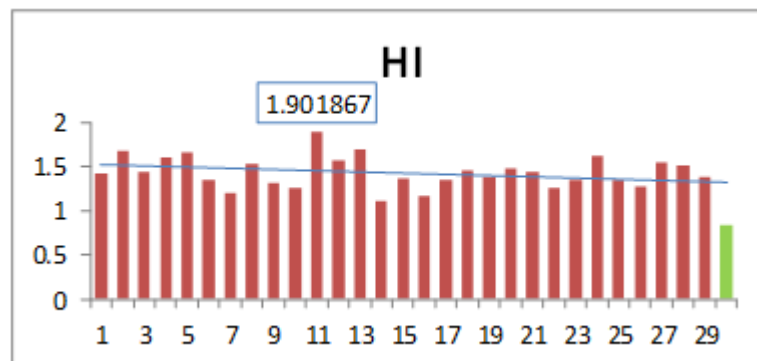


Figure (7): The Hazard Index (HI) of (NO_3^- & F^-) and selected heavy metals in sampled houses

3.3.2 Carcinogenic health risk assessment

Cancer Risk (CR) calculated of Cr, Cd and Ni to estimating the probability of developing cancer due to exposure to a specified carcinogen such as heavy metal in drinking water. Heavy metals (Cr, Cd, and Ni) can potentially enhance the metals might, consequently, result in many types of cancers (Ghahramani, et al:2020,p6; Mohammadi, et al:2019,p1649). For heavy metals, an acceptable carcinogenic risk value of less than 1×10^{-6} is considered as insignificant and the cancer risk can be neglected; while an acceptable carcinogenic risk value of above 1×10^{-4} is considered as harmful and the cancer risk is worrisome(Seleem, et al: 2021,p6). The CR values ranged from (1.95×10^{-5} to 9.73×10^{-5}) for Cr, (1.48×10^{-5} to 2.96×10^{-5}) for Cd and (6.62×10^{-5} to 3.30×10^{-4}) for Ni as shown in **Table (7)** and the mean of cancer risk(CR) values of Cr, Cd and Ni were (4.93×10^{-5} , 2.32×10^{-5} and 1.94×10^{-4}) respectively. The CR values of Cr and Cd in all households drinking water samples studied were fall within

safe limit (1×10^{-6} to 1×10^{-4}) recommended by USEPA as illustrated in **figures (8) and (9)** but the CR values of Ni were higher than safe limit (10^{-4}) in (83%) of samples as illustrated in **figure (10)** indicating that the Ni had a chance of Cancer Risk. The CR result of Ni agree with the CR result of Ni in ground water (mean value of Ni : 4.42×10^{-4}) in Radaa city according to (Meftah, et al:2024,p4). The results of Cancer Risk of Ni in present study were higher than those obtained by(Luvhimbi, et al:2022,p14) which the mean value was 7.52×10^{-6} . The mean values of CR of drinking water in rural areas of Divandarreh County, Kurdistan Province were 9.74×10^{-4} , 1.38×10^{-3} , 3.00×10^{-3} of Cd, Cr and Ni Respectively, according to (Ghahramani, et al:2020,p8) which it was higher than the results of CR in present study and it was above safe limit by USEPA (10^{-4}).

Table(7): The Cancer Risk (CR) associated with the levels of Cr, Ni and Cd

Sample No	CR		
	Cr	Ni	Cd
1	5.83748E-05	0.000198474	1.47883E-05
2	7.78331E-05	0.000330791	2.95766E-05
3	1.94583E-05	0.000264633	2.95766E-05
4	5.83748E-05	0.000132316	1.47883E-05
5	3.89166E-05	0.000198474	1.47883E-05
6	7.78331E-05	0.000132316	2.95766E-05
7	5.83748E-05	0.000330791	1.47883E-05
8	9.72914E-05	0.000264633	2.95766E-05
9	7.78331E-05	0.000198474	1.47883E-05
10	1.94583E-05	0.000198474	2.95766E-05
11	7.78331E-05	0.000132316	2.95766E-05
12	5.83748E-05	0.000264633	1.47883E-05
13	3.89166E-05	0.000330791	2.95766E-05
14	1.94583E-05	6.61582E-05	2.95766E-05
15	7.78331E-05	0.000264633	1.47883E-05
16	3.89166E-05	0.000132316	2.95766E-05
17	1.94583E-05	6.61582E-05	1.47883E-05
18	3.89166E-05	0.000264633	2.95766E-05
19	7.78331E-05	0.000198474	1.47883E-05
20	5.83748E-05	0.000264633	2.95766E-05
21	3.89166E-05	0.000198474	2.95766E-05
22	1.94583E-05	6.61582E-05	1.47883E-05
23	3.89166E-05	0.000198474	2.95766E-05
24	5.83748E-05	0.000132316	2.95766E-05
25	3.89166E-05	0.000264633	1.47883E-05
26	5.83748E-05	0.000264633	1.47883E-05
27	3.89166E-05	6.61582E-05	2.95766E-05
28	1.94583E-05	0.000198474	1.47883E-05
29	1.94583E-05	0.000132316	2.95766E-05
30	5.83748E-05	6.61582E-05	2.95766E-05
Mean	0.0000493	0.0001941	0.0000232
Max	0.0000973	0.0003308	0.0000296
Min	0.0000195	0.0000662	0.0000148

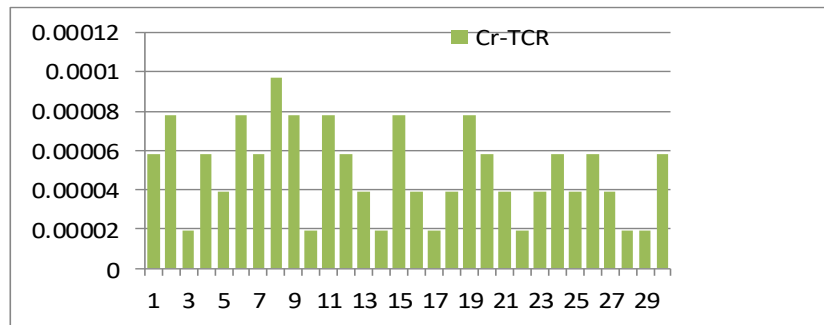


Figure (8): The CR of Cr in Drinking Water Samples

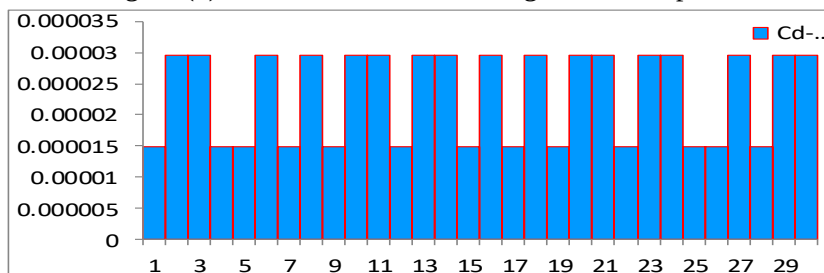


Figure (9): The CR of Cd in Drinking Water Samples

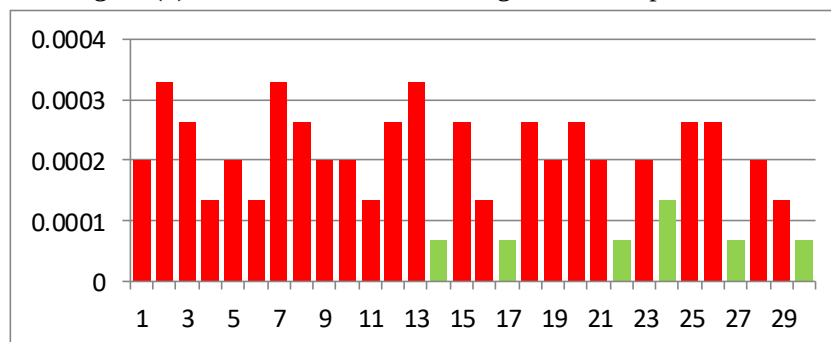


Figure (10): The CR of Ni in Drinking Water Samples

Conclusions and Recommendations

The current study investigated the bacterial quality and health risk assessment to humans of F^- , NO_3^- , Cu, Zn, Cd, Cr, Mn, Co, Ni, Fe, Al and Ba of household drinking water in Zabid City. The results of microbiological content showed that Nineteen (63%) out of 30 water samples were found positive for faecal coliform (*E. coli*). *Klebsiella P* *Pneumoniae*, *Enterobacter aerogenes*, *Proteus mirabilis*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Salmonella Typhimurium* and *Salomonella Typhi* were identified after conducting the biochemical tests. This results surpassed the safe limits of WHO(2011) and YMWE(1999) Which, that means dangerous indicator of the water pollution. The concentrations of F^- , NO_3^- and analyzed heavy metals were within permissible limits of WHO and local standard. The results of analysis health indices (CDI, HQ, HI and CR) showed that there is potential health risk (non-carcinogenic) from (NO_3^- & F^-) and selected heavy metals concentration due to the consumption of drinking water in Zabid City. The Cancer Risk values of Ni were higher than safe limit (10^{-4}) in (83%) of samples indicating that the Ni had a chance of cancer risk. we suggest that the local authorities should ensure water is pumped a minimum of three times each week to mitigate the health risks associated with storing and transporting water. And educate the public on the important of treating drinking water at home through methods such as

boiling and chlorination , in order to reduce microbiological pollution. Additionally, proper maintenance of both the water distribution system and household storage facilities is necessary. Furthermore, there is a need to inform the public about the dangers posed by heavy metals found in drinking water. On other hand we propose that researchers conduct studies to detect microbiological contamination in human bodily fluids. The overall conclusions drawn from this work can assist local authorities in developing an effective plan aimed at enhancing the quality of drinking water.

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