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Water quality hazard assessment for hand dug wells in Rafin Zurfi, Bauchi State, Nigeria

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ABSTRACT

The Nigeria Centre for Disease Control recently reported an outbreak of yellow fever in Bauchi state. To strategize mitigation measures, an investigation into water sources became necessary. This study adopted Water Quality Index (WQI), Target Hazard Quotient (THQ) and Hazard Index (HI) approaches to evaluate water quality from hand-dug wells within Rafin Zurfi area, Bauchi State. The specific objectives were; sample characterization, statistical analysis by SPSS, and determination of health risk analysis by WQI. Water from Hand-dug wells were examined using standard methods of the American Public Health Association (APHA). Experimental results proved that pH values of samples are adequate according to NSDWQ, while samples E and L exceeded the WHO permissible limits. Turbidity, Total hardness, TSS, EC, BOD, Ca, SO_4^{2-}, Cl^-, Cu and Zn measurements were all within permissible limits. The analytical results were taken in to Geographic Information Systems environment (GIS) to generate numerical spatial variation maps for parameters examined and show the health risk associated to heavy metals. HI values for adults and children were found to be 4.365119×10^{-3} and 5.180528×10^{-3}, respectively. Therefore, the study concludes that, there is no significant danger of metal toxicity from the sample wells (since HI < 1).

1. Introduction

Survival of living things solemnly depends on water [1]. A limited resource that needs sustainable management. Globally, the sustainable development goal for every society depends on factors such as public health, food security, industrial growth, livelihood and economic development. These cannot be achieved without quality water [2]. The quality and quantity of water resource worldwide is a subject of ongoing concern [3]. Thus, knowledge of the impact of pollution sources on water resources is essential in environmental water studies [4]. Water quality studies and monitoring programs are being increasingly used due to an increase in water pollution incidents [5]. Evaluation of water quality is complicated because water pollution is caused by both natural and human factors [6]. Human factors such as the release of effluents from human waste, chemical discharges, pesticides, fertilizers, insecticides and herbicides, radioactive wastewater, petroleum hydrocarbons, dyes, detergents [7,8] and community market waste, have resulted in excessive loading of pollutants in hand-dug wells. Natural factors to include; temporal changes in the hydrologic cycle, the origin and constitution of the recharged water. Water pollution is a threat to human health, economic development, and social prosperity [9]. Human, plants and aquatic exposure to organic pollutants along with heavy and organic metal compounds through water and food can result in chronic and sometimes dangerous acute toxicities [7]. Therefore, it is significant to control water pollution and monitor water quality [10].

Groundwater is considered the major portion of the world's freshwater resources. It accounts for 26% of global renewable freshwater resources [11]. Its quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and on sub-surface geochemical processes [10]. Groundwater,

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generally collected from profound or shallow hand-dug wells, boreholes and springs are the rural community's primary source of drinking water [12]. It is the most appropriate water resource for use [13] as it becomes their main source of clean water [14]. The easiest and cheapest alternative water supply is groundwater because it occurs in a broad spectrum of rock types. It is the life support for humanity as they depend on it for domestic, agricultural and industrial activities [15]. Liquefied mineral ions that usually degrade water quality class and influence its usefulness for different reasons are mostly present in groundwater. It then becomes necessary to check the groundwater quality to confirm its appropriateness for the intended purpose [16].

The availability and affordability of qualitative groundwater are declining throughout the globe [17]. For the past two decades, Nigeria has continuously been in a stage where the quantity of water supply is increasingly depleting while there is rapid increase in the water demands [18]. The challenges facing water sector in Nigeria are enormous and require the mobilization of all resources in an integrated manner [19]. The rapid increase in human population coupled with their daily activities was found to be the root causes [20] of water scarcity. Improper solid waste management [21] causes many ecological and public health issues [22], in addition to socio-environmental effects [23].

Nigeria is faced with the environmental impact of poor waste management [24], such as odour, blockage of drainages, water and air pollution [25]. Environmental health experts in Nigeria are concerned about heavy metal contamination in groundwater [26]. The presence of major ion concentration, either introduced by human activity or occurring naturally in groundwater is a threat to human life. Thus, rendering it unfit for domestic use [15] because drinking such contaminated water may result to death [27]. The most common waterborne diseases in Nigeria include cholera, typhoid, dracunculiasis, hepatitis etc [28]. Therefore, a more integrated approach [29] is important to evaluate water sources to confirm their adherence to water standards for citizen's well-being [16].

Nigeria, as a developing nation has failed to provide appropriate sanitation facilities and potable water from enhanced sources to its populace [30]. Citizens heavily rely on unprotected water sources like hand-dug wells, streams, springs and rivers. They also result in using open sources like drainages, dry wells, rivers etc. for dumping refuse. Thereby, making the environment highly vulnerable to flooding and contamination of birds, animals and humans by pollutants [31]. The negative effects of these pollutants to include, depletion of the ozone layer, global warming and significant raise of ocean level [32].

Studies by several researchers have revealed that hand-dug wells in Nigeria require frequent monitoring and protection [12]. This results from the inappropriate location of wells, shallow depth, land use, low construction standards and vulnerability to multiple pollution sources [33]. Due to the insufficient water supply for the municipal, boreholes and hand-dug wells have been the main sources of water in Bauchi state and its surroundings for many years. Expanding ascend in the populace, poor sanitation propensities, huge flooding and nonchalant attitude towards enforcement of environmental legislation in the Bauchi state have greatly led to the outbreak of water-borne diseases between in 2016 and 2019 [34].

Rafin Zurfi area, made up of poorly built hand-dug wells with some located near pollution sources have no functional surface drainage and disposal facilities [35]. However, the characterisation of groundwater from the area for domestic use has not been prioritised, as water from these sources are used without quality test [17]. Therefore, physicochemical evaluation of water from sampled hand-dug wells around the research area was undertaken to determine their contamination levels [36]. The ratios of the individual parameter concentration against the baseline standard, which offers data on the comparative pollution from individual samples are referred to as the pollution index [37]. According to [38–40], WQI is a significant technique used for classifying water as excellent, good, poor, very poor or unsuitable for drinking. To the best of our knowledge, no study conducted using WQI, THQ and HI approach to prove the quality of water from hand-dug wells in Rafin Zurfi area of Bauchi state.

This study examined fifteen (15) hand-dug wells at the said location using the aforementioned approaches. The specific objectives were; (i) sample characterization (ii) statistical analysis by SPSS (iii) comparison between NSDWQ and WHO standards (iv) hand-dug well water classifications by water quality index technique (iv) determination of health risk analysis (Target Hazard Quotient and Hazard Index Assessment). Finally, the analytical results taken into Geographic Information Systems (GIS) environment as an innovative technology to generate the numerical spatial variation maps for the parameters examined to show the health risk analysis of heavy metals at various sampling location.

2. Method and materials

2.1. Study area

Rafin Zurfi area is located around Yelwa, Lushi district, Bauchi Local Government Area, Bauchi State, North-eastern, Nigeria as best illustrated in Fig. 1(a-d). It is a developing area without master plan bordered by two federal tertiary institutions (Abubakar Tafawa Balewa University Bauchi and Federal Polytechnic Bauchi). It is a student densely populated suburban area between Latitude 10°17′ 0″North and Longitude 9°47′ 0″ East. It covers all the well fields serving the community. Bauchi, classified as a tropical area lies on 625 m above sea level. Two major distinct seasons (wet and dry) characterise the area [40]. The summers have a good deal of rainfall, while the winters have very little. With an annual average rainfall of 1009 mm, the temperature averages 25.3 °C. The area drained by River Gongola originating from Jos Plateau state, transverses in a southwest-northeast direction through Dass, Tafawa – Balewa, Bogoro, Bauchi and Kirfi and hence to Gombe state. Fig. 2 shows the sampling locations within the study area.

2.2. Sample collection

Sample collection and analysis influences the reliability of data obtained on chemical, physical and bacteriological constituents of water. To achieve this, the study randomly sourced water from fifteen (15) hand-dug wells during the dry season from discharge points of existing wells at different locations shown in Fig. 3. Sampling carried out early in the morning before water abstraction commenced by residents. Two separate samples fetched in airtight plastic sampling bottles (Make-Tarsons) of 1-L capacity and subsequently rinsed in distilled water before sample collection [41]. This was to provide microorganisms present in water with oxygen from each water point and determine the presence of anions and cations respectively. Samples were filtered using 0.45 μm membrane, filled up to the brim of the bottle and preserved [4] as per standard methods for the examination of water as prescribed by [42]. The samples labelled (A-O) were transported on ice bags to the laboratory for storage and subsequent characterization [43].

2.3. Water quality analysis

To examine the water quality in compliance with the WHO and NSDWQ baseline, standard methods were adopted. Fig. 4 unfold the step-by step procedure for the study. The parameters examined

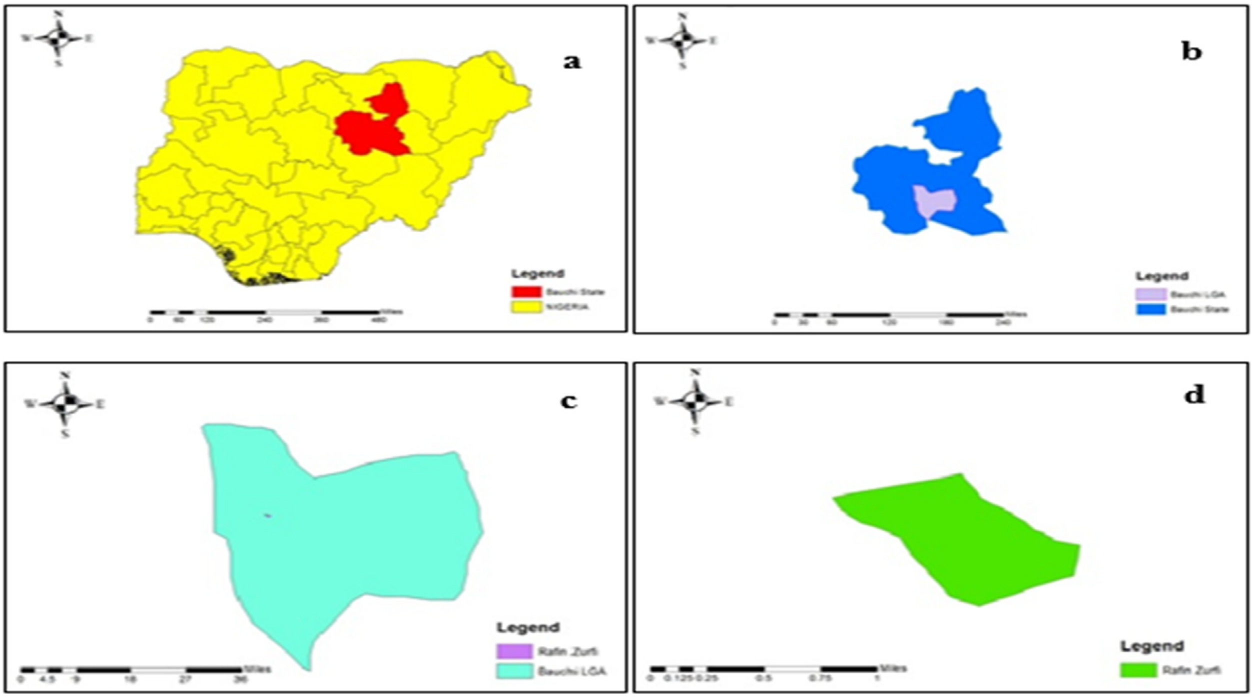

Fig. 1. Map of (a) Nigeria (b) Bauchi state (c) Bauchi Local Government Area (d) Rafin Zurfi Area.

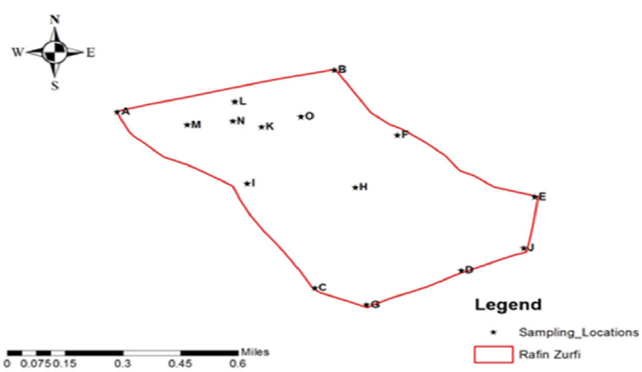

Fig. 2. Map Rafin Zurfi area showing sampling locations.

were; pH, temperature, taste, odour, turbidity, colour, total suspended solids, total dissolved solids (TDS), electrical conductivity (EC), hardness, BOD, COD, NO^{3-}, Cr, SO_4^{2-}, Ca, Fe, Cl^-, Zn, Pb, Ni, Cu, Mn and the total bacteriological count (TBC). Some parameters (pH, temperature, EC and TDS) were analysed at the points of sample collection while others in the laboratory. Table 1 summarized the equipment, standard and analytical methods adopted for variables. The EC meter was pre-calibrated with 84 µS/cm and 1413 µS/cm conductivity solutions before use. From the EC values, TDS were values were calculated by TDS (mg/L) = EC (µS/cm) × 0. 64 [41]. Duplicates have been also accomplished all through the analysis for quality assurance and quality control (QA/QC) purposes [44].

2.4. Quality control and statistical analysis

To guarantee the accuracy of data obtained for quality control purposes, samples were analyzed in triplicate using analytical grade reagents [2] and two standards tested for each sample [45]. Statistical measures (descriptive statistics) of water quality parameters of the hand-dug wells [3] for determined cations and anions [46] presented in Table 6 were calculated by using the SPSS software ver. 18. Origin 9 was employed for plotting graphs. The data were displayed using the parameters of the minimum value, maximum value, mean value, the median, standard deviation and 95% confidence level [45]. To identify the highly correlated and interrelated water quality parameters [47] with the likelihood of polluting hand-dug wells at different locations, correlation coefficient (r) values presented in Table 7 have been determined between WQI and measured water quality parameters [48] using correlation matrix. One-Way ANOVA was conducted to check the differences in physicochemical properties among the fifteen different hand-dug wells. Significance is considered in a circumstance where $p < 0.05$.

2.5. Water quality index

In this study, WHO and NSDWQ standards were used to compute the WQI's for different metals by the Weighted Arithmetic Index method developed by Tiwari and Mishra [49] to determine the suitability of groundwater for drinking purposes. This requires three key parameters (assigned weight, relative weight and quality rating scale) [16]. Several authors have reported variable weights assigned to a particular water quality parameter. Based on the literature, this study assigned weight values ranging from 1 to 5 as presented in Tables 2 and 3, where 5 was considered the most significant and 1 as less significant. The relative weights, quality rating scale and WQI were computed using equations (1)–(4) [2,10,38,43,46,50–55].

$$W_i = w_i / \sum_{i=1}^{n} w_i \quad (1)$$

where

Wi is the relative weight
wi is the weight of each parameter
n is the number of parameters.

Tables 2 and 3 also highlights the relative weight for each parameter as computed

Fig. 3. Hand-Dug Wells (A-O). Source: Fieldwork.

For each of the parameters, a quality rating scale (q_i) was determined using the relationship in

Equation (2) below:

$$q_i = \frac{C_i \times 100}{S_i} \tag{2}$$

where

qi is the quality rating
Ci is the concentration of each chemical parameter in (mg/L)
Si is the WHO or NSDWQ drinking water standard for each of the parameter.

The sub-index and WQI were computed using the relationship in Equations (3) and (4) respectively

$$Sl_i = W_i \times q_i \tag{3}$$

$$WQI = \sum Sl_i \tag{4}$$

where

SIi is the sub-index of the i^{th} parameter
qi is the rating based on the concentration of the i^{th} parameter.

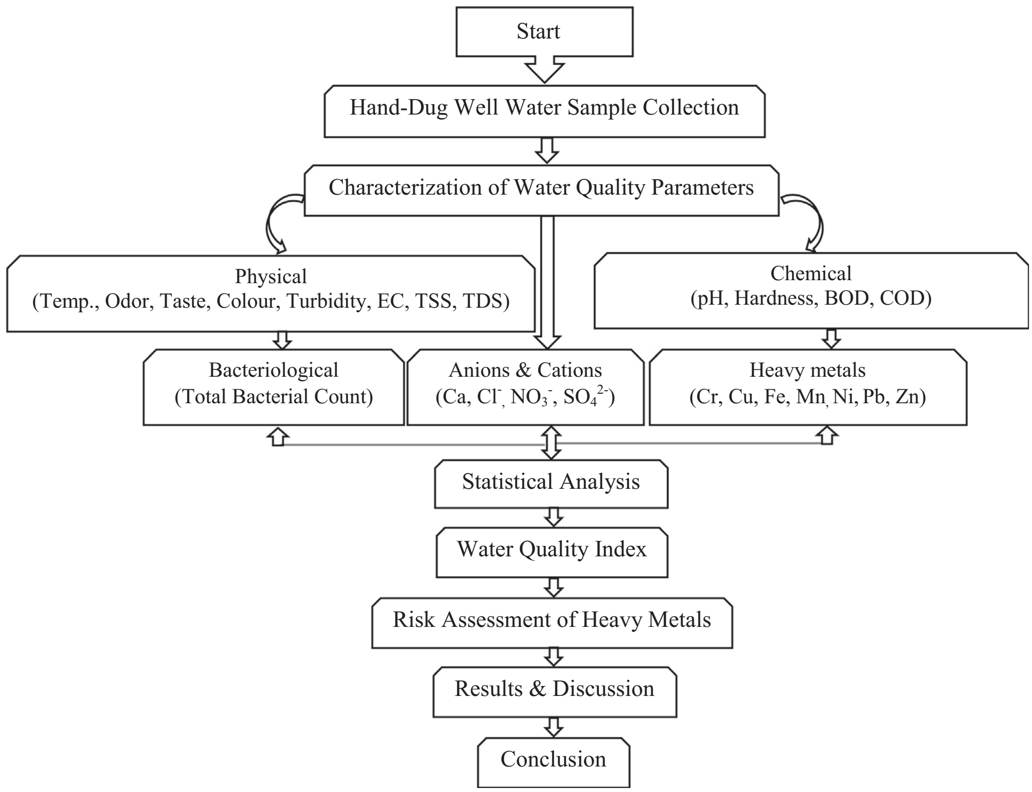

Fig. 4. Flowchart for the study outline.

Table 1
Water quality parameters, standard Methods, analytical method and equipment.

Variable	Standard	Analytical method	Equipment
pH	APHA 4500H+B	Electrometric Method	Portable pH Meter
EC	APHA 2510B		Portable EC meter
Temperature	APHA 2550B	Temperature of Water	Thermometer
TDS	APHA 2510A	Gravimetric method	YSI professional plus multi-parameter (Model- 6050000, USA).
TSS	APHA 2540D		GAST DOA-P404-BN filtration apparatus
Sulphate	APHA 4500-SO_4^{2}- C		Oven, aluminium dishes and scale for weighing, refrigerator
Taste	APHA 6040D	Solid-Phase Microextraction (SPME)	Two amber glass vials, mercuric chloride/L, Ice bag, Refrigerator
Odour	APHA 2150 B	Threshold Odor Test	Glass bottles with TFE-lined closures
Hardness	APHA 2340C	EDTA Titrimetric Method	EDTA and Calmagite indicator
BOD_5	APHA 5210B	5-Day BOD Test	Photometric, Non-Stirring BOD Probes, BOD Refrigerated Incubator
Calcium	ASTM D511-14	Complexometric titration method	Glass containers
Chloride	APHA 4500-Cl- B	Argentometric Method	Chemically resistant glass bottles, Spectrophotometer
Nitrate	APHA 4500-NO_3- C	Colorimetry and Cadmium reduction method	Polarized Zeeman Atomic Absorption Spectrophotometer ZA3000 Series
Turbidity	APHA 2130B	Nephelometric method	
Colour	USEPA 8025	Platinum-cobalt method	
COD	APHA 5220C	Closed Reflux Method	
Zinc	APHA 3500-Zn B	Atomic absorption spectrophotometry (AAS)	
Lead	APHA 3500-Pb D		
Nickel	APHA 3500-Ni D		
Copper	APHA 3500-Cu C		
Chromium	APHA 3500-Cr B		
Iron	APHA 3500-Fe B		
Manganese	APHA 3500-MN B		
Total Bacterial Count	APHA 9222B	Most Probable Number Technique	Media Culture Agar (MCA), Petri Dish, sterile pipette

* Temp.: Temperature (°C); Turbidity (NTU); Colour (Pt.Co.); TDS: Total Dissolved Solids; BOD: Biochemical Oxygen Demand; EC: Electrical Conductivity (µS/cm); COD: Chemical Oxygen Demand; TSS: Total Suspended Solids; TBC: Total Bacterial Count (cfu/ml); NO_3^-: Nitrate; Cr: Chromium; Pb: Lead; SO_4^{2-}: Sulfate; Ca: Calcium; Cu: Copper; Fe: Iron; Cl^-: Chloride; Zn: Zinc; Ni: Nickel; Mn: Manganese.
* Unit for all other parameters are in mg/L.

Table 4 shows the classification of water type to be based on obtained WQI values and the range of water quality index specified for drinking water [43].

Furthermore, the analytical results were taken into the GIS environment to generate the numerical spatial distribution maps of the parameters at various sampling points. The individual

Table 2
Water quality parameters, assigned weight and relative weights for WHO standard.

Parameter	WHO Standard	Assigned Weight (w_i)	Relative Weight (W_i)
pH	7.0–8.5	4[2,38,43,46–48,51,52]	0.067797
Colour (Pt.Co.)	15	2[56]	0.033898
Turbidity (NTU)	5	2[50]	0.033898
TDS (mg/L)	1500	5[2,10,30,47,51,52,55]	0.084746
EC (μS/cm)	1000	4[38,46,48,51,52]	0.067797
TSS (mg/L)	1000	2[55]	0.033898
Hardness (mg/L)	NS	2[2,48,54]	0.033898
BOD (mg/L)	6	3[50]	0.050847
COD (mg/L)	10	2[50]	0.033898
Nitrate (mg/L)	45	5[2,10,30,38,46,51,52,54,55]	0.084746
Chromium (mg/L)	0.05	2[43]	0.033898
Sulphate (mg/L)	200	5[10,30,47,55]	0.084746
Calcium (mg/L)	75	3[10,47,52,55]	0.050847
Iron (mg/L)	0.3	1[57]	0.016949
Chloride (mg/L)	250	5[10,47,52,55]	0.084746
Zinc (mg/L)	3	1[46]	0.016949
Lead (mg/L)	0.01	2[56]	0.033898
Nickel (mg/L)	0.02	3[47]	0.050847
Copper (mg/L)	0.3	4[43]	0.067797
Manganese (mg/L)	0.2	2[48]	0.033898
		$\sum w_i = 59$	$\sum W_i = 1.0000$

Table 3
Water quality parameters, assigned weight and relative weights for NSDWQ standard.

Parameter	NSDWQ Standard	Assigned Weight (w_i)	Relative Weight (W_i)
pH	6.5–8.5	4[2,38,43,46–48,51,52]	0.067797
Colour (Pt.Co.)	15	2[56]	0.033898
Turbidity (NTU)	5	2[50]	0.033898
TDS (mg/L)	500	5[2,10,30,46,47,51,52,55]	0.084746
EC (μS/cm)	1000	4[38,46,48,51,52]	0.067797
TSS (mg/L)	500	2[55]	0.033898
Hardness (mg/L)	150	2[2,48,54]	0.033898
TBC (cfu/ml)	10	5[56]	0.084746
Nitrate (mg/L)	50	5[2,10,30,38,46,51,52,54,55]	0.084746
Chromium (mg/L)	0.05	2[43]	0.033898
Sulphate (mg/L)	200	5[10,30,47,55]	0.084746
Calcium (mg/L)	75	3[10,47,52,55]	0.050847
Iron (mg/L)	0.3	1[57]	0.016949
Chloride (mg/L)	250	5[10,47,52,55]	0.084746
Zinc (mg/L)	3	1[46]	0.016949
Lead (mg/L)	0.01	2[56]	0.033898
Nickel (mg/L)	0.02	3[47]	0.050847
Copper (mg/L)	1	4[43]	0.067797
Manganese (mg/L)	0.2	2[48]	0.033898
		$\sum w_i = 59$	$\sum W_i = 1.0000$

Table 4
Classification of water type based on WQI value. Source: [2,10,40,43,46–48,50–52,55].

Range	Water Type
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking purposes

groundwater quality parameters were compared with NSDWQ and WHO standards to evaluate its suitability for drinking purpose. Beside this, the suitability of the water for drinking was evaluated based on the water quality index.

2.6. Target hazard quotient and hazard index

THQ is the estimation of the level of risk due to pollutant exposure by humans [58]. This study determined THQ to assess the health risk of humans exposed to the heavy metals concentrations from hand-dug well water consumption. THQ values were computed for Cu, Cr, Fe, Zn, Pb, Ni and Mn respectively using eqn. (5).

Target health quotient (THQ) is:

$$THQ = \frac{C^{*} IR^{*} EF^{*} ED^{*} 10^{-3}}{RfD^{*} BW^{*} AT} \quad (5)$$

where

C - geometric mean concentration (mg/L) of heavy metal,
IR - water intake rate, 3.49 and 2.14 L/day for adults and children respectively,
EF - exposure frequency (365 days/year),
ED - exposure duration (70 years (adults) and 10 years (children), respectively),
BW - average body weight 48.56 kg for adults and 31 kg for children
AT - average time 70 years (adults) and 10 years (children) respectively)
RfD – reference oral dose (mg/kg/day)

The non-carcinogenic risk was calculated as the Hazard Index (HI) using equation (6) [2,58–60];

$$HI = THQ(Cr) + THQ(Fe) + THQ(Zn) + THQ(Pb) + THQ(Cu) + THQ(Mn) \quad (6)$$

3. Results and discussion

The results obtained in the process of this study were from the analysis of samples fetched from fifteen (15) hand-dug wells situated at different locations within the study area. This section discusses the relationship between the parameters obtained from the analysis of the samples and that recommended by NSDWQ and WHO. Sampling was conducted during the dry season and characterized in the laboratory to obtain the physical, chemical, bacteriological parameters alongside heavy metals. Fig. 3 highlights 15 samples tagged A to O from different hand-dug well locations within Rafin Zurfi.

3.1. Physical parameters

3.1.1. Temperature

Temperature is a measure of the degree of hotness or coldness of water [61]. Its measurements were taken as soon as water sampling was conducted to investigate the presence of thermal input in the well water [62]. Temperature variation ranges from 29.8 °C to 31 °C with a mean value of 30.353 °C as indicated in Tables 5a and 6. Although, both NSDWQ and WHO have not defined temperature values for drinking water, all the values surpassed standard room temperature of 20–22 °C [63]. Thus, the temperatures considered desirable, as the high nature may be due to the area's climate at the time of sampling. It is also similar to findings by [31,51,64] as no ill-health effect is necessarily associated with water samples having temperatures exceeding room temperature [61].

3.1.2. Taste, Odour and Colour

"Taste and Odour Wheel", Odour Triangle alongside the Flavour Profile Analysis [65] were used to evaluate samples for taste and odour characteristics. From the results obtained, most samples were as per the recommended standards of taste for both NSDWQ and WHO standards, except for samples D, E, L and O with objectionable taste as shown in Table 5b. Just as reported by Onoja, All samples were found to be odourless. This indicates that the water from the sampled wells are not affected by rainfall runoff and infiltration [64]. The mean value of 76.8 Platinum-Cobalt Scale (Pt.Co) was recorded for hand-dug wells and all the values exceeded the recommended value by both NSDWQ and WHO of 15 Pt.Co. This indicates the presence of colloidal particles like Fe and Mn [63]. The ions need to be removed through precipitation. Serious attention needs to be given to sample L, having the highest value of 319 Pt.Co

3.1.3. Turbidity and Electrical conductivity (EC)

Factors responsible for the high turbidity level in water are suspended particles, colloidal organic matter and micro-organisms [66]. Table 6 showed that the mean turbidity value of water from hand-dug wells is 47.13 NTU. This is above the maximum acceptable limits of 5 NTU recommended by both NSDWQ and WHO. Similarly, most samples were not within permissible limit except for samples M and N. This high turbidity levels could be attributed to an increase in human activities leading to mismanagement in sewage disposal [67]. Clay textures observed during sampling at the base of the wells are assumed to be accountable for the elevated levels of turbidity recorded. This conclusion was made, as there were no clay textures at the base of hand-dug wells M and

Table 5a
Results of Physico-Chemical Parameters for samples from Hand-dug wells in Rafin Zurfi Area.

Sample	pH	Temp.	Colour	Turbidity	TDS	EC	TSS	Hardness	BOD	COD	TBC	NO_3^-	Cr	SO_4^{2-}	Ca	Fe	Cl^-	Zn	Pb	Ni	Cu	Mn
A	6.3	31	32	7	145	227	300	2.67	1.06	3.87	0	89.8	0.02	29.8	49.27	0.33	5.83	0.68	0.01	0	0.04	0.16
B	6.9	31	84	12	106	166	100	2.49	0.93	5.48	5	35.1	0.05	6.7	33.11	0.41	6.55	1.54	0	0.03	0.01	0.01
C	6.6	30.9	46	9	68	106	100	2.6	0.13	6.77	1	70.3	0.15	40.5	26.8	0.02	2.16	1.18	0.06	0.17	0	0.34
D	6.6	30.6	68	10	138	215	300	1.21	0.93	4.51	0	122.6	0.02	7	25.7	0.12	4.97	1.32	0.03	0	0	0.05
E	9.1	29.9	61	9	132	206	0	3.29	1.22	5.18	0	141.8	0.17	12	34.42	0.01	7.52	1.53	0.68	0.09	0.03	0
F	7.7	30.5	77	9	122	191	200	2.85	0.39	6.12	1	21.4	0.04	14	26.6	0.25	2.14	1.77	0	0.01	0.02	0.2
G	6.4	30.8	64	8	120	187	100	2.83	0.98	7.41	0	51.1	0	8.3	61.82	0.1	8.37	1.42	0.87	0.17	0.04	0.05
H	6.4	30.4	35	6	49	76	0	3.01	0.28	2.58	1	34.2	0.03	16	55.9	0.17	5.91	0.14	0.01	0	0	0.08
I	6.1	30	55	10	77	121	100	3.58	0.67	5.8	0	204.4	0.03	10	34.52	0.19	4.28	0.45	0	0.02	0.02	0.15
J	5.9	29.8	61	7	66	103	100	3.7	0.17	3.87	11	28.2	0	5	51.81	0.03	5.15	0.45	0.23	0	0.01	0.07
K	6.6	30.2	61	7	113	177	400	2.5	0	6.77	0	177	0.01	7	51.7	0.37	3.23	0.79	0.21	0.11	0.01	0
L	9	30.1	319	54	163	254	0	2.98	1.12	24.01	7	111.7	0.06	39	35.2	0.02	5.42	1.23	0.15	0.22	0.04	0.01
M	7.4	30.1	34	5	128	200	100	3.16	0.69	8.38	3	41.9	0.21	17	23.3	0.13	2.38	0.74	0	0.09	0	0.03
N	7	29.9	30	4	63	99	100	2.56	1.27	6.12	0	66.9	0.01	5	27.9	0.24	7.21	0.68	0.08	0	0.02	0.21
O	7.2	30.1	125	550	36	57	300	2.84	1.31	9.02	18	201.4	0.25	0	50.14	0.05	4.72	1.9	0.02	0.04	0.01	0.45
NSDWQ	**6.5–8.5**	**NS**	**15**	**5**	**500**	**1000**	**500**	**150**	**NS**	**NS**	**10**	**50**	**0.05**	**200**	**75**	**0.3**	**250**	**3**	**0.01**	**0.02**	**1**	**0.2**
WHO	**7.0–8.5**	**Ambient**	**15**	**5**	**1500**	**1000**	**1000**	**150**	**6**	**10**	**0**	**45**	**0.05**	**200**	**75**	**0.3**	**250**	**3**	**0.01**	**0.02**	**0.3**	**0.2**

* Temp.: Temperature (°C); Turbidity (NTU); Colour (Pt.Co.); TDS: Total Dissolved Solids; BOD: Biochemical Oxygen Demand; EC: Electrical Conductivity (µS/cm); COD: Chemical Oxygen Demand; TSS: Total Suspended Solids; TBC: Total Bacterial Count (cfu/ml); NO_3^-: Nitrate; Cr: Chromium; Pb: Lead; SO_4^{2-}: Sulfate; Ca: Calcium; Cu: Copper; Fe: Iron; Cl^-: Chloride; Zn: Zinc; Ni: Nickel; Mn: Manganese.
* Unit for all other parameters are in mg/L.

Table 5b
Results of Physico-Chemical Parameters for samples from Hand-dug wells in Rafin Zurfi Area.

Sample	Obtained Result		NSDWQ		WHO	
	Taste	Odour	Taste	Odour	Taste	Odour
Samples A, B, C, F, G, H, I, J, K, M & N	Tasteless	Odourless	Tasteless	Odourless	Tasteless	Odourless
Samples D, E, L & O	Objectionable					

Table 6
Descriptive Analysis of Physico-Chemical Parameters.

	pH	Temp.	Colour	Turbidity	TDS	EC	TSS	Hardness	BOD	COD	TBC	NO_3^-	Cr	SO_4^{2-}	Ca	Fe	Cl^-	Zn	Pb	Ni	Cu	Mn
Mean	7.013	30.353	76.800	47.133	101.733	159.000	146.667	2.818	0.743	7.059	3.133	93.187	0.070	14.487	39.213	0.163	5.056	1.055	0.157	0.063	0.017	0.121
Std. Error	0.247	0.109	18.417	36.053	22.371	15.605	32.170	0.149	0.115	1.290	1.352	16.407	0.021	3.198	3.309	0.034	0.505	0.137	0.068	0.019	0.004	0.034
Std. Deviation	0.957	0.421	71.327	139.634	37.474	60.438	124.595	0.579	0.447	4.996	5.235	63.545	0.082	12.387	12.817	0.133	1.955	0.532	0.265	0.074	0.015	0.133
Sample Variance	0.916	0.177	5087.600	19497.695	1404.329	3652.714	15523.810	0.335	0.200	24.963	27.410	4038.021	0.007	153.437	164.287	0.018	3.822	0.283	0.070	0.006	0.000	0.018
Kurtosis	1.166	−1.349	10.933	14.724	−1.202	−1.211	−0.483	3.781	−1.338	10.911	4.078	−0.908	0.210	0.647	−1.415	−0.844	−0.832	−1.120	3.779	−0.309	−1.054	1.442
Skewness	1.330	0.398	3.162	3.826	−0.2365	−0.242	0.726	−1.261	−0.393	3.102	2.063	0.672	1.262	1.281	0.395	0.574	−0.100	−0.052	2.126	0.975	0.514	1.377
Min.	5.900	29.800	30.000	4.000	36.000	57.000	0.000	1.210	0.000	2.580	0.000	21.400	0.000	0.000	23.300	0.010	2.140	0.140	0.000	0.000	0.000	0.000
Max.	9.100	31.000	319.000	550.000	163.000	254.000	400.000	3.700	1.310	24.010	18.000	204.400	0.250	40.500	61.820	0.410	8.370	1.900	0.870	0.220	0.040	0.450
Count	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Conf. Level(95.0%)	0.530	0.233	39.500	77.327	30.841	33.469	68.998	0.321	0.248	2.767	2.899	35.190	0.046	6.860	7.098	0.074	1.083	0.294	0.147	0.041	0.008	0.074
F	0.698	371.467	13.901	1.177	63.152	93.123	18.556	19.808	39.104	0.295	7.494	26.824	47.148	3.639	79.297	46.027	5.458	35.674	45.977	47.230	47.800	46.522
P-value	0.410	0.000	0.001	0.287	0.000	0.000	0.000	0.000	0.000	0.591	0.011	0.000	0.000	0.067	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000

N. The result of this finding disagree with the reports by [31,61], where most samples were below the minimum 5 NTU.

Electrical conductivity is a quantitative measure of the ability of water to pass electric current [67]. It is used to estimate the number of dissolved minerals [53]. EC is directly correlated with the total dissolved solids [63,68]. Results from the sampling locations as presented in Table 5a indicated 57 µS/cm and 254 µS/cm as the obtained smallest and highest EC values respectively. While sample L got the highest EC value, sample D had the lowest. The higher value of EC obtained for the sample well could be attributed to high degree of anthropogenic activities like waste disposal, household waste, and chemicals runoff from agricultural and apiculture activities [50]. In this study, the measured EC values indicates that all the 15 hand-dug wells examined had values below the 1000 µS/cm WHO and NSDWQ maximum permissible EC level for drinking water. This indicates that contamination due to dissolving ions is relatively low [31]. Thus, water suitable for drinking purpose from the EC point of view [16].

3.1.4. Total suspended solids and total dissolved solids

The TSS values of water samples indicate the quality of non-filterable particles contained in it. About 500 mg/L was recommended by NSDWQ and 1000 mg/L by WHO as the acceptable standard for potable water. TSS concentration ranged from 100 to 400 mg/L in samples evaluated. With a mean value of 146.667 mg/L as highlighted in Table 6, it poses no health risk to human [30]. The results for all samples are in the recommended range of both standards. This implies that the sampled hand-dug well water is suitable for drinking. The absence of TSS value for samples E, H and L is due to a very static water level [69].

Total dissolved solids (TDS) is an indication of drinking water aesthetic characteristics [62]. It consists mainly of inorganic salts such as NO^{3-}, SO_4^{2-}, Cl^-, Mg, Ca, Na, Fe with small amount of organic matter and dissolved gases [51,67]. The high concentration of these may affect people suffering from kidney and heart diseases [31]. Spatial distribution map shown in Fig. 5(f) proved that TDS in the hand-dug wells of the study area ranges from 36 to 163 mg/L with an average of 146.93 mg/L. All samples in the study area had TDS value less than 500 mg/L and fall in the freshwater group [46] as they do not exceed the limits of 500 mg/L and 1500 mg/L recommended by NSDWQ and WHO respectively. The lowest value of 66 mg/L was obtained for sample B indicating less influence of domestic and agricultural waste in the groundwater quality [2]. Sample D obtained the largest value of 275 mg/L. The high TDS value observed for sample D could be due to sewage, septic tanks, chemical discharge, aquifer materials, urban and agricultural runoff [16,50,51]. This explains the reason why water from the sample well D had an objectionable taste [64] and colour above the maximum permissible limit [68].

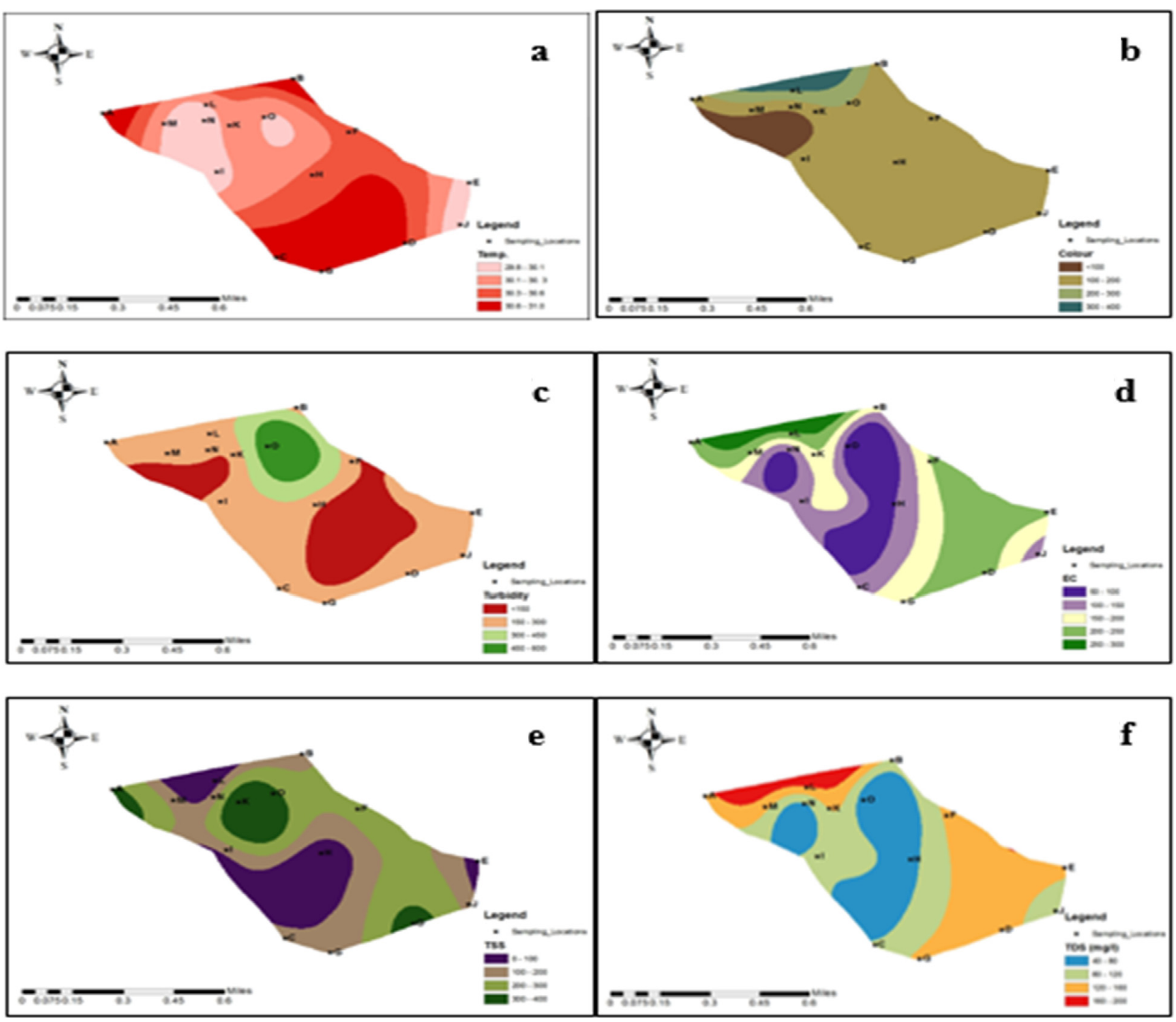

Fig. 5. Spatial distribution maps of (a) Temperature (b) Colour (c) Turbidity (d) EC (e) TSS (f) TDS.

3.2. Chemical parameters

3.2.1. pH, Hardness, BOD and COD

pH is an important variable in evaluating the acid-base balance of water. It indicates the strength of water to react with the acidic or alkaline material present [31]. The obtained pH values for this study varied from 5.9 to 9.1. The spatial variation map of pH shown in Fig. 6(a) indicates that water from some sample wells exceeded both the NSDWQ and WHO standards. Thus, portraying their acidic, alkaline and neutral nature [67]. Samples E and L recording the highest values are not acceptable for drinking as they are not within 6.5–8.5 (NSDWQ) and 7.0–8.5 (WHO) permissible limits [64]. This may be attributed to underground sulphide mineralization [57]. If the pH value of the water doesn't meet the WHO standard, the taste of the water becomes more salty or bitter and causes eye irritation and skin disorder [68,70]. This reflected in Table 5b as taste for both samples were unacceptable. Results for samples B, C, D, F, I, K, M, N, and O were in agreement with studies by [45,46,51,58,69]. However, samples A, J, G, H were slightly acidic and are likely to be corrosive due to the lower nature of their pH values [67,71]. This could largely be attributed to the geology of the hand-dug well sample locations within the study area [72], or the deposition of acidic forming substances [50,61]. According to Sudarshan et al [68], water with pH values < 6.5 causes discontinuation in the production of vitamins in the human body.

Hardness in water is the concentration of all multivalent metallic cations present in solution. Thus, making it unsuitable for domestic and industrial use [67]. For hand-dug wells, high values of hardness could result from regular addition of large quantities of detergents used by residents which later drains into water bodies. The hard water can cause indigestion problem and possibilities of forming calcium oxalate crystals in urinary tracts [68]. It leads to deposition of scaling in pipelines, reduces water treatment efficiency, increases the cost of soap used for domestic and laundry purposes [2], affect the taste of water as well as influence its lathering ability when used for washing [67]. Long-term consumption of this hard water may also lead to an increased incidence of urolithiasis, anencephaly, prenatal mortality, cardiovascular disorders and some types of cancer [30]. However, when the hardness is very low, the water becomes corrosive and capable of dissolving heavy metals [71]. In this study, hardness values ranged from 1.21 to 3.7 mg/L with samples D and J recording minimum and maximum values respectively. Spatial distribution map on Fig. 6 (b) illustrates the narrative as mean hardness concentration value of 2.818 mg/L was recorded. All values were within the permissible limit of 150 mg/L set by WHO and NSDWQ. The relative lower values recorded in this study may be due to the presence of lower concentrations of dissolved calcium and magnesium in the hand-dug wells [72]. Since water samples fell below standard, they will not result in skin itching, and would not require so much soap to form lather [61].

BOD test measures the number of microorganisms in a water sample and the nutrients available to them [68]. Fig. 6 (c) show the spatial distribution map, proving that all the samples were less than 6 mg/L stipulated by WHO with a mean value of 0.743 mg/L. A condition which implied that each of the tested water samples had less organic pollution, and constitutes aquatic habitats that could support the existence of marine organisms [61]. The BOD values obtained in this study tally with those reported by [69].

COD results for all the samples were within the acceptable value recommended by WHO except sample "L" which exceeds the recommended value of 10 mg/L. This reveals the presence of

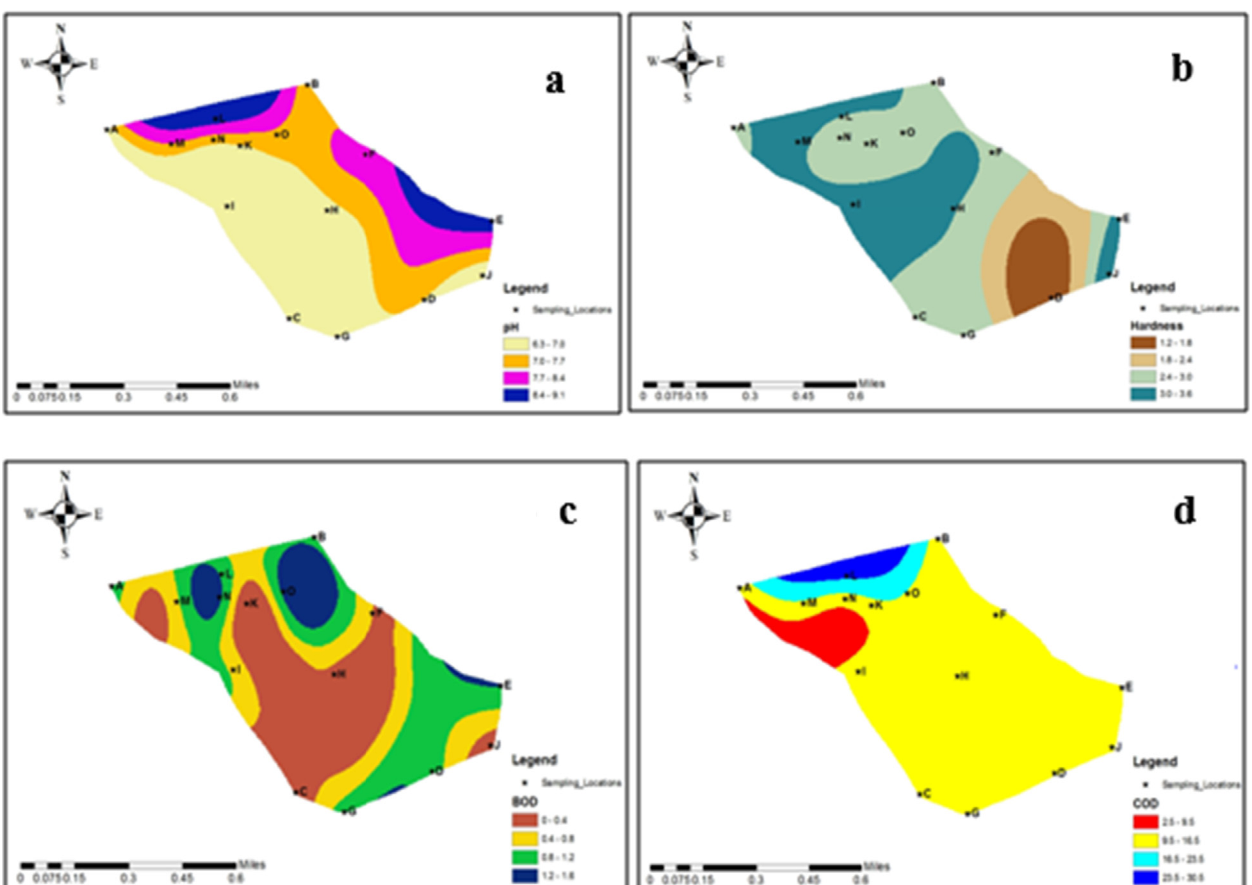

Fig. 6. Spatial distribution maps of (a) pH (b) Hardness (c) BOD (d) COD.

strong organic contaminant concentration in the sample throughout the sampling duration [50].

3.3. Anions and cations

3.3.1. Ca, Cl^{-}, NO^{3-} and SO_4^{2-}

All-natural water contains a reasonable quantity of Ca, but the discharge of sewage and wastewater enhances its concentration [68]. Calcium concentration in all the water samples investigated varied from 23.3 to 61.82 mg/L with a mean value of 39.213 mg/L (Tables 5a and 6). According to WHO and NSDWQ, the permissible limit for calcium specified is 75 mg/L. Distribution of calcium in all the water samples analysed had low concentrations. However, very low concentration of Ca in drinking water may cause defective teeth, poor blood clotting, bones fracture and rickets [31]. Calcium are essential for the nervous system, cardiac function and coagulation of blood [67]. The maximum concentration of calcium ions is undesirable for domestic purposes as it causes abdominal ailments, encrustation and scaling [51]. Thus, adequate intake of calcium is essential for normal growth and good health [63].

Chloride usually originates from water-soluble chloride salts present in minerals [2]. It has key importance for metabolism activity in the human body and other main physiological processes [31]. Some studies [46,51] have reported rainwater, weathering, and leaching of domestic and agricultural effluents as sources of chloride in water. High chloride concentration in water is an index of pollution [68]. It damages metallic pipes and gives water a salty taste that can lead to hypertension, osteoporosis, asthma and renal stones. Chloride values ranged between 2.14 and 8.37 mg/L in the study area with an average value of 5.066 mg/L (Table 6). Samples F and G had the minimum and maximum concentrations. All the water samples evaluated had chloride concentration within the 250 mg/L permissible limits stipulated by both by NSDWQ and WHO. This is per the observations in other similar studies [16,46,63].

Five (5) out of the fifteen (15) evaluated hand-dug wells tagged (samples B, F, H, J, and M) recorded values below the maximum 45 mg/L and 50 mg/L stipulated by WHO and NSDWQ respectively. Therefore, water from 10 hand-dug well samples (K, A, O, D, L, E, G, I, N & C) with nitrate concentrations beyond 50 mg/L are not suitable for drinking. Hence, treatment becomes necessary. Presence of high concentration of nitrate contaminants is unconnected to poor sanitary conditions, septic tanks, seepage of human sewage, soak ways, nitrogen cycle, nitrogenous fertilizers, with some contribution from domestic effluents within the study area [7,8,31,55,69]. Excess amounts of nitrates in drinking water is a potential health hazard [47]. It can lead to respiratory and heart problems [68].

Sulphate concentrations recorded were between 5.0 and 40.5 mg/L, with an average value of 14.487 mg/L. Concentrations were all less than the 200 mg/L recommended by both WHO and NSDWQ. The findings coincide with the results obtained by [51,63]. Surprisingly, sample O recorded 0.00 mg/L. These proved the fact that sulphate concentration in groundwater usually remains low due to reducing conditions in the aquifers which inhibits sulphide oxidation [2]. Considering the sulphate concentration alone, the study concludes that water from the sampled hand-dug wells in Rafin Zurfi area are safe for drinking. Fig. 7 illustrates the spatial distribution maps for Ca, Cl^{-}, NO^{3-} and SO_4^{2-} concentrations across all the sampled hand-dug wells.

3.4. Heavy metals

The trace metals considered during evaluation of the fifteen (15) samples labelled A to O were Cr, Fe, Zn, Pb, Ni, Cu and Mn.

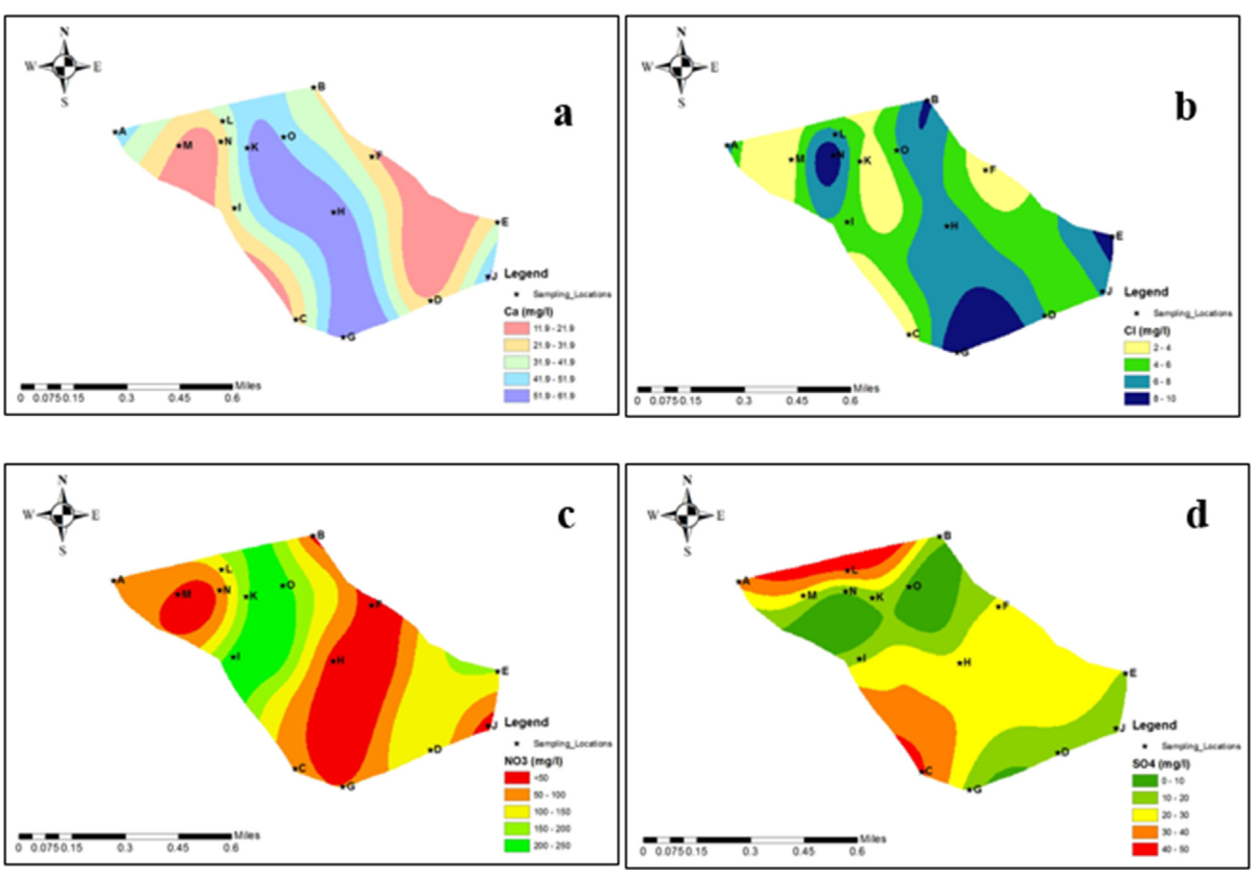

Fig. 7. Spatial distribution maps of (a) Ca (b) Cl^{-} (c) NO^{3-} (d) SO_4^{2-}.

Table 7
Correlation coefficients for water quality parameters of samples from Hand-dug wells.

	pH	Temp.	Colour	Turbidity	TDS	EC	TSS	Hardness	BOD	COD	TBC	NO_3^-	Cr	SO_4^{2-}	Ca	Fe	Cl^-	Zn	Pb	Ni	Cu	Mn
pH	1																					
Temp.	−0.2929	1																				
Colour	0.5928	−0.1582	1																			
Turbidity	0.1038	−0.1749	0.2701	1																		
TDS	−0.1931	−0.0090	0.0081	−0.3496	1																	
EC	0.4684	0.2405	0.3495	−0.4280	0.3589	1																
TSS	−0.3531	0.2217	−0.1950	0.3141	0.4005	0.0673	1															
Hardness	0.0895	−0.5113	0.0376	0.0140	−0.4345	−0.2545	−0.5165	1														
BOD	0.4440	−0.0587	0.2950	0.3717	−0.2913	0.2318	−0.1069	−0.1525	1													
COD	0.6123	−0.1922	0.9310	0.1885	−0.0201	0.3903	−0.2290	0.0786	0.2896	1												
TBC	0.0752	−0.2986	0.4255	0.8050	−0.3716	−0.3912	0.0774	0.2503	0.1792	0.2982	1											
NO_3^-	0.1105	−0.3274	0.2018	0.4819	0.1901	−0.0549	0.3969	−0.0360	0.2451	0.1767	0.1642	1										
Cr	0.4431	−0.1773	0.0857	0.6028	−0.5006	−0.1591	−0.0696	0.1605	0.2504	0.1746	0.4522	0.2608	1									
SO_4^{2-}	0.2681	0.3387	0.3653	−0.2778	−0.0471	0.3629	−0.2768	0.0322	−0.1278	0.4716	−0.2179	−0.1664	0.0942	1								
Ca	−0.3807	0.0506	−0.0340	0.2264	−0.0387	−0.2407	0.1427	0.2540	−0.1204	−0.1397	0.2348	0.0764	−0.2729	−0.2241	1							
Fe	−0.3236	0.3879	−0.3162	−0.2590	−0.0750	0.1210	0.4402	−0.2723	−0.1181	−0.3279	−0.3483	−0.0893	−0.4479	−0.2218	0.0265	1						
Cl^-	0.0783	0.0030	0.0401	−0.0434	−0.1608	0.0468	−0.3335	0.0058	0.6098	−0.0524	−0.0557	−0.0465	−0.2937	−0.2817	0.4134	−0.0244	1					
Zn	0.5049	0.2540	0.3418	0.4565	−0.0437	0.2437	0.1787	−0.3146	0.4150	0.2611	0.2875	0.1246	0.4145	−0.0886	−0.2147	−0.1431	0.0189	1				
Pb	0.2234	−0.0714	0.0066	−0.1433	0.1773	0.2364	−0.2569	0.1913	0.1926	0.0307	−0.1727	0.0035	−0.0717	−0.1458	0.4157	−0.3464	0.5873	0.2345	1			
Ni	0.4342	0.0830	0.5466	−0.0367	0.0734	0.3537	−0.2571	0.0755	−0.0034	0.7028	−0.0214	0.0922	0.2333	0.5458	0.0296	−0.4034	−0.0404	0.2726	0.4622	1		
Cu	0.3476	0.0416	0.3869	−0.0866	0.0041	0.5056	−0.1405	0.2350	0.5112	0.3960	−0.1307	0.1001	−0.2608	0.2272	0.2716	−0.0060	0.5263	0.1817	0.5162	0.3126	1	
Mn	−0.1797	0.0668	−0.1000	0.6639	−0.2756	−0.6116	0.2515	−0.0143	0.0887	−0.0856	0.4119	0.2135	0.4250	0.0445	−0.0502	−0.1953	−0.2970	0.2517	−0.3483	−0.1450	−0.1741	1

* Temp.: Temperature (°C); Turbidity (NTU); Colour (Pt.Co.); TDS: Total Dissolved Solids; BOD: Biochemical Oxygen Demand; EC: Electrical Conductivity (μS/cm); COD: Chemical Oxygen Demand; TSS: Total Suspended Solids; TBC: Total Bacterial Count (cfu/ml); NO_3^-: Nitrate; Cr: Chromium; Pb: Lead; SO_4^{2-}: Sulfate; Ca: Calcium; Cu: Copper; Fe: Iron; Cl^-: Chloride; Zn: Zinc; Ni: Nickel; Mn: Manganese.
* Unit for all other parameters are in mg/L.

Table 7a highlights the concentrations obtained for individual elements at the fifteen different sample locations. The concentration values fluctuated for almost all metals. It can also be observed that some trace metals were not detected (0.0 mg/L) in certain wells which could be associated with the nature of activities undertaken at those places. Similarly, certain element at some locations met the recommended permissible limits of WHO and NSDWQ standards. Painstakingly, it was observed that the presence of most trace metals was because of indiscriminate dumping of municipal solid waste, poor handling of the wells, and lack of drainages within the study area. Spatial distribution maps shown in Fig. 8 (a-g) were used to discuss the range of values (minimum and maximum) obtained for different trace metals, explain whether the results are within the standard limits or not and to visually see the potential risk of each element.

3.4.1. Cr, Cu, Fe, Mn, Ni, Pb and Zn

The concentration of chromium observed in the water samples ranged from 0.01 to 0.25 mg/L. There were no traces of chromium in samples G and J. Only 33.33% of all the samples evaluated complied with the WHO & NSDWQ drinking water standards (0.05 mg/L). Spatial distribution map shown on Fig. 8a portrays the presence of high chromium concentration in sample wells C, E, L, M, & O. This indicates the contribution received by anthropological sources of chromium such as old waste disposal sites and community markets [16].

The concentration of copper recorded for samples ranged from 0.01 to 0.04 mg/L. There were no copper concentrations detected in samples C, D, H and M. Samples A, G and L recorded the maximum concentrations for Cu. Interestingly, all the 15 samples had the concentration of copper below the maximum permissible threshold of 0.3 mg/L and 1.0 mg/L for the two (2) standards considered in this study. The findings coincide with the results obtained by [2,16,43,58,67,72]. Based on copper concentration, water samples are safe for drinking.

Iron concentrations measured had a mean value of 0.163 mg/L. Sample E and B attained the minimum and maximum values of 0.01 mg/L and 0.41 mg/L respectively. Even though 80% of the analysed samples had values below the 0.3 mg/L recommended by the two standards considered in this study, there were marginally high levels of Iron recorded for samples A, B and K. These make water from the sample wells (A, B and K) unpleasant for drinking. Discharges from geological sources, industrial & domestic wastes or the oxidation of steel components in wells are potential causes of increased high Iron concentration [16]. Aeration and filtration are the most acceptable and widely used methods to remove iron from water [69] as the excess iron concentration in water causes increase in respiration, pulse rate, coagulation of blood vessels and hypertension [67].

Manganese concentrations measured in water from Hand-dug wells varied from 0.00 to 0.45 mg/L. Sample G and J indicates zero concentration values (Table 5a). Table 6 presents the average concentration value of 0.121 mg/L obtained from the statistical analysis. Similar to iron, about 80% of the samples evaluated for manganese concentration obtained values below the 0.2 mg/L recommended by the two standards considered in this study. However, samples C, N and O had value above the permissible. This connects to the fact that anaerobic groundwater often contains elevated levels of dissolved manganese. High concentrations of Mn can cause mental diseases such as Alzheimer's which affect the intellectual functions of children ≤ 10 years [2]

Nickel concentration was not detected from samples A, D, H, J and N. Evaluation of the samples revealed that the maximum concentration value of 0.22 mg/L was obtained from sample L. 53.33% of the samples evaluated were beyond the 0.02 mg/L permissible limit recommended by the NSDWQ and WHO standards. Thus,

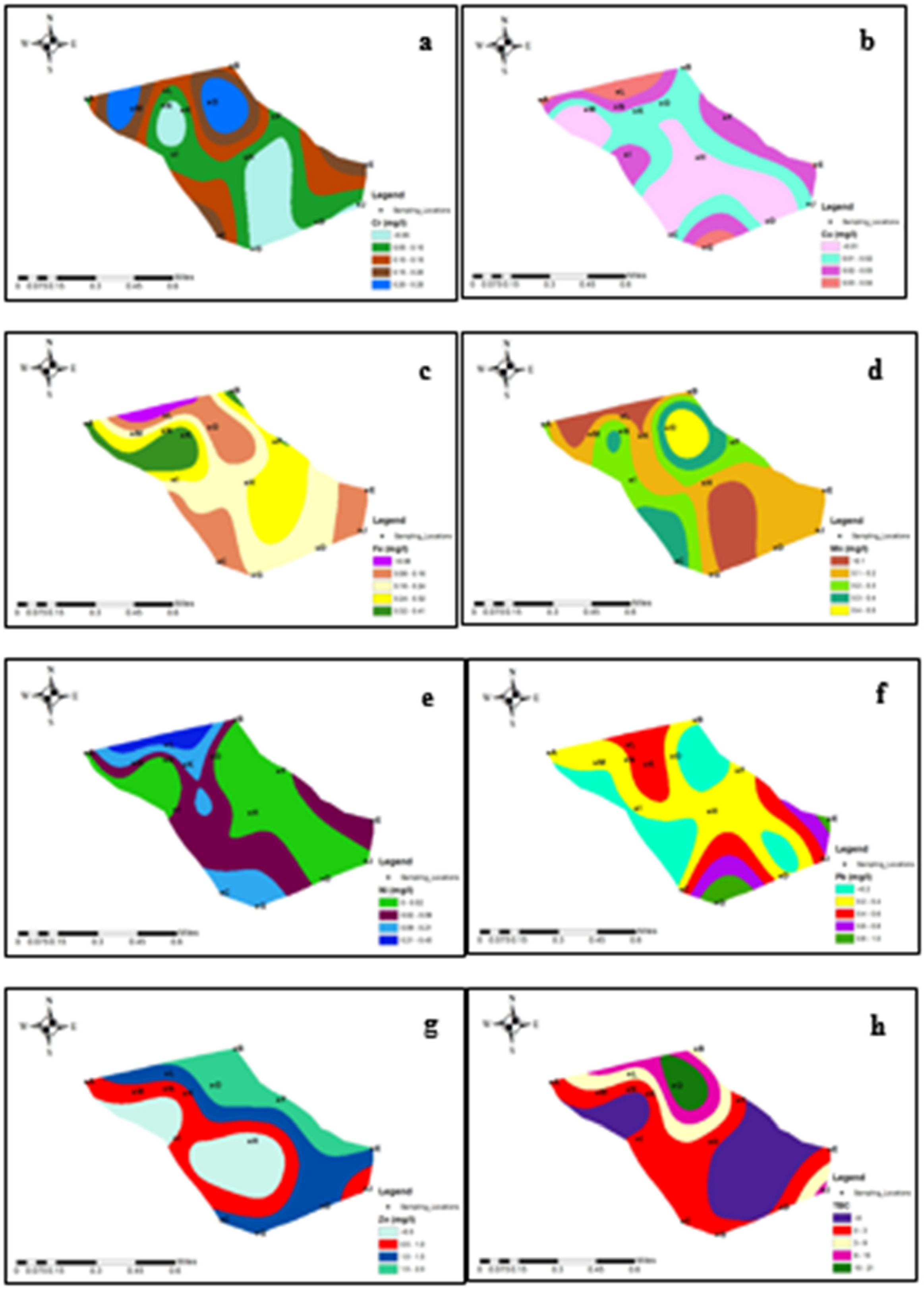

Fig. 8. Spatial distribution maps of (a) Cr (b) Cu (c) Fe (d) Mn (e) Ni (f) Pb (g) Zn (h) TBC.

making it generally unsuitable for drinking. According to [41], sewage sludge, wastewater from sewage treatment plants and groundwater near dumpsites are potential sources of Ni in water.

The lead concentration in the water samples ranged from 0.01 to 0.87 mg/L. The study recorded 0.157 mg/L as the mean value. There were 0.00 mg/L of lead in samples B, F, I, and M. However, findings revealed significant lead concentration levels even above permissible limits of both WHO and NSDWQ in most of the samples. The findings coincide with the results obtained by [58]. These results raise much concern since lead is a poisonous metal capable of damaging the nervous system. Haphazard disposal of waste from lead-containing substances have been reported as the major contributor of lead in water resources [72].

The concentration of zinc in the examined samples ranged between 0.14 and 1.90 mg/L. Samples H and O had the minimum and maximum values. Statistical analysis revealed 1.055 mg/L as the mean value for zinc. Interestingly, water from hand-dug wells examined showed 100% compliance with the NSDWQ and WHO standards.

3.5. Bacteriological parameter

3.5.1. Total bacterial count

Total coliform refers to a group of bacteria used to indicate the potential presence of harmful bacteria in water resulting from human and animal wastes [69]. The bacteriological evaluation of the water sample showed a variable result where some wells had coliform bacteria beyond the recommended standards and some within the range. However, for safe drinking water quality in Nigeria, NSDWQ recommends 10 cfu/100 ml as the highest allowable limit for complete coliform concentration. Therefore, thirteen out of fifteen samples were within values of 10 cfu/100 ml. Hence, suitable for drinking. Samples J and O with values above 10 cfu/100 ml were considered not suitable for drinking based on the NSDWQ guidelines. This shows that water from the two hand-dug wells were microbiologically poor. According to Nwankwo et. al., open drainage systems, improper disposal of wastes, constructing wells close to latrines and poorly constructed latrines, could be responsible for well water contamination with microorganisms [71]. Therefore, consuming water from these wells is unacceptable as waterborne diseases are the leading causes of underage death [43]. Table 5a shows that only samples A, D, E, G, I, K and N met the WHO recommended standard. This means that the remaining samples are not safe for drinking due to the non-conformity with the WHO standard [72].

3.6. Level of significance (p-values) and correlation matrix

Characterization for all samples of hand-dug wells was carried out considering the physical, chemical, bacteriological and trace metal concentrations. The results were statistically analysed and values for standard error, skewness, standard deviation, confidence level, mean, minimum, variance, maximum, and kurtosis were obtained as presented in Table 6. The results were also analysed using SPSS version 20 to compute the one-way analysis of variance. *p*-values for most parameters (Temperature, Colour, TDS, EC, TSS, Hardness, BOD, TBC, NO^{3-}, Zn, Cr, Ca, Fe, Ni, Cu, Pb and Mn) were found to be $p < 0.05$. This signifies that there was a statistically great difference between the concentrations of the parameters in water from the different hand-dug wells. However, *p*-values for pH, Turbidity, COD, SO_4^{2-}, Ca and Cl^-were found to be $p > 0.05$ which implies that there was no statistically great difference between the concentrations of the parameters in water from the different hand-dug wells. Results from the correlation analysis displayed in Table 7 have also proven the affinity strengths within cations.

3.7. Water quality Index

WQI concept is an effective monitoring tool used to compare water quality parameters with given regulatory standards. It provides a single value that expresses the general water quality in certain areas and its potential application for drinking purposes. Generating the WQI of hand-dug wells at different locations based on the WHO regulatory standards, fifteen (15) samples were evaluated for WQI. The calculated WQI values displayed on Table 8 ranged from 38.1809 to 497.46718. Sample O recorded the highest value while sample H shows the lowest WQI values. Based on the hand-dug well WQI's, 6.67% of the samples indicated excellent water, 46.67% under the category for good water while 20% showed poor water. Similar to excellent water, 6.67% signified very poor water while 20% of the samples fell under the water unsuitable for drinking purposes. Adopting the NSDWQ standard for the evaluated samples, WQI shown in Table 9 ranged from 38.4591 to 506.5651. A similar pattern was maintained as Samples O and H recorded the highest and lowest WQI values. Based on the hand-dug well WQI's, 6.67% of the samples indicated excellent water, 46.67% under the category for good water while 20% in the poor water category. Similar to excellent water, 6.67% signified very poor water while 20% of the samples were also under the water unsuitable for drinking purposes. The aforementioned percentages were similar to those obtained from the WHO standard with little variability in the values. Thus, the classifications were not affected as best illustrated in Figs. 9 and 10. The poor, very poor and water unsuitable for drinking classifications were obtained from hand-dug wells C, E, G, J, K, L and O. This could be attributed to indiscriminate domestic waste discharge, lack of run-off control measures, lack of maintenance for the wells etc.

Table 8
Water Quality Classification for hand-dug wells from Rafin Zurfi based on WHO Standard.

Sample	WQI	WQI Classification Type
A	54.80413721	Good water
B	61.04755556	Good water
C	123.1598618	Poor water
D	72.83571573	Good water
E	328.3390257	Water unsuitable for drinking purposes
F	52.97926007	Good water
G	386.6341769	Water unsuitable for drinking purposes
H	38.18089887	Excellent water
1	81.53177149	Good water
J	115.7059159	Poor water
K	169.7013031	Poor water
L	265.5322087	Very poor water
M	71.72280748	Good water
N	68.4176023	Good water
O	497.4671832	Water unsuitable for drinking purposes

3.8. Target hazard quotient and hazard index

The toxicity risks for ingestion of each metal in the research area is quantified in Tables 8 and 9. Results presented in Tables 10 and 11 were achieved by combining field, laboratory experiments, and data exposure to multiple pollutants results in additive and or

Table 9
Water Quality Classification for hand-dug wells from Rafin Zurfi based on NSDWQ Standard.

Sample	WQI	WQI Classification Type
A	52.80496583	Good water
B	62.9608889	Good water
C	122.3257752	Poor water
D	72.36155378	Good water
E	323.9022649	Water unsuitable for drinking purposes
F	53.35421299	Good water
G	384.1222371	Water unsuitable for drinking purposes
H	38.45909096	Excellent water
1	77.11644192	Good water
J	125.2601532	Poor water
K	167.7792692	Poor water
L	261.4473876	Very poor water
M	71.62491671	Good water
N	65.49974919	Good water
O	506.5650739	Water unsuitable for drinking purposes

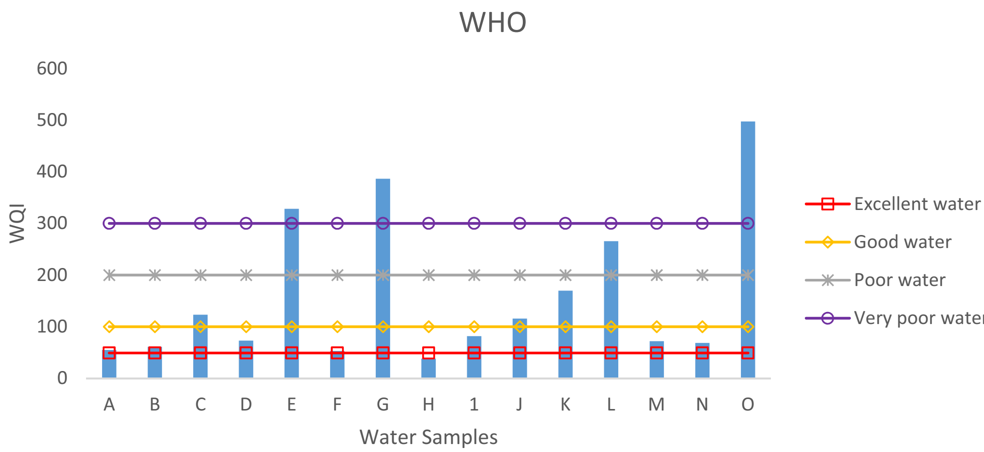

Fig. 9. Graphical Representation of WQI and Water Classification Based on WHO Standard.

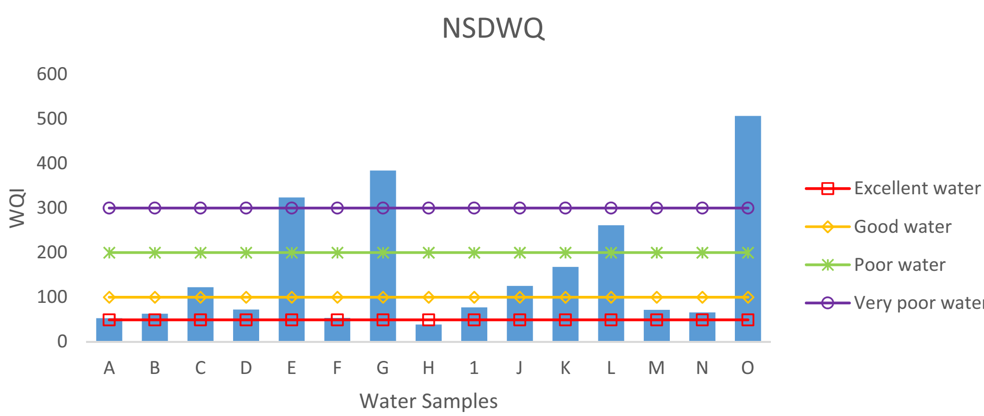

Fig. 10. Graphical Representation of WQI and Water Classifications Based on NSDWQ Standard.

Table 10
Target Hazard Quotient for Trace metals (Adult consumption).

Element	Oral reference dose RfD (mg/kg/day)	Total Hazard Quotient
Chromium	0.003[41,53,57,74]	1.35722×10^{-3}
Iron	0.7[75]	1.35168×10^{-5}
Zinc	0.3[41,53,74,75]	2.04488×10^{-4}
Lead	0.0036[41,53,74]	2.53133×10^{-3}
Nickel	0.02[41,53,74]	1.84194×10^{-4}
Copper	0.04[53,75]	2.42361×10^{-5}
Manganese	0.14[41]	5.01341×10^{-5}
		Hazard Index (HI) = 4.365119 × 10^{-3}

Table 11
Target Hazard Quotient for Trace metals (Children consumption).

Element	Oral reference dose RfD (mg/kg/day)	Total Hazard Quotient
Chromium	0.003[41,53,57,74]	1.61075×10^{-3}
Iron	0.7[75]	1.60418×10^{-5}
Zinc	0.3[41,53,74,75]	2.42687×10^{-4}
Lead	0.0036[41,53,74]	3.00418×10^{-3}
Nickel	0.02[41,53,74]	2.18602×10^{-4}
Copper	0.04[53,75]	2.87634×10^{-5}
Manganese	0.14[41]	5.94992×10^{-5}
		Hazard Index (HI) = 5.180528 × 10^{-3}

interactive effects [73]. The THQ values ranged between 1.35168×10^{-5} and 2.53133×10^{-3} in the adult category. Obtained THQ values for metals considered were in the order Pb > Cr > Zn > Ni > Mn > Cu > Fe respectively. The children's category exhibits the same pattern even though the THQ values were between 1.60418×10^{-5} to 3.00418×10^{-3}. The noncancer HQs of all the trace metals in water were below the recommended HQ threshold of 1 for both adult and children's water intake. Hazard index (HI), resulting from the summation of THQ's for anticipated poisonous metals analysed in this study was also calculated and found to be 4.365119×10^{-3} and 5.180528×10^{-3} for adult and children respectively. The consuming populace has been assumed to be safe since the HI < 1 for the two categories.

4. Conclusion

This study focused on health risk assessment of water from Hand-dug well in Rafin Zurfi area. To examine water quality in compliance with the WHO and NSDWQ baseline, APHA standard methods were adopted. Experimental investigations led to a better understanding of hand-dug well water quality for the study area. Hence, the following conclusions were made:

- pH values of the samples were adequate according to NSDWQ, while samples E and L exceeded WHO permissible limits. Turbidity, Total hardness, TDS, TSS, EC, BOD, Ca, SO_4^{2-}, Cl^-, Cu and Zn measurements were within permissible limits.

- Statistical analysis revealed that p-values for most parameters were found to be ($p < 0.05$). Thus, the null hypothesis is discredited. Based on the hand-dug well water quality index, 6.67%, 46.67% and 20% of the samples indicated excellent, good and poor water respectively. Similar to excellent water, 6.67% signified very poor water while 20% of the samples fell under the water unsuitable for drinking purposes. The poor, very poor and water unsuitable for drinking classifications were obtained from hand-dug wells C, E, G, J, K, L and O.
- THQ values for metals considered for children's and adults category were in the order Pb > Cr > Zn > Ni > Mn > Cu > Fe respectively.
- HI values found for all of the subjected heavy metals in two age groups (children and adults), suggested no possibility of adverse health effects to the local population by consuming water from hand-dug wells in Rafin Zurfi area.

Declaration of Competing Interest

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

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