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Health risk assessment of heavy metal–contaminated well water around mechanic workshops

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Abstract

The study investigated the pH, Total Dissolved Solids, Electrical Conductivity, turbidity and heavy metal levels in six well water samples collected from 3 automobile workshops located in New GRA, Yelwa and Wuntin Dada in Bauchi LGA of Bauchi State. Results from analysis showed that the metals investigated were present in all the water samples, except Pb in the wells in New GRA, Wuntin Dada and Well 2 in Yelwa. With the exception of Cd (0.001mg/l) in Well2 in New GRA and Cu in all the samples, the means of each of the metals in the well samples were higher than the values obtained from control sites, the recommended values obtained from the Nigeria Standards for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO). The mean pH value of the water samples examined were observed to be within the recommended standard, except in the wells 1 (6.35) and 2 (6.34) in New GRA, showing that the water in these wells are slightly acidic. The turbidity of the well water was lower than the standard, except in well2 (10.05NTU) in Yelwa. The electrical conductivity and total dissolved solid were lower than the recommended value but far above the values obtained for the control samples. The heavy metal pollution indices show that the well water samples are polluted with the various heavy metals studied, except Cu. The HQ and HI values exceeded 1, showing high potential non-carcinogenic risk to humans. The well water in the mechanic workshops are therefore not suitable for drinking and other domestic purpose.

Keywords: Heavy metal, pollution, mechanic workshops, well water, human health risk

Introduction

Groundwater is sourced throughout the world through wells and boreholes (Ajibade, 2011; Abdulkadir *et al*. 2017; Obuekwe *et al*., 2021) [38, 12, 1]. Sometimes this water collects on the top of the impervious layers and can only be reached by digging deep down the water table. These openings are what is referred to as wells (Usman *et al*., 2013). Wells, as sources of water are often unpolluted due to restricted movement of pollutants in the soil profile (Murhekar, 2011) [35]. However, when water travels through the ground, it dissolves parts of the soil components and so may contain objectionable concentration of salts generated from anthropogenic activities such as mining, fuels, smelting of ores and improper disposal of industrial and automobile wastes (Igwemmar *et al*., 2013; Musa *et al*., 2013; Amoo *et al*. 2021) [36, 24]. Water contamination/pollution, a situation where the water quality is compromises may occur. Toxic materials generated from residential and industrial activities leach into underground water sources, making it potentially harmful to biological life at such locations (Adelekan and Abegunde, 2011; Lekan *et al*. 2019) [28, 8]. The level of contamination of water sources, especially well and boreholes, has attracted concerns from scholars, as a result of its health implications on biotic organisms especially man (Ndububa and Nwafor, 2015; Jabbo *et al*., 2016; Abdulkadir *et al*. 2017; Gloria and Token, 2021; Abugu *et al*. 2022) [37, 26, 3, 1]. While proximity of wells to drainages of sewage, laundry water and refuse dumps/landfills are reasons for well water pollution, the proximity of wells to mechanic village sites and small scale industries have also been identified as major sources of well pollution (Usman *et al.*, 2013; Adewoyin *et al.*, 2013; Popoola and Ayodele, 2016) [44, 9].

Auto-mechanic workshops are areas designated for artisans such as auto-electricians, battery servicemen, vulcanizer, and panel beaters who are involved in auto-repairs and maintenance of automobiles, and other various forms of business activities involving daily use of water from wells located in these workshops. They have been identified as a major source of pollution in the environment. This is because scrap batteries and solder, suspended solids, cyanides, alkali, organic solvents, waste engine oil, brake fluid and other fluid containing heavy metals, generated by the activities of these artisans are improperly disposed off on the soil (Ipeaiyeda and Dawodu, 2007; Adelekan and Alawode, 2011; Usman *et al*., 2013; Osakwe, 2014) [42, 8]. Soil, being a complex porous material and one of the repositories for these anthropogenic wastes and biochemical processes can mobilize these hazardous chemical substances contained in it; gradually contaminating the entire ground water in the area and impairing ground water quality (Sadick *et al*., 2015; Agbaji *et al*., 2015; Raddy *et al*., 2014) [48, 10].

Despite the abundance of literature on sources of water contamination, there is paucity of information on the impact of auto-mechanic workshops on well water in Bauchi Local Government Area. Bauchi state, especially its metropolis, is not an exception to the foregoing contamination problems. Over the last fifteen years, Bauchi metropolis has experienced a steady influx of automobiles, thus increasing the number of auto-mechanical workshops operating in virtually every corner of her streets. It is worthy of note that some auto-mechanic workshops are being reclaimed for Residential purposes. Residents in these reclaimed workshops dig wells in their compounds, making these residents directly vulnerable to contaminants. There is therefore a need to monitor the water quality of wells in these workshops in order to understand the distribution of pollutants and extent of contamination in the vicinities of auto-repair workshops. In this research work, an attempt has been made to assess the pH, electrical conductivity, total dissolved solids, turbidity, and heavy metal concentration of the well water samples; and evaluate risk assessment indices of the metals.

Heavy Metal Pollution indices for well water samples

The high toxic and persistent nature of heavy metals in the environment has made them priority pollutants. Their pollution of the environment even at low levels and the resulting long-term cumulative health effects are among the leading health concerns all over the world (Abechi *et al.*, 2010; Adams *et al*., 2015) [5, 2]. Two major assessment indices for heavy metals (pollution index and geoaccumulation index) have been used here to ascertain the level of pollution by heavy metals in water samples. Results obtained from these assessments serve as baseline data for future monitoring of contamination/pollution due to anthropogenic effects.

Geoaccumulation index: The degree of metal contamination or pollution in terrestrial, aquatic and marine environment can be evaluated using Index of geo-accumulation (I_{geo}) (Tijani and Onodera, 2009) [51]. The I_{geo} of a metal in the soil is calculated as thus:

$I_{geo}=\log 2C_{metal}/1.5C_{metal\ (control)}$.

Where C_{metal} is the concentration of the heavy metal in the enriched sample and $C_{metal\ (control)}$ is the concentration of metal in the unpolluted sample or control. The factor 1.5 is introduced to minimize the effect of possible variations in the background or control values which may be attributed to lithogenic variation in the soil (Loska, *et al.*, 2003, Adaikpoh, 2013) [32, 4].

Huu *et al.*, (2010) [23] gave seven contamination classes used to define the degree of metal pollutants in soils ranging from uncontaminated to very highly contaminate.

Igeo < 0 means unpolluted
0 ≤ Igeo <1 means unpolluted to moderately polluted
1 ≤ Igeo <2 means moderately polluted
2 ≤ Igeo <3 means moderately to strongly polluted
3 ≤ Igeo <4 means strongly polluted
4 ≤ Igeo <5 means strongly to very strongly polluted
Igeo >5 means very strongly polluted

Pollution Load index (PLI): Pollution index is used to evaluate the pollution index by considering the joint effect of all the polluting metals in the water. Pollution load index is calculated using: $PI = (PR_1 \times PR_2 \times PR_3 \times \ldots \times PR_n)^{1/n}$. Where PR_1, PR_2, PR_3...., PR_n are the pollution ratios, PR value = Metal concentration in water sample/Metal concentration in background sample and n is the total number of metals. PLI < 1 indicates no pollution; 1 < PLI < 2 shows moderate pollution; 2 < PLI < 3, heavy pollution; and 3 < PLI, extremely polluted (Adedosu, 2013; Ganiyu *et al*. 2021) [20, 7].

Health risk assessment of the well water samples

Human health risks of contaminated water include non-carcinogenic risks and carcinogenic risks. The non-carcinogenic risks have to do with the chronic levels of the metals to which an individual is exposure to. This includes genetic and teratogenic effects. Carcinogenic risk is used to determine the possibility of an individual to develop cancer due to prolonged exposure to pollutant(s) (Ye *et al*. 2023).

Chronic daily intake (CDI): CDI is the average daily exposure dose of heavy metals humans are exposed to, through ingestion and dermal contact. The Chronic Daily Intake (CDI) through ground water ingestion and dermal absorption is calculated by using the following equation:

$CDI_{\ ingestion} = (C_w \times IR_w \times EF \times ED) / (BW \times AT)$............. (1)

$CDI_{\ dermal} = (C_w \times EF \times ED \times ET \times SA \times K \times CF) / (BW \times AT)$....... (2)

Where CDI = chronic daily intake (mg/kg/day), C_w = mean concentration of heavy metal in water (mg/l),
IR = ingestion rate (l/d) (0.75, 1, and 2 L/day for infant, child, and adult, respectively), EF = exposure frequency (365days/year), ED = exposure duration in years (70 years for adult and 10 years for children), BW = average body weight (kg) over the exposure period (equivalent to 5 kg for infant, 10 kg for children and 60 kg for adult), AT = average time period of exposure in days (equals 3650 days and 25,550 days for child and adult, respectively). ET = exposure time taken as 0.58 hour/day, SA = surface area of contact is 18000 cm^2, K = dermal permeability coefficient is 0.001 cm/h, CF = unit conversion factor ($0.001 l/cm^3$). (Li *et al*. 2022; Mawari *et al*. 2022) [34, 31]

Since AT = EF × ED, equation (1) and (2) is therefore reduced to;

$CDI_{\ ingestion} = (C_w \times IR_{w}) / (BW)$
$CDI_{\ dermal} = (C_w \times ET \times SA \times K \times CF) / (BW)$

Hazard quotient (HQ): HQ is used to calculate the potential non-carcinogenic risk to human health posed by hazardous materials in contaminated groundwater. The quotient gives the ratio of the estimated heavy metals exposure of test water to the oral reference dose.

$HQ_{ingestion} = CDI_{ingestion} / RfD_{ingestion}$
$HQ_{dermal} = CDI_{dermal} / RfD_{dermal}$

Where, CDI = Chronic daily intake and RFD = Reference dose RFD is the reference dose of a particular heavy metal (mg/kg/day) (Egbueri and Mgbenu 2020; Kumar *et al*. 2020b; Ganiyu *et al*. 2021) [33, 20, 18].

Table 1: Oral Reference dose and Dermal Reference Dose of some heavy metals in mg/kg/day

Heavy metals	Oral Reference dose	Dermal Reference Dose
As	0.0003	0.000123
Cd	0.0010	0.000010
Pb	0.0035	0.000525
Hg	0.0100	0.000021
Ni	0.0200	0.005400
Cu	0.0400	0.01200
Mn	0.0140	0.00005
Zn	0.3000	0.06000
Fe	0.0600	0.05820
Cr	0.0030	1.50000

(Mawari *et al*., 2022) [34]

Hazard index (HI): The HI is the sum of the hazard quotients and evaluates the potential effect of all the dissolved heavy metals on human health. The hazard index is the sum of the hazard quotients as described in the following equation.

$$HI_{ingestion} = \sum HQ_{ingestion}$$
$$HI_{dermal} = \sum HQ_{dermal}$$

An index of HI ≥ 1 is considered as not safe for human health. HI value >1, indicates a high potential health risk with a higher possibility of non-carcinogenic health effects while HI values < 1 shows that the non-carcinogenic health risk lies within the acceptance limit (Egbueri and Mgbenu 2020, Ganiyu *et al*., 2021; Mawari *et al*. 2022) [34, 20, 18]
The total non-carcinogenic risks can be calculated using the equation:

$$HQ_T = HQ_{ingestion} + HQ_{dermal}$$

$HI_{Total} = \sum HQ_T$ (Li *et al*., 2022) [31]

Materials and method

Sampling sites

Six partially protected shallow wells in three mechanic workshops in New GRA, Yelwa and Wuntin Dada were assessed in order to ascertain the pollution status of the well water. These auto-mechanic workshops within Bauchi metropolis were strategically selected due to their age of establishment, size and patronage.

Pre-treatment and sterilization of apparatus

Prior to sampling, all glassware and sample bottles were washed with liquid detergents, rinsed with tap water and soaked in 10% HNO_3 for 48 hours. They were thereafter rinsed with distilled water to preclude trace metal contaminations, before oven drying. The plastic bottles meant for sampling were further rinsed thrice on site with well waters being sampled **(**Ogunfowokan *et al*., 2013; Usman *et al*., 2013) [40].

Samples collection

The composite water sampling method was used in collection of sample in each sampling sites. Water samples were drawn with a plastic bucket. About 2 L well water sample for physical and chemical parameters determination were collected. A 2 litre wide mouth polyethylene container thoroughly cleaned was used. Samples were adjusted to pH 2 to prevent further microbial degradation and stored below 4^0C in a refrigerator before analysis (Ogunfowokan *et al*., 2013) [40]. Control samples were similarly collected from wells, 200 meter away from the sample sites.

Sample digestion and analysis

A 200 cm^3 aliquot of the sample was concentrated with some drops of concentrated HNO_3 in a beaker at 120° C to about 100 cm^3. The samples were analyzed for Cu, Pb, Ni, Mn, Cd, Cr, using Atomic Absorption Spectrophotometer (AAS). All assays were done in triplicates (Usman *et al*., 2013; Adedosu *et al*., 2013) [7].

Physico-chemical properties of water samples

The pH, Electrical conductivity, total dissolved solids and turbidity of the water samples was determined using the POTALAB WAG-WE 10010 using standard procedure.

Statistical analysis

SPSS 15 statistical package was used to calculate the mean, standard deviation and weighted means of the metal concentration and physico-chemical properties of the water samples.

Results and discussion

The mean results of the heavy metal concentration and physico-chemical properties of the well water samples were compared with the Nigerian Standard for Drinking Water Quality (NIS) and WHO values, and are presented in Tables 1 and 2, while Figure 1 and Table 3 shows the Geo-accumulation index and pollution index assessment for the metal pollutants.

Mean metal content of well water in study sites

The results of the mean concentration of Cd in all well water samples determined at the various locations as presented in Table 1, indicated that the level of Cd in the water sampled were higher than NIS/WHO recommended values (0.003mg/l) and control samples, except in NeG2 (0.001 mg/l) and Y 2 control (0.003mg/l), where the Cd concentration was equal to the recommended value. The order of accumulation of Cd in the various workshops are WD2 (0.030mg/l) > NeG1 (0.020mg/l) > Y1 (0.017mg/l) = Y1 (0.017mg/l) >WD1 (0.005mg/l) > NeG2 (0.001mg/l). The result obtained for Cd in this study is consistent with those reported by Kerketta *et al.*, (2013) [27] (0.03± 0.01ppm) and Esan *et al*., (2015) [19] (0.012 – 0.016mg/l) but higher than those reported by Musa *et al*., (2013) [36]. Higher values greater than 0.1mg/l were recorded by Alhassan and Ujoh, (2012) [13] and Adewoyin *et al*., (2013) [9] in water samples. The high level of Cd as seen in the result may be due to motor vehicle repairs such as body work, painting, soldering, brake fluid, lubricating oils, corrosion of metals, nickel-cadmium batteries and metal parts such as radiators in these sites (Dabkowska- Naskret, 2004; Rajappa, *et al*., 2010; Odoh *et al*., 2011) [46, 39, 15]. Groundwater Cd concentrations as great as 3.2 mg/l, have been reported to result from the seepage of Cd from electroplating plants (Usman *et al*., 2013). Cd is found in nature largely as an impurity of Zn-Pb ores. Cd is a cumulative poison and is not known to be either biologically essential or beneficial. It is believed to promote renal arterial hypertension. Elevated concentrations of Cd may cause liver and kidney damage, or even anaemia, retarded growth, and death (USEPA 1999) [53].

Table 1: Means levels of heavy metals (mg/l) in water samples from the workshops

Mechanic Workshop	Cd	Cr	Cu	Pb	Mn	Ni
NeG1	0.020±0.01	0.091±0.04	0.094±0.01	BDL	0.640±0.13	0.095±0.03
NeG1 C	0.002±0.02	0.001±0.02	0.004±0.00		0.011±0.01	0.003±0.00
NeG 2	0.001±0.02	0.130±0.05	0.125±0.04	BDL	0.160±0.04	0.105±0.02
NeG 2C	0.00 ±0.00	0.010±0.00	0.002±0.01		0.020±0.02	0.022±0.01

Y1 Y1C	0.017±0.01 0.001±0.00	0.155±0.04 0.003±0.00	0.207±0.01 0.012±0.01	0.040±0.04 0.004±0.01	0.182±0.01 0.031±0.01	0.040±0.02 0.013±0.01
Y2 Y2C	0.017±0.01 0.003±0.00	0.615±0.04 0.005±0.00	0.160±0.01 0.085±0.01	BDL	3.110±0.12 0.027±0.0	0.080±0.01 0.012±0.00
WD1 WD1C	0.005±0.01 0.000±0.00	0.652±0.04 0.006±0.01	0.104±0.02 0.000±0.00	BDL	3.550±0.14 0.054±0.01	0.049±0.00 0.010±0.01
WD2 WD2C	0.030±0.01 0.002±0.00	0.364±0.03 0.003±0.00	0.059±0.01 0.002±0.00	BDL	0.110±0.02 0.015±0.00	0.030±0.01 0.004±0.00
NSDWQ (mg/l)	0.003	0.050	1.000	0.01	0.200	0.020
WHO (mg/l)	0.003	0.050	2.000	0.01	0.100	-

Nigerian Standard for Drinking Water Quality (NSDWQ, 2007), World Health Organization (WHO, 2011), **C**=control, NeG=New GRA, Y=Yelwa, WD=Wuntin Dada,

The concentration of Cr in all the water samples exceeded the control concentrations, NSDWQ and WHO standards (0.05 mg/L). The order of accumulation for this metal was WD1 (0.652mg/l)> Y2 (0.615mg/l) > WD2 (0.364mg/l) > Y1 (0.155mg/l) > NeG2 (0.130mg/l) > NeG1 (0.091mg/l). Results for Cr obtained in this study are consistent with the values greater than 0.14mg/l reported in Alhassan and Ujoh, (2012) [13] for wells and borehole water samples. One major source of Cr is steel. Steels are at times coated with Cr, which helps to prevent the steel from rusting. When this deteriorates, it finds itself into underground waters through seeping (Usman *et al*., 2013). Chromium is also used in metal alloys and pigments for paints. Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage too circulatory and nerve tissue.

Copper in all the samples were found to be lower the standards (1.0mg/l and 2.0mg/l for NSDWQ and WHO respectively) but were higher than the values for the background samples. Cu accumulation in the studied wells was in the following order: WD2 (0.059)<NeG1(0.094mg/l)<WD(0.104mg/l)<NeG2(0.125mg/l)< Y2(0.160mg/l) <Y1 (0.207mg/l). Researchers have also reported values lower than these values in hand dug wells and boreholes, Musa *et al*., (2013) [36] (0.001 – 0.052 mg/l), Alhassan and Ujoh (< 0.12mg/l). Values obtained for well water samples in Gwallameji, Bauchi were also below detection limits (Esan *et al*., 2015) [19]. Copper is used in electroplating of metals to prevent corrosion and may enter water when it deteriorates (Usman *et al*., 2013). Copper is essential to metabolism in human life, its deficiency in infants and young animals results in nutritional anaemia. In high doses it is toxic, causing anaemia, liver and kidney damage, stomach and intestinal irritation. Lenntech, 2009 [29] reported that there is a link between long term exposure to copper and decline of intelligence in young adolescents.

Lead was not detected in the water samples, except in Y1 (0.04mg/l). This value exceeded the standards (0.01mg/l) and control sample (0.004mg/l). The proportion of lead (Pb) in almost all the sampled wells was zero, indicating the absence of lead contamination. The result obtained here are consistent with the 0.000-0.004mg/l reported by Musa *et al*., (2013) [36] and 0.00mg/l in Esan *et al*., (2015) [19] but less than the concentrations of 0.07±0.03ppm and 0.08±0.02ppm for Pb were reported in Priscilla *et al*., (2013) for well and hand pumps respectively and values close to 0.09mg/l in Alhassan and Ujoh, (2012) [13]. Higher concentration of 6.59±5.71 to 21.35±4.91mg/l has been reported in well water samples in auto-mechanic workshops in Ibadan (Adewoyin *et al*., 2013) [9]. Possible sources of Pb in water include motor batteries and lead materials used by mechanics (Usman *et al*., 2013)

The level of manganese in all the samples exceeded the background concentrations and WHO standard (0.1mg/l). Only in NeG1, Y2 and WD1 did the levels of Mn exceed the NSDWQ standard (0.2mg/l). Although the values in NeG2 (0.160mg/l) and Y1 (0.182mg/l) may be lower than the NSDWQ standard for this metal, the values in these two workshops are substantial, as they may not be significantly different from the NIS standard. WD1 has the highest concentration of Mn (3.550mg/l) while WD has the lowest (0.110mg/l). Musa *et al*. (2013) [36] reported lower concentrations of Mn (0.001-0.031mg/l) in well water samples in Obajana. One can deduce that Mn concentrations in water could be mainly from mechanic activities judging from the control samples. Values of 0.55 – 2.55mg/l have also been reported by Alhassan and Ujoh (2012) [13]. The high concentrations of Mn implies that water from the sample wells will impacts a bitter taste to water, stains cloths and metal parts; precipitate in foods when used for cooking and it also promotes the growth of algae in reservoirs or collection tanks (Musa *et al*., 2013) [36].

The concentrations of nickel in all the samples were above the NIS standard (0.02mg/l). Ni accumulated in the order: NeG2(0.105mg/l)>NeG1(0.095mg/l)>YW2(0.080mg/l)>WD1(0.049mg/l)>Y1(0.049mg/l)>WD2 (0.030mg/l). Ni is a possible carcinogen and very toxic to some plants and animals. Its toxicity for humans is believed to be very minimal (NSDWQ, 2007) but in 2008, Ni was named "Allergen of the year" and the frequency of its allergy is still growing (Gillette, 2008) [21]. The distribution of Ni in these study sites could be attributed to the disposal of spent automobile batteries from auto-battery chargers and various paint wastes discharged in these workshops (Udousoro *et al*., 2010) [52]. These wastes can seep into ground water.

Mean levels of physico-chemical properties of well samples in study sites

pH: The weighted mean pH of the water samples in study sites ranged from 6.34 to 7.36 as shown in Table 2. The pH of NeG1 (6.35) and NeG2 (6.34) were below the WHO and NSDWQ recommended range of 6.5-8.5, while the pH values for the other sites, including those of the control samples lie within the recommended pH range. All the samples in the study sites have pH value below 7.0 (acidic), except MV1, with the highest pH value of 7.36. This shows that pollutants, especially metals may be present in the samples obtained from the wells. Water sample from MV1is slightly alkaline probably due to presence of carbonates and bicarbonates; and may possibly be hard (David, 2004) [16]. pH values obtained here compared favourably with values obtained for well water samples in Gwallameji, Bauchi (Esan *et al*., 2015) [19], mechanic workshops in Ibadan with pH values of 5.87±0.27 to 7.17±0.19 (Adewoyin *et al*., 2013) [9] but are lower than those reported for well samples in (Olutona *et al*., 2012) [41]. Values obtained in WD1 agree with results in similar studies in Kerketta *et al*. 2013; Ikeme *et al*., 2014; Lekan *et al*., 2019, Abugu *et al*., 2021 [28, 27].

Table 2: Means of some Physico-chemical properties of well water samples in the Workshops

Mechanic workshop	pH	EC(μ*Scm*$^{-1}$)	TDS(mg/l)	Turbidity(NTU)
NeG1	6.35±0.05 (7.22± 0.04)	681.8± 2.04 (165.7± 0.03)	335.9± 2.02 (86.6± 0.04)	0.396± 0.02 (0.10± 0.00)
NeG2	6.34± 0.13	761.2± 1.32	393.5± 1.30	0.530±0.03
	(6.97± 0.02)	(278.4± 1.04)	(135.0± 0.04)	(0.28± 0.01)
Y1	6.60±0.14 (6.70± 0.02)	650.4±1.41 (250.2± 0.14)	326.5±1.30 (125.3± 0.20)	4.020± 0.04 (2.70± 0.02)
Y2	6.72± 0.10 (7.96± 0.02)	792.7± 1.13 (304.8± 1.09)	394.2± 1.02 (153.1± 1.13)	10.05± 0.21 (6.00± 0.05)
WD1	7.36±0.17 (6.95± 0.03)	609.9±0.71 (109.5± 0.04)	305.3±0.71 (57.1± 0.04)	0.620±0.06 (0.00± 0.00)
WD2	6.53± 0.06 (7.60± 0.03)	616.8± 3.54 (287.3± 1.40)	308.5± 2.10 (149.8± 0.73)	0.792± 0.06 (0.12± 0.01)
NSDWQ (mg/l)	6.5-8.5	1000	500	5.00
WHO (mg/l)	6.5-8.5	1000	-	5.00

Values in parentheses are levels of parameters in control sites, Nigerian Standard for Drinking Water Quality (NSDWQ, 2007), World Health Organization (WHO, 2011)

Electrical Conductivity (EC) and total dissolved solid (TDS): The weighted mean EC and TDS values in all samples ranged from 609.9 to 792.7μs/cm and 305.3 to 394.2mg/L respectively. All the water samples in the study sites have values below the WHO and NSDWQ permissible limits of 1000μs/cm but substantially high, when compared to the control values. This may be due to high dissolved inorganic minerals in ionized form, which may also be an indication of pollution in the mechanic workshop. The degree of weathering of rocks and soil beneath the ground always contribute to the level of TDS in water. Some dissolved organic matter may also contribute to increased level of TDS, which also indicates that water is polluted (Rao *et al.*, 2012) [47]. However, some of the values obtained in this study are consistent with the range of literature values of 650μs/cm and 320mg/l (Ahmed and Eyaife, 2014) [11] and 170 - 650μs/cm (Jabbo *et al*., 2016) [26] in selected hand dug wells and a borehole in Bauchi; groundwater values of 423-1197 μS/cm have also been reported in Devi and Premkumar (2012) [17]. The values obtained here were higher than values reported in well sample in mechanic workshop in Ibadan (Adewoyin *et al*., 2013) [9]; wells and bore-hole water in Abugu *et al*. (2021) (133 – 187μs/cm^3). The findings in this study are above the TDS values ranged of 145 - 245 mg/l reported by Pandey and Tiwari, (2009) [43]. TDS value of 1846 mg/l has been reported in wells (Kerketta *et al*., 2013) [27].

Turbidity: The turbidity values of the water samples were found to be between of 0.396 and 10.05 NTU in the study sites. The order for turbidity values in NTU obtained was NeG1 (0.396) < NeG 2 (0.530) < WD1 (0.620) < WD2 (0.792) <Y1 (4.020) <Y2 (10.05). The turbidity values were lower in the control samples, except in YW2 control, when compared to the other mechanic workshops. The values obtained in all the sites compared well with the WHO and NIS permissible limit (5.0 NTU) for portable water, except YW2 with value of 10.05 NTU, exceeding the compared limits. The turbidity values in the present study is consistent with those recorded by Tiimub *et al.*, 2012 (0.59-23.3) [50] in underground water analysis. The values here are lower than the range of turbidity values recorded for wells (30 – 71 NTU) and boreholes (23 – 34 NTU) by Abdulkadir *et al*. (2017) [1]. The high turbidity value in YW2 and its control may be due to the presence of clay, silt, finely divided organic matter, plankton and other microscopic organisms (Esan *et al*., 2015) [19].

Pollution index of heavy metals in well water samples

Geoaccumulation index (I_{geo}) results obtained revealed that the water sampled in the workshops was polluted by the study metals at different degrees with reference to control samples (Figure 1) except for Pb in NeG1, NeG2, Y2, WD1and WD2 (with $I_{geo} = 0$), Cu in NeG2 and WD1 (with $I_{geo} = 0$); Cd in Y2 and WD1 (with $I_{geo} = 0$). The pollution levels for the metals ranged from moderate pollution ($I_{geo} \geq 1$) to very strong pollution ($I_{geo} > 5$). The I_{geo} levels for Cr, Mn and Cu were very prominent in the study. Ganiyu *et al*. (2021) [20] reported similar Igeo < 0 for Pb and Cd in shallow groundwater sources within Ibadan metropolis, southwest Nigeria.

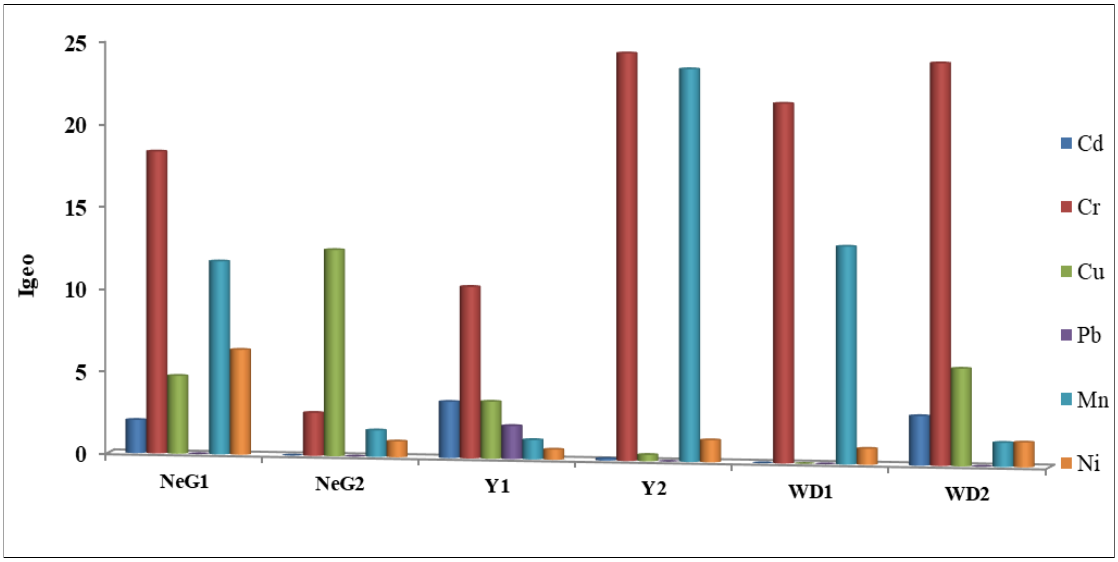

Fig 1: Geoaccumulation Index of the heavy metals in water samples

The results of the Pollution Load Index (PLI) for the well water samples in all the study locations were greater than one (Figure 2). This shows that the wells sampled in the investigated workshops are polluted with heavy metals to various degrees and unsafe for drinking. The PLI for the study wells are in the order: Y2>WD1>WD2>NeG1>Y1>NeG1. With the exception of wells NeG2 and Y1 with moderate pollution and heavy pollution respectively, the other wells were extremely polluted with heavy metals.

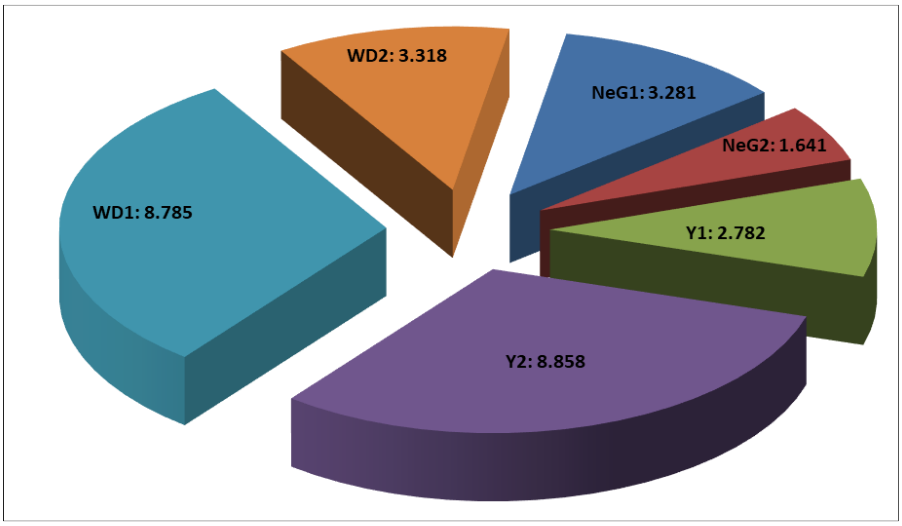

Fig 2: Pollution Load Index (PLI) for well water in the study workshops

The PLI values for heavy metals in this study were higher than those reported in Ganiyu *et al.* 2021 [20] for groundwater samples.

Health risk assessment of heavy metals in the well water samples

The non-carcinogenic risks (CDI and HQ) involved in the use of the sampled well water are shown in Tables 3 and 4. Only values of metals detected were used for calculation. The CDI (through ingestion) in the various wells followed the order. NeG1: Mn>Cr=Ni=Cu>Cd>Pb; NeG2: Mn>Cr>Cu>Ni>Cd>Pb; Y 1: Mn>Cr>Cu>Ni=Pb>Cd; Y2: Cr>Mn>Cu>Ni>Cd>Pb; WD1: Mn>Cr>Cu>Ni>Cd>Pb. In WD2, it changed to Cr>Mn>Cu>Cd=Ni>Pb (Table 3). In the study locations, the CDI$_{dermal}$ for the metals followed the descending orders. NeG1 and WD2: Cr>Mn>Cu=Ni>Cd>Pb; NeG2: Mn>Cr>Cu>Ni>Cd>Pb; Y1: Cr>Cd>Cu>Mn>Ni=Pb: Y2: Cr>Mn>Cd>Cu>Ni>Pb, WD1: Cr>Mn>Cu>Ni>Cd>Pb (Table 3). From all indications, the CDIs for Cr, Mn and Cu were predominant in most of the studied wells.

Table 3: Chronic daily intake (CDI) through ingestion and dermal contact

Wells	Cd	Cr	Cu	Pb	Mn	Ni
CDI through ingestion						
NeG1	6.7E-4	0.0033	0.0031	-	0.0213	0.0032
NeG2	3.3E-5	0.0043	0.0042	-	0.0053	0.0035
Y1	5.7E-4	0.0052	0.0042	0.0013	0.0061	0.0013

Y2	5.7E-4	0.2050	0.0053	-	0.1037	0.0027
WD1	1.7E-4	0.0217	0.0035	-	0.1183	0.0016
WD2	0.0010	0.0121	0.0020	-	0.0037	0.0010
CDI through dermal contact						
NeG1	3.8E-6	0.0011	1.8E-5	-	1.2E-4	1.8E-5
NeG2	1.9E-7	2.5E-5	2.4E-5	-	3.1E-5	2.0E-5
Y1	2.0E-4	0.0018	4.0E-5	7.7E-6	3.5E-5	7.7E-6
Y2	2.0E-4	0.0013	3.1E-5	-	6.0E-4	1.5E-5
WD1	9.6E-7	0.0021	2.0E-5	-	6.8E-4	9.4E-6
WD2	5.7E-6	7.0E-5	1.1E-5	-	2.1E-5	5.7E-6

The HQ$_{\text{Ingestion}}$ values obtained for the metals in the well water were observed to follow the patterns: NeG1: Mn>Cr>Cd>Ni>Cu>Pb; NeG2: Cr>Mn>Ni>Cu>Cd>Pb; Y1: Cr>Cd>Mn>Pb>Cu>Ni. In Y2, WD1 and WD2, the order was Mn>Cr>>Cd>Cu=Ni>Pb; Mn>Cr>>Cd>Cu>Ni>Pb and Cr>Cd>>Mn>Ni>Cu>Pb respectively (Table 4). The HQ$_{\text{dermal}}$ of the study metals in NeG1, NeG2 and W2 were observed to follow the order: Mn>Cd>Ni>Cu>Cr>Pb; while in Y1, Y2 and WD1, the pattern is Cd>>>Mn>Pb>Cu>Ni>Cr; Cd>Mn>>>Ni>Cu>Cr>Pb and Mn>>>Cd>Cu=Ni>Cr>Pb respectively. The estimated HQ$_{\text{dermal}}$ values obtained for the various metals in the study differed considerably from the HQ$_{\text{Ingestion}}$ values in terms of Cr and Cd values. While Mn and Cr dominated the calculated HQ$_{\text{Ingestion}}$ values, Mn and Cd had elevated levels of the HQ$_{\text{dermal}}$ values. Mawari *et al.* (2022) [34] also reported that Cr and Cd are two metals with high HQ values in groundwater. Ganiyu *et al.*, (2021) [20] affirmed that Cd has high HQ values compared to other metals, implying that this metal poses significant health risk.

Table 4: Hazard quotient (HQ) values for heavy metals

Wells	Cd	Cr	Cu	Pb	Mn	Ni
HQ$_{\textit{ingestion}}$						
NeG1	0.6671	1.011	0.0780	-	1.524	0.1602
NeG2	0.0333	1.440	0.1051	-	0.381	0.1750
Y1	0.5670	1.720	0.1733	0.381	0.433	0.0670
Y2	0.5670	6.830	0.1333	-	7.405	0.1333
WD1	0.1673	7.240	0.0875	-	8.452	0.0817
WD2	1.0000	4.040	0.0490	-	0.262	0.0502
HQ$_{\textit{dermal}}$						
NeG1	0.3831	7.0E-4	0.0015	-	2.450	0.0034
NeG2	0.0191	1.7E-5	0.0020	-	0.613	0.0037
Y1	19.523	0.0012	0.0033	0.0150	0.697	0.0014
Y2	19.523	8.0E-5	0.0026	-	11.900	0.0028
WD1	0.0957	1.4E-4	0.0017	-	13.590	0.0017
WD2	0.0574	4.7E-5	9.0E-4	-	0.421	0.0011

Figure 3 shows the calculated HIs (HI$_{\text{Ingestion}}$, HI$_{\text{Dermal}}$, HI$_{\text{Total}}$) of metals via groundwater. All the HI values exceeded 1, except in NeG2 (0.638) and WD2 (0.481). The HI$_{\text{Ingestion}}$ calculated for the well water samples increased in the order: NeG1<NeG2<Y1<WD2<<Y2<WD1. For HI$_{\text{Dermal}}$, the order is WD2<NeG2<NeG1 <<<WD1<Y1<<Y2. While the major contributors to the estimated HI via ingestion of the well water are Cr, Mn and Cd, the major contributors to the HI values via dermal absorption are Mn and Cd. The hazard risks posed by ingesting the well water is higher in mechanic workshops in New GRA(NeG1 and NeG2) and Wuntin Dada (WD1 and WD2) while the hazard index through dermal absorption of the well water is higher in Yelwa (Y1 and Y2).

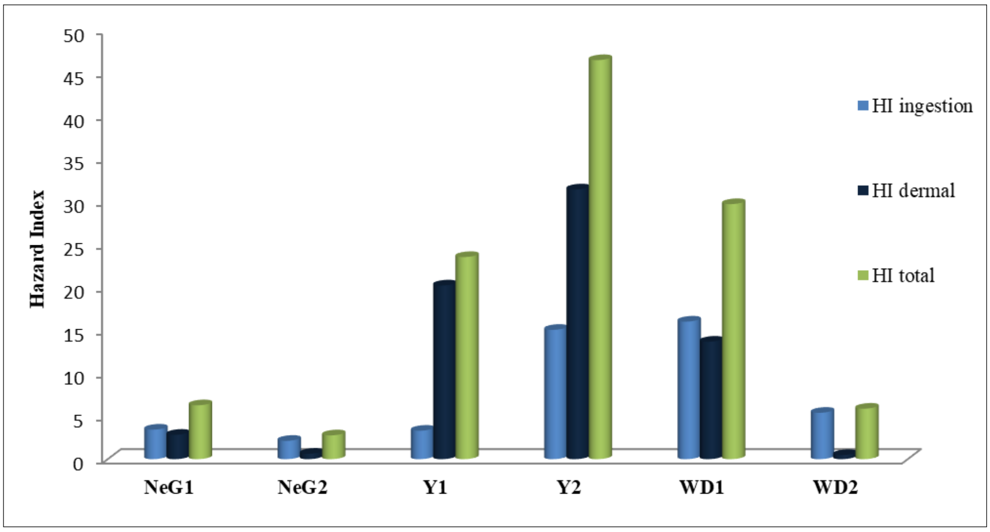

Fig 3: Hazard Index of heavy metals in Well Water in the Study Locations

HI_{Total} values obtained in Figure 3 indicates that total health hazard in Y2 (46.50) is highest while NeG1 (2.772) is the lowest. All the calculated HI is greater than 1. This is an indication that the major health risk posed to humans within these workshops is through the ingestion of this well water polluted by heavy metals.

Conclusion

This study revealed that mechanic workshops situated within the study locations in Bauchi LGA pose serious threat to the underground water plume. The amount of heavy metals generated by the unhygienic practice of artisans in the auto-mechanic workshops investigated has systematically polluted the well water over time. The well water in these areas is therefore unsuitable for drinking and other domestic purposes.

To therefore avoid further increase in the level of heavy metals in these waters and prevent pollutants from travelling through groundwater channels to pollute nearby wells, it is recommended that auto-mechanic workshops soil should be heavily cemented. Code of practice and specific regulations guiding the establishment and the operation of mechanic villages and workshops must be in place and accordingly enforced. Houses should be situated far away from the mechanic workshops to minimize pollution of nearby well water and wells which are used for drinking should not be dug near mechanic villages. Finally, periodical assessment of both physico-chemical and metal content analysis of the well water samples in area some meters away from these workshops should be carried out, as this would be helpful in assessing the risk posed by these workshops on the surrounding.

References

1. Abdulkadir A Gidado, Ibrahim Halliru, Christiana A Kendeson, Yusuf Abdullahi. Comparative Analysis of Physico-Chemical Parameters of Borehole, Pond and Well Water in Kashere Metropolis. European Journal of Engineering Research and Science,2017:2(6):42–47.
2. Abechi ES, Okunola OJ, Zubairu SMJ, Usman AA. Apene A. Evaluation of Heavy metals in roadside soils of major streets in Jos Metropolis, Nigeria. Journal of Environmental chemistryand Ecotoxicology,2010:2(6): 98–102.
3. Abugu NA, Nwokocha PO, Yero AB. Assessment of the Physico-Chemical Properties of Borehole Water in Gwagwalada Area Council Abuja, Nigeria. Global Journal of Geological Sciences,2022:2:19-24.
4. Adaikpoh EO. Distribution and Enrichment of Heavy Metals in Soils from Waste Dump Sites within Imoru and Environs, Southwest Nigeria. Journal of Environment and Earth Science,2013:3(14):45-54.
5. Adams Sadicka, Richard Amfo-Otub, Samuel Joe Acquahc, Kwabena Abrefa Nketiad, Eric Asamoahe, Eric Owusu Adjeif. Assessment Of Heavy Metal Contamination In Soils Around Auto Mechanic Workshop Clusters In Central Agricultural Station, Kumasi-Ghana. Applied Research Journal,2015:1(2):12–19.
6. Adebisi OO, Obuekwe IS, Akinsolu FT, Olayemi AB. Evaluation of Escherichia coli as indicator of point-of-use chlorination efficiency of drinking water. Journal of Applied Science and Environmental Management,2016:20(4):955-962.
7. Adedosu HO, Adewuyi GO, Adie GU. Assessment Of Heavy Metals In Soil, Leachate And Underground Water Samples Collected From The Vicinity Of Olusosun Landfill in Ojota, Lagos, Nigeria, Transnational Journal of Science And Technology,2013:6:74-86.
8. Adelekan BA, Abegunde KD. Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigeria - International Journal of the Physical Sciences,2011:6(5):1045-1058.
9. Adewoyin OA, Hassan AT, Aladesida AA. The impacts of auto-mechanic workshops on soil and groundwater in Ibadan metropolis African Journal of Environmental Science and Technology,2013:7(9):891-898.
10. Agbaji EB, Abechi SE, SA Emmanuel. Assessment of Heavy Metals Level of Soil in Kakuri Industrial Area of Kaduna, Nigeria. Journal of Scientific Research & Reports,2015:4(1):68-78.
11. Ahmed S, Eyaife OC. Physicochemical And Bacteriological Quality of Ground Water at Abubakar Tatari Ali Polytechnic Bauchi, Nigeria European Scientific Journal,2014:10(18):466–478.
12. Ajibade OM, Omisanya KO, Odunsi GO. Groundwater potability and flow direction of urban aquifer, Ibadan, South western Nigeria. Journal of the Nigerian Association of Hydrogeologists,2011:21:38-55.
13. Alhassan MM, Ujoh F. Assessment of the Chemical Quality of Potable Water Sources in Abuja, Nigeria. British Journal of Applied Science & Technology,2012:2(2):146-172.
14. Amoo AO, Adeleye AO, Bate GB, Sadiq IS, Amoo FK, Raji M, *et al*. Groundwater Quality Assessment: Physicochemical and Bacteriological Evidences from Hand-Dug Wells in Gaya Town, Nigeria. Sule Lamido University Journal of Science and Technology,2011:2(2):16-24.
15. Dabkowska-Naskret H. The mobility of heavy metals in urban soils used for food production in Poland. Land Contamination and Reclamation,2004:12(3):205-212.
16. David C. Small water supplies. Cromwell Press, Trowbridge, Wiltshire. India, 2004, 234- 268.
17. Devi S, Premkumar K. Physico-chemical parameters of groundwater samples near industrial area, Cuddalore District, Tamil Nadu, India. Int. J. Chem Tech Res.,2012:4(1):29-34.
18. Egbueri JC, Mgbenu CN. Chemometric analysis of pollution source identification and human health risk assessment of water resources in Ojoto Province, southeast Nigeria. Appl Water Sci,2020:10:98.
19. Esan OA, Yusuf NM, Ogwu WA. Treatment Requirements of Well Water in Gwallameji, Bauchi, Nigeria Asian Journal of Engineering and Technology,2015:3(1):16-23.
20. Ganiyu SA, Oyadeyi AT, Adeyemi AA. Assessment of heavy metals contamination and associated risks in shallow groundwater sources from three different residential areas within Ibadan metropolis, southwest Nigeria. Applied Water Science,2021:11(81):1-20.
21. Gillette B. Nickel named,, Allergen of the Year‟. ACDS adds to list of substances warranting more attention. Dermat. Times,2008:4:15-16.
22. Gloria N Wokem, Token Lawson-Jack. Physicochemical Quality of Borehole Water in

Abonnema and Its Public Health Importance. Global Journal of Pure and Applied Sciences,2015:21:97-104.

23. Huu HH, Rudy S, Damme AV. Distribution and contamination status of heavy metals in estuarine sediments near Cau Ong harbor, Ha Long Bay, Vietnam. Geol. Belgica,2010:13(1-2):37-47.
24. Igwemmar NC, Kolawole SA, Okunoye LK. Physical and Chemical Assessment of Some Selected Borehole Water in Gwagwalada, Abuja. International Journal of Scientific & Technology Research,2013:2(11):324-328
25. Ilemobayo O, Kolad I. Profile of heavy metals from automobile workshops in Akure, Nigeria. J. Environ. Sci. Technol.,2008:1:19-26.
26. Jabbo JN, Ugodulunwa FXO, Yusuf UM, Maiauduga, NA, Gin NS, *et al*. Water Quality Assessment of Some Selected Hand Dug Wells and a Borehole in North Eastern Parts of Bauchi Metropolis, Nigeria Journal of Environment and Earth Science,2016:6(6):137–145.
27. Kerketta PP, Baxla SL, Gora RH, S Kumari S, Roushan RK. Analysis of physico-chemical properties and heavy metals in drinking water from different sources in and around Ranchi, Jharkhand, India. Vetworld,2013:6(7):370-375.
28. Lekan TP, Adeyinka SY, Tajudeen AA. Assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. Applied Water Science,2019:9:191.
29. Lenntech WT. Chemical Properties, Health and Environmental Effects of Copper. Lenntech Water Treatment and Purification Holding B.V, 2009.
30. www.lenntech.com/periodic/elements/cu.htm
31. Li FJ, Yang H-W, Ayyamperumal R, Liu Y. Pollution, sources, and human health risk assessment of heavy metals in urban areas around industrialization and urbanization-Northwest China. Chemospherem,2022:308:136396.
32. Loska K, Wiechula D, Barska B, Cebula E. Chojnecka A. Assessment of arsenic enrichment of cultivated soil in Southern Poland, Pol. J Environ Stud.,2003:12(2):187–192.
33. Kumar A, Cabral-Pinto M, Kumar A, Kumar M, Dinis, PA. Estimation of risk to the eco-environment and human health of using heavy metals in the Uttarakhand Himalaya, India. Appl Sci,2020:10:7078.
34. Mawari G, Kumar N, Sarkar S, Daga MK, Singh MM, Joshi TK, *et al*. Heavy Metal Accumulation in Fruits and Vegetables and Human Health Risk Assessment: Findings From Maharashtra, India Environmental Health Insights,2022:16:1–10
35. Murhekar GH. Determination of Physico-Chemical parameters of Surface Water Samples in and around Akot City. Int. J. Res. Chem. Environ,2011:1(2):183-187.
36. Musa OK, Shaibu MM, Kudamnya EA. Heavy Metal Concentration in Groundwater around Obajana and Its Environs, Kogi State, North Central Nigeria. American International Journal of Contemporary Research,2013:3(8): 170-177.
37. Ndububa O, Nwafor I. Hazard Analysis of Domestic Ground Water Sources in Abubakar Tafawa Balewa University (ATBU, Yelwa Campus), Bauchi Nigeria. Energy and Environmental Engineering,2015:3(3):61-66
38. Obuekwe IS, Oshoma CE, Omorogbe JN. Evaluation of Physicochemical and Bacteriological Properties of Borehole Water in Selected Areas of Benin City, Edo State. Nigerian Journal of Life Sciences,2021:11(1&2):10-17.
39. Odoh R, Agbaji EB, Kagbu JA. Assessment of Trace Metals Pollution in Auto-Mechanic Workshop in Some Selected Local Government Area of Benue State, Nigeria International Journal of Chemistry. International Journal of Chemistry,2011:3(4):78–88.
40. Ogunfowokan AO, JAO Oyekunle, Olutona GO, Atoyebi AO, Lawal A. Speciation Study of Heavy Metals in Water and Sediments from Asunle River of The Obafemi Awolowo University, Ile-Ife, Nigeria, International Journal of Environmental Protection,2013:3(3):6-16.
41. Olutona GO, Akintunde EA, Otolorin JA, Ajisekola SA. Physico-chemical quality assessment of shallow well waters in Iwo, southwestern Nigeria. Journal of Environmental Science and Water Resources,2012:1(6):127-132.
42. Osakwe SA. Heavy metal contamination and physicochemical characteristics of soils from automobile workshops in Abraka, Delta State, Nigeria. International Journal of Natural Sciences Research,2014:2(4):48-58.
43. Pandey SK, Tiwari S. Physico-chemical analysis of ground water of selected area of Ghazipur city-A case study. Nat. Sci.,2009:7(1):17-20.
44. Popoola OO, Ayodele FO. Effects of Automobile Repair Workshop on Water Quality of Selected Area in Ado–Ekiti, Nigeria. Journal of Multidisciplinary Engineering Science and Technology,2016:3(8):5363–5635.
45. Raddy MS, Basha S, Kumar VGS, Joshi HV, Ramachandraiah G. Distribution, Enrichment and Accumulation of Heavy Metals in Coastal Sediments of Alang-Sosiya Ship Scrapping Yard, India. Marine Pollution Bulletin,2004:48:1055-1059
46. Rajappa B, Manjappa S, Puttaiah ET. Monitoring of heavy metal concentration in groundwater of Hakinaka Taluk, India, Contemp. Eng. Sci,2010:3(4):183-190.
47. Rao VS, Prasanthi S, Shanmukha KJV, Prasad KRS. Physico-chemical analysis of water samples of Najendle area in Gunter District of Andhra Pradesh, India. Inter J. Chem. Tech. Res,2012:4(2):691-699.
48. Sadick A Amfo-Otub A, Acquahc SJ, Nketiad KA, Asamoahe E, Adjeif EO. Assessment of Heavy Metal Contamination in Soils around Auto Mechanic Workshop Clusters in Central Agricultural Station, Kumasi-Ghana. Applied Research Journal,2015:1(2):13–19.
49. Standard Organization of Nigeria. Nigerian standard for drinking water quality, hand book, Wuse Zone 7, Abuja, Nigeria, 2007.
50. Tiimub BM, Kuffour RA, Akwatia GA. Quality Determination of Groundwater for Drinking at Nkawkaw in the Eastern Region of Ghana, Civil and Environmental Research,2012:2:9.
51. Tijani M, Onodera S. Hydrogeochemical Assessment of Metals Contamination in an Urban Drainage System: A Case Study of Osogbo Township, SW-Nigeria, Journal of Water Resource and Protection,2009:1(3):164-173.

52. Udousoro II, Umoren IU, Asuquo EO. Survey of some heavy metal concentrations in selected soils in South Eastern parts of Nigeria. World J. Appl. Sci. Technol,2010:2(2):139-14.
53. USEPA. National Center for Environmental Assessment, Office of Research and Development: Washington, DC, 1999.
54. Usman AA, Odoma AN, 3Ozulu GU. Impact of Automobile Workshop Activities on Heavy Metals in Some Ground Water of North Central Nigeria. International Journal of Water Research,2014:2(1):1-4
55. Ye P, Abdugheni A, Sun X, Halidan A. Human health-risk assessment of heavy metal contaminated soil based on Monte Carlo simulation. Scientific Reports,2023:13:7033