Chemistry Africa (2019) 2:689–698
https://doi.org/10.1007/s42250-019-00077-8

ORIGINAL ARTICLE

Physicochemical Assessment of Borehole Water in a Reclaimed Section of Nekede Mechanic Village, Imo State, Nigeria

Chidi Edbert Duru[1] · **Margaret Chinyelu Enedoh**[1] · **Ijeoma Akunna Duru**[2]

Received: 29 March 2019 / Accepted: 8 June 2019 / Published online: 27 June 2019

Abstract

The quality of borehole water in a reclaimed and about to be habited section of the Nekede mechanic village in Imo State, Nigeria, was determined. Five sampling points in this area were chosen for the study. Preliminary characterization of soil at these points using energy dispersive X-ray fluorescence method identified leachable heavy metals that can contaminate groundwater. The physical and chemical properties of the borehole water samples were analyzed using standard instrumental methods. The data obtained showed that the water samples were considerably acidic with pH ranging between 5.12 and 5.58. Lead, nickel and phosphate levels in the borehole water samples from all the sampling points were above tolerable limits and ranged between 0.22–0.42 mg/L, 1.03–1.12 mg/L and 0.14–0.34 mg/L respectively. The contamination factor model showed that all the borehole water samples were highly contaminated by lead and nickel, with values ranging between 38.00–42.00 and 14.71–16.00, respectively. The calculated Water Quality Index at all the sampling points gave values between 554.31 and 935.35 and indicated that the water samples were unsuitable for drinking. Constant consumption of borehole water from this area therefore would pose serious health risks to its intending and existing occupants.

Keywords Borehole water · Heavy metal · Phosphate · Contamination factor · Water Quality Index

1 Introduction

Potable water or drinking water is water that does not present any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages [1]. Though access to safe drinking water has been considered a basic human right by the World Health Organization, about one to two billion people in the world lack safe drinking water [2]. Access to portable water is a daily challenge for many people in Nigeria and other parts of Africa [3–6]. The United Nations Children's Fund (UNICEF) has said that sixty nine million Nigerians do not have access to safe drinking water and forty percent of households do not have access to clean water sources [7]. In most cities in Nigeria, the major sources of water are protected wells and long narrow wells drilled to access groundwater referred to as boreholes.

Land areas called mechanic villages are mapped out by the government of some countries like Nigeria for auto repair activities to reduce traffic congestion within the townships. The activities by the artisans in these sites have greatly polluted the soil and groundwater within and around their environs [8]. Many environmentally unfriendly chemical species like petroleum hydrocarbons [9–15], polychlorinated biphenyls [16], polybrominated diphenyl ethers [17], polycyclic aromatic hydrocarbons [18–20], anions [21–23] and heavy metals [24–29] from automobile repair and maintenance activities have been found in the air, soil and portable water sources in these areas.

Few reports are available on the quality of groundwater within and around the numerous mechanic villages in Nigeria. In a study by Arinze et al. [30] on the quality of potable water within automobile junk markets in Obosi and Nnewi, Nigeria, levels of manganese, copper, iron and nickel were found to be above WHO recommended standards for drinking water. Duru et al. [31] studied the quality of borehole water within the evacuated section of a mechanic village located in Orji, Imo State, Nigeria.

✉ Chidi Edbert Duru
chidiedbertduru@gmail.com

[1] Department of Chemistry, Imo State University, PMB 2000, Owerri, Imo, Nigeria

[2] Department of Chemistry, Federal University of Technology, PMB 1526, Owerri, Imo, Nigeria

The pH, nitrites, nitrates and phosphates levels in the portable water samples fell short of World Health Organization (WHO) standards. Adekitan et al. [32] studied the quality of groundwater within five mechanic villages in Abeokuta, Nigeria. They reported high levels of lead in all the water samples analyzed.

With the high rate of rural to urban migration to cities in Nigeria which has put a lot of stress on accommodation, many of these mechanic villages have been reclaimed and relocated to areas off the city settlements. Construction of residential buildings have long commenced in these evacuated sections without any form of environmental impact assessment.

The Nekede mechanic village is one of such locations. There is no published report on the quality of borehole water in the reclaimed section of this mechanic village and its environs. This study therefore carried out a comprehensive physicochemical assessment of the quality of water from borehole sources in this area to determine its suitability for consumption and possible impact on human health.

2 Materials and Methods

2.1 Study Area

The Nekede mechanic village is situated in Owerri West Local Government Area of Imo State. It lies between the geographical coordinates 5°26′0″ North and 7°2′0″ East. It is located in the sandy Benin Formation with undulating land surface, and drained by Otamiri and Nworie Rivers. In September 2017, the Imo State Government relocated the mechanics, welders, auto electricians and panel beaters in this area after more than 35 years of occupation (Fig. 1).

2.2 Borehole Water Sample Collection and Analysis

The borehole water samples were collected at five different points marked A–E (Fig. 2) within the reclaimed land area where human settlement has already began. The coordinates at the sampling points were referenced with Garmin GPSMAP 76, a handheld global positioning system (GPS) unit and are shown in Table 1.

Three sets of water samples were collected monthly between August and October 2018. The colour, pH, electrical conductivity (EC) and total dissolved solids (TDS) of the borehole water samples were analyzed in situ. Samples for heavy metal and anion determination were collected with sterile plastic bottles and transported to the laboratory for analysis. Analytical grade chemicals and double distilled water were used for preparing the chemicals for the analysis. For heavy metal analysis, an atomic absorption spectrophotometer was used. The proper hollow cathode lamp for a given metal was chosen and allowed to warm-up for 15 min. A series of standards of the element under analysis was run to obtain a calibration curve. This was followed by sample aspiration and determination of the concentration of the element. Anions in the water samples were analyzed with a photometer using the appropriate reagents for each anion under study.

Triplicate determinations were carried out for each parameter. A control set was taken from the borehole water source at the female hostel of the Federal Polytechnic in Nekede town, situated at about 2.5 km from the study area.

2.3 Preliminary Soil Analysis

Soil samples from each sampling point were analyzed to identify the presence, types and abundance of the heavy metals in the study area. Samples were collected in triplicates at a depth of 30 cm from each of the sampling points using

Fig. 1 A section of the mechanic village evacuated for the construction of residential buildings

Fig. 2 Map of Nekede mechanic village and its environs showing sampling points

Table 1 Coordinates at sampling points

Sampling points	Coordinates	
	Latitude	Longitude
A	N 5°26′51″	E 7°2′24″
B	N 5°26′50″	E 7°2′24″
C	N 5°26′49″	E 7°2′22″
D	N 5°26′49″	E 7°2′20″
E	N 5°26′51″	E 7°2′19″
Control	N 5°26′06″	E 7°1′47″

a soil auger. The samples from each point were thoroughly mixed together, then spread on a glass plate and dried in an oven at 105 °C for 2 h. After cooling, they were sieved to particle size of 30 mesh using American Society for Testing and Materials (ASTM) standard sieves. The sieved soil samples were then subjected to X-ray fluorescence analysis.

2.4 Instrumentation

The percentage content of heavy metals in the soil samples was determined using a compact multi-element bench top Energy Dispersive X-ray Fluorescent Analyzer (EDXRF) EDX3600B by Skyray Instrument [precision: 0.0% deviation; detection limit: 0.0001% (1 ppm) – 99.99%]. The concentration of heavy metals in the water samples was determined using Agilent 240 AA Atomic Absorption Spectrophotometer (accuracy level: 99.776%; precision: 97.568%). The colour and concentration of anions in the water samples was determined using multiparameter bench photometer HI 82300 by HANNA Instruments.

2.5 Data Analysis

Contamination factor (C_f), Pollution Load Index (PLI) and Water Quality Index (WQI) models were used to assess the contamination and pollution status of the water samples in this area.

The C_f was used to ascertain the level of soil contamination by a single element or ion [33]. It assessed the presence and intensity of a given contaminant in groundwater and was determined using Eq. (1):

$$C_f = \frac{C_m}{C_b}, \tag{1}$$

where C_m is the concentration of a particular parameter in the water and C_b is the reference concentration of that parameter. The WHO standards for drinking water were taken as the reference concentrations.

The PLI gives a summative indication of the overall level of toxicity at a particular sampling point. It was determined mathematically using Eq. (2):

$$\mathrm{PLI} = (\mathrm{C}_{\mathrm{f1}} \times \mathrm{C}_{\mathrm{f2}} \times \mathrm{C}_{\mathrm{f3}} \times \cdots \times \mathrm{C}_{\mathrm{fn}})^{\frac{1}{n}}, \tag{2}$$

where n is the number of parameters considered in the study and C_{fn} is the contamination factor for each individual parameter.

The WQI was calculated to ascertain the overall suitability of the borehole water in this area for human consumption. Three steps were followed in computing the WQI. In the first step, each parameter was assigned a weight (w_i) according to its relative importance in the overall quality of the borehole water for drinking purposes. Weights ranging from 1–5 were assigned to the parameters, with the highest weights assigned to parameters with adverse health effects.

In the second step, the relative weight (W_i) was computed using Eq. (3):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \tag{3}$$

where W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale (q_i) for each parameter was calculated from Eq. (4) by dividing the concentration of a given parameter in the water sample by its reference standard (WHO) and then multiplying the result by 100:

$$q_i = \frac{C_i}{S_i} \times 100, \tag{4}$$

where C_i is the concentration of each parameter in each water sample in mg/L, and S_i is the reference standard (WHO).

To compute the WQI, the *SI* was determined for each chemical parameter from Eq. (5), which was then used to calculate the WQI using Eq. (6):

$$SI_i = W_i \times q_i, \tag{5}$$

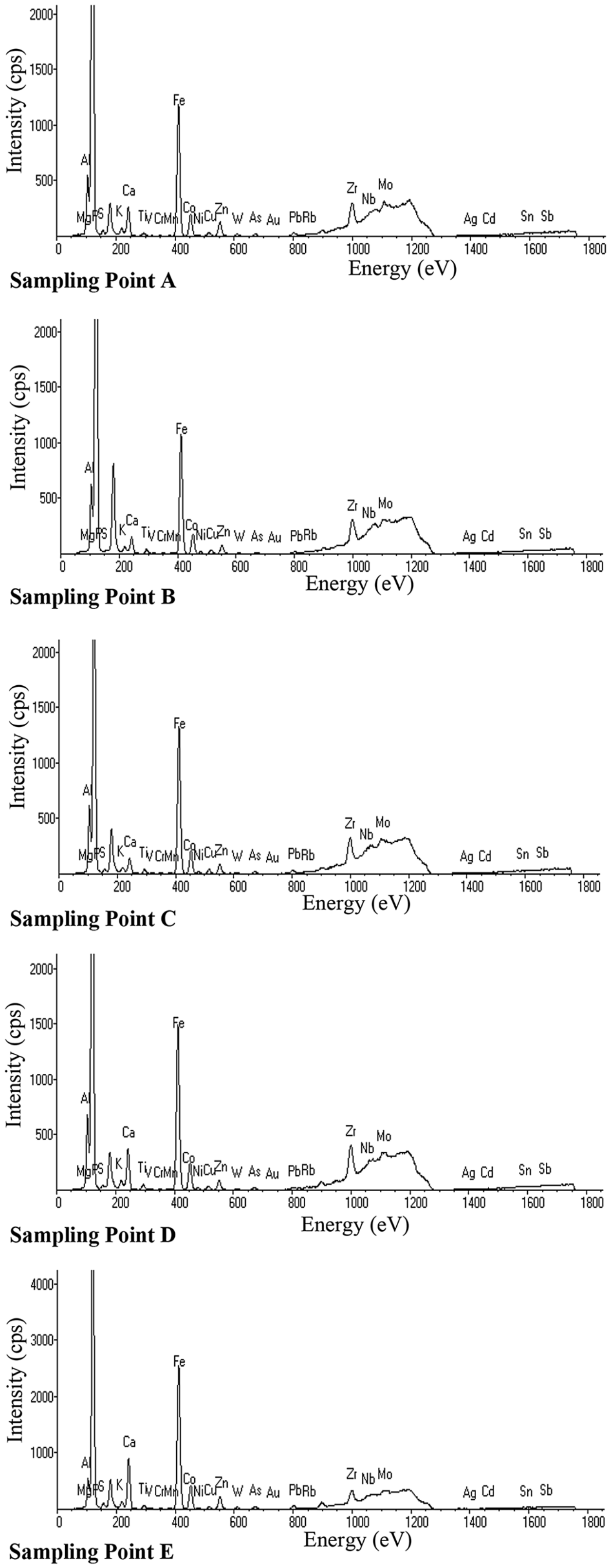
$$\mathrm{WQI} = \sum SI_i, \tag{6}$$

where SI_i is the sub index of the *i*th parameter.

3 Results and Discussion

The energy dispersive X-ray spectra of soil from the different sampling points in the study area are shown in Fig. 3.

The percentage contents of the detected toxic metallic elements from the above plots are given in Table 2.



Sampling Point A

Sampling Point B

Sampling Point C

Sampling Point D

Sampling Point E

Fig. 3 X-ray fluorescence spectra of soil samples collected at 30 cm depth from sampling points A, B, C, D and E

Table 2 Percentage composition of toxic metals in the soil at the different sampling points

Elements	Soil toxic metal composition (%)					
	A	B	C	D	E	Mean
Ti	0.1916	0.2869	0.3534	0.4206	0.4563	0.3418
V	0.0090	0.0146	0.0158	0.0111	0.0291	0.0159
Cr	0.0204	0.0316	0.0356	0.0298	0.0637	0.0362
Mn	0.0296	0.0356	0.0455	0.0556	0.0925	0.0518
Co	0.1143	0.1030	0.0864	0.1268	0.2303	0.1322
Fe	7.4892	6.6273	9.1427	8.9401	12.6029	8.9604
Ni	0.0654	0.0758	0.0954	0.0959	0.0864	0.0838
Cu	0.0802	0.0777	0.0853	0.0784	0.0828	0.0809
Zn	0.2734	0.1941	0.2512	0.2125	0.2870	0.2436
As	0.0047	0.0000	0.0059	0.0041	0.0133	0.0056
Pb	0.0630	0.0301	0.0608	0.0279	0.1029	0.0570
Mo	0.1710	0.1642	0.1511	0.1268	0.1793	0.1585
Cd	0.0002	0.0002	0.0000	0.0000	0.0000	0.0001

Their mean composition increased in the order Cd < As < V < Cr < Mn < Pb < Cu < Ni < Co < Mo < Zn < Ti < Fe. The concentration of these heavy metals and those of the other water quality parameters in the water samples from the sampling points are summarized in Table 3. Molybdenum, titanium, vanadium, sulphate and nitrite were not detected in all the water samples. The mean values of the detected parameters were compared with WHO standards for drinking water [34] and are shown in Table 4.

The control data for the analyzed quality parameters indicated that their elevated levels at the study area were due to the anthropogenic activities that took place at the time before the area was reclaimed. These activities include discharge of waste automobile oils on the bare ground, metal welding, scrap metal collection and storage in open spaces, spraying of automobile parts etc. Heavy metals and other pollutants from these activities leach into the soil and over time are washed into the groundwater (Fig. 4).

The conductivity, total dissolved solids, alkalinity, manganese, zinc, chromium, copper, arsenic, iron, chloride and nitrate were all below the permissible limit set by the WHO. The colour of the water at sampling point C was 20 Platinum Cobalt Units (PCU) which is above 15 PCU stipulated by the WHO. Colour is not a toxic characteristic of portable water but a secondary parameter that affects its appearance and palatability.

The pH of portable water measures its degree of acidity or alkalinity and is an aesthetic quality of water. However, too high or too low pH can be a sign of chemical or heavy metal pollution. The pH of all the samples investigated were acidic ranging between 5.12 and 5.58 as against the 6.50–8.50 stipulated by the WHO. Exposure to extreme pH values can result to irritation to the eyes, skin and mucous membranes [35].

Lead is a cumulative toxicant that affects multiple body systems. It is distributed in the bones, brain, liver and kidney where it accumulates over time [36]. Lawal et al. [37] reported lead levels ranging from 0.01 to 1.05 mg/L in water samples from boreholes close to auto mechanic workshops in Obio/Akpor local government area in Rivers State, Nigeria. In this study, lead levels were found to range between 0.22 and 0.42 mg/L. These values were much higher than the value 0.01 mg/L stipulated by WHO. Young children are very vulnerable to the toxic effects of lead and can suffer adverse health effects, which impair brain and nervous system development. It causes long-term harm like high blood pressure and kidney damage in adults. It can also result to miscarriages, stillbirths, premature births or low birth weights in pregnant women. More than three quarters of global lead consumption is form the manufacture of lead-acid batteries for motor vehicles [38].

The possible sources of nickel in groundwater around mechanic villages includes dumping of stainless steel, non-ferrous alloys and super alloys from automobile parts around the workshop area, use of nickel containing automobile pigments and paints, indiscriminate discard of automobile electronic parts and welding activities by panel beaters [39]. The nickel levels in the borehole water samples in the studied area ranged between 1.03 and 1.12 mg/L which is higher than the guideline set by the WHO. High nickel intakes in humans can lead to nausea, vomiting, diarrhea, giddiness, lassitude, headache, and shortness of breath [40].

Cadmium compounds are used in batteries, electronic components and often times electroplated onto steel as an anticorrosive material [41]. Cadmium levels in borehole

Table 3 Values of water quality parameters in the triplicate studies

Parameters	Concentrations at sampling points																			
	*A*1	*A*2	*A*3	Mean	*B*1	*B*2	*B*3	Mean	*C*1	*C*2	*C*3	Mean	*D*1	*D*2	*D*3	Mean	*E*1	*E*2	*E*3	Mean
pH	5.77	5.35	5.62	5.58	5.01	5.14	5.22	5.12	5.03	5.33	5.28	5.21	5.11	5.48	5.35	5.31	5.41	5.57	5.63	5.54
Conductivity (µS/cm)	13.50	14.70	14.20	14.13	11.30	13.40	13.80	12.83	15.00	8.10	8.50	10.50	13.50	7.50	8.30	9.80	10.10	8.10	10.80	9.80
TDS (mg/L)	8.10	8.82	8.52	8.48	6.78	8.04	8.28	7.70	9.00	4.86	5.10	6.32	8.10	4.50	4.98	5.86	6.06	4.86	6.48	5.80
Colour (PCU)	2.00	0.00	0.00	1.00	2.00	0.00	3.00	2.00	36.00	14.00	11.00	20.00	11.00	3.00	5.00	6.00	19.00	0.00	4.00	8.00
Alkalinity (mg/L)	10.00	5.00	7.00	7.00	0.00	0.00	0.00	0.00	5.00	5.00	4.00	5.00	0.00	0.00	0.00	0.00	27.00	40.00	32.00	33.00
Co (mg/L)	0.17	0.22	0.12	0.17	0.11	0.07	0.08	0.09	0.15	0.18	0.13	0.15	0.03	0.10	0.07	0.07	0.09	0.16	0.12	0.12
Mn (mg/L)	0.04	0.05	0.07	0.05	0.16	0.10	0.13	0.13	0.04	0.09	0.03	0.05	0.11	0.16	0.15	0.14	0.07	0.04	0.09	0.07
Pb (mg/L)	0.37	0.45	0.31	0.38	0.24	0.32	0.27	0.28	0.23	0.22	0.27	0.24	0.31	0.32	0.32	0.22	0.42	0.41	0.44	0.42
Ni (mg/L)	1.10	1.11	1.14	1.12	1.01	1.06	1.03	1.03	1.12	1.04	1.21	1.12	1.13	1.13	1.10	1.09	1.12	1.03	1.16	1.10
Mo (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (mg/L)	0.15	0.05	0.10	0.10	0.14	0.13	0.17	0.15	0.16	0.24	0.22	0.21	0.16	0.21	0.24	0.20	0.24	0.13	0.21	0.19
Cd (mg/L)	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.02	0.02
Cr (mg/L)	0.02	0.05	0.04	0.04	0.01	0.00	0.00	0.00	0.04	0.04	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.02
Ti (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (mg/L)	0.22	0.21	0.24	0.22	0.43	0.44	0.41	0.43	0.24	0.40	0.28	0.31	0.42	0.26	0.23	0.30	0.40	0.42	0.47	0.43
As (mg/L)	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Fe (mg/L)	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.01	0.04	0.02	0.02	0.02	0.01	0.02
SO_4^{2-} (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PO_4^{3-} (mg/L)	0.24	0.17	0.33	0.25	0.30	0.21	0.19	0.23	0.17	0.15	0.11	0.14	0.32	0.22	0.27	0.27	0.38	0.33	0.31	0.34
Cl^- (mg/L)	0.07	0.03	0.05	0.05	0.06	0.06	0.04	0.05	0.06	0.01	0.03	0.03	0.03	0.07	0.04	0.05	0.04	0.04	0.04	0.04
NO_2^- (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_3^- (mg/L)	32.08	36.11	27.54	31.91	28.13	31.00	39.28	32.80	29.02	36.37	34.83	33.41	34.21	27.54	30.31	30.69	27.47	36.23	22.71	28.80

Table 4 Mean concentration of analyzed parameters compared with WHO standards

Parameters	Mean concentrations at sampling points						WHO standards
	A	*B*	*C*	*D*	*E*	Control	
pH	5.58 ± 0.21	5.12 ± 0.11	5.21 ± 0.16	5.31 ± 0.19	5.54 ± 0.11	6.53 ± 0.04	6.50–8.50
Conductivity (μS/cm)	14.13 ± 0.60	12.83 ± 1.34	10.50 ± 3.87	9.80 ± 3.26	9.80 ± 1.40	5.70 ± 1.09	2500
TDS (mg/L)	8.48 ± 0.36	7.70 ± 0.81	6.32 ± 2.32	5.86 ± 1.95	5.80 ± 0.84	3.16 ± 0.61	500
Colour (PCU)	1.00 ± 1.15	2.00 ± 1.53	20.00 ± 13.65	6.00 ± 4.16	8.00 ± 10.01	3.00 ± 1.00	15
Alkalinity	7.00 ± 2.51	0.00 ± 0.00	5.00 ± 0.58	0.00 ± 0.00	31.0 ± 6.56	0.00 ± 0.00	200
Co (mg/L)	0.17 ± 0.05	0.09 ± 0.02	0.15 ± 0.03	0.07 ± 0.04	0.12 ± 0.04	0.00 ± 0.00	Not stated
Mn (mg/L)	0.05 ± 0.02	0.13 ± 0.03	0.05 ± 0.03	0.14 ± 0.03	0.07 ± 0.03	0.01 ± 0.01	0.40
Pb (mg/L)	0.38 ± 0.07	0.28 ± 0.04	0.24 ± 0.03	0.22 ± 0.01	0.42 ± 0.02	0.00 ± 0.00	0.01
Ni (mg/L)	1.12 ± 0.02	1.03 ± 0.03	1.12 ± 0.09	1.09 ± 0.02	1.10 ± 0.07	0.03 ± 0.06	0.07
Zn (mg/L)	0.10 ± 0.05	0.15 ± 0.02	0.21 ± 0.04	0.20 ± 0.04	0.19 ± 0.07	0.03 ± 0.01	5.00
Cd (mg/L)	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.00 ± 0.01	0.02 ± 0.01	0.00 ± 0.00	0.003
Cr (mg/L)	0.04 ± 0.02	0.00 ± 0.01	0.04 ± 0.01	0.00 ± 0.00	0.02 ± 0.02	0.01 ± 0.02	0.05
Cu (mg/L)	0.22 ± 0.02	0.43 ± 0.02	0.31 ± 0.08	0.30 ± 0.10	0.43 ± 0.04	0.07 ± 0.11	2.00
As (mg/L)	0.00 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.00	0.01
Fe (mg/L)	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0.02 ± 0.01	0.04 ± 0.10	0.30
PO_4^{3-} (mg/L)	0.25 ± 0.08	0.23 ± 0.06	0.14 ± 0.03	0.27 ± 0.05	0.34 ± 0.04	0.09 ± 0.18	0.03
Cl^- (mg/L)	0.05 ± 0.02	0.05 ± 0.01	0.03 ± 0.03	0.05 ± 0.02	0.04 ± 0.00	0.01 ± 0.01	250
NO_3^- (mg/L)	31.91 ± 4.29	32.80 ± 5.79	33.41 ± 3.88	30.69 ± 3.35	28.80 ± 6.85	11.94 ± 2.43	50

Fig. 4 Nekede mechanic village showing **a** auto waste disposal point, **b** Auto engine servicing pit, **c** abandoned automobiles, **d** auto scrap metal dump

water ranging between 0.01 and 1.20 mg/L have been reported by [37]. At the Nekede mechanic village study site, cadmium concentration ranged between 0.01 and 0.03 mg/L. These values were higher than the 0.003 mg/L limit set by the WHO. Exposure to high cadmium levels can result to kidney dysfunction and osteoporosis in humans [42].

Discharge of chemicals containing phosphate species into the soil and subsequent leaching into ground water can cause damage to the environment and deteriorate water quality [23]. The Phosphate levels in the borehole water samples ranged between 0.14 and 0.34 mg/L which is higher than the 0.03 mg/L set by the WHO. High phosphate intake has been reported to be the cause of cardiovascular diseases, damage to blood vessels and induced aging processes [43].

3.1 Pollution Modeling

The data in Table 4 were analyzed using contamination and pollution models so as to give a lucid picture of the portability of the borehole water samples. The C_f values as specified by [44] are given in four levels and are shown in Table 5.

The values of the C_f were used to determine the PLI (Eq. 2). PLI value greater than 1 is polluted, less than 1 indicates no pollution, whereas values equal to 1 indicates contaminant loads close to the reference concentration [45]. The C_f and PLI of parameters with severe health impacts are shown in Table 6.

All the borehole water samples were highly contaminated by lead and nickel. Samples from points A, B and E were highly contaminated by cadmium and phosphate ions. Water samples from point D were also highly contaminated by phosphate ions. Water contaminant load in samples from point E had value above 1.00 showing that borehole water around this point was polluted. Water samples from point B had pollution load close to WHO reference concentrations.

Table 5 Contamination factor ranking

C_f value	Contamination factor level
$C_f < 1$	Low contamination
$1 \le C_f < 3$	Moderate contamination
$3 \le C_f < 6$	Considerable contamination
$6 \le C_f$	Very high contamination

Table 7 Water Quality Index values and classes

Value	Water quality class
$WQI < 50$	Excellent water quality
$50 < WQI \le 100$	Good water quality
$100 < WQI \le 200$	Poor water quality
$200 < WQI \le 300$	Very poor water quality
$WQI > 300$	Unsuitable for drinking

The WQI of portable water can be classified into five types [46] and are shown in Table 7.

The calculated WQI of the water samples from the sampling points in this study using the mean concentrations of the identified contaminants with health impact are given in Table 8.

The data from this model showed that borehole water from all the points sampled were unsuitable for drinking.

4 Conclusion

The findings from this study showed that all the borehole water samples in this area were acidic and had very high lead and nickel levels. Cadmium contamination in the borehole water at sampling points A, B and E was very high. Phosphate contamination level in all the borehole water samples from all the sampling points apart from sampling point C was very high. Water Quality Index model showed that all the borehole water samples studied were unsuitable for drinking. Dwellers in this area whose only means of portable water are these boreholes stand the risk of developing serious health problems like kidney damage, impaired brain development in children, osteoporosis and cardiovascular diseases.

Table 6 C_f and PLI of heavy metals and anions in the borehole water samples

Sampling points	C_f											PLI
	Mn	Pb	Ni	Zn	Cd	Cr	Cu	As	Fe	PO_4^{3-}	NO_3^-	
A	0.13	*38.00*	*16.00*	0.02	*10.00*	0.80	0.11	0.00	0.07	*8.33*	0.64	0.94
B	0.33	*28.00*	*14.71*	0.03	*6.67*	0.00	0.23	1.00	0.03	*7.67*	0.66	1.00
C	0.13	*24.00*	*16.00*	0.04	3.33	0.80	0.16	1.00	0.07	4.67	0.67	0.86
D	0.35	*22.00*	*15.57*	0.04	0.00	0.00	0.15	0.00	0.07	*9.00*	0.61	0.89
E	0.18	*42.00*	*15.71*	0.04	*6.67*	0.40	0.22	0.00	0.07	*11.33*	0.58	*1.02*

Values in italics show very high contamination levels and polluted site

Table 8 Water Quality Index values of borehole water from the sampling points

Parameters	S_i	w_i	W_i	q_i					SI				
				A	B	C	D	E	A	B	C	D	E
Mn	0.40	3	0.079	12.50	32.50	12.50	35	17.50	0.986	2.37	0.99	2.77	1.38
Pb	0.01	5	0.132	3800	2800	2400	2200	4200	501.60	369.60	316.80	290.40	554.40
Ni	0.07	4	0.105	1600	1471.43	1600	1557.14	1571.43	168	154.50	168	163.50	165
Zn	5.00	2	0.053	2	3	4.20	4	3.80	0.106	0.106	0.22	0.21	0.20
Cd	0.003	5	0.132	1000	666.67	333.33	0.00	666.67	132	88	44	0.00	88
Cr	0.05	4	0.105	80	0.00	80	0.00	40	8.40	0.00	8.40	0.00	4.20
Cu	2.00	2	0.053	11	21.50	15.50	15	21.50	0.58	1.14	0.82	0.80	1.14
As	0.01	5	0.132	0.00	100	100	0.00	0.00	0.00	132	132	0.00	0.00
Fe	0.30	3	0.079	6.67	3.33	6.67	6.67	6.67	0.53	0.26	0.53	0.53	0.53
PO_4^{3-}	0.03	4	0.105	833.33	766.67	466.67	900	1133.33	87.50	80.50	49	94.50	119
NO_3^-	50	1	0.026	63.82	65.60	66.82	61.38	57.60	1.66	1.71	1.74	1.60	1.50
		$\sum w_i = 38$											
WQI									901.36	830.19	722.50	554.31	935.35

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. World Health Organization (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO. p. 631
2. World Health Organization (2019) Fact sheets on drinking-water. https://www.who.int/en/news-room/fact-sheets/detail/drinking-water. Accessed 14 Jun 2019
3. Besser H, Mokadem N, Redhaounia B, Ayadi Y, Faten K, Harabi S, Hamed Y (2018) Groundwater mixing and geochemical assessment of low enthalpy resources in the geothermal field of Southeastern Tunisia. Euro Mediterr J Environ Integr. https://doi.org/10.1007/s41207-018-0055-0
4. Mokadem N, Redhaounia B, Besser H, Ayadi Y, Khelifi F, Hamad A, Hamed Y, Bouri S (2018) Impact of climate change on groundwater and the extinction of ancient "Foggara" and springs systems in arid lands in North Africa: a case study in Gafsa basin (Central of Tunisia). Euro Mediterr J Environ Integr 3:28. https://doi.org/10.1007/s41207-018-0070-0
5. Hamad A, Baali F, Hadji R, Zerrouki H, Besser H, Mokadem N, Legrioui R, Hamed Y (2018) Hydrogeochemical characterization of water mineralization in Tebessa-Kasserine karst system (Tuniso-Algerian Transboundary basin). Euro Mediterr J Environ Integr 3(10):7. https://doi.org/10.1007/s41207-017-0045-6
6. Hamed Y, Ahmadi R, Hadji R, Mokadem N, Ben Dhia H, Ali W (2014) Groundwater evolution of the Continental Intercalaire aquifer of Southern Tunisia and a part of Southern Algeria: use of geochemical and isotopic indicators. Desalin Water Treat 52:1990–1996
7. Premium Times Newspaper (2018). https://www.premiumtimesng.com/news/more-news/262663-69-million-nigerians-lack-access-to-safe-water-unicef.html. Accessed 22 Mar 2018
8. Duru CE (2019) Assessment and modeling of heavy metal pollution of soil within reclaimed auto repair workshops in Orji, Imo State Nigeria. Chem J Mold. https://doi.org/10.19261/cjm.2018.544
9. Adio SO, Omar MH, Saleh TA (2017) Arsenic and selenium removal from water using biosynthesized nanoscale zero-valent iron: a factorial design analysis. Process Saf Environ 107:518–527. https://doi.org/10.1016/j.psep.2017.03.004
10. Saleh TA (2018) Simultaneous adsorptive desulfurization of diesel fuel over bimetallic nanoparticles loaded on activated carbon. J Clean Prod 172:2123–2132
11. Danmaliki GI, Saleh TA (2016) Influence of conversion parameters of waste tires to activated carbon on adsorption of dibenzothiophene from model fuels. J Clean Prod 117:50–55
12. Al-Hammadi SA, Al-Absi AA, Bin-Dahman OA, Saleh TA (2018) Poly(trimesoyl chloride-melamine) grafted on palygorskite for simultaneous ultra-trace removal of methylene blue and toxic metals. J Environ Manag 226:358–364. https://doi.org/10.1016/j.jenvman.2018.08.025
13. Saleh TA, Tuzen M, Sari A (2018) Polyamide magnetic palygorskite for the simultaneous removal of Hg(II) and methyl mercury; with factorial design analysis. J Environ Manag 211:323–333. https://doi.org/10.1016/j.jenvman.2018.01.050
14. Tuzen M, Sari A, Saleh TA (2018) Response surface optimization, kinetic and thermodynamic studies for effective removal of rhodamine B by magnetic AC/CeO_2 nanocomposite. J Environ Manag 206:170–177. https://doi.org/10.1016/j.jenvman.2017.10.016
15. Adeniyi Afolabi JA (2002) Determination of total petroleum hydrocarbons and heavy metals in soils within the vicinity of facilities handling refined petroleum products in Lagos metropolis. Environ Int 28:79–82 **(PMID:12046957)**
16. Wang J, Jia CR, Wong CK, Wong PK (2000) Characterization of polycyclic aromatic hydrocarbon created in lubricating oils. Water Air Soil Pollut 120:381–396
17. Songül AV, Bekir K, Güler C (2010) The automobiles as indoors. TAF Prev Med Bull 9(6):665–672
18. Yu XZ, Gao Y, Wu SC, Zhang HB, Cheung KC, Wong MH (2006) Distribution of polycyclic aromatic hydrocarbons in soils at Guiyu area of China, affected by recycling of electronic waste using

primitive technologies. Chemosphere 65:1500–1509. https://doi.org/10.1016/j.chemosphere.2006.04.006

19. Wcisło E (1998) Soil contamination with polycyclic aromatic hydrocarbons (PAHs) in Poland—a review. Pol J Environ Stud 7(5):267–272
20. Saleh TA, Adio SO, Asif M, Dafalla H (2018) Statistical analysis of phenols adsorption on diethylenetriamine-modified activated carbon. J Clean Prod 182:960–968
21. El-Nahas S, Salman HM, Seleeme WA (2019) Aluminum building scrap wire, take-out food container, potato peels and bagasse as valueless waste materials for nitrate removal from water supplies. Chem Afr 2:143–162. https://doi.org/10.1007/s42250-018-00032-z
22. Jodeh S, Ibsharat I, Khalaf B, Hamed O, Jodeh D, Omar D (2019) The use of magnetic multiwalled carbon nanotubes functionalized with chitosan from nitrate removal from wastewater. Chem Afr 1:1. https://doi.org/10.1007/s42250-019-00056-0z
23. Berkessa YW, Mereta ST, Feyisa FF (2019) Simultaneous removal of nitrate and phosphate from wastewater using solid waste from factory. Appl Water Sci 9:28. https://doi.org/10.1007/s13201-019-0906-0z
24. Adio SO, Asif M, Mohammed AI, Baiga N, Al-Arfaj AA, Saleh TA (2019) Poly(amidoxime) modified magnetic activated carbon for chromium and thallium adsorption: statistical analysis and regeneration. Process Saf Environ 121:254–262
25. Saleh TA (2015) Isotherm, kinetic and thermodynamic studies on Hg(II) adsorption from aqueous solution by silica-multiwall carbon nanotubes. Environ Sci Pollut Res 22:16721–16731. https://doi.org/10.1007/s11356-015-4866-z
26. Saleh TA (2015) Mercury sorption by silica/carbon nanotubes and silica/activated carbon: a comparison study. J Water Supply Res Technol 64(8):892–903. https://doi.org/10.2166/aqua.2015.050
27. Wong CSC, Duzgoren-Aydin NS, Aydin A, Wong MH (2007) Evidence of excessive releases of metals from primitive e-waste processing in Guiyu, China. Environ Pollut 148:62–72. https://doi.org/10.1016/j.envpol.2006.11.006
28. Ipeaiyeda AR, Dawodu M (2008) Heavy metals contamination of topsoil and dispersion in the vicinities of reclaimed auto-repair workshops in Iwo Nigeria. Bull Chem Soc Ethiop 22(3):339–348. https://doi.org/10.4314/bcse.v22i3.61205
29. Iwegbue CM (2007) Metal fractionation in soil profiles at automobile mechanic waste dumps around Port-Harcourt. Waste Manag Res 25(6):585–593. https://doi.org/10.1177/0734242X07080761
30. Arinze IE, Igwe O, Una C (2015) Analysis the heavy metals contamination in soil and water at automobile junk markets in Obosi and Nnewi, Anambra, South Eastern Nigeria. Arab J Geosci 8(12):10961–10976
31. Duru CE, Okoro IP, Enyoh CE (2017) Quality assessment of borehole water within Orji mechanic village using pollution and contamination models. Int J Chem Mater Environ Res 4(3):123–130
32. Adekitan AA, Odunsi H, Martins O, Awomeso JA, Ojekunle ZO (2017) The impact of waste generated from automobile service stations on groundwater in some parts of Abeokuta, Ogun State, Nigeria. SJBS 6(2):38–47
33. Heinike HJ, Eckselman W, Thomasson AJ, Jones RJA, Montanarella L, Buckeley B (eds) (2000) Land information systems for planning the sustainable use of land resources. Office of Official Publication of the European Communities, Luxembourg, pp 393–402
34. World Health Organization (2018a) A global overview of national regulations and standards for drinking-water quality. Geneva. Licence: CCBY-NC-SA3.0IGO
35. World Health Organization (2003) pH in drinking-water. Background document for the development of WHO guidelines for drinking-water quality. WHO/SDE/WHO/03.04/12
36. Saleh TA (2016) Nanocomposite of carbon nanotubes/silica nanoparticles and their use for adsorption of Pb(II): from surface properties to sorption mechanism. Desalin Water Treat 57(23):10730–10744. https://doi.org/10.1080/19443994.2015.1036784
37. Lawal O, Arokoyu SB, Udeh II (2015) Assessment of automobile workshops and heavy metal pollution in a typical urban environment in sub-saharan Africa. EREM 71(1):27–35
38. World Health Organization (2018b) Lead poisoning and health. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health. Accessed 23 Aug 2018
39. IARC (1990) Nickel and nickel compounds. In: Chromium, nickel and welding. International Agency for Research on Cancer, Lyon, pp 257–445 (IARC monographs on the evaluation of carcinogenic risks to humans, vol 49)
40. Sunderman FW, Dingle B, Hopfer SM, Swift T (1988) Acute nickel toxicity in electroplating workers who accidentally ingested a solution of nickel sulfate and nickel chloride. Am J Ind Med 14:257–266
41. Friberg L, Nordberg GF, Vouk VB (eds) (1986) Handbook of the toxicology of metals, vol II. Elsevier, Amsterdam, pp 130–184
42. Jarup L, Berblund M, Nordberg G, Vahter M (1998) Health effects of cadmium exposure—a review of the literature and a risk estimate. Scand J Work Environ Health 24(1):1–51
43. Rattue P (2012) Excessive consumption of phosphate is harmful to health. MEDICALNEWSTODAY. https://www.medicalnewstoday.com/articles/241701.php. Accessed 15 Feb 2012
44. Hakanson L (1980) An ecological risk index for aquatic pollution control, a sedimentological approach. Water Res 14:975–1001
45. Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW (1980) Problems in the assessment of heavy metal levels in estuaries and the formation of a pollution index. Helgol Mar Res 33:566–575. https://doi.org/10.1007/BF02414780
46. Ramakrishnaiah CR, Sadashivaiah C, Ranganna G (2009) Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. Eur J Chem 6(2):523–530