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Research Article

Examining the Effect of Spatial Proximity of Geo-located Dumpsites on Groundwater Quality in Samaru-Nigeria

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Abstract

The effect of improper waste disposal on man's health and environment due to the closeness of solid waste dumpsites to underground water sources in some parts of the world has raised issues of serious concern. This study thus sought to examine groundwater quality dependence on the spatial proximity of dumpsites in Samaru, Kaduna state-Nigeria. The coordinates of 10 solid waste dumpsites in proximity to groundwater sources (boreholes) in the study area were acquired for spatial analyses with a GPS-enabled smartphone. Ten groundwater samples from boreholes in relation to dumpsites were collected for testing and analyses of 11 physical and chemical parameters of water quality based on the Canadian Council of Ministers of the Environment (CCME) and World Health Organisation (WHO) standard limits. Thereafter, the water quality index (WQI) for all the locations was calculated. The results of the spatial proximity analyses carried out revealed that the requirement for locating dumpsites was not met as specified by the Environmental Protection Agency (EPA) regarding the minimum safe distance from groundwater sources as a majority (about 80%) of the dumpsites were located too close to the boreholes. The results of the study, however, revealed that the majority (about 80%) of the groundwater samples met the conditions for good drinking water (suitable for drinking water) even with their closeness to the dumpsites based on the computed WQI values and ratings. Meanwhile, only Calcium, Dissolved Oxygen, and Biochemical Oxygen Demand concentrations were significantly affected ($p < 0.05$ at the 95% significance level) by the closeness of the solid waste dumpsites to the boreholes with very strong (R^2 = 86%) and strong (R^2 = 79%) relationships, respectively. Suggestions were nonetheless made for the monitoring of land use activities in the areas surrounding groundwater sources to prevent groundwater contamination.

Keywords: Geo-location, Groundwater Quality, Solid Waste Management, Spatial Proximity, WHO

Introduction

One of the cardinal objectives of the sustainable development goals (SDGs) is the provision of equitable access to healthy and qualitative water in a clean environment (United Nations [UN], 2020). However, the near-absence of potable water often leads to the indiscriminate sinking of wells and boreholes which are often contaminated by near-by dumpsites and industrial effluents. In other words, there is a decrease in potable water in most parts of the world as a result of polluted fresh waterbodies (Chandra *et al*., 2012; Barut, 2015).

In most of the developing countries as Nigeria, the common practice is to dispose of solid wastes in open dumpsites or by open burning without adopting any acceptable sanitary landfilling practices (El-Fadel *et al.*, 1997). In addition, the increased quantity of waste in a vast majority of developing countries as a result of economic growth, industrialization, and urbanization is not without the attendant problem of indiscriminate waste disposal (Beede and Bloom, 1995; Ferronato and Torretta, 2019). Meanwhile, it was estimated in 2006 that the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tonnes, representing a 7% annual increase since 2003 (United Nations Environmental Programme [UNEP], 2007b).

Solid waste dumpsites pollute the underground water sources thereby decreasing their quality as a result of changes to their physical and chemical characteristics (El-Salam and Abu-Zuid, 2015; Simeon, 2009). This is one of the reasons why some countries from time to time monitor the quality of their underground water sources for the health and well-being of their citizens (Agudelo-Vera *et al*., 2020; Etim *et al*., 2013). This is often done so that appropriate steps may be taken for water resource management practices (Etim *et al*., 2012). The quality of water is also determined to ascertain the suitability of water for different purposes (Boah *et al*., 2015; Kankal, 2012; Oni and Fasakin, 2016).

The water quality index (WQI) has been used as a measure or indicator of groundwater quality and it is accompanied by a 'ranking' and 'confidence value' that express the degree of completeness of the index

(Sarasota County, 2021). The WQI simplifies the expression of the overall water quality behaviour at a certain location and time based on several physical, chemical, and biological parameters of water quality in a single value. In other words, complex water quality data are transformed into simple and useful information for the public and policymakers (Miller *et al*., 1986; Kumar and Dua, 2009; Tyagi *et al*., 2013). In addition, WQI helps to facilitate the comparison between various water sampling sites (Stambuk-Giljanovic, 1999).

Although, there is no universally accepted streamlined index of water quality, aggregated water quality data in the development of water quality indices are being used in some countries (UNEP, 2007a). Often times, water quality indices depend on the normalization of the data parameter by parameter according to the expected concentrations and some interpretations of 'good' or 'bad' concentrations or confidence value. Parameters are often then weighted according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest (Pesce and Wunderlin, 2000; Stambuk-Giljanovic, 2003; Sargaonkar and Deshpande, 2003; Liou *et al*., 2004; Tsegaye *et al*., 2006).

Inability to effectively manage solid waste disposal has become an issue of great concern in different parts of the world (Aibor and Olorunda, 2006; Environmental Protection Agency [EPA], 2016; Hauwa, 2003; New York State Department of Environmental Conservation [NYSDEC], 2016). This is due to the fact that wastes adversely affect the quality of our food, health, and environment (European Environment Agency [EEA], 2019).

The World Bank (2008) emphasized the need for proper solid waste management as being the key to a healthy urban settlement. Pelczar *et al*., (1993) observed that the indiscriminate disposal of solid waste resulted in near-by groundwater sources being contaminated which then aid the transmission of water-borne infections and food-borne diseases such as typhoid, cholera, gastroenteritis, salmonellas among others. Consequently, it has become increasingly difficult for researchers to accurately monitor the spread of hundreds of transmissible diseases including the novel Coronavirus (COVID-19) distributed across the world. The patterns of these diseases often times change from one location to another and season to another.

Arimah and Adinnu (1995) observed that the perceived environmental costs, health-related hazards, social and economic impacts associated with waste dumpsites are often not confined to the immediate environment but extend up to a few kilometres. This is one of the reasons why several research efforts have been carried out in the recent past to understudy the impact of solid waste on groundwater quality in different parts of the world.

Akinbile and Yusoff (2011) investigated the environmental impact of leachate pollution on groundwater supplies in Akure, Nigeria. The physical, chemical, and bacteriological analyses of water samples from three boreholes located near a landfill in the study area were carried out to ascertain the magnitude of dumpsite pollution on groundwater quality. The borehole locations were at radial distances of 50m, 80m, and 100m respectively away from the landfill. The results showed that most of the parameters investigated indicated traceable pollution which was below the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) limits for consumption. The result of the study also showed that there was a significant difference amongst all the parameters tested for at the 95% significance level.

Pande *et al.*, (2015) investigated the impact of leachate percolation on groundwater quality from the uncontrolled and unscientific disposal of MSW on groundwater in Dhanbad city, India. In the study, groundwater quality analysis was carried out on samples collected at various distances from two disposal sites. The study revealed that the groundwater quality nearer the dumpsites did not conform to the drinking water quality standards as per the IS: 10500. The results also revealed that there was a high potential for groundwater contamination.

Remy *et al.*, (2017) assessed the leachate effects on groundwater and soil quality from the Nduba Landfill in Kigali, Rwanda. The physical and chemical analyses of water samples were carried out and the results showed that most of the water samples were contaminated based on the fact that they exceeded the acceptable levels required by the EPA (2016) guidelines for potable water.

Abbas *et al.*, (2018) investigated the impact of municipal solid waste on groundwater quality in Jhang City Punjab, Pakistan. The study area was divided into two parts: solid waste sites and controlled area (locations with proper waste management practices). Water samples were collected near and around the MSW dumpsites and analyzed for the physio-chemical properties of water quality. The results showed that the water condition in the controlled area was more stable and that 90% of the sample results were within the permissible limits set by the WHO on water quality.

Somani *et al.*, (2019) assessed the leachate concentration of six MSW dumpsites located at Delhi, Hyderabad, and Kadapa in India. The leachate samples collected from two different sites of the same landfill (one fresh outflow and the other accumulated in the pond) were analyzed based on the effect of aging. The results revealed that the leachate from the fresh waste was more hazardous than the other. It also revealed that the concentrations of a majority of the physical and chemical parameters of samples obtained from the test sites exceeded the regulatory threshold.

However, with no way of fully compensating for the effects of the proximity of solid waste dumpsites to underground water, coupled with the problems of the ever-increasing urban communities, it is imperative that periodic studies are carried out vis-à-vis proper waste management practices using a simple and cost-effective location technology.

It is therefore against this backdrop that the study assessed the quality of groundwater due to the proximity of solid waste dumpsites in Samaru, Kaduna state-Nigeria with a view to proffering proper waste management practices. This is achieved through the identification of dumpsites in proximity to the groundwater sources in the study area and the testing of the leachate concentration from the groundwater samples, the determination of the spatial distribution of dumpsites in proximity to the groundwater sources, and the effect of dumpsite proximity on the leachate concentration, as well as the assessment of water quality from water quality index (WQI).

Study Area

The study area is situated in the Sabon Gari Local Government Area in the northern part of Kaduna State, Nigeria, and bounded by the Ahmadu Bello University Zaria main campus, Basawa and Bomo communities. It is a growing semi-urban settlement with an estimated population of 393,300 based on the National Population Commission of Nigeria 2006 census and the National Bureau of Statistics (City Population, 2016). It is located approximately between longitudes [7°37’0” and 7°40’0”] E of the Greenwich Meridian and latitudes [11°10’0” and 11°11’0”] N of the Equator with an average elevation of 644 m above sea level (Sawa, 2009). Fig. 1 depicts the study area (top and bottom left: map of Nigeria showing Kaduna state; right: locations of dumpsites and groundwater sources in Samaru, in red and blue coloured point symbols, respectively).

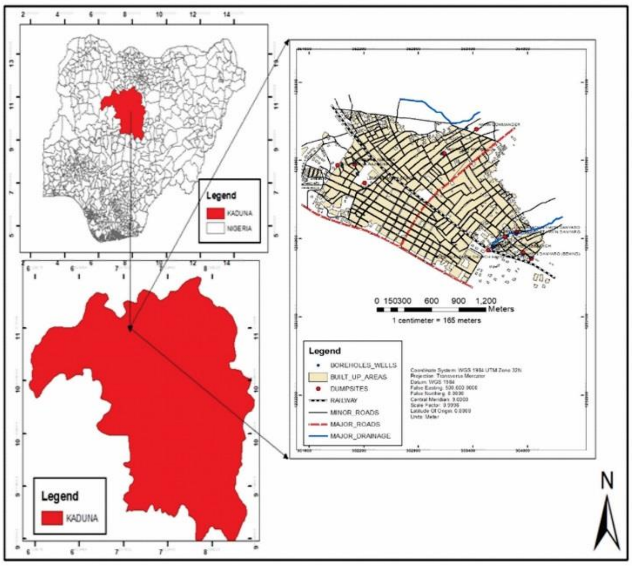

Fig. 1. Study area

The study area has a tropical savannah climate with warm weather all year round, a wet season that starts from April and lasts till September, and a dry season that starts from October and lasts till March. Its geology is predominantly metamorphic rocks of Nigeria basement complex consisting of biotic gneisses and older granite. The major occupations of the people are trading, farming, artisanship, and civil service (Ogenyi, 2010).

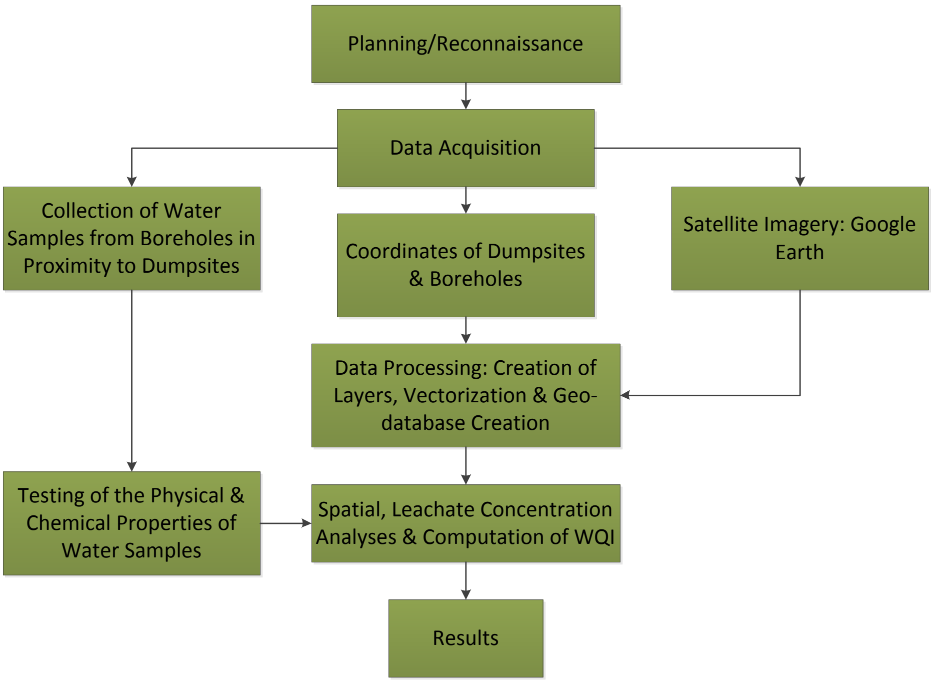

Fig. 2. Simplified workflow diagram

Table 1. Datasets and sources

S/N	Data Name	Data Type	Year	Coverage/Resolution	Source
1	Coordinates (E, N) of Dumpsites & Boreholes	Primary	2019	Samaru, Zaria	Field Survey using GPS-enabled Smartphone
2	Groundwater Samples	Primary	2019	Samaru, Zaria	Field Survey of Boreholes
3	Google Earth Imagery	Secondary	2019	15 m	http://www.google.com

Materials and Methods

The methodology adopted in this study included the planning/reconnaissance, data acquisition, data processing, analyses, and results stages as presented in a simplified workflow diagram (see Fig. 2). It involved the spatial proximity and leachate concentration analyses in relation to the dumpsites and underground water sources.

Data Sources

The details of the datasets and their sources utilized in this study are shown in Table 1.

Planning/Reconnaissance

The planning stage involved both the office and field reconnaissance where the choice of relevant data and information (both spatial and attribute data of the dumpsites and boreholes), survey method, and logistics requirements were considered. It also involved the cross-checking of the information obtained as well as determining the number of locations to be surveyed.

Data Acquisition

The coordinates of dumpsite and borehole locations were acquired using a GPS-enabled smartphone (Tecno WX3 Pro Android Version 7.0) device with an overall average horizontal accuracy to within 13 m (95% of the time) which is consistent with the general accuracy levels observed of recreation-grade GPS receivers in urban environments (Merry and Bettinger, 2019). The attribute information of each dumpsite and borehole was obtained on-site. Water samples of each of the 10 boreholes in proximity to the dumpsites were also acquired at the mid and tail end of the wet season (Ogenyi, 2010) in September 2019 with properly labelled water bottles for testing in the Laboratory.

Data Processing

The downloaded Google Earth imagery and acquired coordinates (E, N) of the existing dumpsites and boreholes were imported into the ArcGIS 10.3 environment where the reference system (WGS 84, UTM zone 32N) was defined. Thereafter, the digitizing process was carried out with the creation of the dumpsite and borehole positions, built-up, roads, railway, and drainage layers as shapefiles. The attribute information of the dumpsites and boreholes were added to the attribute table linking the shapefiles in the ArcGIS environment to create the geo-database.

The collected water samples were tested for 11 (Temperature, pH, Electrical Conductivity [EC], Dissolved Oxygen [DO], Chloride, Hardness, Total Dissolved Solids [TDS], Calcium, Nitrate, Turbidity, and Biochemical Oxygen Demand [BOD]) physical and chemical properties according to the WHO (2017) standard for water quality in the Water Resources and Environmental Engineering laboratory in Ahmadu Bello University Zaria.

Results

Spatial Proximity of Dumpsites to Boreholes

In order to safeguard the health of inhabitants in any given environment regarding the access to quality water, the EPA (2016) specified the requirement for a safe area or the minimum distance between solid waste dumpsites and groundwater sources to be at least 160 m.

In this study, 10 major solid waste dumpsites in proximity to corresponding 10 groundwater sources were investigated to determine the suitability of their positions regarding the EPA (2016). A simple spatial analysis method of spatial distance measurements between the locations (coordinates) of the dumpsites and corresponding groundwater sources were adopted. The technique for calculating the horizontal distance between a dumpsite and groundwater source is as follows (Langdon, 2020):

$$D = \sqrt{\left(\Delta E\right)^2 + \left(\Delta N\right)^2} \quad (1)$$

Where,

D = Spatial distance between dumpsite and groundwater source locations,

ΔE = Change in Easting coordinates between dumpsite and groundwater locations,

ΔN = Change in Northing coordinates between dumpsite and groundwater locations.

Table 2. Proximity of dumpsites to groundwater sources

S/N	Sample Area	DS Easting (m)	DS Northing (m)	GW Easting (m)	GW Northing (m)	Proximity (m)
1	Leather Research	353568.87	1233865.94	353629.70	1233896.00	67.85
2	Lemu Primary School	352209.17	1234643.97	352128.90	1234752.34	134.86
3	Ungwan Malawa	352102.90	1234857.08	352100.82	1234877.93	20.95
4	Alhaji Jumare	351912.25	1234848.08	351960.05	1234832.50	50.28
5	Tagwayin Engine	353085.20	1234982.33	353053.83	1234977.83	31.69
6	Hayin Commander	353439.06	1235262.30	353336.51	1235275.15	103.35
7	Behind Hayin Danyaro	354047.89	1233772.31	354038.77	1233783.76	14.64
8	Apostolic Faith Church Hayin Danyaro	353955.36	1233838.23	353950.13	1233813.60	25.18
9	Madaki Hayin Danyaro	353883.77	1234077.97	353881.87	1234051.95	26.09
10	Napri Water Depot Hayin Danyaro	353753.60	1234025.10	353783.70	1234031.44	30.76

Table 2 presents the spatial proximity of 10 major dumpsites in correspondence to 10 groundwater sources (boreholes) under investigation based on their coordinates (E, N). The locations of the solid waste dumpsites and their corresponding proximal groundwater sources are denoted by 'DS' and 'GW' (DS1 – DS10 and GW1 – GW10), respectively in relation to their sample areas.

The result of Table 2 shows that the closest and farthest dumpsites from groundwater sources are found in the Ungwan Malawa and Lemu Primary School areas at 21 m and 135 m, respectively. Meanwhile, the average distance between a dumpsite and borehole is about 51 m. The results appear to indicate that the requirement set by the EPA (2016) which stipulates that dumpsites should be positioned not less than 160 m from groundwater sources has not been met.

Query Result of Buffering Operation for Selecting Dumpsites

In order to ascertain the reliability of the dumpsite locations in relation to the groundwater sources as well as validate the results in Table 2, a buffering operation was carried out between the dumpsites and boreholes based on the minimum distance required between them as specified by the EPA (2016). The result is shown in Fig. 3.

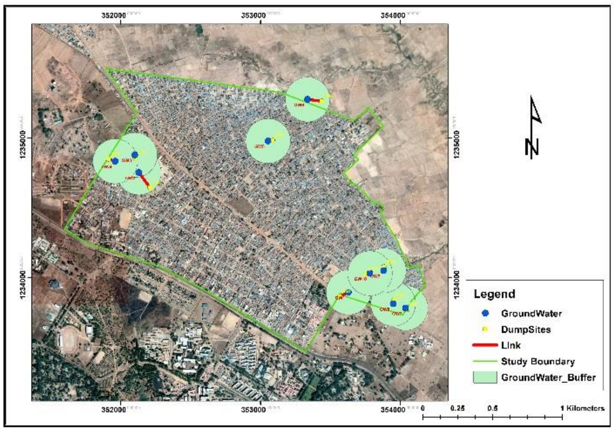

Fig. 3. Result of buffering operation between the dumpsites and groundwater sources

The EPA (2016) stipulates that a minimum distance of 160 m is required between dumpsites and groundwater sources for the purpose of public health safety. However, the result of Fig. 3 shows that the dumpsites were located less than 160m away from the groundwater sources. This means that none of the dumpsites met the requirement set by the EPA guidelines for placing them.

Results of Physical and Chemical Analyses of Groundwater Samples

In this study, 11 physical and chemical parameters (pH, Temperature, Turbidity, Electrical Conductivity, Dissolved Oxygen [DO], Total Dissolved Solids [TDS], Total Hardness, Nitrates (NO3), Biochemical Oxygen Demand [BOD], Chlorides, and Calcium) of water quality in relation to the 10 corresponding groundwater sources in proximity to the 10 solid waste dumpsites in the study area were considered and analyzed based on the testing capacities of availability apparatuses in the laboratory. In addition, these parameters have been known to contribute greatly to the quality of water in any environment. Moreover, the water quality index (WQI) for any station can be calculated with at least four parameters available (Canadian Council of Ministers of the Environment [CCME], 2001).

Table 3 presents the results of the analyses of physical and chemical parameters of water samples obtained from the groundwater sources in proximity to the dumpsite locations as against the WHO (2017) and CCME (2005) standard limits due to their strong correlation (UNEP, 2007a). The milligram per litre (mg/l) was the unit of measure for Dissolved Oxygen [DO], Total Dissolved Solids [TDS], Hardness, Nitrates, Biochemical Oxygen Demand [BOD], Chlorides, and Calcium values. Meanwhile, the values of Temperature, Turbidity, and Electrical Conductivity were measured in degrees Celsius (℃), Nephelometric Turbidity Units (NTU), and micro Siemens per centimetre (S/cm), respectively. The pH was not denoted by any unit.

The pH values obtained for the groundwater samples ranged from 7.74-8.54. When these values were compared to the standard limits set by the CCME/WHO (6.50-9), all of the groundwater locations were within the permissible lower and upper limits. Although a pH value above 8.00 may be inimical to the treatment and disinfection of drinking water with chlorine, the pH values obtained in this study were in the acceptable range of good water quality.

The maximum temperature limit for good drinking water as recommended by the CCME/WHO guidelines is 25 ^{0}C at the tap. Meanwhile, the temperature range across all the groundwater samples appeared to be within the drinking water temperature standard limits of the Netherlands (not exceed 25 ^{0}C), South Africa (20.5-24.5 ^{0}C), and the United Kingdom (3-25 ^{0}C) [Agudelo-Vera *et al*., 2020; Drink Water Directive, 2013]. This is also within the ambient temperature range of 23.9-24.9 ℃ (Al-Habaibeh *et al*., 2015) and indoor or room temperature range of 20-25 ℃ (Dictionary.com, 2020). This meant that the water samples across all the locations in the study area could be considered to be in the healthy water category.

The values of Turbidity obtained from the water samples ranged from 1.75-9.13 Nephelometric Turbidity Units (NTU). The CCME/WHO established that the Turbidity of drinking water should range from 1-5 NTU. Meanwhile, a total of three sample locations (Lemu Primary School [GW2], Behind Hayin Danyaro [GW7], and Napri Water Depot Hayin Danyaro [GW10]) had values that exceeded the upper permissible limit (5 NTU) set by 3.28, 1.27, and 4.13 NTUs, respectively.

This is an indication that they were within the unacceptable range for drinking water. One of the locations (Alhaji Jumare [GW4], 0.77 NTU) fell below the lower permissible limit (1 NTU) by 0.23 NTU. However, the remaining six groundwater locations had values within the permissible limits, which meant that they were in the acceptable drinking water range.

Table 3: Results of analyses of the physical and chemical parameters of groundwater against the CCME/WHO limits

Sample Area	pH	DO mg/l	BOD mg/l	TDS mg/l	T ℃	Tb NTU	EC μ S/cm	Cl mg/l	H mg/l	Ca mg/l	N mg/l
Leather Research	7.95	1.3	0.6	192.8	23.9	2.79	377	31.99	4040.32	2226.62	12.2
Lemu Primary School	8.39	1.1	0.5	442	24.8	8.28	860	100	505.5	2429.04	12
Ungwan Malawa	8.45	1.6	0.6	417	24.6	3.04	796	140	6060.48	1012.1	13
Alhaji Jumare	8.54	1.1	0.2	810	24.9	0.77	1593	179.91	5555.44	1214.52	16.5
Tagwayin Engine	8.43	1.2	0.3	248	24.5	1.86	487	37.99	5555.44	1821.78	12
Hayin Commander	8.37	1.1	0.3	392	24.3	3.88	770	29.49	8585.68	1821.78	6
Behind Hayin Danyaro	8.25	1.3	0.3	116.7	24.7	6.27	228	9.5	444.44	48.58	10.9
Apostolic Faith Church Hayin Danyaro	7.74	1.2	0.2	331	23.9	1.75	662	80	4545.36	1012.1	7.2
Madaki Hayin Danyaro	7.85	1.2	0.4	240	23.9	3.51	470	31.49	6565.52	1214.52	10.6
Napri Water Depot Hayin Danyaro	8.34	2.2	1.7	315	24.2	9.13	613	43.49	5050.4	1214.52	19
CCME/WHO Limit	6.5-9	5-9.5	3	1200	25	5	400	120	180	75	13

Note: DO = Dissolved Oxygen; BOD = Biochemical Oxygen Demand; TDS = Total Dissolved Solids; T = Temperature; Tb = Turbidity; EC = Electrical Conductivity; Cl = Chlorides; H = Hardness; Ca = Calcium; N = Nitrates

The amount of EC obtained from the sample locations ranged from 228-1593 micro Siemens per centimetre (μ S/cm) compared to the standard limit (400 μ S/cm) set by the CCME/WHO for drinking water. Only the values of EC at groundwater locations in the Behind Hayin Danyaro [GW7] (228 μ S/cm) and Leather Research [GW1] (377 μ S/cm) sample areas were within the standard limit. This meant that the groundwater sources in those sample areas could have been acceptable in the good drinking water category. However, the remaining eight groundwater locations had EC values that exceeded the standard limit by at least 70 μ S/cm and at most 1193 μ S/cm in the Madaki Hayin Danyaro [GW9] and Alhaji Jumare [GW4] areas respectively. This meant that water samples in these areas could be considered unacceptable for drinking based on their EC values.

The concentrations of DO obtained from the groundwater sources ranged from 1.10-1.60 mg/l. However, the concentrations of DO necessary for good drinking water should be less than 9.5 mg/l as set by the WHO standard or between 5-9.5 mg/l as prescribed by the CCME standard limit, and between 6.5-8 mg/L and about 80-120 % (Environment and Natural Resources, 2020). In terms of the WHO standard, all the groundwater locations have values within the acceptable drinking water range while in terms of the CCME standard limits, the values were less than the lower limit. This may mean that the groundwater samples across the locations in the study area were not in the acceptable range of good drinking water. However, these values may not indicate any harm to the human body.

The concentrations of TDS across the groundwater locations ranged from 116.7-810 mg/l against the permissible limit of 1200 mg/l set by the WHO. This meant that all the water samples could have been acceptable as drinking water.

The value obtained for Total Hardness across the groundwater locations ranged from 444.44-8585.68 mg/l. These values exceeded the permissible limit (180 mg/l) set by the CCME/WHO for Total Hardness. This meant that the samples could not have been acceptable for good drinking water as there were high levels of water hardness across the groundwater locations in the study area.

The concentrations of Nitrates obtained from the groundwater samples ranged from 6.0-13 mg/l. These values were within the permissible limit of 13 mg/l set by the CCME/WHO guidelines except at the Napri Water Depot (GW10) area (19 mg/l) probably due to its proximity (30.76 m) to the dumpsite with wastes from its treatment plant and the Alhaji Jumare (GW4) area (16.5 mg/l) with the proximity of 50.28 m to the dumpsite. This is an indication that most (80%) of the groundwater locations in the study area could be acceptable for drinking water based on their concentrations of Nitrates.

The concentrations of BOD obtained from groundwater samples ranged from 0.20-1.70 mg/l. In general, the BOD values for the study area were below the permissible limit (3 mg/l) for drinking water set by the WHO. The values suggest a rather low organic content in the groundwater and indicate healthy water conditions.

The concentrations of Chlorides obtained for the water samples ranged from 9.5-179.91 mg/l compared to the standard limits of 120 mg/l set by the CCME and 250 mg/l set by the WHO. In terms of the CCME standard, only one groundwater location (Alhaji Jumare [GW4]) had a value exceeding the permissible limit by 59.91 mg/l. However, in terms of the WHO standard, all the groundwater samples revealed values that were within the permissible limit. This indicates generally that the water samples were in good drinking water condition based on their values of Chlorides.

The concentrations of Calcium in the water samples ranged from 48.58-2226.62 mg/l compared to the permissible limit (75 mg/l) set by the WHO. The results show that only one sample location (Behind Hayin Danyaro [GW7] with 48.58 mg/l) fell below the lower limit while the remaining exceeded the upper limit. This is an indication that a majority (90%) of the groundwater locations contributed greatly to the high levels of hardness observed due to the high concentrations of Calcium across a majority of the groundwater locations in the study area.

Computation of Water Quality Index (WQI) for Groundwater Sources

In this study, the WQI is used to determine groundwater quality from the effect of dumpsites in the vicinity of groundwater sources from the 11 physical and chemical parameters of water quality considered. The WQI was computed using the weighted arithmetic water quality index (WQI_A) method (Brown *et al.*, 1972; Horton, 1965) and it is given as follows:

$$WQI = \sum_{1}^{n} w_i q_i \Big/ \sum_{i=1}^{n} w_i \quad (2)$$

Where,
n = the number of parameters,
w_i = the relative weight of the i^{th} parameter and,
q_i = the water quality rating (sub-index) of the i^{th} parameter.

The unit weight (w_i) (that is, $\sum_{i=1}^{n} w_i = 1$) of the various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters. The value of q_i which relates the value of the parameter in contaminated water to the recommended or standard permissible value is computed as follows:

$$q_i = 100\left[\left(V_i - V_{id}\right)/\left(S_i - V_{id}\right)\right] \quad (3)$$

Where,
V_i = the observed value of the i^{th} parameter,
S_i = the standard permissible value of the i^{th} parameter and,
V_{id} = the ideal value of the i^{th} parameter in pure water.

For most of the times, the ideal value of a parameter for drinking water is taken as zero except for pH (7.0) and DO (14.6 mg/L) according to Tripaty and Sahu (2005).

The unit weight (w_i) which is inversely proportional to the standard permissible values is calculated as:

$$w_i = k/S_i \quad (4)$$

Where,

$$= 1\Big/\sum_{i=1}^{n} 1/S_i \quad (5)$$

The rating of the water quality in this study is based on the index value according to the modified version of Tiwari and Mishra (1985), House and Ellis (1987), and the CCME (2005) designations as shown in Table 4.

Table 4. WQI ratings (modified after; CCME, 2005; House and Ellis, 1987; Tiwari and Mishra, 1985)

Designation	Index value	Description
Excellent	95 and above	Suitable for drinking water
Good	80-94	Slightly polluted water
Fair	65-79	Moderately polluted water
Marginal	45-64	Excessively polluted water
Poor	0-44	Severely polluted water

Table 5 presents the WQI of groundwater samples based on the 11 physical and chemical parameters considered in this study. The groundwater locations are tagged GW1 – GW10 respectively.

Table 5. WQI at groundwater locations

S/No.	Sample ID	Sample Area	WQI
1	GW1	Leather Research	115.313
2	GW2	Lemu Primary School	132.669
3	GW3	Ungwan Malawa	104.916
4	GW4	Alhaji Jumare	97.557
5	GW5	Tagwayin Engine	108.652
6	GW6	Hayin Commander	122.618
7	GW7	Behind Hayin Danyaro	76.538
8	GW8	Apostolic Faith Church Hayin Danyaro	83.019
9	GW9	Madaki Hayin Danyaro	104.448
10	GW10	Napri Water Depot Hayin Danyaro	142.841

The values of the WQI obtained showed that eight of the groundwater locations were within the 'suitable for drinking water' category while the remaining two were within the 'slightly polluted water' and 'moderately polluted water' categories. In this study, a majority (80%) of the water samples appear to be suitable for drinking water based on the index values obtained as described in Table 4. The water sample at the Napri Water Depot Hayin Danyaro area (GW10) appears to have the best water quality with a WQI of 142.841 followed by the Lemu Primary School (GW2) with a WQI of 132.669. The sample with the least WQI was found at GW7 (Behind Hayin Danyaro) with 76.538. The water sample at GW4 (Alhaji Jumare) with a WQI of 97.557 barely made it into the 'suitable for drinking water' category. The somewhat suitability in most of the groundwater locations may not be unconnected to the fact that the groundwater samples resulted from boreholes.

Relationship between Spatial Proximity of Dumpsites and the Concentrations of Parameters

It is pertinent to investigate whether there is a relationship between the proximity of the dumpsites to the boreholes and whether it has significant effects on the levels of the physical and chemical constituents of the groundwater sources. Therefore, Table 6 presents the results of a multiple regression analysis carried out to verify these assumptions.

Table 6. The relationship and effect of proximity of dumpsites to boreholes

VIF Category	Parameter	R	R Squared	Sig.
I	Electrical Conductivity (ms/cm)	0.93	0.86	0.111
	Chloride (mg/l)			0.236
	Total Hardness (mg/l)			0.109
	Calcium (mg/l)			**0.023**
	Nitrate (mg/l)			0.216
II	pH	0.89	0.79	0.547
	Dissolved Oxygen (mg/l)			**0.009**
	Biochemical Oxygen Demand (mg/l)			**0.018**
	Temperature (^{O}C)			0.950
III	Total Dissolved Solids (mg/l)	0.47	0.22	0.298
				0.295

The multiple regression analysis was based on the Variance Inflation Factor [VIF] (Systat Software Inc., 2014) categories of the variables (physical and chemical parameters) at play. The spatial proximity of dumpsites to boreholes formed the dependent variable while the physical and chemical parameters formed the independent variables.

The results in Table 6 show that based on category I (Electrical Conductivity, Chloride, Total Hardness, Calcium, and Nitrate) only the concentrations of Calcium ($p < 0.05$ at the 95% significance level) were significantly affected by the spatial proximity of the solid waste dumpsites. However, there was a very strong relationship (R = 93%; R^2 = 86%) between the proximity of the dumpsites and the concentrations of the parameters. Meanwhile based on category II (pH, Dissolved Oxygen, Biochemical Oxygen Demand, and Temperature), only two of the parameters' (Dissolved Oxygen and Biochemical Oxygen Demand) concentrations were significantly affected ($p < 0.05$ at the 95% significance level) by the proximity of the dumpsites with a strong relationship (R = 89%; R^2 = 79%) between the former and latter. There was, however, little or no effect ($p > 0.05$ at the 95% significance level) of the proximity of dumpsites on the concentrations of the Total Dissolved Solids and Turbidity parameters as the relationship between them was weak (R = 47%; R^2 = 22%).

It is evident from the foregoing, that categories I, II, and III were as a result of 86%, 79%, and 22%, respectively in the variation of the spatial proximity (closeness) of the solid waste dumpsites to boreholes in the study area.

Discussion

The results of this study have shown that solid waste dumpsites were located close to the groundwater sources, residential areas, and roads. This is an indication that the dumpsites did not meet the requirement set by EPA (2016) regarding the minimum distances required for their location. However, all the groundwater sites revealed pH values within the acceptable limit set by the CCME/WHO standard for good water quality.

All of the groundwater sites showed that the concentration of TDS was within the limit of good water quality set by the WHO while the levels of DO were acceptable based on the WHO standard which is likely unacceptable across all the sites based on the requirements by the CCME and Environmental and Natural Resources (2020). However, these values may not portend any harm to human health.

The results of Total Hardness revealed that none of the groundwater sites met the requirement set by the CCME/WHO for good drinking water. Moreover, the results of the concentrations of Calcium revealed that only one groundwater site (Behind Hayin Danyaro [GW7]) had a value less than the acceptable lower limit set by the WHO while others had values that exceeded the acceptable upper limit for drinking water. This shows that a majority (about 90%) of the groundwater locations contributed greatly to the hardness of the water in the study area.

The concentrations of BOD at all the groundwater sites revealed that they were below the limit set by the WHO which is an indication of a condition acceptable for good drinking water. However, the concentrations of Nitrates at only two groundwater locations (Alhaji Jumare [GW4] and Napri Water Depot Hayin Daanyaro [GW10] areas) exceeded the upper limit set by the WHO for the amount of Nitrates in drinking water. This meant that a majority (80%) of the groundwater locations had values of Nitrates within the acceptable drinking water limit.

The concentrations of Chlorides for a majority (90%) of the groundwater sites showed that they were within the acceptable limit for good water quality as set by the CCME. Only one groundwater location (GW4) in the Alhaji Jumare area had levels of Chlorides exceeding the standard limit. However, in terms of the standard limit set by the WHO, all the groundwater locations had values within the acceptable drinking water limit.

Meanwhile, the results of Temperature across the groundwater sites revealed that they were within the limit of being acceptable for good drinking water as set by the CCME/WHO standard. However, the results of the Turbidity revealed that 60% of the groundwater sites fell within the permissible limit set by the WHO while 30% of the sites (Lemu Primary School [GW2], Behind Hayin Danyaro [GW7], and Napri Water Depot Hayin Danyaro [GW10]) exceeded the limit. The remaining 1% (Alhaji Jumare [GW4]) fell below the limit and may be considered as acceptable.

The contents of EC in the study area revealed that only 20% of the groundwater locations (GW1 and GW7) had values within the standard limit set by the CCME/WHO in the Leather Research and Behind Hayin Danyaro sample areas respectively. This meant that only these samples were acceptable for drinking water based on the contents of the EC.

In addition, the results of the study revealed that 80% of the groundwater locations (GW1 – GW6 and GW9 – GW10) had water samples that appeared to be suitable for drinking water while the remaining 20% (that is, 10% apiece) of groundwater locations (Apostolic Faith Church Hayin Danyaro [GW8] and Behind Hayin Danyaro [GW7]) had water samples that were slightly and moderately polluted respectively based on the computed WQI values and ratings (see Table 4). None of the groundwater samples indicated that they were hazardous to human health. This may have been as a result of the fact that the water samples were obtained from boreholes. Moreover, the geology (predominantly metamorphic rocks composed of gneiss and granite) of the study area may have contributed to the minimal or near absence of water contamination. This is due to the fact that consolidated sedimentary formations with confined aquifer are overlain by impermeable layers that prevent recharge (and contamination) by rainfall or surface water. Besides when it involves groundwater (borehole), it usually takes a long time for a confined aquifer to be contaminated due to the slow movement of polluted fluid through the crevices of consolidated sedimentary rocks (Berndt *et al*., 1996; UNEP/WHO, 1996).

The results of the study went further to reveal that only the concentrations of Calcium, DO, and BOD was significantly influenced ($p < 0.05$ at the 95% significance level) by the closeness of the solid waste dumpsites to the groundwater sources with very strong (R^2 = 86%) and strong (R^2 = 79%) relationships, respectively.

This study is in agreement with Arimah and Adinnu (1995), Akinbile and Yusoff (2011), and Pande *et al*. (2015) who reported similar findings on the closeness or otherwise of dumpsites to groundwater sources, but differs slightly from Remy *et al*. (2017) regarding soil quality and the contamination of groundwater due to the fact that soil quality investigations were not carried out in this study. In addition, this study disagrees with Abbas *et al*. (2018) and Somani *et al*. (2019) based on the fact that the adoption of both controlled and uncontrolled conditions was prejudiced. Additionally, this study agrees with the findings of CCME (2005), House and Ellis (1987), Kumar and Dua (2009), and Tiwari and Mishra (1985) but disagrees with Boah *et al*. (2015), Chandra *et al*. (2017), and Oni and Fasakin (2016), based on the adopted WQI ratings.

Implications of the Study

A good number of the dumpsites (about 80%) are located close to the residential areas. This is an indication that most of the dumpsites did not meet the requirement set by EPA (2016) regarding the minimum distance required for their location. The effect of this is that they would not only destroy the aesthetics of the environment, but also have the potential to pollute the underground water table in the surrounding environment with accompanying health implications. This is as a result of the fact that drainage channels support the leaching of contaminants into the soil, which eventually seep over time into the underground water sources such as boreholes and wells in the surrounding environment. The implications of this to the health of the inhabitants cannot be overemphasized. Moreover, the proximity of these dumpsites to residential areas not only expose the inhabitants to all sorts of offensive odour and polluted air, but encourage the constitution of breeding grounds for the transmission of diseases such as malaria, typhoid fever, and cholera. Fig. 4 depicts a dumpsite in proximity to the residential area in the Samaru community.

Fig. 4. A dumpsite at Madaki Hayin Danyaro

Meanwhile, any dumpsite located on existing drainage channels with no evidence of being evacuated would in some cases block the flow of water. The mixture of solid wastes with flowing water inadvertently create toxic liquids which with time leach into the underground water table thereby contaminating the boreholes and wells in the nearby surroundings. Fig. 5 depicts a dumpsite located on a drainage channel in the Samaru community.

A few of these dumpsites date back to 1970 (that is, 51 years ago) when the surrounding semi-urban settlements were established as a result of the formation of the Ahmadu Bello University in 1962 (Devex, 2021). The current population of over 393,300 (City Population, 2016) of the study area is rapidly increasing due to the influx of people for educational purposes, civil service, and commercial activities thereby increasing the demand for potable water that is inhibited by the increased quantity of wastes.

Fig. 5. A dumpsite at Napri Water Depot Hayin Danyaro

Often times, the wastes generated are burnt or disposed of in the open and on sites not earmarked for landfills without any consideration for waste recycling and conversion to organic manure to aid plant growth as alternative techniques for disposing wastes. The implications include the contamination of groundwater from the seeping of pollutants through the crevices of the basement rock of the study area over time into the water table, creation of offensive odour, and polluted air as aforementioned.

Conclusion

This study was set out to assess the quality of ten major underground water sources (boreholes) in proximity to dumpsite locations in the Samaru community of Kaduna state, Nigeria.

The results of the study revealed that the distances between the dumpsites and boreholes were far less than the minimum stipulated by the EPA (2016) regarding safe areas for locating dumpsites. The results also revealed that groundwater quality conditions for drinking water were met at most of the water sample sites despite the closeness of the dumpsites to the groundwater sources based on the permissible limits set by the CCME and WHO, and the computed values of WQI and WQI ratings.

The results of the study showed that the concentrations of only three (Calcium, Dissolved Oxygen, and Biochemical Oxygen Demand) out of the eleven physical and chemical parameters tested were significantly affected by the proximity of the dumpsites to the groundwater sources with very strong and strong relationships, respectively. Consequently, it is possible to estimate the proximity of boreholes to dumpsites in the study area from the concentrations of Calcium, Dissolved Oxygen, and Biochemical Oxygen Demand based on the results of Table 6. Though the CCME (2001) prescribed a minimum of four parameters in the computation of water quality, the results of this study may be greatly improved if other parameters such as sodium, magnesium, ammonia, nitrogen, lead, iron, sulphate, phosphorus, potassium and bacterial constituent (total coliform group) are also investigated.

The results of the separate investigations into the different parameters are corroborated by the results of the computed WQI which show that a majority of the groundwater sources are not polluted (suitable for drinking) in the study area. A substantial reason for the somewhat suitability of the water samples for drinking based on the results of this study is that the low permeable nature of the predominantly metamorphic rock of the study area slows down the contaminant flow into the aquifer. In this study, water samples were collected and analysed at the tail end of the wet season (that is, September). It should be possible to collect water samples at the peak of both the dry and wet seasons for comparison at similar locations with at least four sampling visits for improved water quality decision making for the study area.

In view of the findings of this study, some parameters were identified (see Table 3) to exceed the stipulated CCME and WHO standard limits by some amounts. The parameters include Turbidity (3.28, 1.27 and 4.13 NTU) at the GW2, GW7, and GW10 locations respectively, Electrical Conductivity (460, 396, 1193, 187, 370, 262, 70 and 213 μS/cm) at the GW2 – GW9 locations respectively, Chlorides (59.91 mg/l) at the GW4 location, and Nitrates (3.5 mg/l) at the GW4 location. All the values of Total Hardness exceeded the limit by at least 264.44 mg/l, while all the values of Calcium exceeded the limit by at least 937.1 mg/l except at the GW7 location (48.58 mg/l) where it fell within the acceptable limit.

It is evident from the foregoing, that future study perhaps should investigate other factors such as the topography or elevation, nature of soil or sediment or rock (for example, sand, gravel, and granite), land use pattern and precipitation (Berndt *et al*., 1996; Xia *et al*., 2018; UNEP/WHO, 1996) separately and in combination to determine their roles or not in groundwater pollution in the study area. However, as part of a pollution control mechanism, anthropogenic activities such as land use in areas surrounding groundwater sources (for example, boreholes) should be monitored. This is because human activities in areas where there is rain or surface water can cause pollutants to flow into surrounding aquifers.

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