Assessment of Refuse Dumpsite Impact on Groundwater Quality: A Case Study from Awotan, Ibadan, Oyo State, Nigeria

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Abstract

Groundwater, an essential freshwater resource, is critical to life and supports various industries. Unrestrained urban expansion and inefficient waste management practices endanger groundwater quality. This research examines the groundwater quality and impacts of the Refuse Waste Dumpsite located at Awotan, Ibadan. Additionally, this study provides a framework for assessing dumpsite impacts on groundwater, which can be applied to similar urban contexts worldwide, contributing to global efforts to ensure safe water quality. Samples of residential Well water near the dumpsite were collected to determine their physical, chemical, and bacteriological characteristics. The physical and chemical parameters investigated include Temperature, pH, Electrical conductivity, Nitrate, and Chloride, which were determined using the standard analytical methods. In contrast, bacteriological parameters such as Total Coliform and E.Coli Count were determined. Trace metals such as Pb and Fe were also determined to ascertain the relationship between pollutant levels and distances from the dumpsite and to evaluate compliance with WHO and NSDWQ water quality standards. Regression analysis revealed a strong correlation ($R = 0.999$, $R^2 = 0.998$) between dumpsite distance and chemical water quality, but the results were not statistically significant ($p = 0.066$). Chemical parameters like alkalinity ($p = 0.484$) and nitrate ($p = 0.338$) showed no significant impact from distance. For bacteriological quality, the model was statistically significant ($p = 0.009$) with an R^2 of 0.994. Total coliform ($p = 0.055$) was nearly significant, indicating potential distance-related bacterial contamination. The findings underscore the pressing need for sustainable waste management to safeguard groundwater resources.

Keywords: *Leachates, Landfill, Water Pollution, Waste Management, Water Quality Assessment, Sustainable Development Goals (SDGs).*

1. Introduction

It is evident that the survival of life depends on water, and the consumption of treated water is gradually increasing due to increasing population growth in the world. Statistics from recent years show that many African cities have been growing very fast because of migration from the rural areas, resulting in the formation of 'mega-cities' composed of mostly informal settlements and slums with inadequate infrastructure bases. With the continued sprawl of these cities remaining uninhibited, the risk of polluting the water table remains high, mainly due to rampant industrial and commercial development [1]. The cost and difficulty of providing clean drinking water have become a significant issue in developing nations.

Groundwater is one of the most prominent natural reserves contributing to global freshwater stock. In Nigeria, as it obtains in any part of the globe, groundwater aids the flow of natural rivers, lakes, and wetlands, supports the agriculture and industries sectors, and affords a sizable fraction of the domestic and public water needs. All of these activities assist in keeping the ecosystem in

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balance [2]. In many parts of Nigeria, groundwater is the primary source of potable water supply, especially in rural areas where hand-dug residential/private wells are the only water source. Despite its dependability, [3] suggests that above-ground anthropogenic activities linked to unchecked development, constant trash dumping, and inadequate land use management put this valuable resource at increasing risk. Moreover, since the chemical composition of groundwater broadly defines how healthy it is as a source for human consumption, [3], [4], [5] suggest that the assessment of the water quality is vital for the social and economic development of both developed and developing countries around the Globe.

In many cities, groundwater is the primary source of drinkable water, typically from deep water supply boreholes and shallow hand-dug wells. Like many other developing nations, Nigeria has relied chiefly on open garbage dumping systems to manage solid waste disposal. Following the principle of "out of sight, out of mind," the previous management system focused on collecting and disposing of waste beyond municipal boundaries. [6]. However, to accommodate the growing rate of migration and the ensuing population explosion, there currently needs to be more building land, which has led to the location and development of residential quarters next to waste sites [7], [8].

Solid waste dumpsites are one of the main hazards to groundwater resources. Mixed industrial, commercial, and municipal wastes are dumped in them. Furthermore, research on how unlined garbage dumps affect the host soil and underlying shallow aquifers has demonstrated that inadequately built waste disposal facilities can contaminate soil and groundwater systems [9].

The primary cause of groundwater contamination in dumpsite facilities is the possibility of leachate from the waste body containing contaminants. These leachates are simply solutions saturated with rainfall. They are either organic or inorganic complexes of solid waste components that biodegrade as they flow out of the garbage dumps [10]. According to [11], the open dumpsite technique is still used worldwide as a solid waste disposal method. It is one of the most poorly performed municipal services in underdeveloped countries because the systems are unscientific, antiquated, and inefficient. Furthermore, solid waste disposal sites can be located within and on developing cities' edges. According to [12], many cities in developing nations face significant environmental degradation and health hazards due to poorly designed municipal solid waste management systems. Certain factors determine the contents of municipal solid wastes, including the location (residential and commercial), the economic level (differences between high- and low-income districts), and the type of waste.

This study aims to assess the impact of the Oyo State Refuse dumpsite on groundwater quality in the Awotan community of Ido Local Government Area, Ibadan. The physical and chemical characteristics of the water samples taken from the wells in the study area were carefully determined using standard methods. The distance between the dumpsites and selected wells was measured, and the levels of pollutants in wells were correlated with distances from the dumping site. Underground water quality in the selected wells was compared with the National Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) standards. Furthermore, the depths of each well were measured using a measuring tool, and the depth of the well at which the dumping site will not affect the water quality was determined. A recommendation was made for mitigation and amelioration measures to ensure best practices for preventing well water pollution.

While this study focuses on the Awotan dumpsite in Ibadan, its implications extend far beyond this local context. By understanding the relationship between waste disposal practices and groundwater contamination, the findings can inform environmental policy and waste management strategies in developing and developed countries. Moreover, the results contribute to broader discussions on achieving sustainable development goals related to clean water and sanitation (SDG 6) and climate action (SDG 13), thus providing a valuable global resource for scientists and policymakers.

2. Research Design

A descriptive research design was adopted to evaluate the impact of the Awotan waste dumpsite on nearby groundwater. This research design focuses on describing and understanding environmental phenomena and their characteristics, particularly concerning groundwater quality near dumpsites. Several studies have employed descriptive research designs to evaluate the impact of waste dumpsites on groundwater quality in various locations:

In Egypt, [13] investigated the impact of landfill leachate on groundwater quality. Similarly, [14] conducted a study to assess the heavy metal contamination of groundwater at the Oti landfill site in Kumasi, Ghana. Adedinni et al. [15] investigated the impact of a waste dumpsite in Southwestern Nigeria on groundwater quality through geophysical and geochemical studies.

These studies demonstrate the importance of employing descriptive research designs to assess the impact of waste dumpsites on groundwater quality.

3. Methods

The flow chart presented in Figure 1 is a visual representation of the sequence of the methodology.

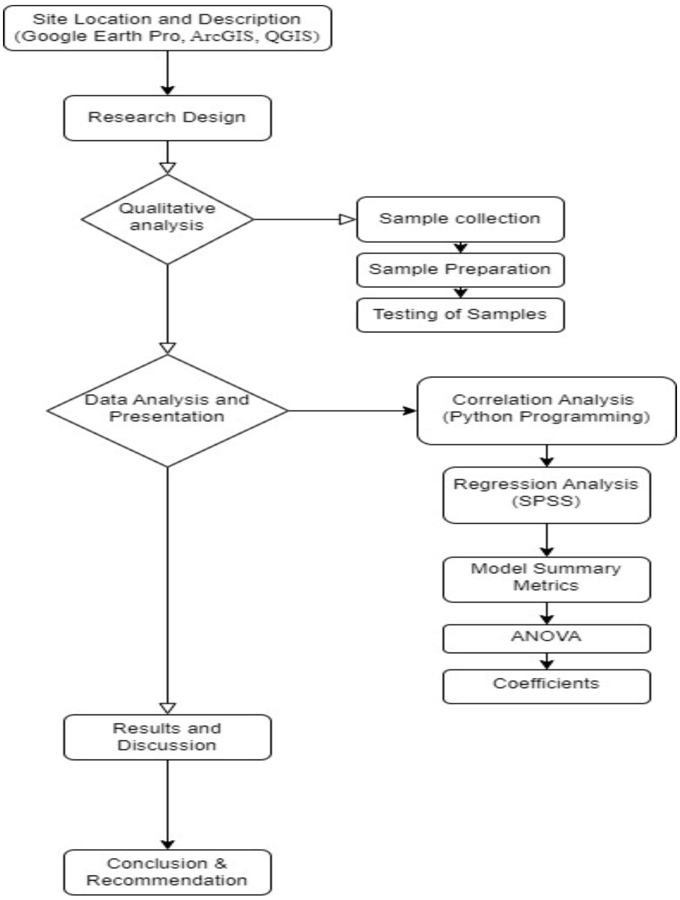

Figure 1. Graphical flowchart of the research methodology.

3.1. Site location and description

The study was carried out in the Awotan community on latitude 7°.27', longitude 3°.50', 247m above sea level, a suburban community situated in Ido Local Government Area (LGA), Oyo State, Nigeria. Awotan hosts one of the primary municipal solid waste dumpsites in Ibadan, Oyo State, Nigeria. The Ibadan metropolis is served by four significant dumpsites: *Lapite, Ajakanga, Abaeku,* and *Awotan*. Awotan is a community where sanitary conditions are below standard, residential areas are underdeveloped with no pipe-borne water supply with residents relying on wells and commercial boreholes for their water needs.

Figure 2. Overview of the Oyo State refuse landfill / dumpsite facility and its environment.

The Awotan municipal solid waste dumpsite, located in the Ido Local Government Area (LGA), is managed exclusively by the Oyo State Government of Nigeria through the Oyo State Waste Management Authority (OYOWMA). As the largest dumpsite in Ibadan, it spans 20 hectares and handles approximately 95,775 metric tons of waste annually from licensed and non-licensed sources. The site primarily receives domestic, commercial, electronic, hospital, and mixed industrial wastes. The facility is surrounded by residential houses, as shown in (Figure 2).

The geology of the Awotan region is predominantly schist, gneiss, migmatite, and different igneous intrusions, which have limited permeability because of their thick, crystalline character [16]. However, cracks, weathering, and structural characteristics such as joints and folds can enhance local permeability, enabling water to flow and thus diminishing groundwater protection. The degree of protection for the water table varies, with less weathered and unfractured rocks offering more significant pollution barriers, whereas more fractured and weathered zones increase groundwater vulnerability.

Awotan is located in a tropical climate zone with two seasons: the rainy season (April-October), with an average temperature of 27ºC, and the dry season (November-March), with an average temperature of 32ºC. The seasons are influenced by a south-westerly wind from the Gulf of Guinea and a dry northeast wind from the Sahara Desert, known as Harmattan. The yearly average rainfall in the region is 1300 mm [17].

3.2. Methodology

3.2.1. Sample collection

Six (6) wells and one Control Point sample taken at a farther distance were from the dump site. The groundwater samples were collected from the wells using a grid method of sampling, and all these samples were collected in January 2023. More water samples could have been taken; however, there are a limited number of private wells around the dump site. A map showing each well's relative location with their coordinates was prepared using geographic information system applications such as MapinR, Google Earth, QGIS, and ArcGIS.

Each well depth was measured using graduated tapes with an attached weight to determine its relative depth. Each well's distance to the dumping site was measured digitally using ArcGIS and Google Earth Pro software, as shown in (Figure 3) and the elevation profile of awotan dumpsite shown in (Figure 4).

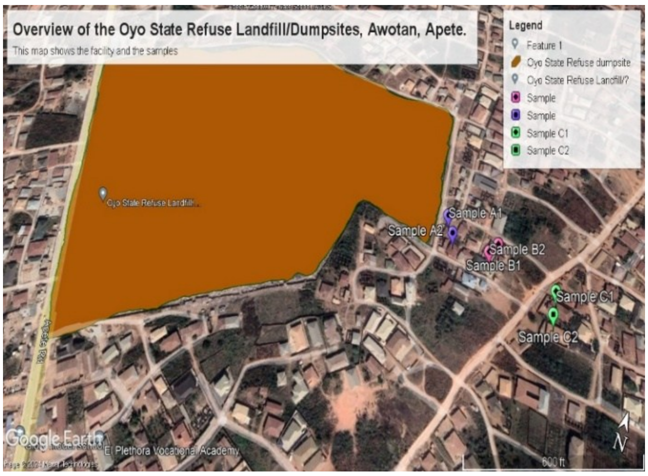

Figure 3. Map of Awotan showing the Oyo State refuse landfill / dumpsite facility and the points at which the well water samples were taken.

3.2.2. Sample preparation

Sample preparations included the following steps:

1. The sampled water was collected in a container for on-site and laboratory analysis.
2. Water samples were collected from 3 hand-dug wells. Using the linear sampling method, the 6 samples were collected from the wells at different proximities to the dump site. The arrangement of the wells and the control point do not strictly adhere to a grid sampling method due to constraints such as site accessibility and the spatial distribution of the wells.
3. All the wells were functional, active, located away from toilets, had not undergone any chemical treatment, and were continuously used for drinking and domestic purposes.
4. Samples were obtained using the same material usually used by the households to draw water from the wells. Water samples were collected in 1L plastic bottles and stored in the refrigerator before analysis using the Standard methods for examining water and wastewater [18].
5. Sample bottles were rinsed several times with distilled water and then rinsed with the sampled water at the sites. Each sample was immediately closed and air-tightened, put in a container for analysis, and transferred to the UCH Department of Public Health laboratory.

3.2.3. Testing of samples

The following tests were conducted to determine the initial and final concentrations of various water quality parameters on-site and in the laboratory. The tests include:

- The physical characteristic tests: Temperature test, Turbidity, pH, and Appearance.
- Chemical parameters: Total dissolved solids, Electrical Conductivity, Nitrate ion, Dissolved Oxygen, Lead ion, Total Hardness, Iron ion, Calcium ion, and Alkalinity.
- Bacteriological test: Total coliform count and Escherichia Coli.

The criteria behind the selection of these parameters are based on the parameters being the common pollutant elements in groundwater around the dumpsites. All tests were conducted in accordance with the APHA (American

Public Health Association) Standard Methods for the Examination of Water and Wastewater.

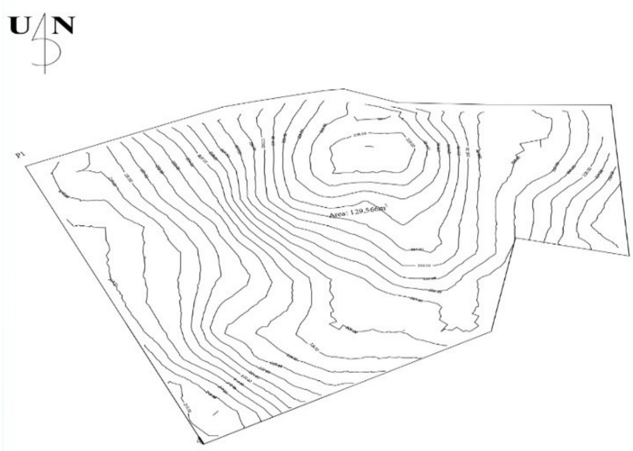

Figure 4. *Elevation profile of the Awotan dumpsite area.*

3.3. Data analysis and presentation method

Data on the level of pollutants in the wells was analysed using descriptive statistics to obtain mean values. Correlation analysis was performed through cross-tabulations to determine the relationship between the level of contaminants in wells as compared to the materials used in the construction of the well, the depth of the well, and the distances between the wells and the dumping sites. The Data was analysed using the Microsoft Excel package, SPSS, and Python Programming.

3.3.1. Correlation analysis

The correlation coefficient between two variables, often denoted as (r), is given by:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (1)$$

Where: n is the number of data points, x and y are the variables, ∑ denote the sum of the values, ∑xy is the sum of the product of x and y, and ∑x and ∑y are the sum of x and y.

Y_i = observed value

$\hat{Y}_i$ = predicted value from the model

$\bar{Y}$ = mean of the observed values

Adjusted R^2:

This formula computes the Pearson correlation coefficient, which expresses the linear connection between two variables. The value of r varies from -1 to 1.

r=1 indicates a perfect positive linear connection; r=-1 indicates a perfect negative linear relationship; and r=0 indicates no linear relationship between the variables.

Python programming was used to measure the strength and direction of the linear relationship between two variables.

3.3.2. Regression analysis

The formula for the multiple Linear Regression is written as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (2)$$

Where:

Y = dependent variable (e.g., groundwater quality parameters)

β_0 = intercept (constant term)

$\beta_1, \beta_2, \ldots, \beta_n$ = coefficients for each independent variable

$X_1, X_2, \ldots, X_n$ = independent variables (e.g., distance to the dumpsite, depth of well)

ε = error term (captures the variability not explained by the model)

SPSS was used to model the relationship between one or more independent variables and a dependent variable.

3.3.3. Model Summary Metrics

Coefficient of Determination (R^2):

$$R^2 = 1 - \left[\frac{(\Sigma(Y_i - \hat{Y}_i)^2)}{(\Sigma(Y_i - \bar{Y})^2)}\right] \quad (3)$$

Where:

$$R^2 = 1 - \left[\frac{(1 - R^2)(n - 1)}{(n - p - 1)}\right] \quad (4)$$

Where:

n = number of observations

p = number of predictors in the model

3.3.4. ANOVA

The F-statistic, used to assess the overall significance of the model, can be expressed as:

$$F = \frac{[Mean\ Square\ Regression]}{[Mean\ Square\ Residual]} \quad (5)$$

3.3.5. Coefficients

The significance of individual predictors in the model can be evaluated using the t-statistic:

$$t = \frac{\beta_i}{SE(\beta_i)} \quad (6)$$

Where SE(β_i) is the standard error of the coefficient β_i.

The p-value is associated with the t-statistic tests to determine whether the coefficient significantly differs from zero.

4. Results and Discussion

4.1. Water quality analysis

4.1.1. Appearance

After the water quality assessment of all the samples collected, all samples taken from each well site were clear and had no undesirable look. However, the clarity of the water samples alone does not assure that the water is safe to use. Other water quality parameters should be tested to ensure safety.

4.1.2. Temperature

The temperature measurements for the water samples vary between 28.0 and 28.3 degrees Celsius (Table A1). The temperature of the water samples is within the range of ambient temperatures, as established by the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO). According to the NSDWQ and WHO criteria, clean water should be at ambient temperature, which means it should be equivalent to the temperature of the surrounding environment. It is crucial to note that water temperature may impact many water quality elements and aquatic ecosystems [19]. Hence, it is often measured as part of water quality evaluations. Table A1 contains field and laboratory analysis results of the Water samples carried out at the Department of Environmental Health Science, University College Hospital (please see appendix).

4.1.3. pH

The PH result from the water sample suggests a lower PH level, indicating that the water is acidic. In comparison with the control point water sample, which was used to determine the original characteristics of the aquifer and groundwater in Awotan/Apete, it can be observed that the groundwater around the dumpsite has a pH value than the pH of the Control Point Sample, this data indicates that the dumpsite resulted in a lower PH of groundwater in Awotan. The mean pH of the water samples during the study was below the acceptable range of NSDWQ and WHO (6.5 – 8.5).

4.1.4. Turbidity

Turbidity is a measure of how much water loses clarity owing to suspended particles. The more total suspended particles in the water, the murkier it appears and the greater the turbidity. The quantity of suspended solid matter determines the turbidity of well samples. The results show that the turbidity readings for the water samples are skewed around the NSDWQ and WHO standards. Samples A1, A2, B2, and C2 met the maximum limit of 5 NTU set by NSDWQ (Table A1). While other samples are slightly higher than the standard, this indicates contamination from clay, silt, organic waste, and plankton.

4.1.5. Conductivity

Electrical Conductivity measures water's capacity to carry an electrical current. Inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions (negatively charged ions) or sodium, magnesium, calcium, iron, and aluminium cations (positively charged ions) influence water conductivity. The conductivity of the water samples decreases from sample A1 to sample C2, possibly due to leachate from the dumpsite, which contains more metal ions than samples further away.

4.1.6. Total dissolved solid

The total dissolved solid is a metric that measures the quantity of dissolved solids in water. The (Table A1) shows a decrease in total dissolved solid values from 1050mg/l to 120mg/l for samples A1 to C2, indicating that samples closer to the dumpsite have higher TDS values than those further away, with the Control Point water sample having Total Dissolved Solids of 100mg/l. Samples A1, A2, and B1 have Total Dissolved Solids values higher than the permissible amount stipulated by NSDWQ and WHO. It can be inferred that the allowable distance for a well to be dug close to the dumpsite facility is 89.2 meters.

4.1.7. Alkalinity

Alkalinity is a measurement of water's ability to neutralise acids. Alkaline substances in water, such as bicarbonates (baking soda), carbonates, and hydroxides, remove H+ ions and reduce acidity. They usually do this by interacting with H+ ions to form new molecules. The alkalinity in the water will aid in maintaining a stable pH. The total Alkalinity levels do not follow a specific sequence. This might be owing to the geological formation of the area, which has a high value of one of the bicarbonates. However, the total alkalinity of the well samples varies from 48 to 184 mg/l. All of the well samples met the NSDWQ and WHO threshold of 200mg/l.

4.1.8. Hardness

Total hardness of water refers to the amount of calcium and magnesium, expressed as calcium carbonate, in milligrams per litre (mg/L). Various circumstances may alter water hardness, including proximity to pollution sources such as landfills or waste sites [9].

Samples A1 and A2, the closest to the dumpsite at 24.3 and 37.7 metres, respectively, exhibit total hardness values of 364 and 379 mg/L $CaCO_3$. These values exceed the acceptable threshold. Samples B1 and B2, 88.4 and 89.2 metres from the dumpsite, respectively, had total hardness values of 335 mg/L $CaCO_3$ and 220 mg/L $CaCO_3$. These values are higher than the norms but lower than samples A1 and A2, which indicates that the closer the well water is to the dump site, the higher the total hardness. Samples C1 and C2, which are farther removed from the dumpsite at 154 and 156 metres, had total hardness values of 180 mg/L $CaCO_3$ and 92 mg/L $CaCO_3$. These values meet the NSDWQ and WHO criteria.

The findings indicate that there may be a relationship between the overall hardness of the water samples and their distance from the dump site. Samples collected closer to the dumpsite had greater overall hardness values, which may indicate landfill contamination. This finding is consistent with the report from [20]

Calcium and magnesium ions contribute to overall hardness and may have leached into the groundwater from waste products at the dump site.

4.1.9. Calcium hardness

Similar to the total hardness of the water samples, Samples A1 and A2, which are the closest to the dumpsite at 24.3 and 37.7 metres, respectively exhibit calcium hardness values of 123 mg/L $CaCO_3$ and 140 mg/L $CaCO_3$, these values exceed the acceptable standards of the NSDWQ (Nigerian Standard for Drinking Water Quality) calcium hardness standard of 75 mg/L $CaCO_3$ and the WHO (World Health Organisation) recommendation of 100 mg/L $CaCO_3$. However, there is a decrease in the values of calcium hardness in the water samples as we move farther away from the dump site. Samples B1 and B2 exhibit calcium hardness values of 108 mg/L $CaCO_3$ and 95 mg/L $CaCO_3$, respectively.

Samples C1 and C2 exhibit calcium hardness values of 85 mg/L $CaCO_3$ and 43 mg/L $CaCO_3$, respectively. The CP (Control Point) value is 40 mg/L $CaCO_3$; this indicates that the natural property of the groundwater in Awotan/Apete has far lower Calcium hardness, and therefore, the Oyo State Refuse Landfill/Dumpsite facility has an impact on the level of Calcium hardness on the groundwater level.

4.1.10. Chloride

The chloride content gradually decreases with an increased distance from the dump site.

Sample A1, nearest to the dumpsite, had the most significant quantity of chloride (296 mg/L).

Sample C1, the farthest from the dumpsite, had the lowest chloride content (44 mg/L). This trend shows chloride concentrations fall as one moves away from the dump site. This might be due to dilution effects, where toxins spread and become increasingly diluted in groundwater as it flows away from the dump site facility. Other variables that might impact chloride concentrations include groundwater flow direction and geology.

4.1.11. Nitrate

The Nitrate ion concentration tends to decrease as we move away from the dumpsite (Table A1). Sample A1, located closest to the dumpsite, had the greatest nitrate content (4.22 mg/L), while Sample C1, located farthest from the dumpsite, had the lowest nitrate content (2.58 mg/L).

This pattern indicates that nitrate concentrations decrease with increasing distance from the dumpsite [21]. This might be due to dilution effects, where toxins spread and become increasingly diluted in groundwater as it flows away from the dump site. However, like chloride concentrations, other variables, such as groundwater flow direction and geology, must be considered since these may also affect nitrate concentrations. Geology affects nitrate levels by affecting groundwater flow patterns, nitrate migration and transformation via various soil and rock types, and chemical reactions in groundwater [22].

4.1.12. Lead

The National Standard for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO) lead limits are set at 0.0 mg/L, implying that no detectable lead should be present in drinking water. Samples B1 and B2 had no detectable lead, but samples A1, A2, C1, and C2 had higher lead contents, although at extremely low levels (0.001 to 0.003 mg/L). However, considering the trace amount of lead in the water sample at the control point, it can be inferred that the aquifer property of the water in Awotan/Apete contains a trace amount of lead, but at a close distance to the dumpsite facility, the lead quantity in the water increased.

The presence of lead, especially in low quantities, is problematic owing to its hazardous nature. Chronic exposure to lead may cause significant health problems, particularly in sensitive groups such as children and pregnant women [23]. Continuous monitoring is required to guarantee that lead levels stay below acceptable limits and to detect possible sources of lead contamination.

4.1.13. Iron

The WHO and NSDWQ permissible iron levels (0.3 mg/l) are not exceeded in all wells. Table A1 highlights that Iron levels range from 0.0002 to 0.024 mg/l in the sampled wells. However, the control point sample has a relatively lower amount of Iron ions than samples close to the dumpsite facility.

4.1.14. Total Coliform and E-Coli Count

Total Coliform bacteria are naturally occurring bacteria utilised as water quality indicators [24]. Their presence in drinking water may suggest pollution from surface water, sewage, or other sources of faecal matter. While not all Total Coliform bacteria are dangerous, their presence may indicate the existence of additional harmful pathogens in the water.

All the water samples exceed the NSDWQ and WHO standards for Total Coliform. Samples A1, A2, B1, and B2 exceed the standards significantly, indicating a potential contamination issue.

E. coli is a bacterium that lives in the intestines of warm-blooded animals, including humans. Its presence in drinking water suggests faecal contamination and the danger of waterborne illness. All samples exceeded the NSDWQ and WHO E. Coli criteria.

The correlation of the physical properties with the distance to the dumpsite is as follows (Table A2):

- **Temperature (-0.94):** Temperature and distance show a high negative connection (-0.94). As the distance from the dumpsite rises, the temperature of the water decreases. The increase in temperature around landfills is mostly caused by the heat created during organic waste decomposition, the formation of heated leachate, and less plant cover, which allows for more solar radiation absorption. Studies have indicated that waste decomposition under anaerobic circumstances may result in significant temperature rises, particularly at shallow levels near the surface, which impacts the surrounding ecosystem [25].

- **pH (-0.80):** Strong negative correlation, indicating that wells nearer to the dumpsite tend to have lower pH levels.
- **Electrical Conductivity (-0.95):** A very strong negative correlation suggests that wells closer to the dumpsite have higher electrical conductivity.
- **Total Dissolved Solids (-0.92):** Strong negative correlation, meaning higher total dissolved solids are found in wells nearer to the dump site.
- **Turbidity (0.71):** Positive correlation, indicating that wells closer to the dumpsite tend to have higher turbidity levels.

The correlation of physical properties with the depth of the well is as follows:

- **H (-0.52):** Moderate negative correlation, meaning deeper wells tend to have lower pH levels.
- **Temperature (-0.74):** Strong negative correlation, indicating that deeper wells tend to be cooler.
- **Turbidity (0.74):** Strong positive correlation, suggesting deeper wells have higher turbidity.
- **Electrical Conductivity (-0.89):** Strong negative correlation, meaning deeper wells tend to have lower electrical conductivity.
- **Total Dissolved Solids (-0.87):** Strong negative correlation, indicating deeper wells usually have lower total dissolved solids.

The correlation of the chemical properties with the distance to the dumpsite is as follows (Table A3):

- **Alkalinity (-0.715):** Strong negative correlation, indicating that the alkalinity decreases as the distance from the dumpsite increases.
- **Total Hardness (-0.908):** A strong negative correlation suggests that wells closer to the dumpsite have higher total hardness.
- **Calcium Hardness (-0.885):** Strong negative correlation, meaning wells nearer to the dumpsite have higher calcium hardness.
- **Chloride (-0.680):** Moderate negative correlation, indicating higher chloride levels in wells closer to the dump site.
- **Nitrate (-0.948):** Very strong negative correlation, showing significantly higher nitrate levels in wells closer to the dump site.
- **Dissolved Oxygen (-0.110):** Very weak negative correlation, indicating almost no relationship between dissolved oxygen and distance from the dump site.
- **Lead (0.173):** Weak positive correlation, suggesting no significant link between lead concentration and distance from the dump site. The weak positive correlation between lead concentration and distance from the dumpsite could be attributed to factors such as localized contamination sources (e.g., leachate hotspots or industrial waste) that disrupt a consistent gradient. Additionally, lead's low mobility in soil due to adsorption onto organic matter or clay particles may result in uneven distribution, weakening the relationship with distance.
- **Iron (-0.788):** Strong negative correlation, indicating that iron levels are higher in wells closer to the dump site.

The correlation of the chemical properties with the depth of the well is as follows (Figure 5):

- **Alkalinity (-0.897):** Strong negative correlation, indicating that as depth increases, alkalinity decreases [26].
- **Total Hardness (-0.829):** Strong negative correlation, suggesting that deeper wells have lower total hardness.
- **Calcium Hardness (-0.840):** Strong negative correlation, meaning deeper wells typically have lower calcium hardness.
- **Chloride (-0.489):** Moderate negative correlation indicates deeper wells have lower chloride levels.
- **Nitrate (-0.695):** Strong negative correlation, meaning deeper wells tend to have lower nitrate levels.
- **Dissolved Oxygen (-0.007):** No significant relationship (correlation around 0) between dissolved oxygen concentration and depth. However, studies have established a direct link between dissolved oxygen concentration and depth [27], [28], [29].
- **Lead (-0.143):** Weak negative correlation, suggesting a slight decrease in lead concentration with increased well depth.
- **Iron (-0.865):** A strong negative correlation indicates deeper wells have lower iron levels.

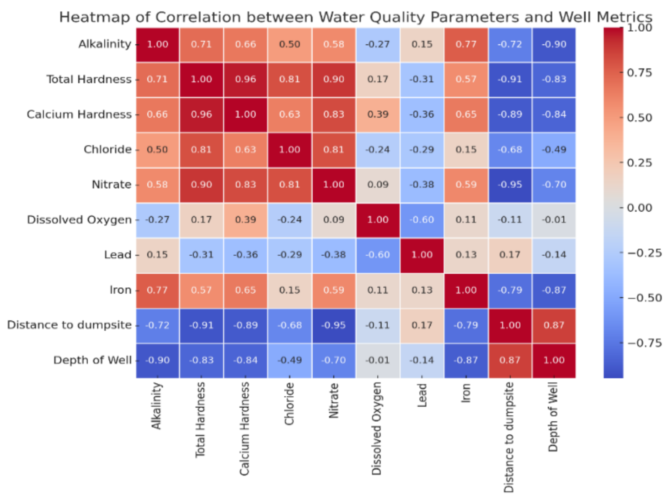

Figure 5. *Heatmap of correlation between water quality parameters and well metrics.*

4.2. Regression analysis

The regression analysis explores the relationships between various factors and groundwater quality. Key variables include the distance to the dumpsite, well depth, and groundwater quality indicators, categorized as physical, chemical, and bacterial. The relationship between the distance to the dumpsite and physical groundwater quality was analyzed. The model summary indicated a strong correlation (R = 0.998) with an R^2 of 0.996, suggesting that 99.6% of the variance in the dependent variable is explained by the model (See Tables B1). The ANOVA results (p = 0.005) confirmed the model's significance, though individual predictors like pH and turbidity showed p-values above the 0.05 threshold, indicating a lack of statistical significance.

The regression results also examined how well depth influences physical groundwater quality. The model demonstrated a robust correlation (R = 0.991) with high explanatory power (R^2 = 0.982). Despite this, the marginal p-value from the ANOVA (p = 0.066) and non-significant predictors suggest that well depth may not significantly impact the physical groundwater quality (See Table B2).

Further analysis assessed the chemical quality of groundwater in relation to the distance to the dumpsite and well depth. The model for dumpsite distance revealed an excellent correlation (R = 0.999) with an R^2 of 0.998 (See Table B3). However, individual predictors like alkalinity and chloride were not statistically significant ($p > 0.05$). Similarly, the regression model for well depth (R = 0.995; R^2 = 0.990) suggested potential significance for some predictors, such as nitrate and alkalinity, but none achieved statistical significance (See Table B4).

The analysis of bacterial groundwater quality revealed distinct trends. For dumpsite distance, the model showed a strong correlation (R = 0.997; R^2 = 0.994), with the ANOVA confirming significance (p = 0.009). Total coliform was identified as a potential predictor (p = 0.055), though not definitively significant (See Table B5). Regarding well depth, the model (R = 0.987; R^2 = 0.975) indicated that predictors, including E. Coli, did not significantly impact the dependent variable ($p > 0.05$).

5. Conclusion

The groundwater quality in the Awotan area has been significantly impacted by the nearby dumpsite. Reduced pH levels (5.7 – 6.95) suggest acidification from leachates, while elevated turbidity indicates the presence of suspended particles, likely originating from pollution sources such as clay, silt, organic waste, and plankton. Samples near the dumpsite showed increased levels of electrical conductivity (2.16 – 26.6μS/cm), total dissolved solids, total hardness, calcium hardness, chloride (69–296 mg/L), and nitrate (2.70 – 4.22 mg/L), further confirming leachate contamination. These pollutants pose serious health risks, including hypertension, kidney problems, methemoglobinemia, and gastrointestinal disorders, and can also lead to environmental issues like soil salinization, which reduces crop yield.

Additionally, trace amounts of lead and iron, along with high total coliform counts (28–92 CFU/100 mL) and E. coli counts (10–45 CFU/100 mL), indicate possible heavy metal and faecal contamination, which are harmful to human health. The bacteriological contamination far exceeds WHO and NSDWQ standards for drinking water, highlighting the risk of waterborne diseases. To strengthen the understanding of groundwater contamination in Awotan, future research could explore the seasonal variations in contamination levels, the long-term health risks posed to the community, and the impact of other potential sources of contamination, such as agricultural runoff.

Groundwater extraction systems, such as hand-dug wells, should only be installed after extensive sanitary examinations and authorized recommendations to avoid contamination. Well lining and cover should be provided for all hand-dug wells to reduce contamination of water from these sources. Immediate efforts should be made to reduce the landfill's influence on groundwater quality. This involves improving waste management techniques at the dumpsite, periodically monitoring groundwater quality, and taking corrective action if contamination is discovered. Regular testing of water sources for lead, nitrates, and other contaminants is critical, especially near the dumpsite. Public education and awareness campaigns should be launched to warn communities about the dangers of lead exposure and how to protect themselves, such as utilizing certified lead-free water filters. Ongoing monitoring is required to verify that trace metal levels in Awotan's groundwater stay within acceptable ranges. This will assist in quickly detecting and resolving any new sources of pollution. Meanwhile, residents should be encouraged to take precautionary measures, such as using alternative water sources or treating water before use, to protect themselves from the potential health risks of contaminated groundwater.

Competing Interest Statement

'The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.'

Data and Materials Accessibility

All data generated or analysed during this study are included in this article.

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References

[1] A. Tariq and A. Mushtaq, “Untreated wastewater reasons and causes: A review of most affected areas and cities,” *Int. J. Chem. Biochem. Sci*, vol. 23, pp. 121–143, 2023.

[2] Ap. Aizebeokhai, “Potential impacts of climate change and variability on groundwater resources in Nigeria,” *African Journal of Environmental Science and Technology*, vol. 5, no. 10, pp. 760–768, 2011.

[3] P. Kumar, M. Kumar, A. L. Ramanathan, and M. Tsujimura, “Tracing the factors responsible for arsenic enrichment in groundwater of the middle Gangetic Plain, India: a source identification perspective,” *Environmental geochemistry and health*, vol. 32, pp. 129–146, 2010.

[4] C. G. Achi, A. M. Omoniyi, A. O. Coker, and M. K. C. Sridhar, “Multivariate analysis of sediment quality in River Ogbere, Ibadan, South-West Nigeria,” *H2Open Journal*, vol. 4, no. 1, pp. 1–11, 2021.

[5] S. B. Adeloju, S. Khan, and A. F. Patti, “Arsenic contamination of groundwater and its implications for drinking water quality and human health in under-developed countries and remote communities—a review,” *Applied Sciences*, vol. 11, no. 4, p. 1926, 2021.

[6] A. Arukwe, T. Eggen, and M. Möder, “Solid waste deposits as a significant source of contaminants of emerging concern to the aquatic and terrestrial environments—A developing country case study from Owerri, Nigeria,” *Science of the Total Environment*, vol. 438, pp. 94–102, 2012.

[7] L. A. Adeniyi, T. M. Adebara, and G. J. Oladehinde, “Evaluation of implications of changing land-use pattern on solid waste disposal practices in traditional city in Nigeria,” *International Journal of Environmental Science and Technology*, vol. 19, no. 12, pp. 12119–12130, 2022.

[8] A. Ikem, O. Osibanjo, M. K. C. Sridhar, and A. Sobande, “Evaluation of groundwater quality characteristics near two waste sites in Ibadan and Lagos, Nigeria,” *Water, Air, and Soil Pollution*, vol. 140, pp. 307–333, 2002.

[9] A. Siddiqua, J. N. Hahladakis, and W. A. K. Al-Attiya, “An overview of the environmental pollution and health effects associated with waste landfilling and open dumping,” *Environmental Science and Pollution Research*, vol. 29, no. 39, pp. 58514–58536, 2022.

[10] M. Pazoki and R. Ghasemzadeh, *Municipal landfill leachate management*. Springer, 2020.

[11] F. P. Sankoh, X. Yan, and Q. Tran, “Environmental and health impact of solid waste disposal in developing cities: a case study of granville brook dumpsite, Freetown, Sierra Leone,” *Journal of Environmental Protection*, vol. 2013, 2013.

[12] L. A. Guerrero, G. Maas, and W. Hogland, “Solid waste management challenges for cities in developing countries,” *Waste management*, vol. 33, no. 1, pp. 220–232, 2013.

[13] M. M. Abd El-Salam and G. I. Abu-Zuid, "Impact of landfill leachate on the groundwater quality: A case study in Egypt," *Journal of advanced research*, vol. 6, no. 4, pp. 579–586, 2015.

[14] T. K. Boateng, F. Opoku, and O. Akoto, "Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi," *Applied water science*, vol. 9, no. 2, p. 33, 2019.

[15] M. O. Adedinni *et al.*, "Geophysical and geochemical study of the contaminant impact of Oke-Tage solid waste dumpsite, Southwestern Nigeria," *Scientific Reports*, vol. 13, no. 1, p. 4704, 2023.

[16] O. M. Akanji Ao, "Groundwater Exploration in Alakuta-Awotan area of Ibadan, Southwestern Nigeria," *J Geol Geosci*, vol. 02, no. 03, 2013, doi: 10.4172/2329-6755.1000124.

[17] P. Ogunseiju, R. F. Ajayi, and V. O. Olanrewaju, "Trace metals and hydraulic characterization of soils and groundwater around Ajakanga dumpsite in Ibadan metropolis, Southwest Nigeria," *J Environ Earth Sci*, vol. 5, no. 22, pp. 75–94, 2015.

[18] E. W. Rice, L. Bridgewater, and A. P. H. Association, *Standard methods for the examination of water and wastewater*, vol. 10. American public health association Washington, DC, 2012.

[19] R. Bhateria and D. Jain, "Water quality assessment of lake water: a review," *Sustainable water resources management*, vol. 2, pp. 161–173, 2016.

[20] O. A. Mokuolu, S. O. Jacob, and A. M. Ayanshola, "Groundwater quality assessment near a Nigerian dumpsite," *Ethiopian Journal of Environmental Studies and Management*, vol. 10, no. 5, pp. 588–596, 2017.

[21] N. A. Ojo-Awo, H. I. Agbabiaka, and A. O. Ilesanmi, "Refuse dumpsite and its associated pollutants: Spatial variations of the impact of leachates on groundwater quality," *Management of Environmental Quality: An International Journal*, vol. 29, no. 3, pp. 572–591, 2018.

[22] E. Abascal, L. Gómez-Coma, I. Ortiz, and A. Ortiz, "Global diagnosis of nitrate pollution in groundwater and review of removal technologies," *Science of the total environment*, vol. 810, p. 152233, 2022.

[23] A. C. Olufemi, A. Mji, and M. S. Mukhola, "Potential health risks of lead exposure from early life through later life: implications for public health education," *International journal of environmental research and public health*, vol. 19, no. 23, p. 16006, 2022.

[24] X. Wen *et al.*, "Microbial indicators and their use for monitoring drinking water quality—A review," *Sustainability*, vol. 12, no. 6, p. 2249, 2020.

[25] N. Yeşiller, J. L. Hanson, and H. Yoshida, "Landfill temperatures under variable decomposition conditions," in *Geo-Frontiers 2011: Advances in Geotechnical Engineering*, 2011, pp. 1055–1065.

[26] N. S. Rao, R. Das, H. K. Sahoo, and S. Gugulothu, "Hydrochemical characterization and water quality perspectives for groundwater management for urban development," *Groundwater for Sustainable Development*, vol. 24, p. 101071, 2024.

[27] A. Akkoyunlu, H. Altun, and H. K. Cigizoglu, "Depth-integrated estimation of dissolved oxygen in a lake," *Journal of Environmental Engineering*, vol. 137, no. 10, pp. 961–967, 2011.

[28] A.-M. Mavropoulou, V. Vervatis, and S. Sofianos, "Dissolved oxygen variability in the Mediterranean Sea," *Journal of Marine Systems*, vol. 208, p. 103348, 2020.

[29] W. S. Moore *et al.*, "SGD-OD: investigating the potential oxygen demand of submarine groundwater discharge in coastal systems," *Scientific Reports*, vol. 14, no. 1, p. 9249, 2024.

Appendix A

Table A1. Field and laboratory analysis results of the water samples carried out at the Department of Environmental Health Science, University College Hospital.

Parameters	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**	**CP**
Physical Properties							
pH	6.49	6.52	6.05	6.75	5.71	5.81	6.95
Temperature(ºC)	28.3	28.2	28.1	28.2	28.0	28.0	28.0
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Turbidity (NTU)	4.25	2.69	5.10	4.03	5.33	4.92	4.98
Electrical Conductivity(µs/cm)	26.6	23.1	17.16	8.59	2.61	3.15	2.16
Total Dissolved Solids(mg/l)	1050	810	670	270	141	120	100
Chemical Properties							
Alkalinity (mg/l)	135	184	96	48	52	88.4	88
Total Hardness (mg/ $CaCO_3$)	364	379	335	220	180	92	100
Calcium Hardness (mg/ $CaCO_3$)	123	140	108	95	85	43	40
Chloride(mg/l)	296	211	378	109	44	69	10
Nitrate (as mg/l NO_3)	4.22	4.01	3.95	3.74	2.58	2.70	20
Dissolved Oxygen(mg/l)	3.95	5.38	4.28	6.52	6.04	2.62	6.65
Lead (pb) (mg/l)	0.003	0.001	0.000	0.000	0.002	0.003	0.0003
Iron (Fe) (mg/l)	0.021	0.024	0.011	0.017	0.012	0.014	0.0002
Bacteriological Analysis							
Total Coliform (MPN/100ml)	623	1100	1600	1100	<2400	<2400	200
E. Coli (MPN/100ml)	269	464	652	513	1600	961	100
OTHER PARAMETERS							
Distance to dumpsite (m)	24.3	37.7	88.4	86.2	154	156	1246
Depth of Well (m)	5.92	5.80	6.70	6.84	6.81	6.95	N/A
Covered	Yes	Yes	Yes	Yes	Yes	Yes	
Lining	Unlined	Unlined	Unlined	Unlined	Unlined	Unlined	

Table A2. Correlation Analysis of the physical groundwater quality.

S/N	Parameters	pH	Temperature	Turbidity	Electrical conductivity	Total dissolved solids	Distance to dumpsite
1	pH						
2	Temperature	0.88					
3	Turbidity	-0.75	-0.64				
4	Electrical conductivity	0.59	0.83	-0.59			
5	Total dissolved solids	0.52	0.80	-0.49	0.99		
6	Distance to dumpsite	-0.80	-0.94	0.71	-0.95	-0.92	
7	Depth of well	-0.52	-0.74	0.74	-0.89	-0.87	0.87

Table A3. Correlation Analysis of the chemical groundwater quality.

Parameters	Alkalinity	Total hardness	Calcium hardness	Chloride	Nitrate	Dissolved Oxygen	Lead	Iron	Distance to dumpsite
Alkalinity									
Total hardness	0.707								
Calcium hardness	0.661	0.961							
Chloride	0.501	0.814	0.631						
Nitrate	0.582	0.895	0.826	0.810					
Dissolved Oxygen	-0.272	0.166	0.394	-0.238	0.090				
Lead	0.148	-0.311	-0.357	-0.289	-0.382	-0.600			
Iron	0.767	0.572	0.651	0.150	0.591	0.109	0.126		
Distance to dumpsite	-0.715	-0.908	-0.885	-0.680	-0.948	-0.110	0.173	-0.788	
Depth of well	-0.897	-0.829	-0.840	-0.489	-0.695	-0.007	-0.143	-0.865	0.869

Appendix B

Table B1. Regression analysis for hypothesis one.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.998	0.996	0.986	5.169	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	24863.230	5	4972.646	185.77	0.005
Residual	133.854	1	133.854		
Total	24997.084	6			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	2052.344		4.129	0.151
	pH	-394.563	-0.508	-6.017	0.105
	Temperature	49.379	0.391	3.910	0.159
	Turbidity	50.175	0.227	2.717	0.226
	Electrical Conductivity	6.287	0.262	2.715	0.226
	Total Dissolved Solids	-2.474	-1.474	-3.370	0.183

Table B2. Regression analysis for hypothesis two.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.991	0.982	0.930	0.0918	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	1.275	5	0.255	30.32	0.066
Residual	0.008	1	0.008		
Total	1.283	6			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	6.661		7.429	0.085
	pH	-0.033	-0.207	-0.557	0.674
	Temperature	0.022	0.285	0.965	0.519
	Turbidity	0.005	0.048	0.142	0.905
	Electrical Conductivity	0.008	0.749	2.197	0.269
	Total Dissolved Solids	-0.001	-0.503	-0.859	0.551

Table B3. Regression analysis for hypothesis three.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.999	0.998	0.986	5.654	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	24885.447	8	3110.681	97.34	0.066
Residual	111.637	1	111.637		
Total	24997.084	9			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	551.352		1.407	0.392
	Alkalinity	-0.523	-0.315	-1.063	0.484
	Total Hardness	0.486	0.391	0.968	0.512
	Calcium Hardness	0.499	0.081	0.292	0.828
	Chloride	0.103	0.267	1.123	0.468
	Nitrate	-15.463	-0.353	-1.692	0.338
	Dissolved Oxygen	-8.471	-0.189	-1.050	0.489
	Lead	2349.858	0.192	1.127	0.467
	Iron	-506.939	-0.103	-0.474	0.719

Table B4. Regression analysis for hypothesis four.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.995	0.990	0.951	0.0598	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	1.298	8	0.162	45.37	0.086
Residual	0.003	1	0.003		
Total	1.301	9			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	5.424		29.014	0.022
	Alkalinity	0.005	0.583	6.306	0.100
	Total Hardness	-0.003	-0.651	-7.479	0.085
	Calcium Hardness	0.005	0.117	2.625	0.233
	Chloride	-0.002	-0.769	-10.640	0.060
	Nitrate	0.211	0.946	11.972	0.053
	Dissolved Oxygen	-0.102	-0.822	-6.029	0.105
	Lead	-30.312	-0.947	-8.620	0.073
	Iron	4.185	0.758	3.654	0.170

Table B5. Regression analysis for hypothesis five.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.997	0.994	0.986	8.786	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	16911.88	2	8455.94	109.39	0.009
Residual	231.95	3	77.32		
Total	17143.83	5			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	-45.379		-1.185	0.318
	Total Coliform	0.043	0.703	3.119	0.055
	E. Coli	0.059	0.411	1.761	0.180

Table B6. Regression analysis for hypothesis six.

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate R	
1	0.989	0.978	0.956	0.0528	
ANOVA					
Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	0.881	2	0.4405	15.82	0.060
Residual	0.019	3	0.0063		
Total	0.900	5			
Coefficient					
Model		Unstandardized Coefficients B	Standardized Coefficients	t	Sig.
1	(Constant)	5.724		15.681	0.001
	Total Coliform	0.00030	0.863	3.046	0.056
	E. Coli	0.00019	0.282	0.713	0.529