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*Original Paper*

# Effects of Household Waste Disposal on Surface and Ground Waters in the Rapidly Urbanising Mamfe Town (South-West Region, Cameroon)

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***Abstract***

*Huge waste generation by the rapidly growing Mamfe town is posing enormous environmental challenges. This work that aimed at examining the implications of household waste on potable water sources, used the mixed research design, combining descriptive and experimental approaches. Ground (Two wells, one borehole) and surface (two streams) sources were sampled and empirical data for physicochemical parameters (PH, EC, water temperature, TDS, and salinity) of the five water samples were measured in-situ using a multi-meter and complemented by questionnaires and interviews information. Data obtained were analysed using the One-way ANOVA and chi-square tests. Except for the pH, values of 11 of the 12 physical and chemical elements (Temperature, EC, TDS, pH, Ca~~3~~$^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^{-}$, $Cl^{-}$, $NO_3^{-}$) were within permissible limits of WHO drinking water standard. Hierarchical cluster analysis revealed two clusters: EC and TDS; and temperature (℃), pH, $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^{-}$, $Cl^{-}$, $NO_3^{-}$, and salinity. Spearman correlation analysis for minor parameters as Temperature, EC, TDS and $Cl^{-}$ and major parameters of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$ and $HCO_3$, reveals a strong positive correlation between $HCO_3^{-}$ and $Ca^{2+}$, temperature and $NO_3^{-}$. Therefore, municipal authorities are entreated to implement sustainable waste and water management strategies.*

***Keywords***

*household waste disposal, practices, surface water, groundwater, water quality, Mamfe Town*

## 1. Introduction

Development in the 20th Century has changed rural communities to urban centres that today face a lot of environmental challenges. Such environmental issues are being addressed at global, regional and local levels. The most current environmental issue is disposal of waste from domestic, commercial and industrial sources. The production of waste remains a major source of concern today as it has been since prehistoric times (Chandler *et al.*, 1997). A substantial increase in the volume of waste generated started in the sixteenth century when people began to move from rural areas to cities due to the industrial revolution (Wilson, 2007). This migration of people to cities led to population explosion that in turn led to a surge in the volume and variety in the composition of waste they generated. It was then that materials such as metals and glass began to appear in large quantities in municipal waste streams (Williams *et al.*, 2001). In most Developing Countries, municipal solid waste (MSW) disposal has been a chronic problem, particularly in areas with high population densities and high refuse production. Scarcity of land for landfills often gives rise to indiscriminate dumping of refuse in surface water bodies and improper landfill systems. Open dumps have been highlighted by many workers to pose serious threats to groundwater and surface water resources (Slomczynka, 2004). The degree of threat is strongly influenced by the composition of the waste in the landfill, the volume of leachates generated as well as the location of the landfill from water bodies such as groundwater and surface water (Slomczynka, 2004). This in turn has led to pollution of surface and groundwater causing over 20% of the world population not to access safe drinking water. In Port Harcourt, River State Nigeria, a slaughter area is surrounded by water bodies and is the hub for major commercial and industrial activities. These water bodies have become sites for indiscriminate waste disposal for the commercial activities as well as effluents from the industries within and around the slaughter houses. Mamfe (Figure 1) is the chief town of Manyu Division, one of the oldest divisions of modern Cameroon.

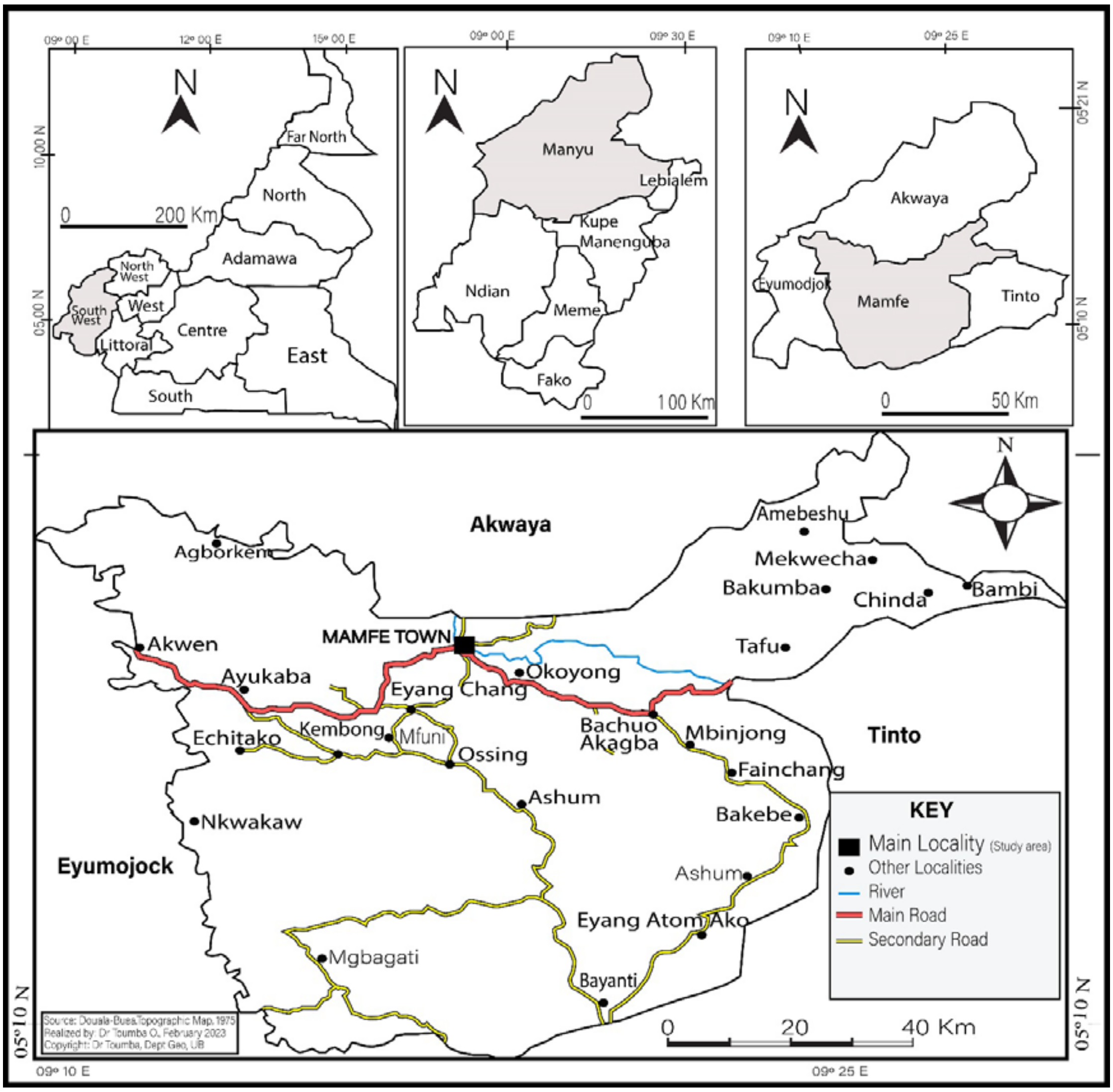


**Figure 1. Location of Mamfe Town**

*Source*: National Institute of Cartography Cameroon geodata base modified by Cosmos (2020).

It is an important hub of agricultural and commercial activities which are categorised as great waste generating endeavours. Since the year 2010, human population has burgeoned, due to influx of people from surrounding villages of Mamfe Central, Eyumojock; Upper Bayang and Akwaya subdivisions; neighbouring areas of the Northwest (Bali, Batibo, & Widikum) as well as Nigerians (Ibos) for business. This has contributed to increased waste disposal into some of the surface water bodies such as "john-hold" River, Baku stream, and others small streams running in Lala Quarter. The absence of trash bins, the HYSACAM Company, as well as a landfill for waste dumping, most of the household, and agricultural wastes end up in streams and open wells.

Poor management of waste water in the city of Mamfe is due to uncontrolled urbanisation. As a matter of fact, the use of streams as open dumps as well as drains and soak-ways for septic tanks such as in Baku and John-hold River, is a current practice which leads to surface and groundwater pollution in these quarters of the town. This waste management challenge and linked water consequences are compounded by the fact that the rapid urbanisation of Mamfe municipality is not accompanied by a Water Supply Board to cater for quality assurance of water and ensure its treatment and safe distribution This has raised the concerns about water quality and since most people rely predominantly on these wells, streams and river sources for water supply, the risks associated with polluted water sources is even higher. It is necessary to determine the water quality content of these water sources so as to ascertain their suitability for domestic use.

Environmental quality and antipollution legislation are the most widely used interventions to control and reduce environmental pollution (Agarwal, 2005). In most countries, environmental laws have been enacted by the government and enforced through its administrative structures. This is not the practice in Mamfe.

## 2. Method

### *2.1 Selection of Sample Sites*

A total of five points-for the water sample-comprising three wells and two streams-were selected using the systematic sampling technique because of its ease. The streams were chosen because they were the regular domestic water source. The wells were chosen because they were located at the nucleated areas of the town and where most people depend solely on this ground water source for their daily use. The choice of the sampling points was also guided by the proximity to the inhabitants and surface dumpsites. For the streams, water samples were collected from up and down stream points at an average depth of 30 cm. Water samples were collected in plastic bottles. From these samples, information was obtained for physiochemical properties of water as pH range, electrical conductivity (EC) temperature ranges, and the presence of bacterial, water hardness (magnesium - $Mg^{2+}$ and calcium $Ca^{2+}$), turbidity (total dissolved solids –TDS), nitrates and colour of the water.

### *2.2 Data Sources and Collection Techniques*

Primary data were obtained through empirical measurements with standard instruments and research tools of questionnaires and interview guides.

Data on some water quality parameters were obtained directly in the field through empirical procedures of onsite measurements through instruments like:

- The pH meter that to determine the acid-base content of the water,
- The conductivity meter to test the presence of inorganic pollutants such as lead, magnesium and calcium content in the water.

- Strips graduated with nitrite/nitrate readings used to indicate the presence of nitrite/nitrate in the water.
- Strips aligned with bacterial like E-coli readings tested the presence of bacterial in the water introduce by animals and human excreta.
- Colour graduated strips to assess the colour of the water.

Through field observation data were obtained on the different types of waste disposed in streams, wells and on the dumpsites.

Questionnaires were administered to 50 respondents and interviews conducted with municipal authorities to obtain information on the challenges they face in the proper control of waste.

Secondary data were obtained from the "Cameroonaise Des Eaux" (CDE) Water Company centre in Mamfe and the Water Quality Laboratory Centre in Yaounde to confirm and compare the analyses taken from the field.

*2.3 Data Analysis Techniques*

A reference chart was used to compare water sample strip readings of pH, electrical conductivity, colour, inorganic contaminants, turbidity and hardness of the water ($Ca^{2+}$ and $Mg^{2+}$ levels), and nitrites ($NO_2$)/nitrate ($NO_3$) with the standard values.

Data collected from field observations and interviews on the different types of waste disposed into wells and unto surface water and challenges faced in the control of waste were processed to obtain summaries of the views and supported from documentary sources.

The spearman correlation matrix of was used to establish the relationships between values of major and minor elements obtained from water quality analysis.

Correlation analysis of major and minor element characteristics of water samples, which can reveal the sources and pathways of major and minor elements that generated the observed water compositions.

The R-mode Hierarchical Cluster Analysis (HCA) was done on water quality data obtained so as establish points of clusters of similarities and dissimilarities.

## 3. Result

*3.1 The Categories of Waste Disposed on Surface Water*

It is found that there is a waste dumpsite in Mamfe Central with deferent types of waste disposed. This waste originates from households and commercial places such as markets and shops. Waste characterisation can be expressed in several forms. Some commons characteristics used in the classification of waste include the physical state, physical properties, source of production and the degree of environmental impact (Dixon & Jones, 2005) as shown on Table 1.

**Table 1. Classification of Types of Waste**

| Physical state | Source | Environmental impact |
|---|---|---|
| • **Solid waste** | Household waste | Hazardous |
| • **Liquid waste** | Agricultural waste | Non-hazardous |
| | Commercial waste | |

*Source*: Fieldwork, 2022.

Waste originated therefore from households, agricultural, commercial and industrial activities in the town of Mamfe. These wastes were established to be in both the liquid and solid categories as well as found to be non-hazardous and hazardous. It was observed that these wastes were dumped haphazardly on the land and water sources both surface and ground. This very action makes waste to stand out as a great negative impacting factor on the environment through water pollution, and soil degradation. Table 2 reveals the views of respondents on the typology of waste generated in Mamfe Town and their predominant dumping sites.

**Table 2. Typology of Waste Generated in Mamfe Town**

| SN | Categories of Waste | Frequency | Percentage |
|---|---|---|---|
| **1** | Solid waste | 25 | 50 |
| **2** | Organic waste | 15 | 30 |
| **3** | Liquid waste | 10 | 20 |
| **Total** | | **50** | **100** |

*Source*: Fieldwork, 2022.

It is deciphered from the table that 20% of respondents identified liquid waste as the category of waste disposed on surface water in Mamfe, while 50% talked of solid waste and 30% underscored but organic waste. These views lead to the conclusion that solid rubbish waste is the most dominant waste disposed on surface water in Mamfe municipality.

It was established that there are few proper landfills for waste. This has coerced the people to dump their waste haphazardly at nonconventional sites as shown on Table 3.

**Table 3. Waste Disposal Sites**

| SN | Disposal Site | Frequency | Percentage |
|---|---|---|---|
| **1** | On surface water | 17 | 34 |
| **2** | Waste dump site | 16 | 32 |
| **3** | Adjacent to well | 7 | 14 |
| **4** | On street | 10 | 20 |
| **Total** | | **50** | **100** |

*Source*: Fieldwork, 2023.

This reveals that the most common waste disposal points are out of the conventional waste dumpsite. Water sources both surface (streams) and ground (well) combined are the dominant waste dumps.

*3.2 Effect of Household Waste on Surface and Groundwater*

It was established from the field that Mamfe has several sources of water for drinking and other household activities. The respondents gave main water sources as boreholes (36%), followed by springs and streams (32%), and wells (20%). Commercialised water sources as pipe borne (8%) and bottled mineral water (4%), were considered very limited sources by the respondents.

Field observations revealed that water from most streams (surface water source) had taste and brown colour. Despite these visible water characteristics, 40% of the 50 respondents sampled, still posited that water from both the underground and surface water sources is good for consumption. The remaining 60% rather held that water from these sources was unsafe for consumption. This finding lends credence to a conclusion that water is significantly not good for consumption in the Town of Mamfe. This is more so as up to 70% of the respondents asserted that there are negative effects of household waste on surface and groundwater, with only 30% of the respondents stating the contrary. The different effects of waste disposal on water raised by the respondents is shown on Table 4.

**Table 4. Effects of Household Waste on Ground and Surface Water**

| SN | Effect of waste | Frequency | Percentage |
|---|---|---|---|
| **1** | Water Pollution | 22 | 44 |
| **2** | Water Borne diseases | 16 | 32 |
| **3** | Water scarcity | 7 | 14 |
| **4** | Blockage of streams | 5 | 10 |
| **Total** | | **50** | **100** |

*Source*: Fieldwork, 2023.

The table reveals the respondents saw the greatest effects being pollution of water sources (44%) both surface and ground, followed by water borne diseases (32%), and then water scarcity (14%). Some 10% of the respondents saw the effects going beyond water directly to blockage of stream channels. More importantly, the 20% using wells consume water from phreatic aquifers that lie in zones of saturation below the water table in which all pores and fractures are saturated with water and are in contact with the atmosphere. Since they are in contact with the atmosphere, it means they are shallow aquifers and can easily be contaminated by leachates and other surface effluents and solid waste haphazardly dumped.

This pollution of water sources has induced water stress in Mamfe town as attested by 54% of the respondents that pointed out that pollution was the cause of the unreliability of potable water supply. Up to 46% of the respondents however still held that the problem of water supply in Mamfe Town is not linked to pollution stemming from poor waste disposal. With a significant proportion of the respondents rejecting a likely water pollution thesis as an explanation for water problems in Mamfe Town, water quality analysis was done to assess the main physicochemical properties of water and draw a more reliable conclusion on the pollution of the water sources.

*3.3 Field Physicochemical Parameters*

Data of the physicochemical parameters of water in the different parts of Mamfe tested using the recording multi-meter are presented on Table 5.

**Table 5. Sample Sites and Field Measurements**

| Sample | Temperature | pH | Salinity | TDS | EC |
|---|---|---|---|---|---|
| Badi River Upstream | 27.3 | 6.35 | 0 | 11 | 22 |
| Badi Rivers Downstream | 26.4 | 6.21 | 0 | 9 | 19 |
| Baku Stream Upstream | 26.7 | 5.8 | 0 | 44 | 85 |
| Baku Stream Downstream | 26.5 | 5.92 | 0 | 41 | 84 |
| Gari Quarter | 27.2 | 5.41 | 0.02 | 201 | 404 |
| Banso Quarter | 27.3 | 5.16 | 0 | 88 | 188 |
| New Layout Quarter | 26.9 | 5.13 | 0.01 | 130 | 260 |
| **Min** | **26.4** | **5.13** | **0** | **9** | **19** |
| **Max** | **27.3** | **6.35** | **0.02** | **201** | **404** |
| **Mean** | **26.90** | **5.71** | **0.00** | **74.86** | **151.71** |
| **Stdv** | **0.38** | **0.49** | **0.01** | **70.28** | **141.52** |

**Upstream (US) and Downstream (DS)**

*Source*: Fieldwork, 2022.

These results indicate spatial variations in the physical parameters of surface and ground water sources measured. A parameter by parameter discussion of the results follows.

3.3.1 Water Temperature Analysis

Temperature is the physical property of water that quantitatively expresses how hot or cold water is. It is the manifestation of thermal energy presence in all water. The recorded temperature of the various sources is presented on Figure 2.

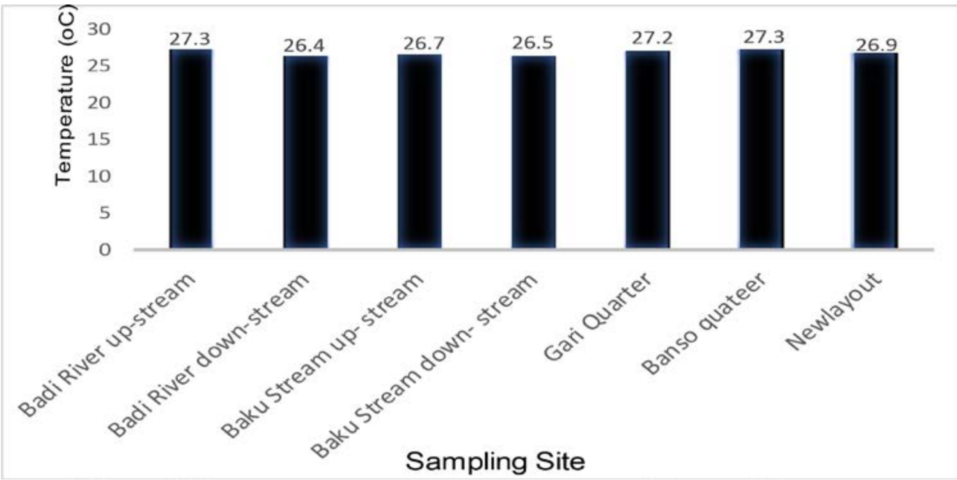


**Figure 2. Water Temperature Sampled on the Field**

*Source*: Fieldwork, 2022

The Figure reveals that there is spatial variation in the temperature of water points sampled. The ground water temperature in the study points range from 26.9℃ – 27.3 ℃ while for surface water, temperature ranges from 26.4℃ – 27.3℃. Specifically, temperature of ground water points was highest at Banso Quarter with 27.3℃, followed by Garri Quarter with 27.2 ℃ with the New-layout source having the lowest temperature with 26.9 ℃.

For surface water samples, Badi Upstream recorded the highest temperature of 27.3℃, followed by Baku Upstream and Downstream respectively with temperatures 26.7℃, and 26.5 ℃, whereas Banso Quarter and Badi Downstream with 26.4℃ recorded the lowest surface temperature. A closer look at the temperature values reveal that just as in most water bodies there are only slight variations in surface and groundwater temperatures at the various points.

3.3.2 pH

The pH is the measure of the degree of acidity (acidic) or alkalinity (basic) of water. The pH scale ranges from 0-14 with 7 being neutral. The pH value of a water sample is recognized as an index of classifying water into acidic < 5.5, slightly acidic 5.5 - 6.5, neutral 6.5 - 7.5, slightly alkaline 7.5 - 8, moderately alkaline 8 - 9 and alkaline > 9. The pH values of the various sources are presented on Figure 3.

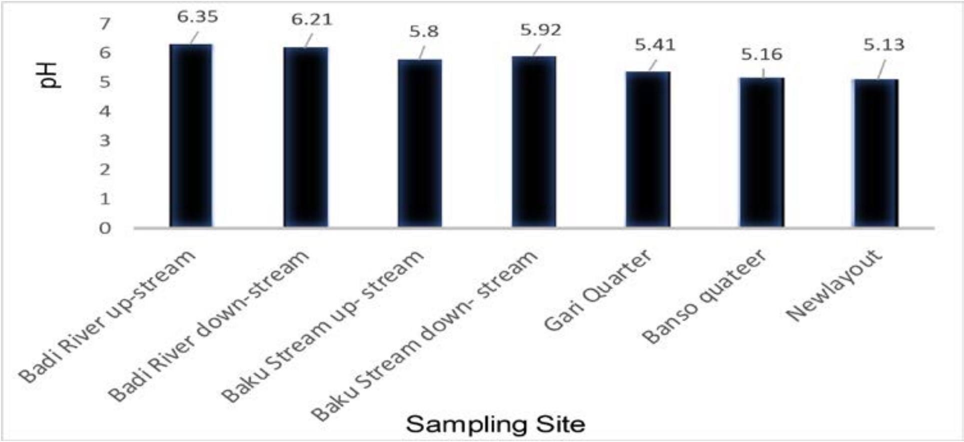


**Figure 3. The pH Values of Sampled Water Points on the Field**

*Source*: Fieldwork, 2022

It is deciphered from Figure 3 that the values of pH range from 5.13 – 6.35. It is established that all surface water sampled points on the streams were slightly acidic with the pH values for Badi Upstream being 6.35 and Downstream 6.21, while for Baku Upstream it is 5.8 and Downstream it is-5.92. On the other hand, all the ground water sampled points were acidic with the well at Gari Quarter having a pH of 5.41, and that at Banso Quarter, 5.16 and New-layout 5.13.

Drawing from these values the most frequently used water sources in Mamfe Town are acidic since all have pH values less than 6.5. This high acidity of water is connected to high concentration of $H^+$ (hydrogen ions) in water resulting from soil composition and leachates from domestic waste disposed into surface and ground water. This indicates a likelihood of high level of water pollution and may contribute to adverse health effects with diseases like diarrhoea and vomiting being common place especially among children who regularly consume the water.

3.3.3 Electrical conductivity (EC)

Electrical conductivity of water is ability of water to conduct electric current. Salt and other chemicals that dissolve in water can breakdown into negatively and positively charged ions. Salinity and total dissolved solid (TDS) are used to calculate the EC of water which is an indicator of water purity and the level of concentration of dissolved salts in water. The measured EC values for the different water points are shown on Figure 4.

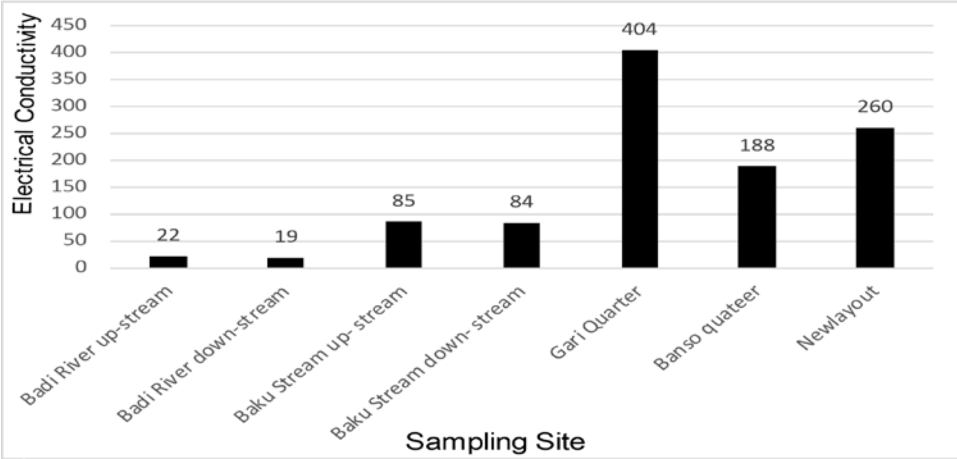


**Figure 4. Electrical Conductivity (EC µs/cm) of the Water**

*Source*: Fieldwork, 2022

The Figure show that EC ranges from 19 - 404µS/cm in the study area. The ground water point at Gari Quarter had the highest conductivity with an EC value of 404µs /cm, followed in descending degree of EC by that at New Layout with an EC of 260µs/cm, Banso Quarter (188µs/cm), Baku Upstream (85µs/cm) and Downstream (84µs/cm) meanwhile the surface source of Badi Stream had the lowest values with Badi Upstream recording 22µs/cm and Downstream 19µs/cm as the lowest of all seven samples. It is concluded from these values that the ground water sources had more EC than the surface sources. However, all sources had EC values within the permissible limits. The high electrical conductivity is due to high solute concentration in the water (Akoachere *et al.*, 2019). In the present study EC values were in the permissible limits.

3.3.4 Salinity

Salinity is a measure of the concentration of dissolve salt in water. Salinity is measured indirectly by testing the electrical conductivity (EC) of the water and so the two are closely connected. Salt water conducts more electricity than water with no salt. Common inorganic salts that can be present in water include, cations as calcium, magnesium, potassium and sodium and anions as carbonate, nitrate, bicarbonate, chloride and sulphate. The normal water salinity should range from 0-0.001%. The measured salinity of the water samples is shown on Figure 5.

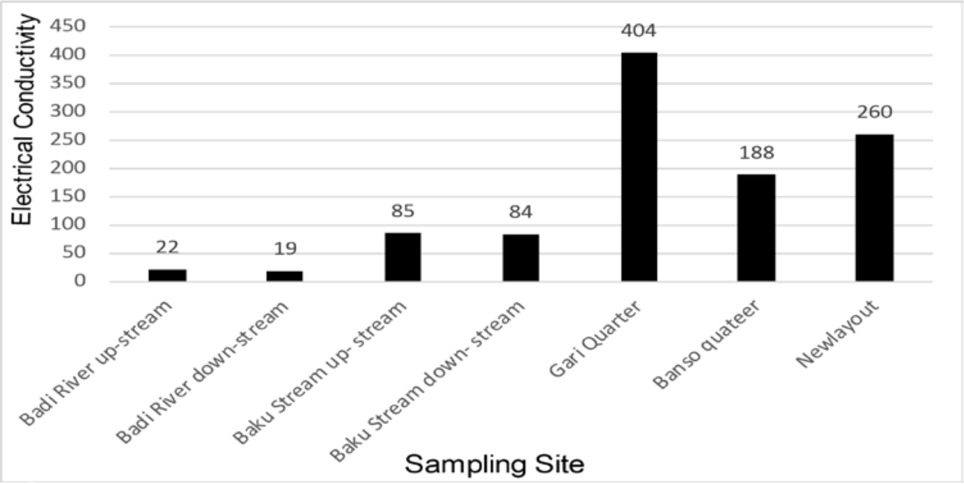


**Figure 5. The Salinity of the Water Sample**

*Source*: Fieldwork, 2022

The ground source at Gari Quarter recorded a high salinity value of 0.02%, followed by that at New Layout with 0.01%. Contrarily the ground water source at Banso Quarter as well as all surface water sources as the Badi and Baku Streams were noted to be salt free as their salinity values recorded were 0%. The low salinity is due to low solute concentration in the water. Areas with high salinity may not be good potable water sources since high salinity in water can cause health problems like cholera and skin diseases.

3.3.5 Total Dissolved Solids (TDS)

Total dissolve solid represents the total concentration of particulate matter in water. Those measured in the water samples are presented on Figure 6.

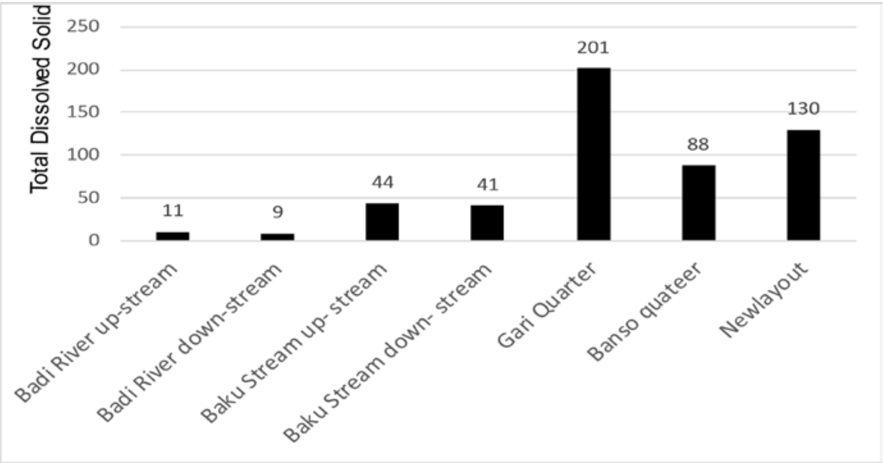


**Figure 6. Total Dissolve Solids of the Water Sample**

Source: Fieldwork, 2022

The total dissolved solids range from 9-201 mg/L. In descending order of magnitude, high TDS values were recorded in Gari Quarter (201mg/L), New Layout (130mg/L) Banso Quarter (88mg/L), Baku Upstream (44mg/L) and Downstream (41mg/L). Conversely, very low TDS were in the samples at Badi Upstream (11mg/ L) and Downstream (9mg/L). The higher TDS values at Garri Quarter and New Layout are due to high solute concentration in the water linked to intense domestic activities in the area that have enhanced inorganic liquid waste seeping into groundwater sources.

3.3.6 Correlation analysis of the measured physicochemical properties

To expose more about the isolated treated physical elements of the sampled water, correlation and cluster analyses of the measured values were done.

3.3.6.1 Spearman Correlation Matrix of Major and Minor Elements

Correlation analysis establishes the relationships between major and minor element characteristics of water samples, which can reveal the sources and pathways of major and minor elements that generated the observed water compositions. The correlation matrix for major and minor elements for the sampled water sources is shown on Table 6.

**Table 6. Correlation Matrix Analysis for Measured Physicochemical Parameters**

| | $K^+$ | $Na^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $HCO^{3-}$ | $Cl^-$ | $NO^{3-}$ | T(ºC) | pH | EC | TDS | Salinity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$K^+$** | 1 | | | | | | | | | | | |
| **$Na^+$** | 0.459 | 1 | | | | | | | | | | |
| **$Ca^{2+}$** | 0.598 | $0.899^{++}$ | 1 | | | | | | | | | |
| **$Mg^{2+}$** | $0.998^{++}$ | 0.438 | 0.558 | 1 | | | | | | | | |
| **$HCO^{3-}$** | $0.907^{+}$ | 0.709 | $0.872^{+}$ | $0.884^{+}$ | 1 | | | | | | | |
| **$Cl^-$** | $-0.769^{+}$ | -0.434 | $-0.761^{+}$ | -0.732 | $-0.893^{+}$ | 1 | | | | | | |
| **$NO^{3-}$** | $-0.232^{+}$ | 0.059 | 0.077 | -0.246 | -0.072 | -0.023 | 1 | | | | | |
| **T(ºC)** | 0.260 | 0.466 | 0.553 | 0.238 | 0.473 | -0.492 | $0.837^{+}$ | 1 | | | | |
| **pH** | $-0.870^{+}$ | -0.496 | $-0.775^{+}$ | $-0.841^{+}$ | $-0.947^{++}$ | $0.971^{++}$ | 0.155 | -0.365 | 1 | | | |
| **EC** | 0.491 | 0.113 | 0.528 | 0.446 | 0.619 | $-0.875^{++}$ | 0.174 | 0.451 | $-0.788^{+}$ | 1 | | |
| **TDS** | 0.481 | 0.082 | 0.502 | 0.437 | 0.601 | $-0.867^{+}$ | 0.171 | 0.040 | $-0.778^{+}$ | $0.999^{++}$ | 1 | |
| **Salinity** | 0.234 | -0.240 | 0.178 | 0.198 | 0.291 | -0.625 | 0.260 | 0.336 | -0.512 | $0.917^{++}$ | $0.927^{++}$ | 1 |

*Source*: Laboratory analysis.

Table 6 reveals that moderate positive correlation exists between $Ca^{2+}$ and $Mg^{2+}$, temperature, EC, and TDS, and also between EC and $HCO_3^-$, TDS and $HCO_3^-$; meanwhile strong positive correlation exists between the following; $HCO_3^-$ and $Ca^{2+}$, temperature and $NO_3^-$. On the other hand, very strong negative correlation exists between $Ca^{2+}$ and $Na^+$, $Mg^{2+}$ and $K^+$, $HCO_3^-$and $K^+$, $HCO_3^-$ and $Mg^{2+}$, TDS and EC, salinity and EC, salinity and TDS, pH and $Cl^-$. From the correlation analysis, it revealed that parameters with high positive correlation such as $HCO_3^-$, and $Ca^{2+}$, temperature and $NO_3^-$ may exceed WHO drinking water standard in the near future if not regularly monitored.

3.3.6.2 Hierarchical Cluster Analysis (HCA)

The R-mode Hierarchical Cluster Analysis (HCA) performed on the physicochemical parameters of the water samples based on spatial similarities and dissimilarities is shown on Figure 7.

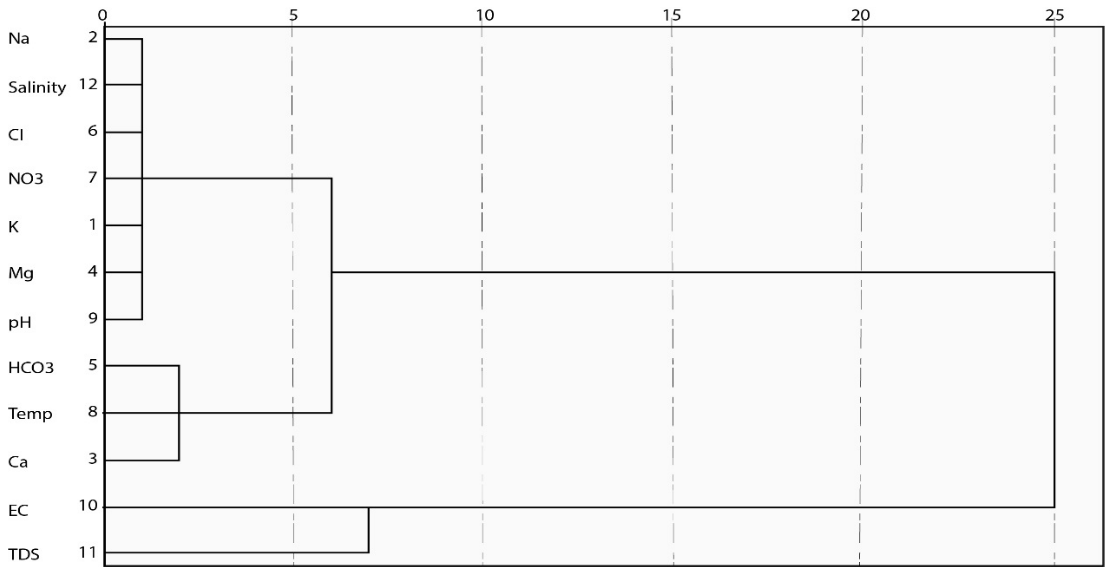


**Figure 7. Dendrogram Showing Two Clusters**

*Source*: Fieldwork, 2022.

Figure 7 reveals two clusters. Cluster 1, is made up of EC and TDS which indicates that they are from the same source since EC is related to TDS. Cluster 2 is made up of $K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$, $HCO_3^-$, $Cl^-$, $NO_3^-$-, temperature, pH and Salinity which show that these cations and ions are insoluble probably due to high solute content.

*3.4 Suitability of Water for Drinking*

The World Health Organization (2017), provided drinking water standards. Table 7 shows a comparison between physiochemical parameters obtained from the field and WHO drinking water standard.

**Table 7. Classification of Surface and Groundwater for Drinking Purposes WHO (2017)**

| Parameter | Min | Max | WHO standard (2017) | Observation | % within limits | % not within limits |
|---|---|---|---|---|---|---|
| **Temperature (ºC)** | 26.4 | 27.3 | 0-30 | Suitable | 100 | 0 |
| **Electrical conductivity (EC)** | 19 | 404 | 0-750 | Suitable | 100 | 0 |
| **Total Dissolve solid (STD)** | 9 | 201 | 0-500 | Suitable | 100 | 0 |
| **pH** | 5.13 | 6.35 | 6.5-8.5 | Unsuitable | 0 | 100 |
| **$Ca^{2+}$** | 0.22 | 55.92 | 200 | Suitable | 100 | 0 |
| **$Mg^{2+}$** | 0.55 | 10.67 | 150 | Suitable | 100 | 0 |
| **$Na^{+}$** | 0 | 0.001 | 200 | Suitable | 100 | 0 |
| **$K^{+}$** | 0.32 | 8.44 | 200 | Suitable | 100 | 0 |
| **$HCO_3^-$** | 21.96 | 63.75 | 240 | Suitable | 100 | 0 |
| **Cl** | 0 | 0.7 | 250 | Suitable | 100 | 0 |
| **$NO_3^-$** | 0 | 2.6 | 250 | Suitable | 100 | 0 |

*Source*: WHO (2017) and Fieldwork (2022).

From Table 7, looking at the values of the chemical and physical properties of the water from all sampled points measured, it is deciphered that physically and chemically not all the water parameters are within WHO permissible limit. Chemically, it was observed that all the water is suitable for drinking since all the ions ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $Cl^-$ and $NO_3$) have values within WHO's permissible limits. Conversely, physically, values of some parameters fall within the limit such as, TDS, EC, salinity and temperature while the pH has its value below the drinking water standard limit. The pH is very important in drinking water quality (WHO, 1989) with 6.5 to 8.5 being the suitable range. With the values for the study area (5 to 6.3) being lesser than the lower expected limit of less than 6.5, there are likely negative health impacts on the local population of Mamfe town such as vomiting, diarrhoea, kidney and liver diseases.

The number of open dump sites in Mamfe has contributed to major environmental problems around these dumpsites. This, coupled with the fact that the geology of Mamfe is predominantly sedimentary in nature, makes the soils and rocks very permeable. Percolation of leachates from dumpsites into water sources is common place especially during the rainy season when the physical, chemical and biological processes interact simultaneously to bring about the overall decomposition of waste. Washing into streams of decomposing waste by overland flow and groundwater contamination via discharged leachates (Mor *et al*., 2006), has heightened the propensity of pollution of nearby water sources by pollutants from nearby open dumpsites.

*3.5 Possible Solutions to the Effects of Household Waste on Surface and Ground Water*

The respondents advanced seven mitigation strategies to solve the problem of pollution of water sources by household waste. These are summarised on Figure 8.

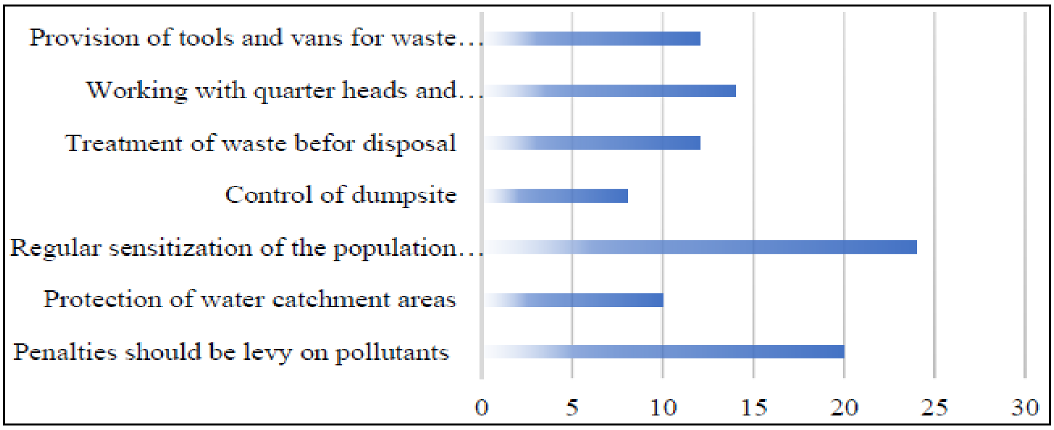


**Figure 8. Possible Solution for Effects of Household Waste**

*Source*: Fieldwork, 2022.

Figure 8 reveals that the population of Mamfe Town believes that regular sensitisation of people about the dangers of poor waste disposal and advantages of proper waste management is the best option as advanced by 23% of the respondents. This was followed by the implementation of coercive measures as levying penalties on defaulters suggested by 20% of the respondents. Next was the involvement of quarter heads and chiefs in the waste collection process by the Mamfe Council so as to enhance collaboration between waste collectors and inhabitants of the town, as advanced by 14% of the respondents. Some 12% of the respondents proposed the acquisition of more waste collection trucks and introduction of a reliable waste infrastructure maintenance policy since it was observed that waste collection vehicles were few and some broken down.

The treatment of waste before disposal was added to the package of possible solutions to reduce water pollution by another 12% of the respondents since they hold that dumpsites are located close to water sources and the current practice is haphazard disposal of untreated waste into nearest easy dump and with streams and wells inclusive. This should be reinforced by regular treatment (purification) of wells and bore holes and waste clearance from the streams. Another 10% of the respondents emphasised on the protection of water catchments areas as a possible solution to reduce the negative effects of household waste on surface and groundwater in Mamfe. Last but not the least, 8% of the respondents advanced proper location of dumpsites by avoiding the siting of waste dumps adjacent water sources and building of pit latrines near wells, the current situation preponderant across Mamfe Town. It is drawn from these suggested solutions that the population of Mamfe Town see more in preventive measures than the often belated and inadequate half-hearted curative measures.

## 4. Discussion

Water is considered polluted if some substances or condition is present to such a degree that the water cannot be used for specific purpose. Olaniran (1995) defined water pollution as the presence of excessive amounts of hazardous waste (pollutants) in water in such a way that it is no longer suitable for drinking, bathing, cooking or other uses. Pollution is the introduction of a contaminant into the environment (Webster.com, 2010). Water can be polluted by substances that dissolve in it or by solid waste particles and insoluble liquid droplets that become suspended in it. Workers have detected elevated levels of both organic and inorganic pollutants and heavy metals in surface and underground water and water in the vicinity of solid waste landfills (Abu-Daabes, Qdais and Alsyouri, 2013). Human settlements, industries and agriculture, are the major sources of water pollution.

Globally, 80% of municipal wastewater is discharged into water bodies untreated and industry is responsible for dumping millions of tons of heavy metals, solvents, toxic sludge and other waste into water bodies each year (WWAP, 2017). Agriculture which accounts for 70% of water abstraction worldwide, plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies. The resultant water pollution poses demonstrated risk to aquatic ecosystems, human health and productive activities (UNEP, 2013). In most high-income countries and many emerging economies, agricultural waste has already overtaken contamination from settlements and industries as the major factor in the degradation of inland and coastal waters. Nitrate from agriculture is the most common chemical contamination in the world's groundwater aquifers (WWAP, 2013). Pollution of groundwater by liquid or solid waste from existing or proposed waste activities is considered to be an issue of great concern. Small amount of leachate can pollute large amounts of groundwater, rendering the resource unusable for domestic and many other purposes (Lee and Jones-Lee, 1996).

Sewage effluent treatment ponds contain a hydraulic head and if unlined can allow diffused contamination of groundwater in surrounding soil and bedrock. Organic concentration and microbiological characteristics of the effluent can cause physicochemical changes in soil, as a result of the nutrient and pathogen levels in the groundwater (Dawes and Goonetilleke, 2001)

Open dumps have been demonstrated by several workers to posed serious threat to groundwater and surface water resources (Slomczynka, 2004). The degree of threat is strongly influenced by the composition of the waste in the landfill, the volume of leachates generated as well as the location of the landfill from water bodies such as groundwater and surface water (Slomczynka, 2004). This in turn has led to pollution of surface and groundwater causing over 20% of the world population not to access safe drinking water.

According to Ocheri et al. (2008), contamination of surface waters represents a growing environmental health challenge in several regions around the globe. Uting *et al.* (2007) noted that surface water pollution is a major environmental problem in many Developing Countries and that it is mainly due to human activities resulting from rapid population growth and increased productive activities. One of such human activities that currently threatens the quality of stream water is the age-old practice of dumping waste into or along stream channels.

Pollution of surface water sources occurs in both urban and rural areas (Ikem *et al.,* 2000). Leachates and other pollutants from waste dumps migrate into surface waters and pollute them. In the rural areas, water scarcity and poor quality of drinking water from natural sources such as rivers and streams are major challenges facing inhabitants of most communities (Bichi, 2000).

Water naturally contains small amounts of dissolved substances such as zinc, calcium, magnesium and even impurities like silt, sand and microbial substances under normal circumstances. These quantities are considered safe for human use; however, when they exceed threshold limits, then the water is polluted. Cadmium and lead have significant hazardous effects to human health. Long-term exposure to lead may cause severe disruption of biosynthesis of haemoglobin and/or anaemia, damage of kidneys, high blood pressure, brain damage, miscarriage and sperm damage in males. Mercury can be responsible for brain and kidney damage and interferes with the nervous system and regeneration of haemoglobin (Nylander, Friberg, Lind, 1987). When these pollutants are carelessly dumped in the landfills, the resulting leachates find way to percolate into the groundwater or washed into surface water and streams causing water pollution.

Water quality standards and guidelines are primarily aimed at protecting public health and aquatic life. The standards and guidelines are established case wise by each country to regulate the levels of contaminants permitted in their various water sources (Onemano and Otum, 2003). The WHO, Guidelines for Drinking Water Quality (GDWQ) covers the physical, chemical and microbiological aspects of water quality (WHO, 2006). The guidelines are regularly updated based on scientific research and consultations with various stakeholders and professionals which lead to the periodic release of revised documents (WHO, 2011)

The current rate of uncontrolled and unplanned urbanization in Africa has given rise to a huge amount of liquid and solid waste being produced. So much is generated that these wastes have long outstripped the capacity of city authorities to collect and disposed of them safely and efficiently in Solid Waste Disposal in Ghana.

**5. Conclusion**

Implications of waste on surface and groundwater shows that most of the categories of wastes found in Mamfe Town are liquid, organic and solid wastes. From the findings, it could be revealed that solid rubbish category of waste was the predominant waste type discarded into rivers and other places. This could result from the domestic activities carried out by the inhabitants. Respondents hold the opinion that surface water and groundwater sources are not good for consumption and this was due to pollution of the sources from household waste. On the other hand, the field and laboratory analyses show that, chemically this water is good for consumption since all the chemical ions are within WHO (2017) drinking water standard limit. Water parameters are within the limits apart from pH, (min 5.13 and max 6.35), that is less than 6.5 and below the limit. Therefore, though the water is good for drinking, it is not balanced since pH is below the limit and so acidic. This can result to negative health impacts on to the people consuming the water in Mamfe town. It should be understood that pH is one of the most important operational water quality parameters (WHO, 1986), so careful attention to pH control is necessary at all stages of water treatment in Mamfe town to ensure satisfactory water clarification and disinfection. But for better understanding, the quality of the water in Mamfe Town, further studies should be carried out for two hydrological seasons to better identify in which season the water is fit or unfit for drinking.

From the correlation analysis for the measured parameters and physicochemical parameters that was carried out shows positive correlation, moderate and negative correlation. There is a strong positive correlation between $HCO_3^-$and $Ca^{2+}$, temperature and $NO_3^-$ This simply means, if their concentrations are not monitored regularly, they might exceed the WHO suitability limit for drinking water in the future which may affect the human health in the area.

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