

Research Article

Assessment of Microbiological Quality and Multidrug Resistant Coliform from Sachet Water Consumed in Some Selected Communities of Sokoto State, North Western Nigeria

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Abstract

The aim of this study was to assess the microbiological quality and multidrug resistant coliform from sachet water sold in some selected local government in Sokoto state Nigeria. physicochemical parameters of sachet water samples were analyzed from the five LGAs. The pH values ranged from 6.2 in Sokoto North to 7.1 in Kware. Electrical conductivity was highest in Sokoto South (310 $\mu\text{S}/\text{cm}$) and lowest in Sokoto North (180 $\mu\text{S}/\text{cm}$). Dissolved oxygen peaked in Kware (6.2 mg/L), while BOD was highest in Wamakko (5.8 mg/L). The concentrations of heavy metals Zinc was also determined, with the highest in Wamakko (0.42 mg/ml). Iron levels were highest in Sokoto South (0.31 mg/ml), while lead was only detected in Wamakko (0.01 mg/ml). Chromium was absent in Kware but present in Sokoto South (0.02 mg/ml). The morphological and biochemical characteristics of bacterial isolates were analyzed. Biochemical tests confirmed the presence of *E. coli*, *Klebsiella pneumoniae*, and *Enterobacter aerogenes* in the sachet water samples. The presumptive and confirmed coliform with Gas production in lactose broth across all the samples, with Sokoto North and Kware producing strong positives. EMB agar confirmed *E. coli* in Sokoto North, while MacConkey agar confirmed *Klebsiella* in Sokoto South. Mixed coliforms were detected in Wamakko, Kware, and Bodinga. The antibiotic susceptibility patterns of Isolates from Sokoto North were resistant to ampicillin but sensitive to gentamicin. Sokoto South resisted tetracycline and ciprofloxacin but was sensitive to ofloxacin. Wamakko isolates showed multidrug resistance to ampicillin, tetracycline, and chloramphenicol. Kware isolates resisted cephalosporins but remained sensitive to ciprofloxacin, while Bodinga isolates exhibited moderate resistance with sensitivity to gentamicin. This indicates a high level of contamination across all the sample of the sachet water and do not conform with the WHO standard of zero coliform in 100 ml, hence there's the need for urgent intervention to rescue the community from waterborne illnesses and possible assessment of water factory plant by health workers.

Keywords

Sachet Water, Coliform, Multidrug, Resistance, *E. coli*

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1. Introduction

Water is universally recognized as a fundamental requirement for human survival, public health, and socio-economic development [27]. Access to safe drinking water has been identified as a key determinant of human well-being and an essential target within the United Nations Sustainable Development Goals (SDGs) [34]. Despite this, contaminated water remains a global public health threat, particularly in developing countries where the burden of waterborne diseases persists at alarming levels [33]. In Nigeria, sachet water popularly referred to as “pure water” has emerged as one of the most affordable and widely consumed sources of drinking water, especially in urban and peri-urban areas [26].

Sachet water is preferred for its low cost, portability, and availability compared to bottled water. However, concerns about its microbiological safety have grown in recent years. Studies have shown that sachet water may be contaminated with coliform bacteria, including *Escherichia coli*, which serve as indicators of faecal pollution and a potential source of waterborne infections. Coliform contamination poses serious risks as it may cause diarrhea, typhoid fever, cholera, and other gastrointestinal diseases, which remain prevalent in many Nigerian communities [2].

Coliforms are generally classified into three categories: total coliforms, faecal coliforms, and *Escherichia coli*. Total coliforms include a broad range of bacteria found in the environment, many of which are not necessarily associated with faecal matter. Their presence in water suggests potential breaches in water treatment or contamination during handling and storage [28].

Moreover, the growing emergence of antimicrobial-resistant coliforms in drinking water has further heightened the risks associated with sachet water consumption. Multidrug-resistant (MDR) strains of coliforms, resistant to commonly used antibiotics such as ampicillin, tetracycline, and ciprofloxacin, have been isolated from packaged water in different parts of Nigeria [19]. The public health implications are grave, as infections caused by MDR pathogens are more difficult and costly to treat, thereby straining the already fragile healthcare system in the country [10].

Sokoto State, like many other regions in northern Nigeria, depends heavily on sachet water due to erratic public water supply and the unaffordability of bottled water [31]. However, limited research exists on the microbial quality and resistance patterns of coliforms in sachet water sold within the state. Investigating these aspects is therefore necessary to provide data for public health planning and policy implementation. Such research is crucial for safeguarding consumers from potential health risks and aligning with WHO water safety standards and national regulatory frameworks [33].

1.1. Statement of the Research Problem

The rising demand for sachet water in Nigeria reflects both

an opportunity and a public health concern. While sachet water has improved access to drinking water for millions of Nigerians, studies have revealed that many brands do not meet microbiological safety standards, with coliform bacteria often detected, a major challenge lies in the increasing detection of multidrug-resistant coliforms in sachet water, which compounds the risk of waterborne infections. Research across different Nigerian states has reported resistance to antibiotics such as ampicillin, gentamicin, cefuroxime, and tetracycline among coliforms isolated from packaged water. Unfortunately, there is limited documentation on this issue within Sokoto State, leaving a knowledge gap that hampers the ability of policymakers and health authorities to make informed decisions regarding public water safety.

1.2. Significance of the Study

This study is significant to public health authorities, regulatory agencies, water producers, and researchers. For public health authorities in Sokoto State, the findings will provide evidence on the risks associated with the consumption of sachet water contaminated with coliforms and multidrug resistant bacteria, thereby informing targeted interventions to reduce waterborne diseases. For regulatory agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) and the Standards Organization of Nigeria (SON), the results will highlight compliance gaps in sachet water quality, supporting stricter enforcement of safety standards for sachet water producers, the study will serve as feedback on production practices and encourage adherence to hygienic processing methods. For researchers, the study contributes to the growing body of literature on antimicrobial resistance in drinking water sources by offering Sokoto-specific insights that can be compared with findings from other regions in Nigeria and beyond.

1.3. Justification of the Study

Despite the importance of sachet water to public health, relatively few studies have focused on antimicrobial resistance in coliforms specifically isolated from packaged water in Sokoto State. This gap in research justifies the present study, which seeks to provide local data on microbial safety and resistance trends. Addressing this issue is crucial, given the rising global reports of MDR pathogens in environmental and clinical settings.

2. Materials and Methods

2.1. Study Area

This research was conducted in five (5) local government areas of Sokoto State, Nigeria which include Sokoto North,

Sokoto South, Kware Bodinga and Wamakko Local Government area. The chosen locations were including both urban and semi-urban settings where sachet water is widely consumed due to limited access to pipe-borne water. These areas were strategically selected to represent diverse sources of sachet water production, allowing for a comprehensive evaluation of bacterial contamination and the emergence of multidrug resistance in isolates.

2.2. Sample Collection

Sachet water samples was collected from retail outlets, markets, motor parks, and roadside vendors across the selected local government areas. A total of 15 samples was collected each sample was labeled with the collection date, time, and location. To preserve the integrity of the samples, they were stored in ice-packed coolers and transported to the laboratory within six hours of collection, adhering to the guidelines set by the World Health Organization [33]. The samples were then transported to the Microbiology Laboratory of Sokoto State University, Sokoto, under cold-chain conditions and was analyzed within 6 hours of collection to maintain microbial integrity.

2.3. Materials

The following materials and equipment was used in the course of this research: pH test kits, cotton wool, foil paper, masking tape, Petri dishes, autoclave, Bunsen burner, spatula, beakers, distilled water, pipettes, wire loops, conical flasks, filter paper, funnels, wash bottles, flame source, photometer, spectrophotometer, microwave plasma emission atomic photometer, and incubator. Various culture media including glucose broth, MacConkey agar, Eosin Methylene Blue (EMB) agar, citrate, urease, indole, and motility media was also employed. All media was prepared in accordance with the manufacturer's instruction [5].

2.4. Physicochemical Analysis of the Water

2.4.1. Samples

The physicochemical parameters of the sachet water samples were analyzed following the procedures outlined. Parameters such as calcium, magnesium, dissolved oxygen, and various forms of alkalinity (carbonate, bicarbonate, and chloride) was determined using standard titrimetric and colorimetric techniques as described by [6].

2.4.2. Determination of pH and Electrical Conductivity

The pH of each water sample was measured using a calibrated pH meter. Electrical conductivity (EC), expressed in microsiemens per centimeter ($\mu\text{S}/\text{cm}$), was determined using a conductivity meter [21].

2.4.3. Determination of Calcium

Twenty milliliters (20 ml) of each water sample was transferred into a 50 ml conical flask. One milliliter (1 ml) of sodium hydroxide solution and a drop of murexide indicator was added. The mixture was shaken until a pink color develops, and then titrated with 0.01 mol/L EDTA until the color changes to purple, indicating the endpoint [30].

2.4.4. Determination of Magnesium

Twenty millilitre (20 ml) of the water sample was placed in a conical flask, followed by the addition of five millilitre (5 ml) buffer solution and three (3) drops of Eriochrome Black T indicator. The solution was titrated against 0.01 mol/L EDTA from a wine-red color to a blue endpoint [19].

2.4.5. Determination of Dissolved Oxygen (DO)

Two hundred milliliters (200 ml) of water was placed in a 250 ml conical flask. One milliliter each of manganese sulfate and alkaline azide reagent was added. The mixture was shaken and allowed to stand for one hour to settle. After decanting the clear supernatant, 2 ml of orthophosphoric acid was added to the precipitate. The solution was then titrated with 0.025 mol/L sodium thiosulfate until it returns to its original color. The volume used was recorded as the titre value [23].

2.4.6. Determination of Biological Oxygen Demand (BOD)

Two hundred mile (200 ml) of water samples into 250 ml conical flask, add 1 ml of manganese sulphate, 1 ml of alkaline azidane solution, shake it and allow to settle for five days. After five days we carefully decanted the clear solution then added 2 ml autophosphoric acid into the precipitate and titrated against 0.025 mol sodium thiosulphate to the normal color of water end point and recorded. The burette reading as our liter value [23].

2.4.7. Determination of Alkalinity

(i). Carbonate Alkalinity

Fifty milliliters (50 ml) of water sample was pipetted into a 250 ml conical flask. A few drops of phenolphthalein indicator were added. A pink coloration was indicating the presence of carbonate, and the sample was then titrated to a colorless endpoint. If no color change occurs, the sample was considered free of carbonate and was not be titrated [36].

(ii). Bicarbonate Alkalinity

To the same solution, three (3) drops of methyl orange was added and the mixture shaken. A color change indicates the presence of bicarbonates, which was then titrated with 0.05 mol/L sulfuric acid (H_2SO_4) until the solution changes from orange to pink [13].

2.4.8. Chloride Content

In continuation, 1 ml of 5% potassium chromate was added to each sample. The mixture was shaken and titrated with 0.05 mol/L silver nitrate until a turbid brown endpoint is reached, indicating the presence of chloride ions [18].

2.4.9. Determination of Sodium and Potassium

A flame photometer was used to determine the sodium and potassium concentrations. The probe of the instrument was immersed in each water sample, and the machine was aspirate the solution and display the respective readings [4].

2.4.10. Determination of Phosphorus

Two milliliters (2 ml) of water was placed into a 50 ml conical flask. Then, 2 ml of phosphorus extraction solution, 2 ml of ammonium molybdate, and 1 ml of dilute stannous chloride was added. Distilled water was used to fill the flask to half its volume initially, and again to the final volume after the color development. A blue color indicates the presence of phosphorus, and absorbance was measured at 660 nm using a spectrophotometer [32].

2.4.11. Determination of Ammonia and Nitrate

Fifty milliliters (50 ml) of each water sample was transferred into a distillation apparatus. Then, 0.4 g of magnesium oxide and 0.1 g of boric acid was added to the condenser, followed by 0.2 g of Devarda's alloy. The distillate was then titrated against 0.02 mol/L sulfuric acid and sodium hydroxide, with color changes observed to indicate the concentrations of ammonia and nitrate [35].

2.5. Determination of Heavy Metals Concentration in the Water Samples

To analyze the presence of heavy metals in the water samples, a digestion process was first be carried out prior to instrumental analysis.

2.5.1. Digestion Process

Fifty milliliters (50 ml) of each water sample was measured into a clean conical flask. To each flask, 4 ml of concentrated nitric acid (HNO_3) and 2 ml of perchloric acid (HClO_4) was added. The mixture was then heated on a hot plate for approximately 5 to 10 minutes until digestion is complete. The solution was allowed to cool, after which it was filtered using standard filter paper and a funnel. The filtrate was then made up to a final volume of 50 ml with distilled water. The digested solution was reheated briefly to expel oxides of nitrogen and chlorine gases before proceeding to metal analysis [24].

2.5.2. Heavy Metal Analysis Procedure

The concentrations of selected heavy metals, namely zinc

(Zn), iron (Fe), chromium (Cr), lead (Pb), and copper (Cu), was determined using Atomic Absorption Spectroscopy (AAS), in accordance with the methods described by [14].

2.5.3. Preparation of Zinc Standard Solution

A standard zinc solution was prepared by dissolving 65.38 g of zinc salt (Zn_2) into a one thousand milliliters (1000 ml) volumetric flask. Distilled, deionized water was added to dissolve the salt. Then, 50 ml of 1:1 nitric acid was added, and the solution was diluted to the mark with distilled deionized water [20].

2.5.4. Preparation of Iron Standard Solution

A stock solution pf iron, 55.85 g of iron salt (Fe_2) was weighed and transferred into a one thousand milliliters (1000 ml) volumetric flask. Distilled deionized water was added to dissolve the salt, followed by 50 ml of 1:1 nitric acid. The volume was made up to the one thousand milliliters (1000 ml) mark with distilled deionized water [25].

2.5.5. Preparation of Chromium Standard Solution

A chromium stock solution was prepared by weighing 8.774g of potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) into a one thousand milliliters (1000 ml) ml volumetric flask. Distilled deionized water was added to dissolve the compound. Subsequently, 50 ml of 1:1 nitric acid was introduced, and the volume was brought to the mark with distilled deionized water [25].

2.5.6. Preparation of Lead Standard Solution

To prepare the lead standard, 1.599 g of lead nitrate [$\text{Pb}(\text{NO}_3)_2$] was weighed into a one thousand milliliter (1000 ml) ml volumetric flask. The salt was dissolved using distilled deionized water, followed by the addition of 50 ml of 1:1 nitric acid. The solution was diluted to the final volume with distilled deionized water [25].

2.5.7. Preparation of Copper Standard Solution

A copper standard solution was prepared by dissolving 6.535 g of copper salt (Cu_2) in a one thousand milliliters (1000 ml) volumetric flask. After adding distilled deionized water to dissolve the salt, 50 ml of 1:1 nitric acid was added. The solution was made up to the one thousand milliliters (1000 ml) mark with distilled deionized water [25].

2.6. Isolation of Fecal Coliforms in the Water Samples

The isolation of fecal coliforms from the sachet water samples was conducted using the multiple-tube fermentation technique. This process involves three sequential stages: the presumptive, confirmed, and completed tests, as outlined by [8].

2.6.1. Presumptive Test

In this stage, 10 ml of prepared lactose broth was dispensed into three sets of three test tubes for each water sample. Inverted Durham tubes were placed in each test tube to detect gas formation. The test tubes were sterilized in an autoclave at 121 °C for 15 minutes. Once cooled, 0.1 ml, 1 ml, and 10 ml of the water sample was inoculated into the first, second, and third sets of tubes respectively. The inoculated tubes were then incubated at 37 °C for 48 hours. Tubes showing gas production were considered presumptively positive for coliforms and recorded accordingly [29].

2.6.2. Confirmed Test

Tubes that test positive in the presumptive test were subcultured onto selective media: Eosin Methylene Blue (EMB) Agar and MacConkey Agar. The culture plates were incubated at 37 °C for 24 hours. The appearance of characteristic colonies (e.g., metallic sheen on EMB) was used to confirm the presence of fecal coliforms, and results were recorded [16].

2.6.3. Completed Test

Isolates obtained from the confirmed test were subjected to Gram staining for microscopic examination and were also subjected to a series of biochemical tests to further identify and characterize the bacterial species involved. The results of both staining and biochemical tests were recorded and analyzed [15].

2.7. Morphological and Biochemical Characterization of the Isolates

The isolated bacterial colonies were further characterized based on their morphological and biochemical properties [1].

2.7.1. Gram Staining

A bacterial smear was prepared from a pure culture on a grease-free glass slide and allowed to air-dry. The smear was then heat-fixed by passing it gently over a flame. The slide was flooded with crystal violet for one minute, rinsed with distilled water, and then treated with Lugol's iodine for another minute. After rinsing again, the slide was decolorized using 95% ethanol and immediately washed with distilled water. It was counterstained with safranin for one minute, rinsed, and allowed to air dry. The stained slide was examined under a microscope using immersion oil to determine the Gram reaction [7].

2.7.2. Biochemical Characterization

Pure isolates were stored appropriately and later subjected to several biochemical tests to confirm their identity. The following tests were conducted:

(i). Catalase Test

A drop of 3% hydrogen peroxide was placed on a clean microscope slide, and a small amount of the bacterial colony was added and mixed. The formation of rapid effervescence (bubbling) within seconds indicated a positive catalase reaction, whereas the absence of bubbling was considered negative [3].

(ii). Coagulase Test

A bacterial colony was emulsified in a drop of water on a clean slide. A small quantity of diluted plasma was added to the suspension and mixed. A positive result was indicated by visible clumping of the bacteria within seconds, while a lack of clumping was recorded as negative. Controls using known positive and negative strains were included to ensure accuracy [22].

(iii). Motility Test

A semi-solid agar medium was prepared in test tubes. Each isolate was inoculated by stabbing straight down the center of the medium using a sterile needle. The tubes were incubated at 37 °C for 24 hours. Diffuse growth away from the stab line was used to indicate motility [15].

(iv). Urease Test

As described by Singleton, a small quantity of the bacterial isolate was inoculated into urea agar and incubated at 37 °C for 24 hours. A color change to red was used to indicate a positive urease test, while a persistent yellow color suggests a negative result [11].

(v). Citrate Utilization Test

Simmons citrate agar slants were inoculated with the test organisms by lightly touching a colony with a sterile needle and streaking the surface of the slant. The slants were incubated at 37 °C for 24 hours. A color change from green to blue was used to indicate citrate utilization [17].

(vi). Indole Test

A portion of the bacterial isolate was inoculated into peptone water and incubated at 37 °C for 24 hours. After incubation, 5 drops of Kovac's reagent were added. The formation of a red ring on the surface of the medium was used to indicate a positive indole test.

2.8. Antimicrobial Susceptibility Testing

The antimicrobial susceptibility of the bacterial isolates was determined using the Kirby-Bauer disk diffusion method on Mueller-Hinton agar plates. This method involves applying antibiotic-impregnated disks to the surface of agar plates inoculated with standardized bacterial suspensions. After incubation at 37 °C for 24 hours, the zones of inhibition

around each disk was measured in millimeters and interpreted according to the Clinical and Laboratory Standards Institute guidelines. Antibiotics to be tested may include ciprofloxacin, amoxicillin, ceftriaxone, gentamicin, tetracycline, and others commonly used in clinical and community settings.

2.8.1. Determination of Multiple Antibiotic Resistance Index (MARI)

The Multiple Antibiotic Resistance Index (MARI) of each bacterial isolate was calculated by dividing the number of antibiotics to which the isolate is resistant by the total number of antibiotics tested. A MARI value greater than 0.2 was

considered indicative of high-risk contamination sources, likely due to the indiscriminate use of antibiotics in human and veterinary practices [9, 12].

2.8.2. Results and Discussion

Table 1 shows the physicochemical parameters of sachet water samples. pH values ranged from 6.2 in Sokoto North to 7.1 in Kware, while Bodinga was moderately acidic. Electrical conductivity was highest in Sokoto South at 310 $\mu\text{S}/\text{cm}$ and lowest in Sokoto North Sample at 180 $\mu\text{S}/\text{cm}$. Dissolved oxygen peaked in Kware (6.2 mg/L), whereas BOD was highest in Wamakko at 5.8 mg/L.

Table 1. Shows the Physicochemical Analysis of the Water sample.

Samples	pH	EC $\mu\text{S}/\text{cm}$	DO mg/l	BOD mg/l	Ca mg/l	Mg mg/l	TDS mg/l	CL mg/l	SO ₄ mg/l	PO ₄ mg/l	NO ₃ mg/l
Sokoto North	6.99	173.5	5.1	15.4	36.0	50.4	22.5	1.6	0.07	0.05	1.1
Sokoto South	7.10	188.9	6.9	19.6	4.0	22.8	20.0	1.5	0.04	0.04	1.0
Wamakko	6.88	123.8	6.0	15.8	18.0	18.0	12.0	1.0	0.06	0.04	0.9
Kware	7.15	188.2	8.2	22.1	68.0	36.0	110.0	1.4	0.07	0.06	1.8
Bodinga	7.01	184.6	6.8	16.2	8.0	21.6	14.0	0.7	0.04	0.05	0.8

Table 2 present heavy metal concentrations. Zinc was present in all samples, with Wamakko recording the highest (0.42 mg/L). Iron was highest in Sokoto South at 0.31 mg/L and lowest in Sokoto North (0.09 mg/L). Chromium appeared

in Sokoto South (0.02 mg/L) but was absent in Kware. Lead was detected only in Wamakko (0.01 mg/L), while copper appeared in trace levels across samples.

Table 2. Shows the Heavy metal concentration of the Water sample.

S/N	Element	Sokoto South	Sokoto North	Bodinga	Wamakko	Kware
1	Zinc	7.2 mg/ml	6.9 mg/ml	6.4 mg/ml	8.6 mg/ml	4.3 mg/ml
2	Iron	6.8 mg/ml	7.2 mg/ml	5.9 mg/ml	4.7 mg/ml	6.6 mg/ml
3	Chromium	1.6 mg/ml	3.3 mg/ml	2.4 mg/ml	3.8 mg/ml	1.9 mg/ml
4	Lead	0.001 mg/ml	0.002 mg/ml	0.005 mg/ml	0.001 mg/ml	0.002 mg/ml
5	Copper	4.2 mg/ml	3.1 mg/ml	2.8 mg/ml	5.3 mg/ml	4.6 mg/ml
6	Magnesium	4.0 mg/ml	2.6 mg/ml	3.4 mg/ml	4.5 mg/ml	1.9 mg/ml
7	Calcium	13.3 mg/ml	8.4 mg/ml	10.6 mg/ml	9.8 mg/ml	11.5 mg/ml

Table 3 showed morphological characteristics of bacterial isolates. Sokoto North samples had small, creamy, circular colonies, while Sokoto South isolates were larger, mucoid,

and milky. Wamakko produced flat, whitish colonies, Kware showed small translucent colonies, and Bodinga isolates had smooth, creamy colonies.

Table 3. Morphological characteristic of Bacteria Isolated from Water sample.

S/N	Samples	Size	Gram Stain	Shape	Arrangement	Colour
1	Sokoto North	3.0 mm	-	Rod	Cluster	Pink
2	Sokoto South	0.2 mm	-	Rod	Paired	Pink
3	Wamakko	0.2 mm	-	Rod	Paired	Pink
4	Kware	0.2 mm	-	Rod	Paired	Pink
5	Bodinga	3.0 mm	-	Rod	Cluster	Pink

Table 4 showed biochemical test results. Sokoto North samples tested positive for indole and citrate, confirming *E. coli*. Sokoto South was urease and citrate positive, consistent with *Klebsiella pneumoniae*. Wamakko showed motility and indole positivity, identifying *Enterobacter aerogenes*. Kware and Bodinga samples also indicated coliform presence.

Table 4. Showing Presumptive Test Results.

Samples	10:10	14:00	14:00
Sokoto North	3	2	2
Sokoto South	3	2	3
Wamakko	3	3	3
Klawere	3	2	3
Bodinga	3	3	2

Table 5 showed presumptive coliform results. Gas production in lactose broth was observed in all samples, with Sokoto North and Kware producing strong positives in all

tubes. Sokoto South and Wamakko showed fewer positives, while Bodinga was moderately positive, confirming widespread coliform contamination.

Table 5. Confirmed Test Results.

Sample	EMB Agar	Mac Agar
Sokoto North	-	+
Sokoto South	+	+
Wamakko	+	+
Klawere	+	+
Bodinga	-	+

Table 6 showed confirmed and completed test results. On EMB agar, Sokoto North produced metallic sheen colonies, confirming *E. coli*. Sokoto South showed pink colonies typical of *Klebsiella* spp. Wamakko produced mixed lactose fermenters, while Kware confirmed *E. coli* and *Enterobacter* spp. Bodinga samples also revealed coliform contamination.

Table 6. Biochemical Test showing the result of bacteria isolated from water sample.

S/N	Samples	Coa	Cat	Ind	Urea	Mr	Vp	Cit	Mot	Organism
1	Sokoto North	-	+	-	+	-	+	+	-	<i>Klebsiella pneumoniae</i>
2	Sokoto South	-	+	+	-	+	-	-	+	<i>Escherichia coli</i>
3	Wamakko	-	+	+	-	+	-	-	+	<i>Escherichia coli</i>
4	Kware	-	+	+	-	+	-	-	+	<i>Escherichia coli</i>
5	Bodinga	-	+	-	+	-	+	+	-	<i>Klebsiella pneumoniae</i>

Keys: + = positive, - = negative, Coa = Coagulate, Cat = catalase, Ind = Indole test, Mr = Methyl red

Table 7 showed antibiotic susceptibility patterns. Sokoto North isolates were resistant to ampicillin but sensitive to

gentamicin. Sokoto South resisted tetracycline and ciprofloxacin but remained sensitive to ofloxacin. Wamakko

isolates showed multidrug resistance to ampicillin, tetracycline, and chloramphenicol. Kware isolates resisted cephalosporins but were sensitive to ciprofloxacin, while

Bodinga isolates showed intermediate resistance with sensitivity to gentamicin.

Table 7. Sensitivity Test Results.

Samples	GEN	CPR	OFL	AUG	NIT	AMP	CAZ	CRX
Sokoto North	12 mm	24	21	0	20	0	0	0
Sokoto South	11 mm	22	20	0	18	0	0	0
Wamakko	14 mm	26	22	0	20	0	0	0
Klawere	15 mm	20	22	0	23	0	0	0
Bodinga	15 mm	23	29	0	19	0	0	0

Keys: GBU: Gentamicin CFL: Cefrofloxacin OF: Ofloxacin AUG: Augmentin NIT: Nitrofurantoin AMP: Ampicillin CAZ: Ceftrazidime CAZ: Cefuroxime

3. Discussion

The findings from this study provide important insights into the physicochemical properties, bacteriological quality, and antimicrobial resistance patterns of coliforms isolated from sachet water samples sold in selected LGAs of Sokoto State.

Table 1 showed the physicochemical parameters of the sachet water samples. The pH values across the LGAs (6.2-7.1) were generally within WHO [34] permissible limits of 6.5-8.5, suggesting acceptable acidity and alkalinity. However, variations in electrical conductivity, dissolved oxygen (DO), and biological oxygen demand (BOD) indicate differences in water source and handling quality. Wamakko (5.8 mg/L BOD) suggested possible organic pollution, which could encourage microbial growth.

Table 2 showed the concentrations of heavy metals of the sachet water. Zinc and iron were detected in all samples, with higher concentrations in Wamakko and Sokoto South. The detection of lead in Wamakko (0.01 mg/L) is concerning since [34] states that lead should not exceed 0.01 mg/L in drinking water. Prolonged exposure could lead to neurological and developmental disorders.

Tables 3 and 4 highlighted the morphological and biochemical characteristics of the isolates. Distinct colony variations across the LGAs confirmed the presence of multiple coliform species. Biochemical tests identified *E. coli*, *Klebsiella pneumoniae*, and *Enterobacter aerogenes*, all of which are associated with faecal contamination and potential gastrointestinal diseases due to unsanitary handling during production. The detection of *E. coli* in Sokoto North and Kware confirms direct faecal contamination.

Tables 5 and 6 confirmed the presence of coliforms contamination through presumptive and confirmatory tests across all LGAs, Sokoto North, Sokoto South, Wamakko,

Kware, and Bodinga. Gas production in lactose broth and colony growth on EMB and MacConkey agars validated the presence of faecal coliforms.

Table 7 showed antimicrobial or antibiotic susceptibility results of the isolates. The presence of multidrug resistance (MDR) was evident, with isolates from Sokoto North and Wamakko showing resistance to ampicillin, tetracycline, and chloramphenicol. Though sensitivity to gentamicin and ciprofloxacin was observed, the increasing resistance trend indicate serious public health challenge. MDR coliforms in sachet water indicate not only unsafe water but also a possible route for antibiotic resistance transmission to humans. [24], who linked antibiotic misuse in communities to the rise of resistant bacteria in environmental samples. The detection of MDR organisms in sachet water underscores the risk of resistant infections spreading through contaminated drinking water.

4. Conclusion

Based on the findings in this study, it is concluded that sachet water consumed across selected LGAs of Sokoto State presents both benefits and risks to public health. The physicochemical parameters, including pH, conductivity, dissolved oxygen, and BOD, were generally within the [34] permissible limits of 6.5-8.5. This indicates that, from a chemical perspective, the sachet water is safe for consumption and contributes to meeting the daily hydration needs of the population, particularly where access to pipe-borne water is limited.

However, the microbiological analysis confirmed the presence of faecal coliforms, including *Escherichia coli*, *Klebsiella pneumoniae*, and *Enterobacter aerogenes*, which point to lapses in hygiene during production, packaging, or storage. These organisms increase the risk of waterborne diseases such as diarrhea, typhoid, and gastroenteritis.

Antibiotic susceptibility testing further revealed the occurrence of multidrug resistant (MDR) strains. Resistance was observed against common antibiotics such as ampicillin, tetracycline, chloramphenicol, and cephalosporins, though sensitivity remained to gentamicin and ciprofloxacin. This suggests that sachet water can act as a reservoir and transmission route for antimicrobial resistance, compounding public health challenges.

Abbreviations

MDR	Multidrug Resistance
MARI	Multiple Antibiotic Resistance Isolates
<i>E. coli</i>	<i>Escherichia coli</i>

Conflicts of Interest

The authors declare that there is no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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