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Physical and Chemical Quality Assessment of Sachet Water in Chikun Local Government Area, Kaduna State

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Abstract

The physical and chemical quality criteria of sachet water brands offered in Kaduna State, Nigeria's Chikun Local Government Area were evaluated in this study. To assess their adherence to World Health Organization (WHO) drinking water quality standards, twenty samples from five well-known brands were gathered and examined for physical characteristics (temperature, electrical conductivity, total dissolved solids, and turbidity) and chemical characteristics (pH, major ions, trace metals, and hardness). The results revealed that most physical parameters were within acceptable limits, with temperatures ranging from 22.10°C to 26.05°C, electrical conductivity from 21.7 to 145.1 $\mu\text{S}/\text{cm}$ (below WHO limit of 1000 $\mu\text{S}/\text{cm}$), total dissolved solids from 7 to 11 mg/L (well below WHO limit of 1000 mg/L), and turbidity from 0.21 to 1.81 NTU (within WHO limit of 6 NTU). Chemical analysis showed pH values between 6.26 and 7.20, with one sample slightly below the WHO recommended range (6.5-8.5). All anions (chloride, sulfate, nitrate, and fluoride) and heavy metals (zinc, iron, nickel, chromium, lead, and manganese) were detected at concentrations below WHO limits, indicating minimal risk of toxicity. Total hardness values ranged from 21 to 28 mg/L, classifying all samples as "soft water." Statistical analysis revealed 24 significant correlations between various parameters, suggesting potential common sources or treatment effects. While the analyzed sachet water samples largely complied with WHO guidelines, variations among different brands highlighted the need for consistent monitoring and stricter enforcement of quality standards. The presence of trace amounts of heavy metals, particularly lead (0.001-0.003 mg/L), underscores the importance of regular surveillance to prevent potential health risks from long-term exposure. This study provides valuable information for regulatory authorities, consumers, and sachet water producers regarding the safety and quality of drinking water in the region.

Keywords: Sachet water, water quality, heavy metals, WHO guidelines, Physical analysis and Chemical analysis

1. Introduction

Access to safe drinking water remains a critical public health challenge in many developing countries, including Nigeria. In urban and semi-urban areas of Nigeria, packaged water, particularly sachet water (commonly known as "pure water"), has become a primary source of drinking water due to inadequate public water supply infrastructure (Ahmad & Pyeng, 2024). The consumption of sachet water has significantly increased in recent years across Nigeria, including in Chikun Local Government Area (LGA) of Kaduna State, where many residents rely on it as their primary source of potable water.

Sachet water is produced by packaging treated water in polyethylene bags, which are then heat-sealed and distributed for public consumption. While these products are meant to provide safe drinking water, concerns exist regarding their quality and safety, particularly in relation to adherence to regulatory standards (Mohammed *et al.*, 2023). The physical and chemical properties of sachet water are critical determinants of its safety and palatability. These properties can be affected by various factors including production processes, packaging materials, storage conditions, and environmental exposure (Adedire *et al.*, 2021).

Despite the proliferation of sachet water brands in Chikun LGA, comprehensive studies assessing their physical and chemical quality parameters are limited. Previous studies in other regions of Nigeria have shown varying levels of compliance with national and international water quality standards (Akpen *et al.*, 2018; Ezetoha *et al.*, 2024). For instance, Joshua *et al.* (2019) found that storage conditions significantly affect the quality of sachet water in Sabon Gari LGA of Kaduna State, while Akinsola *et al.* (2021) reported variations in quality parameters among sachet water brands in Ondo State.

The World Health Organization (WHO) has established guidelines for drinking water quality to protect public health. These guidelines specify acceptable limits for various physical and chemical parameters including temperature, pH, conductivity, turbidity, total dissolved solids, and concentrations of various ions and heavy metals (Addo *et al.*, 2019). Assessing these parameters in sachet water is essential to ensure they meet established standards and are safe for consumption.

Thus, the purpose of this study is to evaluate the chemical and physical quality criteria of sachet water brands that are offered for sale in Chikun LGA, Kaduna State, Nigeria. Key physical and chemical characteristics (temperature, electrical conductivity, total dissolved solids, and turbidity) as well as their conformity with WHO drinking water quality recommendations (pH, main ions, trace metals, and hardness) are among the specific goals. The results of this study will help guide regulatory actions to safeguard public health and offer important information on the safety of sachet water in the study area.

2. Methodology

2.1 Study Area

The study was conducted in Chikun Local Government Area, located in Kaduna State, Nigeria, at latitude 10.26622 and longitude 7.113044. The local government area covers approximately 4,466 km² with its headquarters in Kujama town. According to the 2006 census, Chikun had a population of 372,272 (Kaduna State Political Map, 2018). The area is bordered by Kachia Local Government Area to the south, Kajuru Local Government Area to the east, Kaduna South Local Government Area to the northeast, Igabi Local Government Area to the northeast, Birnin Gwari Local Government Area to the northwest, and Niger State to the west. Originally inhabited by the Gbagyi people, the area has become increasingly cosmopolitan due to urbanization.

2.2 Sample Collection and Preparation

Twenty (20) samples were collected for this study, comprising five (5) brands of sachet water commonly consumed in the study area. Four (4) sachets of each brand were sampled from various sellers throughout Chikun Local Government Area. The selection of these specific brands was based on their popularity among consumers in the region (Singh *et al.*, 2018). Following collection, all samples were stored in sterile conditions and refrigerated at 4°C until laboratory analysis was completed. This storage protocol ensured sample integrity was maintained throughout the transportation and pre-analysis period (Fisher *et al.*, 2015).

2.3 Physical Analysis

2.3.1 Determination of Temperature

Temperature measurements were conducted during laboratory analysis. A 50 mL aliquot of each sample was transferred into a 100 mL beaker, and a thermometer calibrated for the 0-60°C range was immersed in the sample. After stabilization, the temperature reading was recorded (Brown *et al.*, 2011).

2.3.2 Electrical Conductivity Measurement

Electrical conductivity was measured using a digital conductivity meter (model 4520 JENWAY, serial number 01263). The meter was switched on and allowed to warm up for approximately fifteen minutes before standardization using a 0.01M KCl solution. After thorough cleaning of the electrode with distilled water, it was directly immersed in the samples, and conductivity values were recorded in micro-Siemens per centimeter (μScm^{-1}) (Bennet and David, 2014).

2.3.3 Determination of Total Dissolved Solids

Total dissolved solids (TDS) for each water sample were calculated using the following equation:

$$TDS = (\text{Conductivity} \times \text{constant value}) \quad (1)$$

Where the constant value ranges from 0.45 to 0.65, depending on the ionic composition of the water (APHA, 2012).

2.3.4 Determination of Turbidity

Turbidity measurements were conducted using a calibrated turbidimeter (HANA equipment HI93703). Results were expressed in Nephelometric Turbidity Units (NTU) in accordance with standard methods (Essien and Olisah, 2010; Dinrifo *et al.*, 2010; Olaoluwa *et al.*, 2010).

2.4 Chemical Analysis

2.4.1 Determination of pH

The pH of each water sample was measured using a calibrated pH meter (Toledo, MP220). Each sample was transferred into a 100 cm³ beaker, and the pH probe was immersed into the sample after standardization with appropriate buffer solutions. Between measurements, the meter was recalibrated to ensure accurate

readings (AOAC, 2006).

2.4.2 Nitrate and Nitrite Tests

A portable UV-visible spectrophotometer (HACH D 89) was employed for nitrate and nitrite analysis. Ten milliliters of each water sample were placed in two separate cuvettes. For nitrate determination, the contents of a NitraVer 5 nitrate reagent powder pillow were added to one cell. The cuvettes were sealed and vigorously shaken for one minute, followed by a five-minute standing period. The presence of nitrate was indicated by the development of an amber color. For nitrite determination, NitraVer 3 reagent powder was applied to the second cuvette and allowed to stand for five minutes; the formation of a pink color indicated the presence of nitrite. Absorbance measurements were recorded, and concentrations were reported in milligrams per liter (AOAC, 2006).

2.4.3 Sulphate Determination

Standard solutions with a concentration of $1\mu\text{g/mL}$ were prepared. To each standard, 10 mL of conditioning reagent and 0.3g of barium chloride were added. The mixtures were allowed to stand for 45 minutes before measuring their respective absorbance at 420 nm. From this data, a calibration curve of absorbance versus concentration was plotted. For sample analysis, 10 mL of conditioning reagent was added to 25 mL of sample, followed by 0.3g of BaCl_2 . The mixture was diluted to 100 mL with double-distilled water and allowed to stand for 45 minutes. Sulphate concentrations were determined using a UV-visible spectrophotometer at 420 nm. A blank without BaCl_2 was prepared and analyzed at the same wavelength to account for background interference.

2.4.4 Chloride Determination by Argentometric Titration

An aliquot of 50 mL of sample was measured into a conical flask, and the pH was adjusted to 7-10 using H_2SO_4 for high pH samples or NaOH for low pH samples. Two drops of K_2CrO_4 indicator were added, and the solution was titrated against 0.01 M standard AgNO_3 solution until a pinkish-yellow endpoint was reached. A blank titration using only reagents without water sample was also performed. Chloride concentration was calculated using the equation:

$$\text{Chloride (milligrams per liter (mg/L))} = \frac{X \times N \times 35.5}{1 \text{ mL of sample}} \quad (2)$$

where;

X endpoint volume. N= Normality of AgNO_3 .

2.4.5 Fluoride Determination

Fluoride levels were determined spectrophotometrically using the SPADNS method. Two milliliters of SPADNS reagent were added to ten milliliters of each water sample in a dry square sample cell, and the mixture was swirled. After a one-minute reaction time, the absorbance was measured using a spectrophotometer (AOAC, 2006). According to IS: 10500-2012 standards, the permissible maximum for fluoride in drinking water is 1.5 mg/L, with a recommended level of 1.0 mg/L.

2.4.6 Total Hardness Determination

Total hardness was measured using complexometric titration with an ammonium-ammonium chloride buffer solution and Eriochrome Black T (EBT) indicator. The buffer solution was prepared by combining 1.17 g of EDTA, 16.9 g of ammonium chloride, 780 mg of magnesium sulfate, and 143 mL of ammonium hydroxide solution in 500 mL of distilled water. The solution was stirred until all solids dissolved, and the pH was adjusted to 10.

Prior to titration, the burette was rinsed with EDTA solution and filled with 0.02 M EDTA standard solution. An aliquot of 25 mL of sample water was transferred to a conical flask, followed by the addition of 2 drops of EBT indicator and 1 mL of buffer solution. The solution was then titrated against the EDTA solution until the endpoint was reached. Three blank samples underwent the same process. Total hardness was calculated as calcium carbonate equivalent using the following formula (APHA, 2002):

$$\text{Total hardness of CaCO}_3 \text{ (mg/L)} = \frac{\text{Volume of EDTA} \times \text{Molarity EDTA} \times 50 \times 1000}{\text{Volume of sample}} (3)$$

2.5 Heavy Metal Analysis

2.5.1 Method Validation for Metal Analysis

Heavy metals including iron (Fe), lead (Pb), zinc (Zn), and other trace metals were analyzed using Atomic Absorption Spectroscopy (Buck Scientific, VPG 210). A hollow cathode lamp specific to each metal was installed into the apparatus, and the characteristic wavelength for each metal was established. Samples were digested using standard procedures, and acetylene/air flame atomic absorption spectrophotometry was employed for analysis. Analyte concentrations in milligrams per liter (mg/L) were determined by extrapolation from calibration curves following protocols established by the American Public Health Association (APHA, 2015).

2.5.2 Preparation of Stock Standard Solutions

Working standard solutions for heavy metals were prepared from stock standard solutions containing 1000 parts per million of each element in 2 milliliters of nitric acid. The Atomic Absorption Spectrophotometer was calibrated for each element separately. Calibration curves were generated using the least squares approach and linear correlation. When calculating element concentrations, blank readings were obtained and appropriate adjustments were applied (Dugasa and Endale, 2018).

2.5.3 Instrumental Calibration

The concentrations of heavy metals in sample solutions were determined through calibration curves. From stock standard solutions of 1000 mg/L, intermediate standard solutions (100 mg/L) were prepared for each metal. Working standards were created by serially diluting the intermediate solutions with extraction solution. Following the instrument operation manual, working standards were aspirated into the flame atomic absorption spectrometer, and absorbance was measured to optimize sensitivity. Calibration curves plotting absorbance versus concentration (mg/L) were generated for each metal standard solution. After calibration, sample solutions were aspirated into the FAAS instrument, and direct readings of metal concentrations were

recorded (Dugasa and Endale, 2018).

2.6 Statistical Analysis

Statistical analysis was performed to evaluate the significance of differences among water samples. Analysis of variance (ANOVA) was employed to examine the significance level of each measured parameter. Metal and other parameter values for the water samples were reported in milligrams per liter (mg/L). Pearson's correlation analysis was conducted to determine relationships between various water quality parameters, with significance levels set at $p < 0.05$ and $p < 0.01$ (Moore *et al.*, 2013).

2.6.1 Water Quality Index Calculation

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Water Quality Index (WAWQI) method to provide a comprehensive assessment of water quality. The calculation involved establishing ideal values, permissible standards, and weighting factors for key parameters including pH, electrical conductivity, total hardness, turbidity, COD, DO, nitrate, and fluoride. The WQI values were then used to classify water quality according to established grading systems (Brown *et al.*, 2017).

2.7 Quality Assurance and Quality Control

Following collection, water samples were immediately stored in ice and transported to the laboratory at 4°C. All samples were analyzed within ten hours of collection. This timeframe ensures minimal changes in bacterial concentrations, as research has shown that *E. coli* concentrations are not significantly affected when samples are kept below 10°C for up to 12 hours (Fisher *et al.*, 2015).

For chemical parameter analysis, standard solutions were utilized to ensure quality. Laboratory methodologies adhered to the 2008 WHO standard guidelines and the 1999 APHA Standard procedure for inspection of water and wastewater (APHA, 1999; WHO, 1996). A control sample (bottled water from the center of the local government territory) was included in the study to serve as a reference point for comparison with sachet water samples.

3. Results and Discussions

3.1 Results

Table one present the Physical parameters analysis showing temperature, electrical conductivity, total dissolved solids, and turbidity of bottled water (control) and five sachet water samples from Chikun Local Government Area, with all values falling within WHO limits.

Table 1. Physical Parameters Analysis of sachet water samples

Sample	T(°C)	EC(μscm^{-1})	TDS(mg/L)	Turbidity(NUT)
Bwo	24.90	21.7	7	0.21
SW1	25.10	35.1	8	0.27
SW2	26.05	64.5	11	1.33
SW3	25.15	71.1	9	1.81
SW4	22.10	36.0	9	0.73
SW5	25.20	145.1	10	1.80
WHO Limit	20-25	1000	1000	6

Table two shows the Chemical parameters analysis of bottled and sachet water samples showing pH, anions, metals, and hardness measurements with all parameters falling below WHO limits, indicating water samples are chemically safe for consumption.

Table 2: Chemical parameters Samples Analysis of sachet water samples (all values except pH in mg/L).

Sample	pH	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	F ⁻	Zn	Fe	Ni	Cr	Pb	Mn	Mg ²⁺	Ca ²⁺	TH
BW0	7.00	2.0	0.09	1.24	0.14	1.31	0.01	0.01	0.005	0.001	0.03	8	13	21
SW1	6.58	2.1	0.24	3.20	0.20	2.31	0.04	0.04	0.012	0.002	0.04	8	14	22
SW2	6.26	2.5	0.16	2.60	0.18	1.43	0.02	0.03	0.010	0.002	0.02	10	18	28
SW3	7.20	2.3	0.12	3.24	0.22	2.24	0.01	0.02	0.017	0.001	0.04	10	14	24
SW4	7.20	2.1	0.21	2.90	0.21	2.36	0.03	0.04	0.010	0.001	0.01	8	14	22
SW5	6.58	2.2	0.18	3.20	0.18	2.25	0.01	0.03	0.016	0.003	0.02	10	15	25

WHO Limit	6.5- 8.5	250	250	250	1.5	3	0.3	0.1	0.05	0.01	0.5	50	NS	150
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Key: NS = No Standard, ND = No detection limit, BWo = Control Sample, SW1 = Tesram Water, SW2 = Emma Rose Water, SW3 = Shangah Water, SW4 = Gracious Water, SW5 = Kinugu Water

Table three present the Significant correlations between water quality parameters highlighting 24 statistically significant relationships, particularly strong correlations between turbidity-magnesium ($r=0.939^{**}$) and chloride-COD ($r=0.968^{**}$), suggesting related contamination sources in water samples.

TABLE 3: Significant Correlations between Quality Parameters of Bottle Water (BW) and Sachet Water (SW) in Chikun Local Government Area of Kaduna State

Parameter Pair	Correlation Coefficient (r)	Significance Level	Interpretation
Turbidity - Mg^{2+}	0.939**	$p<0.01$	Strong positive correlation suggesting suspended particles may contribute to magnesium content
Cl - COD	0.968**	$p<0.01$	Strong positive correlation indicating potential organic contamination sources that contribute to chloride levels
TDS - TH	0.931**	$p<0.01$	Strong positive correlation between total dissolved solids and total hardness
Cl - TH	0.953**	$p<0.01$	Strong positive correlation between chloride content and total hardness
SO_4 - Ni	0.972**	$p<0.01$	Very strong positive correlation between sulfate and nickel
Ca^{2+} - TH	0.944**	$p<0.01$	Strong positive correlation between calcium and total hardness
COD - TH	0.984**	$p<0.01$	Very strong positive correlation between chemical oxygen demand and total hardness
EC - Turbidity	0.820*	$p<0.05$	Strong positive correlation between electrical conductivity and turbidity
TDS - Cl	0.870*	$p<0.05$	Strong positive correlation between total dissolved solids and chloride
NO_3 - F	0.858*	$p<0.05$	Strong positive correlation between nitrate and fluoride
NO_3 - Zn	0.840*	$p<0.05$	Strong positive correlation between nitrate and zinc
NO_3 - Cr	0.870*	$p<0.05$	Strong positive correlation between nitrate and chromium
SO_4 - Fe	0.851*	$p<0.05$	Strong positive correlation between sulfate and iron

Fe - Ni	0.812*	p<0.05	Strong positive correlation between iron and nickel
Cl - Mg ²⁺	0.816*	p<0.05	Strong positive correlation between chloride and magnesium
TDS - Ca ²⁺	0.888*	p<0.05	Strong positive correlation between total dissolved solids and calcium
Cl - Ca ²⁺	0.894*	p<0.05	Strong positive correlation between chloride and calcium
Mg ²⁺ - TH	0.849*	p<0.05	Strong positive correlation between magnesium and total hardness
Mn - BOD	-0.887*	p<0.05	Strong negative correlation between manganese and biochemical oxygen demand
TDS - COD	0.914*	p<0.05	Strong positive correlation between total dissolved solids and chemical oxygen demand
Mg ²⁺ - COD	0.897*	p<0.05	Strong positive correlation between magnesium and chemical oxygen demand
Ca ²⁺ - COD	0.891*	p<0.05	Strong positive correlation between calcium and chemical oxygen demand
TDS - DO	0.822*	p<0.05	Strong positive correlation between total dissolved solids and dissolved oxygen
Ca ²⁺ - DO	0.848*	p<0.05	Strong positive correlation between calcium and dissolved oxygen

*Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Key:

- EC: Electrical Conductivity
- TDS: Total Dissolved Solids
- TH: Total Hardness
- BOD: Biochemical Oxygen Demand
- COD: Chemical Oxygen Demand
- DO: Dissolved Oxygen

3.2 Discussion

The results of this study provide significant insights into the physical and chemical quality of sachet water sold in Chikun Local Government Area of Kaduna State, Nigeria. The findings reveal both conformities and deviations from WHO drinking water quality guidelines, with important implications for public health.

Physical Parameters

The temperature of the analyzed sachet water samples ranged from 22.10°C to 26.05°C, with most samples slightly exceeding the WHO recommended range of 20-25°C. While these minor temperature variations may not pose direct health risks, they could influence water palatability and potentially accelerate chemical reactions within the polyethylene packaging (Adedire et al., 2021). Similar temperature variations were reported by Okoro *et al.* (2023) in sachet water samples from Yola Metropolis.

Electrical conductivity (EC) values ranged from 21.7 to 145.1 µS/cm, well below the WHO limit of 1000 µS/cm. The relatively low EC values indicate minimal dissolved ionic substances in the water samples, suggesting adequate treatment processes. However, the considerable variation in EC values among different brands (with SW5 showing notably higher conductivity) indicates differences in mineral content and treatment efficacy among manufacturers, consistent with findings by Mohammed *et al.* (2023) in Kano State.

Total dissolved solids (TDS) ranged from 7 to 11 mg/L, significantly below the WHO maximum permissible limit of 1000 mg/L. These low TDS values suggest effective filtration processes but may also indicate excessively demineralized water, which could impact taste acceptability. Ngumbira (2020) similarly reported low TDS values in sachet water samples in Malawi, attributing this to excessive treatment processes that remove beneficial minerals.

Turbidity values ranged from 0.21 to 1.81 NTU, all within the WHO limit of 6 NTU. The low turbidity values indicate good clarity and effective removal of suspended particles during treatment. However, samples SW2, SW3, and SW5 showed relatively higher turbidity values compared to others, suggesting potential differences in filtration efficiency or post-production contamination.

Chemical Parameters

The pH values of the sachet water samples ranged from 6.26 to 7.20, generally within the WHO recommended range of 6.5-8.5, except for SW2 (pH 6.26), which was slightly acidic. This slight acidity in SW2 could potentially increase the leaching of metals from the packaging material, as suggested by Addo et al. (2019). The correlation analysis reveals a negative relationship between pH and lead concentration ($r = -0.768$), supporting this concern.

Chloride, sulfate, nitrate, and fluoride concentrations were well below WHO limits in all samples. The low levels of these anions suggest minimal risk of taste issues or health concerns related to these parameters. However, the correlation analysis revealed a significant positive correlation between nitrate and zinc ($r = 0.840$, $p < 0.05$), as well as between nitrate and chromium ($r = 0.870$, $p < 0.05$), suggesting potential common sources or pathways for these contaminants.

Among the analyzed heavy metals, all samples contained zinc, iron, nickel, chromium, lead, and manganese at concentrations below WHO limits. This is a positive finding, indicating minimal risk of heavy metal toxicity from the consumption of these sachet water brands. However, the presence of lead, albeit at low concentrations (0.001-0.003 mg/L), warrants attention due to its bioaccumulative properties and the absence of a safe threshold for lead exposure, particularly for vulnerable populations like children (Akpen *et al.*, 2018).

Total hardness values ranged from 21 to 28 mg/L, well below the WHO limit of 150 mg/L. These low

hardness values classify the water samples as "soft water," which generally has good lathering properties with soap but may be more corrosive to metal pipes and containers. The correlation analysis showed significant positive correlations between total hardness and calcium ($r = 0.944$, $p < 0.01$), magnesium ($r = 0.849$, $p < 0.05$), and chemical oxygen demand (COD) ($r = 0.984$, $p < 0.01$).

The correlation analysis further revealed significant relationships between various parameters, suggesting potential common sources or treatment effects. For instance, the strong positive correlation between turbidity and magnesium ($r = 0.939$, $p < 0.01$) suggests that suspended particles may contribute to magnesium content in the water. Similarly, the significant correlation between chloride and chemical oxygen demand ($r = 0.968$, $p < 0.01$) indicates potential organic contamination sources that also contribute to chloride levels.

Comparing the results with similar studies conducted in other regions of Nigeria, the sachet water samples from Chikun LGA generally showed better compliance with WHO guidelines than those reported by Ezetoha *et al.* (2024) in Anambra State and Joshua *et al.* (2019) in Sabon Gari LGA of Kaduna State. This suggests potentially better regulatory oversight or manufacturing practices in the study area, though variations among brands indicate inconsistencies in quality control.

Conclusion

Although the physical and chemical characteristics of the examined sachet water samples mostly met WHO criteria, the differences between brands show that quality standards need to be strictly enforced and monitored consistently. Additionally, the detection of trace levels of heavy metals, especially lead, emphasizes the significance of routine monitoring to avoid any health hazards from prolonged exposure.

Declaration of Conflicting Interests

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