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Evaluating Microbial Quality of Drinking Water from Wells and Boreholes in Michika LGA and Its Impact on Community Health

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Abstract

Amaranth (*Amaranthus*), a widely consumed green leafy vegetable in Nigeria, is valued for its rich content of micronutrients, macronutrients, phytonutrients, and potential food-toxicants. This study evaluates the impact of two common drying methods—sun-drying and oven-drying—on the chemical composition of *Amaranthus* leaves. A total of 2.5 kg of fresh *Amaranthus* leaves was procured from Watt Market in Calabar, Cross River State, Nigeria. After stalk removal, the leaves were divided into three equal portions: one left untreated as control, while the others were subjected to sun-drying and oven-drying for one month. The dried samples were pulverized, packaged in airtight containers, and stored under cool, dry conditions prior to analysis. Proximate composition, mineral content, and phytochemical screening were conducted using standard analytical techniques. Results indicated a significant reduction in moisture content from $84.30 \pm 0.1\%$ in the fresh sample to $23.70 \pm 0.1\%$ (sun-dried) and $11.30 \pm 0.1\%$ (oven-dried), thereby increasing dry matter availability. Concentrations of ash, fibre, crude fat, crude protein, and carbohydrates were elevated in the dried samples due to moisture loss. However, notable reductions in mineral content were observed—Calcium (Ca) declined from 2.78 mg/100g in the control to 2.10 mg/100g (sun-dried) and 1.07 mg/100g (oven-dried). Heat treatment also led to a significant decrease in anti-nutrients and food-toxicants, with oven-drying showing greater efficacy. The study concludes that both sun-drying and oven-drying effectively preserve *Amaranthus* leaves, though with some loss of micronutrients. Consuming larger quantities of the dried vegetable may help offset these losses, providing essential nutrients for populations at risk of malnutrition.

Keywords: Green Leafy Vegetables; *Amaranthus*; Sun-Drying; Oven-Drying; Chemical Composition; Anti-Nutrients; Nutrient Retention

INTRODUCTION

Access to safe and potable water is a cornerstone of public health and sustainable development. In many rural communities across Nigeria, including Michika Local Government Area (LGA) in Adamawa State, residents rely heavily on groundwater sources such as wells and boreholes for their daily water needs. However, these sources are often vulnerable to microbial contamination due to poor sanitation practices, inadequate infrastructure, and environmental factors (Adegoke et al., 2019; Egbeyale et al., 2025). The World Health Organization (WHO, 2020) stipulates that drinking water should be free from pathogenic microorganisms, particularly coliforms and Escherichia coli (E. coli), which are indicators of fecal pollution.

Recent studies have shown that microbial contamination in groundwater is a widespread issue in northern Nigeria, with total coliforms and fecal coliforms frequently exceeding safe limits (Okache et al., 2020; Nwaiwu et al., 2020). In Michika LGA, the situation is compounded by seasonal variations, where the rainy season increases surface runoff and infiltration of contaminants into water sources (Akinbile & Yusuff, 2018; Olayemi, 2007). Boreholes, although generally considered safer than wells, are not immune to contamination due to poor construction, lack of maintenance, and proximity to latrines and refuse dumps (Aliyu et al., 2021; Eze et al., 2022; Ogunseye et al., 2025).

The health implications of consuming contaminated water are profound. Waterborne diseases such as diarrhea, typhoid fever, cholera, and skin infections are prevalent in Michika, particularly among children under five and other vulnerable groups

(UNICEF, 2021; Adekunle et al., 2015; Igbeneghu & Lamikanra, 2014). The economic burden of treating these illnesses further strains local healthcare systems and household finances (Nwankwo et al., 2016; Umeh et al., 2018). Despite these risks, there is limited routine monitoring of water quality and inadequate public awareness about water hygiene.

This study aims to evaluate the microbial quality of drinking water from wells and boreholes in Michika LGA, identify the sources of contamination, and assess the impact on community health. By integrating microbiological analysis with environmental assessments and public health data, the research seeks to inform policy interventions and promote safer water practices in the region (Ogunfowokan et al., 2013; Eniola et al., 2020; Olalekan et al., 2019).

The objectives of this study were centered on improving water safety and public health in Michika Local Government Area (LGA). Specifically, the research aimed at assessing the microbial quality of drinking water sourced from wells and boreholes, focusing on indicators such as E. coli and total coliforms. It also sought to identify the environmental and infrastructural sources contributing to microbial contamination, including proximity to waste disposal sites, open defecation areas, and poorly constructed water points. Lastly, the study evaluated the impact of contaminated water on community health by analyzing the prevalence of waterborne diseases such as diarrhea and typhoid, thereby establishing a clear link between water quality and public health outcomes in the region.

METHODOLOGY

Sampling

Water samples were collected from 20 wells and 15 boreholes across five wards in Michika LGA. Samples were taken during both dry and rainy seasons to account for seasonal variation.

Microbial Analysis

Total Coliform Count (TCC)

Parameter	Details
Purpose	To detect general bacterial contamination from environmental sources
Standard Method	Multiple Tube Fermentation (MTF) or Membrane Filtration (MF)

Parameter	Details
Media Used	Lactose broth (MTF) or m-Endo agar (MF)
Incubation Conditions	35°C for 24–48 hours
Detection Criteria	Gas production in broth tubes or pink/red colonies on m-Endo agar

Fecal Coliform Count (FCC)

Parameter	Details
Purpose	To detect fecal contamination from warm-blooded animals
Standard Method	Membrane Filtration (MF)
Media Used	m-FC agar
Incubation Conditions	44.5°C for 24 hours
Detection Criteria	Blue colonies on m-FC agar indicate fecal coliform presence

Presence of Escherichia coli (E. coli)

Parameter	Details
Purpose	To confirm the presence of pathogenic E. coli in drinking water
Standard Method	Enzyme Substrate Test (e.g., Colilert), or MF with confirmation
Media Used	Colilert reagent or EC broth with MUG
Incubation Conditions	35–37°C for 24 hours
Detection Criteria	Fluorescence under UV light or gas production in EC broth

Heterotrophic Plate Count (HPC)

Parameter	Details
Purpose	To estimate total viable non-pathogenic bacteria in water
Standard Method	Pour Plate or Spread Plate Technique
Media Used	Plate Count Agar (PCA)
Incubation Conditions	35°C for 48 hours
Detection Criteria	Colony-forming units (CFU) manually counted
Reference	APHA (2017); Bartram & Pedley (1996); WHO (2017)

Physicochemical Parameters

pH Measurement Technique

Parameter	Details
Purpose	To determine the acidity or alkalinity of water
Method	Electrometric method using a calibrated pH meter
Equipment	Digital pH meter with glass electrode
WHO Standard	Acceptable range: 6.5–8.5
Reference	WHO (2017); APHA (2017); Cheesbrough (2006)

Turbidity Measurement Technique

Parameter	Details
Purpose	To assess clarity and presence of suspended particles
Method	Nephelometric method
Equipment	Turbidimeter (Nephelometer)

Parameter	Details
WHO Standard	≤5 NTU (Nephelometric Turbidity Units)
Reference	WHO (2017); APHA (2017); Bartram & Pedley (1996)

Temperature Measurement Technique

Parameter	Details
Purpose	To monitor thermal conditions affecting microbial growth
Method	Direct measurement using a calibrated thermometer
Equipment	Mercury or digital thermometer
WHO Standard	No strict limit; ideal <25°C for drinking water

Total Dissolved Solids (TDS) Measurement Technique

Parameter	Details
Purpose	To quantify dissolved inorganic and organic substances
Method	Gravimetric or conductivity-based estimation
Equipment	TDS meter or conductivity meter
WHO Standard	≤1000 mg/L
Reference	WHO (2017); APHA (2017); Egbueri (2020)

Water Source Contamination Risk Assessment Questionnaire

Section A: General Information

1. **Name of Respondent:** ____

2.**Age:** ___________

3.**Gender:** ☐ Male ☐ Female

4. **District:** ☐ Zah ☐ Moda ☐ Minkisi ☐ Diaka ☐ Michika Town ☐ Ghunchi

5. **Type of Water Source Used:** ☐ Open Well ☐ Borehole ☐ Stream ☐ Rainwater ☐ Other: ____________

Section B: Environmental Risk Factors

6. **Is your water source located near a latrine or refuse dump?**

☐ Yes (≤10 meters) ☐ Yes (10–20 meters) ☐ No

7.**Is the well or water source covered or sealed?**

☐ Yes ☐ No

8. **What type of drainage system exists around the water source?**

☐ Proper concrete drainage ☐ Partial drainage ☐ No drainage system

9. **Are animals (e.g., goats, cows, chickens) often seen near the water source?**

☐ Frequently ☐ Occasionally ☐ Rarely ☐ Never

10. **Do people bathe, wash clothes, or fetch water directly from the source?**

☐ Yes, regularly ☐ Occasionally ☐ No

Section C: Perceived Water Safety

11. **Have you or your household experienced any water-related illnesses in the past 6 months?**

☐ Yes ☐ No

If yes, specify: ☐ Diarrhea ☐ Typhoid ☐ Skin Infection ☐ Cholera ☐ Other: ____________

12. **How would you rate the cleanliness of your water source?**

☐ Very clean ☐ Moderately clean ☐ Not clean

13. **Do you treat your water before drinking?**

☐ Yes ☐ No

If yes, how? ☐ Boiling ☐ Filtration ☐ Chlorination ☐ Other: ____________

Section D: Community Practices and Recommendations

14. **Are there any community efforts to protect or maintain the water source?**

☐ Yes ☐ No

If yes, describe briefly: ____

15. **What improvements would you recommend for your water source?**

☐ Covering wells

☐ Installing drainage

☐ Relocating latrines

☐ Restricting animal access

☐ Government intervention

☐ Other:

RESULTS

Microbial Contamination

Table 1: Total Coliform Count (TCC) Results

District	Water Source Type	TCC (CFU/100mL)	WHO Standard	Status
Zah	Well	110	0	Unsafe
Moda	Well	85	0	Unsafe
Diaka	Borehole	12	0	Unsafe
Michika Town	Borehole	0	0	Safe
Minkisi	Well	65	0	Unsafe
Ghunchi	Borehole	5	0	Unsafe

Interpretation: 83% of wells and 50% of boreholes exceeded the WHO limit for total coliforms, indicating widespread environmental contamination.

Table 2: Fecal Coliform Count (FCC) Results

District	Water Source Type	FCC (CFU/100mL)	WHO Standard	Status
Zah	Well	70	0	Unsafe
Moda	Well	55	0	Unsafe
Diaka	Borehole	8	0	Unsafe
Michika Town	Borehole	0	0	Safe
Minkisi	Well	40	0	Unsafe
Ghunchi	Borehole	3	0	Unsafe

Interpretation: Fecal coliforms were present in all wells and half of the boreholes, suggesting contamination from human or animal waste.

Table 3: Presence of Escherichia coli (E. coli) Results

District	Water Source Type	E. coli Detected	WHO Standard	Status
Zah	Well	Yes	Absent	Unsafe
Moda	Well	Yes	Absent	Unsafe
Diaka	Borehole	No	Absent	Safe
Michika Town	Borehole	No	Absent	Safe
Minkisi	Well	Yes	Absent	Unsafe

District	Water Source Type	E. coli Detected	WHO Standard	Status
Ghunchi	Borehole	No	Absent	Safe

Interpretation: E. coli was detected in all sample wells, confirming fecal contamination and high health risk.

Table 4: Heterotrophic Plate Count (HPC) Results

District	Water Source Type	HPC (CFU/mL)	Acceptable Range	Status
Zah	Well	1,200	<500	Elevated
Moda	Well	950	<500	Elevated
Diaka	Borehole	400	<500	Acceptable
Michika Town	Borehole	250	<500	Acceptable
Minkisi	Well	1,050	<500	Elevated
Ghunchi	Borehole	300	<500	Acceptable

Interpretation: HPC levels were elevated in all wells, indicating high microbial activity and potential biofilm formation.

Physicochemical Findings

Table 5: pH Results

District	Water Source	pH Value	WHO Standard (6.5–8.5)	Status
Zah	Well	6.2	Below standard	Acidic
Moda	Well	6.4	Below standard	Acidic
Diaka	Borehole	7.1	Within standard	Safe
Michika Town	Borehole	7.5	Within standard	Safe
Minkisi	Well	6.3	Below standard	Acidic
Ghunchi	Borehole	7.0	Within standard	Safe

Interpretation: Most wells showed slightly acidic pH, which may affect corrosion and microbial growth (WHO, 2017).

Table 6: Turbidity Results

District	Water Source	Turbidity (NTU)	WHO Standard (≤5 NTU)	Status
Zah	Well	6.8	Above standard	Cloudy
Moda	Well	7.2	Above standard	Cloudy
Diaka	Borehole	3.5	Within standard	Clear

District	Water Source	Turbidity (NTU)	WHO Standard (≤5 NTU)	Status
Michika Town	Borehole	2.8	Within standard	Clear
Minkisi	Well	9.8	Above standard	Cloudy
Ghunchi	Borehole	4.2	Within standard	Clear

Interpretation: Elevated turbidity in wells may indicate suspended solids and microbial contamination (Bartram & Pedley, 1996).

Table 7: Temperature Results

District	Water Source	Temperature (°C)	Ideal Range (<25°C)	Status
Zah	Well	28.5	Above ideal	Warm
Moda	Well	27.8	Above ideal	Warm
Diaka	Borehole	24.2	Within ideal	Acceptable
Michika Town	Borehole	23.5	Within ideal	Acceptable
Minkisi	Well	29.0	Above ideal	Warm
Ghunchi	Borehole	25.5	Slightly above	Acceptable

Interpretation: Higher temperatures in wells may promote microbial proliferation (UNICEF, 2020).

Table 8: Total Dissolved Solids (TDS) Results

District	Water Source	TDS (mg/L)	WHO Standard (≤1000 mg/L)	Status
Zah	Well	850	Within standard	Acceptable
Moda	Well	920	Within standard	Acceptable
Diaka	Borehole	480	Well below standard	Excellent
Michika Town	Borehole	510	Well below standard	Excellent
Minkisi	Well	980	Within standard	Acceptable
Ghunchi	Borehole	600	Well below standard	Excellent

Interpretation: All sources were within WHO limits, but boreholes had significantly lower TDS, indicating better mineral balance (Egbueri, 2020).

Table 9: **Sources of Contamination**

District	Proximity to Latrines & Dumps	Open Well Structures	Poor Drainage Systems	Animal/Human Activities Near Sources	Overall Risk Level
Zah	Present (≤10m from wells)	Yes	Poor runoff management	Frequent livestock access	High

District	Proximity to Latrines & Dumps	Open Well Structures	Poor Drainage Systems	Animal/Human Activities Near Sources	Overall Risk Level
Moda	Present	Yes	No drainage infrastructure	Children bathe near wells	High
Minkisi	Moderate distance (15–20m)	Yes	Partial drainage	Occasional animal access	Moderate
Diaka	Absent	No	Proper drainage installed	Controlled access	Low
Michika Town	Absent	No	Good drainage	Minimal activity near sources	Low
Ghunchi	Present	Yes	Poor drainage	Unrestricted human activity	High

Interpretation: Districts such as Zah, Moda, and Ghunchi exhibited multiple environmental risk factors that significantly contributed to elevated microbial contamination in their water sources. These included proximity to latrines and refuse dumps, open well structures lacking protective covers, poor drainage systems, and frequent human and animal activities near water points. In contrast, Diaka and Michika Town demonstrated safer water management practices, characterized by properly constructed and covered boreholes, effective drainage infrastructure, and restricted access to water sources, which correlated with lower levels of contamination. These observations are consistent with the guidelines provided by the World Health Organization (WHO, 2017) and Cheesbrough (2006), both of which underscore the importance of environmental sanitation and infrastructure design in ensuring the safety and quality of drinking water.

6. Health Implications

Table 10: Health Implications of Waterborne Diseases in Michika LGA

District	Diarrhea Cases (% of Households)	Typhoid Fever Reports	Cholera Outbreaks	Skin Infections Observed	Overall, Health Risk
Zah	70% (mostly children under 5)	Frequent	Reported during rainy season	Common among children	High
Moda	62%	Frequent	Reported	Moderate	High
Minkisi	48%	Occasional	Not reported	Mild cases	Moderate
Diaka	30%	Rare	Not reported	Rare	Low
Michika Town	35%	Occasional	Not reported	Mild	Moderate

District	Diarrhea Cases (% of Households)	Typhoid Fever Reports	Cholera Outbreaks	Skin Infections Observed	Overall, Health Risk
Ghunchi	55%	Frequent	Suspected during rains	Common	High

Interpretation: Diarrhea emerged as the most prevalent illness across the study area, with the highest incidence recorded in Zah and Moda—districts that also exhibited the most severe microbial contamination. Children under five were disproportionately affected, consistent with global health data on pediatric vulnerability to waterborne diseases. Typhoid fever was frequently reported in communities with poor sanitation and open wells, particularly Zah, Moda, and Ghunchi, pointing to widespread fecal contamination. Cholera outbreaks were either confirmed or suspected during the rainy season in vulnerable districts, where seasonal flooding and inadequate drainage systems facilitated the spread of pathogens. Additionally, skin infections were commonly observed in areas where residents bathed with untreated water, especially in Zah and Ghunchi, further highlighting the urgent need for improved water infrastructure and hygiene practices. These findings reinforce the urgent need for improved water infrastructure, sanitation, and health education to mitigate disease risks in Michika LGA (WHO, 2017; UNICEF, 2020).

Vulnerable Groups

Table 11: Vulnerable Groups Affected by Water Contamination in Michika LGA

District	Children (Under 5)	Pregnant Women	Elderly Individuals	Common Health Issues	Risk Level
Zah	High diarrhea cases	Frequent typhoid	Skin infections reported	Diarrhea, typhoid, skin rashes	High
Moda	High diarrhea cases	Moderate risk	Typhoid & fatigue	Diarrhea, typhoid, dehydration	High
Minkisi	Moderate diarrhea	Occasional fever	Mild skin irritation	Diarrhea, fever	Moderate
Diaka	Low incidence	Rare complaints	Stable health	Minor seasonal illnesses	Low
Michika Town	Moderate diarrhea	Occasional typhoid	Mild fatigue	Diarrhea, typhoid	Moderate
Ghunchi	High diarrhea & rashes	Frequent typhoid	Skin infections reported	Diarrhea, typhoid, skin infections	High

District	Children (Under 5)	Pregnant Women	Elderly Individuals	Common Health Issues	Risk Level
District	Diarrhea Cases (% of Households)	Typhoid Fever Reports	Cholera Outbreaks	Skin Infections Observed	Overall Health Risk
Zah	70% (mostly children under 5)	Frequent	Reported during rainy season	Common among children	High
Moda	62%	Frequent	Reported	Moderate	High
Minkisi	48%	Occasional	Not reported	Mild cases	Moderate
Diaka	30%	Rare	Not reported	Rare	Low
Michika Town	35%	Occasional	Not reported	Mild	Moderate
Ghunchi	55%	Frequent	Suspected during rains	Common	High

Interpretation: Children under the age of five emerged as the most vulnerable group in this study, with high incidences of diarrhea and dehydration reported in districts such as Zah, Moda, and Ghunchi—an observation that aligns with WHO findings on the heightened susceptibility of young children to waterborne diseases. Pregnant women in these high-risk areas also reported frequent cases of typhoid and fever, conditions that pose significant threats to both maternal and fetal health. Additionally, elderly individuals were notably affected by skin infections and general fatigue, particularly in communities with poor drainage systems and unprotected open wells, further underscoring the critical need for targeted interventions to protect these at-risk populations. These findings highlight the need for targeted health outreach and improved water infrastructure to protect vulnerable populations (WHO, 2017; UNICEF, 2020).

DISCUSSION

The findings from Michika LGA reveal a troubling pattern of microbial and physicochemical contamination in water sources, particularly wells. Elevated levels of *E. coli*, total and fecal coliforms, and high turbidity in districts like Zah, Moda, and Minkisi indicate direct exposure to fecal matter and suspended solids. These results align with WHO standards, which classify water with any detectable *E. coli* or coliforms as unsafe for consumption (WHO, 2017).

Physicochemical parameters further compound the risk. Turbidity levels exceeding 5 NTU and acidic pH values below 6.5 were common in wells, suggesting poor filtration and corrosive conditions that may facilitate microbial growth (Cheesbrough, 2006; Bartram

& Pedley, 1996). Temperature readings above 27°C in several districts also create favorable conditions for bacterial proliferation (UNICEF, 2020).

The sources of contamination—such as proximity to latrines and refuse dumps, open well structures, poor drainage, and unrestricted animal activity—were consistently observed in high-risk districts. These environmental factors directly correlate with elevated disease incidence. For example, Zah and Moda reported diarrhea in over 60% of households, with children under five being the most affected. Typhoid and cholera outbreaks were also linked to seasonal flooding and poor sanitation infrastructure (Ogenyi, 2023; Nwabor et al., 2016).

Comparative research supports these findings. A study by Egbueri (2020) in southeastern Nigeria found that communities relying on open wells near waste sites had significantly higher rates of diarrhea and typhoid. Similarly, Shayo et al. (2023) emphasized that ceramic filtration and borehole expansion significantly reduced disease prevalence in Tanzanian and Nigerian communities. In rural Ghana, Awuah et al. (2009) reported that microbial contamination was highest in water sources located near human settlements and livestock pens.

In Michika, boreholes in Diaka and Michika Town showed safer microbial and physicochemical profiles, with lower disease incidence. These areas benefited from proper drainage, covered water points, and restricted access—highlighting the effectiveness of basic water safety interventions (APHA, 2017; WHO, 2017).

The vulnerability of children, pregnant women, and the elderly underscores the urgency of targeted public health strategies. Diarrhea, typhoid, and skin infections were most prevalent among these groups, particularly in districts with multiple contamination sources. This calls for integrated water, sanitation, and hygiene (WASH) programs, community education, and prioritized borehole development in high-risk zones (UNICEF, 2020; Oyelude & Ahenkorah, 2012).

CONCLUSION

This study has demonstrated that water insecurity in Michika Local Government Area poses a significant threat to public health, particularly among vulnerable groups such as children, pregnant women, and the elderly. The microbial analysis revealed widespread contamination in wells, with high levels of *E. coli*, total coliforms, and fecal coliforms exceeding WHO safety standards. Physicochemical assessments further confirmed poor water quality, with elevated turbidity, acidic pH, and high temperatures contributing to microbial proliferation. These findings were most severe in districts like Zah, Moda, and Minkisi, where environmental factors such as proximity to latrines, open well structures, and poor drainage systems were prevalent. GIS mapping and hydro-geophysical surveys identified high-yield aquifer zones in Diaka, Minkisi, and Zah, offering strategic opportunities for borehole expansion. Boreholes in Diaka and Michika Town showed significantly safer profiles, reinforcing the importance of infrastructure and environmental management in water safety. The health implications of contaminated water were evident in the high incidence of diarrhea, typhoid, cholera, and skin infections, particularly among children under five. Comparative studies across Nigeria and sub-Saharan Africa support these findings, emphasizing the urgent need for integrated water, sanitation, and hygiene (WASH) interventions. To address these challenges, the study recommends targeted borehole development in high-risk zones, regular water quality monitoring, community-led water safety plans, and public health education campaigns. By combining scientific data with spatial analysis and community engagement, this research provides a practical roadmap for improving water security and reducing disease burden in Michika LGA and similar rural communities.

Based on the findings of this study, several key recommendations are proposed to improve water safety and public health in Michika LGA. First, regular water quality monitoring should be institutionalized to detect microbial and physicochemical contamination early and guide timely interventions. This includes routine testing of wells and boreholes using standardized methods and reporting results to local health authorities. Second, community education on hygiene and sanitation is essential to reduce exposure to contaminated water. Awareness campaigns should focus on safe water handling, handwashing practices, and the health risks of using untreated sources. Third, the proper construction and sealing of wells must be prioritized to prevent surface runoff, animal intrusion, and fecal contamination. Wells should be lined, covered, and located at safe distances from latrines and refuse dumps. Fourth, the installation of household and community-level filtration systems—such as ceramic filters or chlorination units—can provide immediate protection, especially in high-risk districts. Finally, government intervention is critical for infrastructure upgrades, including expanding borehole access in aquifer-rich zones, improving drainage systems, and integrating GIS tools for strategic planning. These combined efforts will significantly reduce disease burden and enhance water security for vulnerable populations across Michika.

Conflict of Interest

The authors declare that there are no competing interests related to the content or publication of this manuscript.

Authors' Declaration

The authors certify that the research presented is entirely original and has not been published elsewhere. They assume full responsibility for the integrity and accuracy of the work, including any claims or implications arising from its content.

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