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Physical, Chemical, and Biological Characteristics of Water Sources Adopted by Secondary Schools in Mbeere South Sub-County, Kenya

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Abstract

Purpose: This study assessed the quality of water sources used by secondary schools in Mbeere South Sub-County, an arid and semi-arid area of Kenya, and examined schools' adaptive strategies to water challenges. Grounded in Resource Dependence Theory (RDT), the study contributes to SDG 6 (clean water and sanitation).

Methodology: A descriptive survey design was adopted. A census of all 33 secondary schools was conducted. Data were collected through structured questionnaires, observation checklists, and laboratory analysis of water samples from earth dams, rainwater, piped water, and boreholes. Nineteen physico-chemical and microbiological parameters were analysed according to WHO and APHA standards.

Findings: Significant differences in water quality were found across sources (one-way ANOVA: $F(4,335) = 12.62$, $p < 0.001$). Rainwater was the safest, while piped water showed post-treatment coliform recontamination. Earth dams had high turbidity and microbial contamination, and boreholes were microbiologically safe but very hard. Two-way ANOVA confirmed strong source and interaction effects.

Unique Contribution to Theory, Policy and Practice: The study advances Resource Dependence Theory by showing how schools mitigate water risks through source diversification. It recommends first-flush disinfection for rainwater, chlorination of piped water, catchment protection for dams, borehole softening, and regular school-based monitoring. These findings provide practical policy directions for improving WASH resilience in ASAL secondary schools.

Keywords: *Water Sources, Physico-Chemical properties, Biological Characteristics, Secondary Schools*

Introduction

1.1 Background Information

Access to safe and reliable water is fundamental for human health, educational continuity, and environmental sustainability, particularly in water-stressed regions (United Nations, 2021). Globally, schools consume substantial volumes of water for drinking, sanitation, and hygiene; however, in low-income countries, approximately 70% lack basic drinking water services (UNESCO, 2022). In Sub-Saharan Africa, over one-third of schools lack adequate water, sanitation, and hygiene (WASH) facilities, thereby exacerbating health risks and disrupting learning (UNICEF, 2021).

Kenya, with a per capita water availability of 640 m^3 (the lowest in East Africa) faces acute challenges in ASALs, where erratic rainfall and overexploitation intensify scarcity (Gikandi et al., 2020). Mbeere South Sub-County, an ASAL in Embu County, exemplifies these issues, with schools depending on boreholes, rainwater harvesting, piped supplies, and earth dams amid frequent shortages (Njeru, 2021). While national policies promote the use of sustainable sources, such as rainwater harvesting (Ministry of Water and Sanitation, 2020), their adoption is hindered by quality inconsistencies, including contamination from runoff or infrastructure failures (Nyaga et al., 2021). Physicochemical parameters (such as pH, TDS, and turbidity) and microbiological indicators (coliforms) are critical for assessing potability; however, localized data in ASAL schools remain scarce (Sila, 2019). This study addresses this gap by characterizing water sources in Mbeere South secondary schools, providing evidence for targeted interventions to safeguard student health and operational resilience.

1.2 The Statement of the Problem

Secondary schools in Mbeere South Sub-County face challenges with unreliable water sources, which are exacerbated by the ASAL conditions, leading to potential health hazards due to the poor physicochemical and microbiological quality of the water. Despite relying on earth dams, rainwater, piped water, and boreholes, empirical assessments of the safety of these sources are limited, hindering evidence-based management. Existing policies overlook sub-regional variations, resulting in untreated waters with elevated turbidity, hardness, and coliforms, which compromise WASH services and SDG 6 targets. Without comprehensive characterization, schools perpetuate vulnerabilities, including diarrheal diseases and learning disruptions, underscoring the need for this study to evaluate water quality parameters and inform sustainable strategies.

1.3 Research Objective

To determine the physical-chemical and biological characteristics of water sources adopted by secondary schools within Mbeere South Sub-county in Kenya.

1.4 Theoretical Framework

This study was based on Resource Dependence Theory (RDT). RDT was initially developed by Pfeffer and Salancik (1978), who argued that organizations depend on resources from outside the organization, and that trust, courtesy, support, and task behaviour related to acquiring and managing resources influence organizational behaviour. Secondary schools, especially in rural areas, often rely on external sources of water to continue operating. This aligns with RDT, which states that organizational decisions, such as those regarding water use, are influenced by external factors like government policies, community dynamics, and technological availability. In ASAL schools, water sources represent critical external dependencies, where quality variability (including contamination risks) necessitates adaptations such as source diversification or treatment (Davis & Cobb, 2020). RDT explains schools' reliance on multiple sources. For instance, rainwater for low TDS, boreholes for reliability, while highlighting vulnerabilities such as piped contamination from distribution failures (Mworia, 2018). By framing water quality assessment within RDT, the study elucidates how schools manage dependence on safe water to sustain operations, aligning with empirical applications in resource-scarce contexts (Collins & Flynn, 2015). This theory highlights the interplay between external quality constraints and internal conservation strategies, providing insights into pathways to reduced dependence through enhanced monitoring and sustainable sourcing.

Methodology

2.1 Location of Study

The study was conducted in Mbeere South Sub-County, located in Embu County, Kenya.

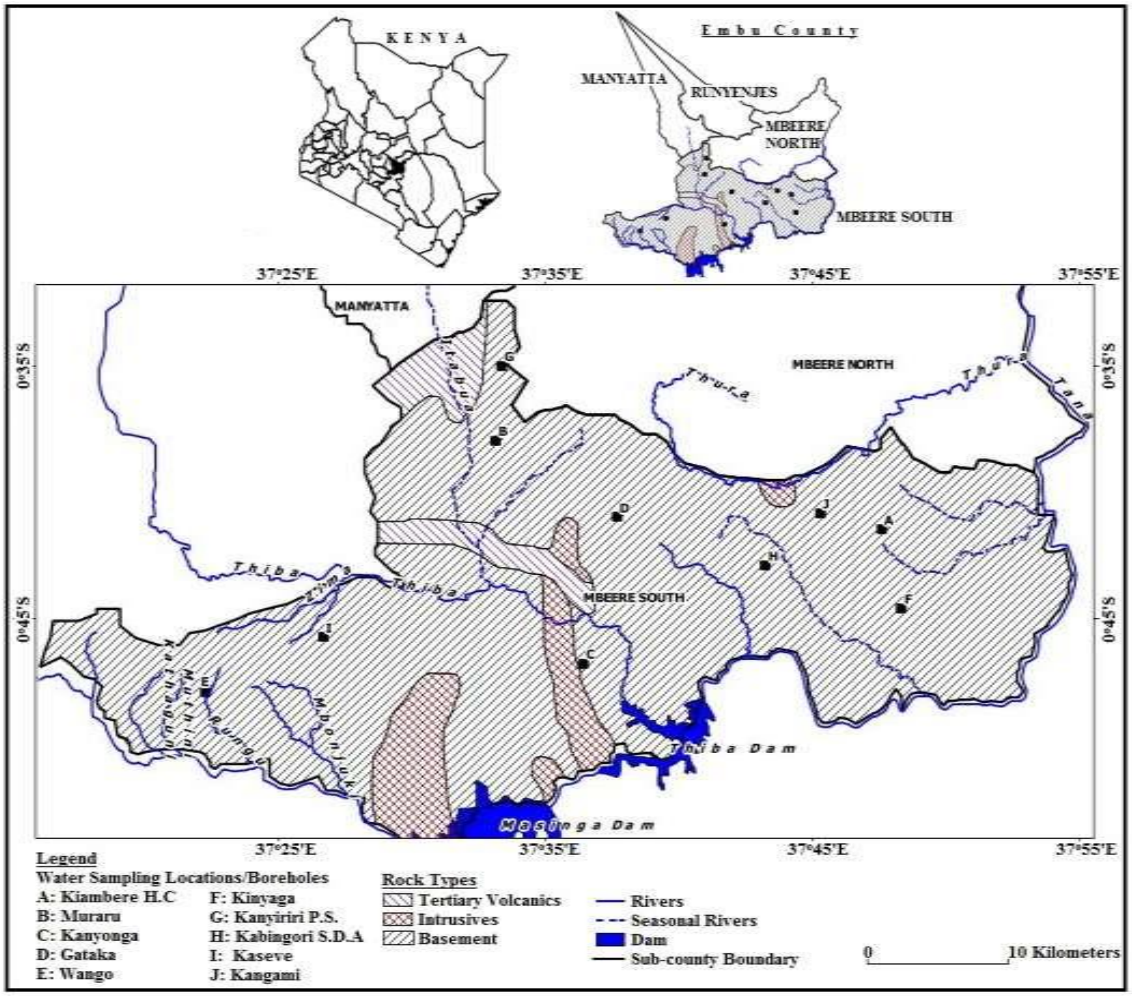


Figure 1: The Map of Mbeere South Sub-County (Source: National Atlas of Kenya)

This Mbeere south sub county is a semi-arid region that experiences erratic rainfall (average 600-800 mm annually) and high evapotranspiration, fostering water insecurity (Njeru, 2021). Predominantly rural, it features agriculture-dependent livelihoods that exacerbate catchment degradation, impacting dam and borehole quality. High solar insolation supports rainwater harvesting, yet infrastructure gaps persist, making it an apt site for evaluating ASAL water sources in schools.

2.2 Research Design

A descriptive survey design was employed to capture quantitative data on water characteristics in a naturalistic setting (Kothari, 2014). This approach facilitated comprehensive sampling and laboratory analysis, enabling statistical comparisons without environmental manipulation.

2.3 Target Population

A census sampling technique was used, including all 33 schools to ensure representation and eliminate selection bias, given the small population size (Yamane, 1967).

2.4 Data Collection Instruments

Structured questionnaires gathered data on water source adoption from principals, while water samples (n = 33 per source type) underwent laboratory analysis for physicochemical (pH, conductivity, TDS, turbidity.) and microbiological (total/fecal coliforms) parameters using standard methods (APHA, 2017). An observation checklist verified infrastructure during site visits (Patton, 2015).

2.5 Reliability and Validity of the Research Instruments

Instrument reliability was assessed via test-retest on three non-study schools, yielding a Spearman's correlation of 0.82 (>0.70 threshold) and Cronbach's alpha of 0.76 for questionnaires (Mugenda & Mugenda, 2003; Tavakol & Dennick, 2011). Validity was ensured through content review by Chuka University experts in environmental management and construct alignment with WHO guidelines, confirming comprehensive coverage of water quality domains.

2.6 Piloting

Instruments were pre-tested in three Mbeere North schools, refining clarity and sequencing based on feedback (Kothari, 2014). Adjustments improved response rates and analytical precision.

2.7 Data Collection Procedures

The researcher obtained ethical approval and a research permit was secured from the National Commission for Science, Technology, and Innovation (NACOSTI). Before collecting data, additional permissions were also requested from the Mbeere South Sub-County Education Office and individual school administrations. Data collection involved school visits, during which the researcher distributed structured questionnaires and carried out direct observations using a checklist. The participants completed the questionnaires, while observations took place immediately after interviews to verify infrastructure and conservation practices. Throughout the data collection process, the researcher strictly followed ethical guidelines, ensuring informed consent, confidentiality, and voluntary participation.

Results and Discussions

3.1 Biophysical and Chemical Characteristics of Water Sources Used

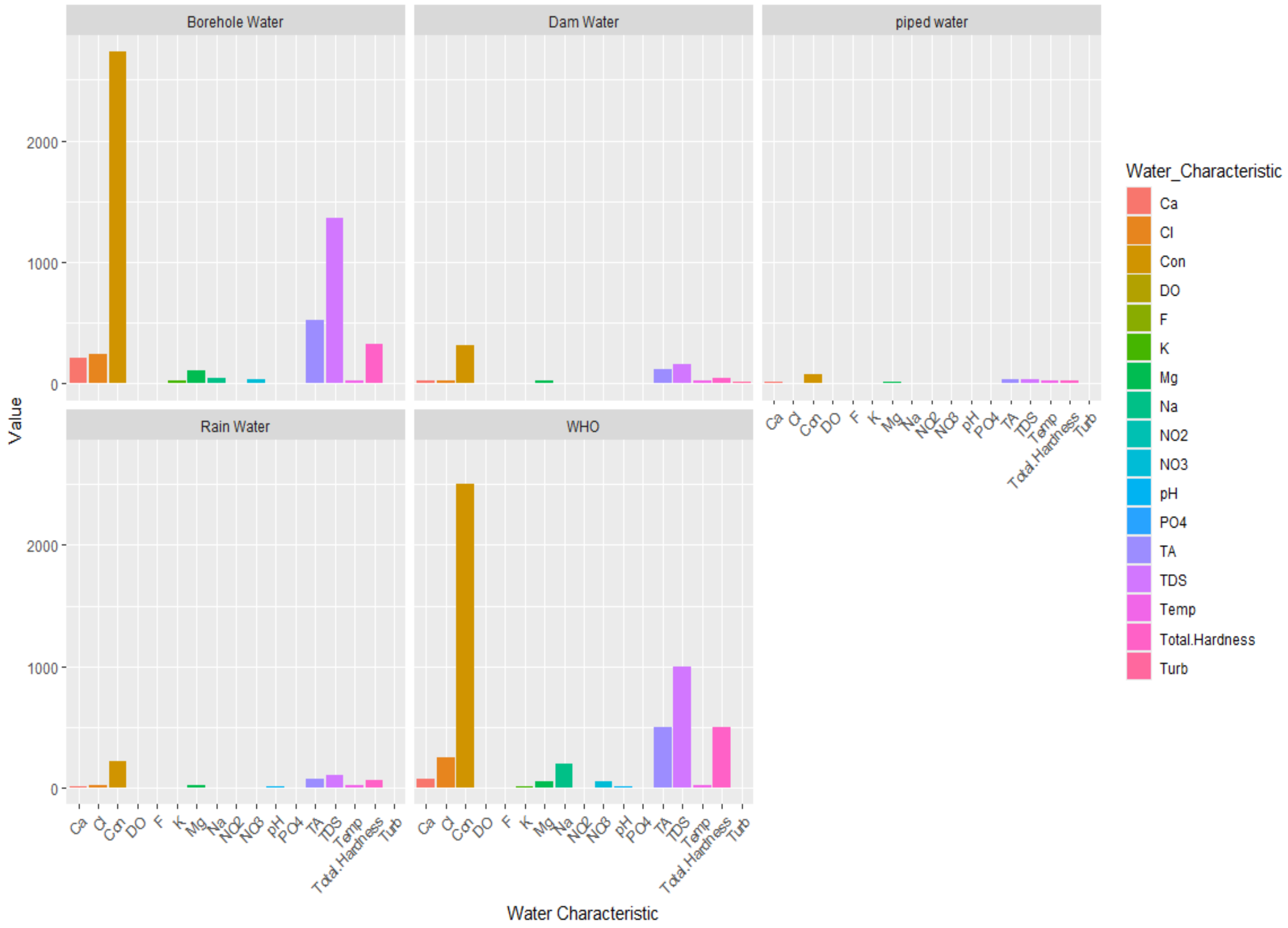
The study obtained samples from various water sources used by secondary schools and tested their biological, physical, and chemical properties. The results obtained are presented in Table 1 and Figure 2.

Table 1: Physical-Chemical and Microbiological Characteristics of Water Sources

Parameter	Source of Water				
	WHO Threshold	Earth dam	Rain	EWAS CO	Borehole
pH	6.5- 8.5	7.6	8.1	8.0	7.6
Dissolved Oxygen (mg/L)	Not stated	5.24	5.16	5.23	5.12
Conductivity (µS/cm)	Not stated	268.5	39.14	61.29	1570
Total Dissolved Solids (mg/L)	<1000	134	19.42	30.57	785
Turbidity (NTU)	<1 NTU	8.5	2.3	0.89	1.2
Temperature (^{o}C)	Not stated	22.07	21.97	22.09	21.98
Nitrites (mg/L)	3	0.25	<0.01	<0.01	0.17
Nitrates (mg/L)	50	2.75	0.77	0.86	15.3
Potassium (mg/L)	NP	2.5	2.83	1.86	8.1
Sodium (mg/L)	200	1.9	1.08	0.9	30.8
Total Alkalinity (mg/L)	NP	96.5	19.43	26.29	393.33
Phosphate (mg/L)	NP	1.04	0.12	0.83	1.55
Fluoride (mg/L)	1.5	0.39	0.19	0.14	0.78
Total Hardness (mg/L)	NP	55.5	13.43	20.29	212
Calcium (mg/L)	NP	20	4.43	7.57	133.33
Magnesium (mg/L)	NP	19	3.71	10	70.67
Chloride (mg/L)	250	20	1.71	3.42	132.67
Total coli (CFU/100 mL)	0	7.5	1	35	Nil
Faecal coliform (CFU/100 mL)	0	Nil	Nil	Nil	Nil

NP: Not provided. (Source: Researcher 2025)

According to the information in Table 1, nineteen parameters (two microbiological, four physical, and thirteen chemical) were examined. These parameters were examined against WHO guidelines for safe drinking water. Further, a multi-panel bar plot was constructed to show the water characteristics by source as shown on Figure 2.



<u>Figure 2:</u> Biophysical and Chemical Characteristics by Water Source (Source: Researcher 2025)

According to information on Figure 2, a unique pattern can deduced for each source of water. Piped (EWASCO) water had consistently very low values for almost all parameters. Borehole water shows the highest value for conductivity and chloride. The earth dam water (with an average pH of 7.6, DO of 5.24 mg/L, and TDS of 134 mg/L) largely met the WHO chemical threshold, although it was slightly turbid (8.5NTU) and the total detectable coliforms were (7.5 CFU/100 mL). These findings align with previous studies on rural dam waters in Kenya. For instance, Gakaria and Nzeve (2021) reported turbidity levels of up to 476NTU (well above the 5NTU guidelines) attributed to intense catchment erosion. Similarly, Sila (2019), in their surveys on rural water sources, found microbial contamination and high turbidity even in deep aquifers, surface waters, and relatively clean deep aquifers, as well as in roof-harvested rainwater concentrations.

The source of water from the dams in the study area showed high coliform levels (but no *E. coli*), indicating possible contamination from animals and runoff. This suggests that raw dam water is not safe to drink. Before use, the water should be settled, filtered, or disinfected (using chlorination or UV) to reduce turbidity. Catchment management practices such reforestation, controlled grazing, and erosion control upstream are essential to minimize sediment load. Without these measures, the dams will be less effective for the schools' water supply due to increased treatment costs and health risks.

The harvested rainwater exhibited extremely low conductivity (39 µS/cm), total dissolved solids (TDS) at 19 mg/L, and nitrate concentration at 0.77 mg/L. Furthermore, the rainwater had a near-neutral pH of 8.1 and only slightly elevated turbidity at 2.3 NTU which exceeded 1 NTU. Similarly, Owusu-Boateng and Gadogbe (2015) in Ghana concluded that roof-harvested rainwater possesses satisfactory physicochemical qualities but falls short microbiologically, necessitating treatment before consumption. The detection of a single coliform indicates favourable initial quality; however, as evidenced by the Nairobi study, turbidity peaks are common in the absence of a first-flush. Consequently, rainwater is primarily suitable for drinking and can help meet school water requirements from alternative sources. From a sustainable management perspective, promoting rainwater harvesting in educational institutions and residential settings aids in conserving groundwater and dam water resources. Proper awareness and maintenance practices, including keeping roofs and storage tanks clean, are crucial to ensure the safety and potability of rainwater for potential use.

Chemically, the piped supply from EWASCO was excellent (pH of 8.0, TDS: 31 mg/L, turbidity: 0.89 NTU) and low in nutrients, indicating that treatment was effective. However, a total coliform count of 35 CFU/100 mL is detected (no E. coli is present), exceeding the standard of zero coliforms for potable water. This suggests the possibility of post-treatment contamination within the distribution system. Similar findings have been reported in Kenya: Mworia (2018) observed that the water from Nairobi's utility reached the plant with zero coliforms; however, pipe leaks and handling contaminated the water by the time it reached consumers' taps. He further noted that treated river water tested negative for E. coli and coliforms, but some coliforms reappeared at household points due to pipe biofilms and sanitation practices.

This suggests that EWASCO water may be microbiologically unsafe at the point of consumption in schools and needs attention. The key is to maintain a residual free chlorine level of 0.4–0.5 mg/L throughout the distribution system. Regeneration will be minimized through routine flushing, leak repairs, and the prevention of water stagnation in pipes. Treated tap water should be chlorinated or boiled for schools with coliform contamination. Ultimately, investing in pipe maintenance and water safety plans is necessary for the utility to provide completely safe water consistently.

The borehole water source was microbiologically safe (0 coliforms) and had a neutral pH level (7.6), indicating no contamination. However, it was rich in minerals, with a conductivity of 1570 µS/cm, TDS of 785 mg/L (approaching the taste threshold of 1000 mg/L), and as hardness of 212 mg/L as $CaCO_3$. Calcium (133 mg/L) and magnesium (71 mg/L) contribute to the water's hardness. By comparison, most Kenyan boreholes are moderately hard (50–150 mg/L). The nitrate (15.3 mg/L) and fluoride (0.78 mg/L) levels were also below the WHO limits (50 and 1.5 mg/L, respectively). This indicates that groundwater was germ-free but hard and unpalatable. To make it suitable for use in schools, it could be mixed with rainwater or treated with water softeners where possible. From a resource management perspective, protecting these wells against surface contamination remains important, even though no coliforms were detected. Over-abstraction or pollution from nearby latrines should be avoided to ensure the sustainability of this water source.

To determine if there was any statistically significant difference in the mean characteristics of water parameters among the four water sources, an ANOVA test was conducted. The results are presented in Table 2

Table 2: One-Way ANOVA for Water Sources

Source of Variation	**Df**	**Sum of Squares (SS)**	**Mean Square (MS)**	**F-Value**	**p-Value**	**Sig**
Between Groups (Source)	4	2,606,926	651,731	12.62	1.41×10^{-9}	***
Within Groups (Residual)	335	17,300,262	51,643			
Total	339	19,907,188				

(Source: Researcher 2025)

The one-way ANOVA test results, shown in Table 2, yielded a p-value of 1.41×10^{9} and an F-value of 12.62. Since the p-value was well below the 0.05 threshold of significance, the study concluded that there was a statistically significant difference in the mean value among the water sources. This implies that one water source had a mean value that is statistically different from the others. To identify which specific pairs of water sources are different from the rest, a post hoc analysis using Tukey’s HSD was conducted. The results are presented in Table 3.

Table 3: Post-hoc Analysis (Tukey's HSD)

Comparison	Mean Difference	Lower Bound (95% CI)	Upper Bound (95% CI)	p-Value (adjusted)	Signif
Dam– Borehole Water	-164.83	-302.82	-26.83	0.0102	*
Piped– Borehole Water	-187.66	-291.97	-83.34	< 0.0001	***
Rain– Borehole Water	-189.23	-293.55	-84.92	< 0.0001	***
WHO – Borehole Water	106.25	-68.30	280.80	0.4543	ns
Piped– Dam Water	-22.83	-144.03	98.37	0.9857	ns
Rain– Dam Water	-24.41	-145.61	96.80	0.9816	ns
WHO – Dam Water	271.08	85.94	456.22	0.0007	***
Rain– Piped Water	-1.58	-82.38	79.23	1.0000	ns
WHO – Piped Water	293.91	132.30	455.51	< 0.0001	***
WHO – Rainwater	295.48	133.88	457.09	< 0.0001	***

(Source: Researcher 2025)

The results presented in Table 3 indicate that borehole water differs significantly from dam water ($p = 0.0102$), EWASCO ($p < 0.0001$), and rainwater ($p < 0.0001$) in terms of mean. These findings confirm that borehole water displays statistically distinct characteristics relative to dam water ($p=0.0102$), EWASCO piped water ($p<0.0001$), and rainwater ($p<0.0001$). Comparisons with World Health Organization (WHO) standards revealed significant differences for dam water ($p=0.0007$), piped water ($p<0.0001$), and rainwater ($p<0.0001$), whereas no significant difference was observed for borehole water ($p=0.4543$). The comparison between WHO standards and borehole water was not statistically significant ($p=0.4543$), indicating that the mean "Value" of borehole water, although elevated, does not significantly differ from the WHO reference value. Additionally, non-significant differences were noted among dam water, piped water, and rainwater, suggesting that the mean "values" for these sources are statistically comparable.

Further, a two-way ANOVA analysis was performed to evaluate the effects of the source of water, the water characteristic, and their interaction on the value. The results obtained are presented on Table 4.

Table 4: Two-Way ANOVA for Water Source and Water Characteristics

Source of Variation	Df	Sum of Squares (SS)	Mean Square (MS)	F-Value	p-Value	Sign
Source	4	2,606,926	651,731	56.89	$< 2 \times 10^{-16}$	***
Water Characteristics	16	3,701,438	231,340	20.19	$< 2 \times 10^{-16}$	***
Source: Water Characteristic	64	10,677,491	166,836	14.56	$< 2 \times 10^{-16}$	***
Residuals	255	2,921,333	11,456			
Total	339	19,907,188				

(Source: Researcher 2025)

The results indicate that all three factors have a highly significant impact. The main effect of water source has an F-value of 56.89 and a p-value of <2×10-16, confirming a statistically significant difference in the mean values across water sources. Similarly, the main effect of water characteristics is also highly significant, with an F-value of 20.19 and a p-value of $<2\times10^{-16}$. This indicates that the mean value varies significantly across different water quality parameters.

Notably, the interaction effect between water source and water characteristic was highly significant ($F = 14.56$, $p < 2 \times 10^{-16}$), indicating that the impact of water source on quality parameters depends on the specific characteristic measured. This significant interaction suggests that the effect of water source on the value varies across different characteristics. Therefore, differences between water sources for one characteristic are not the same as those for another, highlighting a complex relationship between the two factors.

3.2 Conclusions

Water sources in Mbeere South schools vary considerably in quality. Rainwater is identified as the safest option, whereas dams and piped supplies necessitate intervention owing to issues of turbidity and coliform contamination. Boreholes provide reliable microbiological safety, yet pose risks of scaling due to hardness. The notable differences among sources underscore the specific challenges faced by ASAL regions, thereby confirming the importance of RDT in resource-dependent adaptation strategies.

3.3 Recommendations

The paper makes the following recommendations.

i. Schools' management should implement first-flush diverters and chlorination for rainwater and piped sources to enhance safety.

ii. There is need for concerted effort to promote catchment reforestation for dams and routine borehole softening.

iii. Develop school-led monitoring protocols with county support, integrating WHO-aligned testing.

iv. The Ministry of water should subsidize treatment infrastructure to reduce dependence on unsafe externals.

References

American Public Health Association (APHA). (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association, American Water Works Association, & Water Environment Federation

Collins, A., & Flynn, A. (2015). The ecological footprint: New developments in policy and practice. Edward Elgar Publishing.

Davis, G. F., & Cobb, J. A. (2020). *Resource Dependence Theory: Past and Future. Research in the Sociology of Organizations, 58*, 55-84. https://doi.org/10.1108/S0733-558X20200000058003

Gakaria, N. M., & Nzeve, J. K. (2021). Assessment of water quality in selected dams in Machakos Municipality, Kenya. *Journal of Environment and Earth Science*, 11 (10), 1–12. https://doi.org/10.7176/JEES/11-10-01

Gikandi, J., Wambua, P., & Kinyua, S. (2020). Water Scarcity and Conservation in Schools: Case Study of Rural Kenya. *Journal of Environmental Management, 25(3)*, 45-59. https://doi.org/10.1016/j.jenvman.2020.05.033

Kothari, C. R. (2014). *Research Methodology: Methods and Techniques* (2nd ed.). New Age International Publishers.

Mugenda, O. M., & Mugenda, A. G. (2003). *Research Methods: Quantitative and Qualitative Approaches.* Nairobi: Acts Press.

Mworia, J. K. (2018). Water quality in piped supplies in Kenya. *Journal of Water Supply: Research and Technology-AQUA, 67*(5), 456–467. https://doi.org/10.2166/aqua.2018.123

Njeru, J. (2021). Water Resource Management in Schools in Semi-Arid Regions of Kenya: A Case Study of Mbeere South Sub-county. *African Journal of Environmental Sciences, 22(4*), 98-110. https://doi.org/10.1016/j.ajesc.2021.04.003

Nyaga, J., Kinyua, S., & Kamau, M. (2021). Resource Management Practices in Secondary Schools in Kenya: Implications for Sustainable Development. *Sustainability Journal of Education, 12(2),* 59-74. https://doi.org/10.3390/su1202059

Owusu-Boateng, G., & Gadogbe, M. K. (2015). Variation in the Quality of Harvested Rainwater from Source to Storage in a Water-Stressed Community in Ghana. American *Journal of Water Science and Engineering, 1* (2), 9–18. https://doi.org/10.11648/j.ajwse.20150102.11

Patton, M. Q. (2015). Qualitative Research & Evaluation Methods: Integrating Theory and Practice (4th ed.). SAGE Publications.

Pfeffer, J., & Salancik, G. R. (1978). The External Control of Organizations: A Resource Dependence Perspective. Harper & Row.

Sila, O. N. (2019). Physico-chemical and Bacteriological Quality of Water Sources in Rural Settings, A Case Study of Kenya, Africa. Scientific African, 2, Article e00018. https://doi.org/10.1016/j.sciaf.2018.e00018

Tavakol, M., & Dennick, R. (2011). Making Sense of Cronbach's Alpha. *International Journal of Medical Education, 2, 53-55*. https://doi.org/10.5116/ijme.4dfb.8dfd

UNESCO (2022). *Water and Energy Nexus in Education*. Paris: UNESCO Publishing.

UNICEF (2021). Water, Sanitation and Hygiene (WASH) in Schools: Global Baseline Report. New York, NY: UNICEF.

United Nations. (2021). *Sustainable Development Goals Report 2021*. New York, NY: United Nations.

Yamane, T. (1967). *Statistics: An Introductory Analysis* (2nd ed.). New York: Harper and Row.