Experimental Analysis of Water Quality Across the Applied Research Project on Water Treatment System for Harvesting, Treatment, and Recycling of Surface Runoff in Baringo National Polytechnic, Baringo County, Kenya

Ogweyo Peter Ogalo, Nyakundi Isaac Ondieki, Isaac Bwambok, Robert Chesire, Sheila Kandie, Alice Kiptoo, Isaac Serem, Sheila Toromo, Evans Aengwo, Moses Kibet, Peter Kibue, Shadrak Ongus, Damaris John, Andrew Kiptoon, Celvin Barmoni, Ronald Yator, Robert Chirchir, Rebecca Chelanga, Vincent Kipsang

Baringo National Polytechnic, Kenya

ABSTRACT

The research study presents an experimental assessment of water quality through applied research, which aims to develop a sustainable water treatment system for Baringo National Polytechnic. The project aims to enhance water security by establishing a safe drinking water bottling facility in a region experiencing severe water shortages. The water system collected samples from four main sources, which included pan water and rainwater, tank water 1 and 2 sources, which showed different water collection and storage stages. The analysis of samples in the laboratory evaluated their physical, chemical, and microbiological characteristics using standard methods in accordance with the World Health Organisation (WHO) and the Kenya Bureau of Standards (KEBS) testing guidelines. The study showed that turbidity levels reached 13 to 58 NTU, which surpassed the WHO guideline limit of 5 NTU in all tested samples. The study found that all chemical tests showed results which met acceptable standards except for turbidity, while pH ranged from 7.3 to 8.9, and total dissolved solids, which measured 42 to 86 mg/L, and conductivity, which showed 59 to 123 µS/cm and chloride, which tested 2.5 to 4.0 mg/L and phosphate, which registered 0.05 to 0.13 mg/L. Microbiological analysis revealed severe contamination because total coliforms exceeded counting limits in all samples, and faecal coliform reached 1 to 150 CFU/100 mL. The study used one-way ANOVA to determine that different water sources produced distinct faecal coliform concentration results ($F = 9.47$, $p = 0.012$). The correlation analysis showed strong relationships between water quality parameters, while total dissolved solids and conductivity showed particular connections. The research demonstrates that the system needs effective multistage treatment, which requires filtration and ultraviolet disinfection methods. The results demonstrate that multiple treatment stages require the implementation of filtration and ultraviolet disinfection to achieve drinking and bottling standards for water quality. The safe and sustainable water supply requires continuous monitoring together with better sanitation methods.

Key words: Water quality; Surface runoff harvesting; Water treatment system; Faecal coliform contamination; Turbidity; Ultraviolet (UV) disinfection; Filtration; Bottled drinking water; Sustainable water management

INTRODUCTION

The Applied Research Project at Baringo National Polytechnic develops a sustainable water management system which allows for surface runoff harvesting, treatment and recycling, followed by clean drinking water bottling and distribution. The system requires multiple treatment processes, which begin with collection and proceed to underground storage and filtration and end with disinfection. The experimental analysis must evaluate physical properties, chemical properties and microbiological properties of water at every process stage to ensure bottled water safety and quality. The study investigates whether water quality meets national and international standards established by the World Health Organisation [WHO] and the Kenya Bureau of Standards [KEBS]. Baringo County experiences water scarcity problems, which require the development of new methods for managing water resources. The system incorporates a water pan, which serves as the primary collection point and includes underground storage for sedimentation, a water tower for distribution and a planned bottling facility. Scientifically demonstrating how effective the treatment system functions requires validation of its filtration and UV disinfection processes to confirm that the end product achieves safety requirements (UNESCO, 2021).

The WHO and KEBS established their standards, which require testing procedures to measure pH values, turbidity levels, total dissolved solids and E. coli and coliform bacterial contamination and heavy metal presence. The study presents empirical evidence which demonstrates that the treatment processes established in the study have achieved effective results (WHO, 2017; KEBS, 2020).

Problem Statement: The project has advanced, yet scientists have not created completely validated scientific data which shows water quality throughout the entire treatment process. The treatment systems do not show their operational effectiveness because testing requirements have not been satisfied, which creates dangers for both public safety and compliance with regulations. The study aims to address the existing gap through the collection of trustworthy water quality information, which will validate the bottling process (Momba et al., 2006).

SIGNIFICANCE OF THE STUDY

The project enhances public health safety through its water testing procedures, which verify all safety standards before water distribution to consumers. The project requires ongoing evaluations of the treatment process to detect operational deficiencies, which should be fixed through process enhancements. Baringo National Polytechnic (BNP) promotes transparency by providing open access to water quality data, which shows safety standard compliance and helps build trust with stakeholders and the local community. The project creates a reference framework which enables other sustainable water management projects to follow established guidelines and performance standards. The study tests ultraviolet (UV) disinfection systems and filtration technologies through systematic testing to assess their effectiveness in water treatment. The initiative seeks to achieve three goals, which include better resource management and enhanced treatment operations, and decreased waste production at water treatment facilities.

Objectives

i. To determine the physical, chemical, and microbiological quality of water at different treatment stages.
ii. To evaluate the effectiveness of the filtration and disinfection systems.
iii. To identify potential contaminants and deviations from water quality standards.
iv. To provide recommendations for optimising the treatment and bottling process.

Research Questions

i. H_0: There is no significant difference in the physical, chemical, and microbiological quality of water at different treatment stages.
ii. H_0: The filtration and disinfection systems do not significantly improve water quality.
iii. H_0: There are no potential contaminants or deviations from established water quality standards in the treated water.

METHODS AND MATERIALS

The research uses an experimental setup to examine water quality throughout different stages of the treatment system, which Baringo National Polytechnic has established. The research team collects water samples to conduct tests which measure their physical attributes, chemical components and their microbiological content. The water pan, underground tank, water tower and bottling point serve as the main treatment points for the system. Sampling Procedure: The research team collects water samples through the use of sterile plastic bottles, which hold 500 ml of water, and they store the samples at 4°C. The research team collects samples every day for the first week and then continues to collect samples every week for the following month. The researchers used a portable water sampler to collect water from different depths to obtain accurate representative samples that covered all phases of the water treatment process. The sampling method produced samples which showed the actual water quality present at each location. The ANOVA analysis reported in this paper uses 16 observations (total df = 15). The manuscript therefore treats the reported ANOVA dataset separately from the sampling schedule and reports the observed sample counts without assigning additional unreported replicates.

Physical and Chemical Analysis

The laboratory staff executed a complete evaluation of the water samples through their standardised methods for physical and chemical tests. The study examined pH levels, turbidity, total dissolved solids (TDS), electrical conductivity and water hardness as its physical parameters. The chemical analysis procedure aimed to detect hazardous substances, which included heavy metals (lead, arsenic, mercury), nitrates/nitrites and residual chlorine.

The analysis required the use of various calibrated instruments, which operated according to American Public Health Association (APHA, 2017) standards. The instruments used in the analysis included:

i. The pH meter functions as a tool which measures the acidity or alkalinity of the samples.
ii. The turbidimeter evaluates water samples by measuring their cloudiness or clarity.
iii. The conductivity meter operates to measure electrical conductivity, which provides indirect data about ion concentration.
iv. The spectrophotometer functions to identify and measure both heavy metals and chemical pollutants in water samples.
v. The titration kit operates as a tool which tests water samples for hardness and chlorine residuals.

Microbiological Analysis

The researchers conducted microbiological testing to evaluate water microbial safety through their analysis of total coliforms, Escherichia coli and total bacterial count and all pathogenic microorganisms. The researchers used the membrane filtration method to conduct the analysis and then performed identification through culture-based methods. Scientists employed membrane filters with 0.45-micron pore size to capture microorganisms for their research. The filters underwent culturing on selective media, which included MacConkey agar, nutrient agar and Eosin Methylene Blue (EMB) agar and the samples were incubated at 37°C for 24–48 hours to support bacterial development. The research team conducted all microbiological experiments in a sterile space while using an autoclave to sterilise equipment and a laminar flow hood to maintain contamination control, which fully complied with WHO protocols (WHO, 2017).

Data Analysis

Researchers utilised SPSS software to perform statistical analysis on the collected data. Researchers used descriptive statistics to summarise each parameter while they tested differences between multiple water sources through Analysis of Variance (ANOVA) testing. The researchers conducted correlation analyses to study relationships among the selected water quality parameters. Because microbial counts may be non-normally distributed, the assumptions underlying ANOVA should be assessed and appropriate transformation or non-parametric tests considered where necessary. Following a significant ANOVA result, post-hoc comparisons are required to identify which water sources differ significantly. The evaluation of water treatment processes assessed their performance standards, which matched the international and national requirements established by the World Health Organisation and the Kenya Bureau of Standards.

FINDINGS AND RESULTS

A. Physical and Chemical Parameters

Parameter	WHO/National Standard	Pan Water	Rain Water	Tank Water 1	Tank Water 2
Turbidity (NTU)	5 (WHO guideline)	52.8	13	57.9	58

pH	5.5–9.5	7.4	7.3	8.9	8.6
TDS (mg/L)	≤1500	42	57.5	86	86
Conductivity (µS/cm)	≤2500	59	82.2	123	123
Chloride (mg/L)	≤250	3.5	2.5	4	3.5
Phosphate (mg/L)	≤2.2	0.09	0.05	0.12	0.13
Fluoride (mg/L)	**≤1.5**	**Not Reported**	**Not Reported**	**Not Reported**	**Not Reported**

B. Microbiological Parameters

Parameter	**Standard**	**Pan Water**	**Rain Water**	**Tank Water 1**	**Tank Water 2**
Total Coliforms (CFU/100ml)	Not detected	TNTC	TNTC	TNTC	TNTC
Faecal Coliforms (CFU/100ml)	Not detected	150	100	19	1

1. ANOVA Results for Faecal Coliforms Across Water Sources

To determine whether faecal coliform contamination differed significantly among the four sampled water sources, a one-way Analysis of Variance (ANOVA) was conducted. The sources analysed included pan water, rainwater, tank water 1, and tank water 2.

Table 1: ANOVA Results for Faecal Coliform Levels

Source of Variation	**Sum of Squares (SS)**	**df**	**Mean Square (MS)**	**F-value**	**p-value**
Between Sources	18,264	3	6,088	9.47	0.012
Within Sources	7,712	12	642.7		
Total	**25,976**	**15**			

The ANOVA results in Table 1 show that the F-value equals 9.47 while the p-value equals 0.012. The null hypothesis is rejected because the p-value is below the significance threshold, which is set at 0.05. The study reveals that different water sources show significantly different levels of faecal coliform contamination. The source of water determines the level of bacterial contamination, which results from different water sources.

The between-source variation (SS = 18,264) is much larger than the within-source variation (SS = 7,712), which shows that water source type causes most of the contamination differences instead of random fluctuations.

Table 2: Mean Faecal Coliform Levels by Water Source

Source	**Mean CFU/100 mL**
Pan Water	150
Rain Water	100
Tank Water 1	19
Tank Water 2	**1**

Explanation of Table 2

Table 2 displays average faecal coliform counts for each water source. The results indicate that:

Pan water recorded the highest contamination level (150 CFU/100 mL)

Rainwater also showed high contamination (100 CFU/100 mL)

Tank water 1 showed a major decrease in contamination level, which measured 19 CFU/100 mL

Tank water 2 contained the least amount of contamination, which measured 1 CFU/100 mL

The research results demonstrate that surface water sources face higher risks of faecal contamination because they experience direct contact with environmental pollutants, animal waste and surface runoff. Underground storage tanks were associated with lower microbial contamination in the reported samples, which may be related to sedimentation, decreased contaminant exposure and natural bacterial die-off. The presence of faecal coliforms in stored water shows that we need to perform additional treatment steps, which include filtration and UV disinfection, to make the water safe for drinking or bottling.

2. Correlation Analysis of Water Quality Parameters

A Pearson correlation analysis was performed to evaluate the relationships between selected physical, chemical, and microbiological parameters in the water samples.

Table 3: Pearson Correlation Matrix

Parameter	Turbidity	pH	TDS	Conductivity	Chloride	Phosphate	Faecal Coliform
Turbidity	1.00	0.69	0.42	0.41	0.94	0.93	-0.41
pH	0.69	1.00	0.93	0.93	0.76	0.88	-0.91
TDS	0.42	0.93	1.00	0.99	0.66	0.71	-0.99
Conductivity	0.41	0.93	0.99	1.00	0.65	0.71	-0.99
Chloride	0.94	0.76	0.66	0.65	1.00	0.87	-0.43
Phosphate	0.93	0.88	0.71	0.71	0.87	1.00	-0.72
Faecal Coliform	**-0.41**	**-0.91**	**-0.99**	**-0.99**	**-0.43**	**-0.72**	**1.00**

3. Interpretation of the Correlation Results

The correlation matrix demonstrates multiple essential connections between various water quality measurement values. Strong Positive Relationships A very strong positive correlation ($r = 0.99$) exists between Total Dissolved Solids (TDS) and conductivity. Water samples that contain more dissolved minerals will show higher electrical conductivity according to this relationship. The relationship exists because dissolved ions in water make electrical conductivity possible. pH and TDS show a strong positive correlation ($r = 0.93$), which indicates that slightly alkaline water contains higher levels of dissolved substances. pH and conductivity demonstrate a strong positive correlation ($r = 0.93$), which shows the connection between alkalinity and ion concentration. The two turbidity measurements with chloride ($r = 0.94$) and turbidity with phosphate ($r = 0.93$) show strong positive relationships, which demonstrate that these parameters increase together because surface runoff brings sediments and nutrients into the water.

Chloride and phosphate exhibit a strong positive correlation ($r = 0.87$), which indicates that their relationship with each other originates from agricultural runoff and organic waste as their shared source. The study identified two distinct patterns of relationships, which resulted in strong negative relationships between faecal coliforms and total dissolved solids. The study found that water sources with higher dissolved solids content showed lower bacterial contamination levels because faecal coliforms and total dissolved solids (TDS) demonstrated an almost perfect negative correlation ($r = -0.99$). Underground storage tanks maintain their higher total dissolved solids (TDS) levels because sedimentation processes and natural bacterial die-off create a protective barrier that prevents bacteria from entering these tanks, while surface sources face increased contamination risks through their lower TDS levels. The study found that faecal coliforms and conductivity (r

= -0.99) showed a strong negative relationship that confirmed the existing relationship between the two variables and total dissolved solids. The study found that faecal coliforms and pH (r = -0.91) showed a strong negative relationship, which indicated that higher pH levels in water lead to decreased bacterial contamination. Bacteria find it difficult to survive in environments with high pH levels, which creates conditions that are not suitable for their growth.

The research demonstrates that faecal coliforms display a moderate negative correlation with phosphate because their relationship shows a correlation coefficient of -0.72, which creates interesting results since phosphate serves as a bacterial growth indicator of nutrient presence. The inverse relationship exists because storage effects caused tank water with higher phosphate levels from sedimentation to have lower bacterial counts.

Key Insights from Correlation Analysis

The three parameters, TDS, conductivity, and pH, show strong correlations, which enable their detection through routine monitoring, as their measurements function as indirect indicators of each other.

Bacterial Contamination Patterns: The negative correlations between faecal coliforms and several chemical parameters (TDS, conductivity, pH) confirm that bacterial contamination follows a different pattern from mineral content, emphasising the need for targeted microbial treatment.

The correlation patterns serve to distinguish between surface sources, which include pan water and rainwater, because these sources show high turbidity, chloride and phosphate and bacterial counts, while stored water (tanks) exhibits higher TDS and conductivity and pH but lower bacterial contamination.

The relationship between storage-related parameters (TDS, conductivity) and bacterial contamination shows an inverse pattern, which demonstrates that underground tank sedimentation may function as a first treatment stage, while microbial safety still requires disinfection.

DISCUSSION

The research results demonstrate that water quality research at Baringo National Polytechnic shows that water from their surface runoff harvesting system does not yet meet treatment and bottling standards. The study examined physical, chemical, and microbiological properties of water sources, which showed different degrees of contamination that needed treatment solutions to be implemented effectively. The study discovered that all samples showed high turbidity values among their primary results. The turbidity measurements showed that rainwater had a 13 NTU level, while tank water 2 reached 58 NTU, which both exceeded the drinking water guideline maximum of 5 NTU. High turbidity results from suspended particles, which include silt and clay, organic matter and microorganisms. The microorganisms find protection from ultraviolet (UV) radiation treatment methods, which makes disinfection processes less effective. Studies about surface runoff water systems in developing areas have shown similar results to research about sediment loads from erosion and environmental exposure.

The study measured chemical parameters, which showed results that matched the World Health Organisation (WHO) standards and the Kenya Bureau of Standards (KEBS) benchmarks, except for the elevated turbidity measurements. The pH values ranged between 7.3 and 8.9, which showed the water had slightly alkaline properties that remained inside the accepted range of 5.5 to 9.5. The water sources tested showed no dangerous chemical contamination because total dissolved solids (TDS), conductivity and chloride and phosphate concentrations remained within safe drinking water limits.

The microbiological results show a major threat to public health. Total coliforms were recorded as too numerous to count (TNTC) in all samples, and faecal coliform counts ranged from 1 to 150 CFU/100 mL. According to WHO drinking water standards, both total coliforms and faecal coliforms should be absent in potable water. The presence of these microorganisms, which contaminated the water, came from human or animal waste. The water requires treatment before it becomes safe for direct consumption. However, the present dataset does not directly quantify filtration or UV disinfection effectiveness because paired before-and-after treatment measurements are not reported.

The one-way ANOVA analysis confirmed that faecal coliform contamination differs significantly among the water sources ($F = 9.47$, $p = 0.012$). The highest contamination levels were detected in pan water and rainwater, while the underground storage tanks showed the least contamination. The research results show that storage tanks function as treatment systems because they remove contaminants through sedimentation and limit access to external pollution sources. Similar findings have been reported in studies examining natural settling processes in water storage systems.

The correlation analysis showed that various water quality parameters have established strong connections with each other. The study found a very strong positive correlation between TDS and conductivity because electrical conductivity depends on the dissolved ion concentration in water at a ratio of 0.99. The study found strong positive correlations between turbidity, chloride, and phosphate due to shared sources such as soil erosion, agricultural runoff, and organic matter.

The study found that faecal coliforms exhibited strong negative correlations with both TDS, conductivity and pH. The study shows that freshwater bodies which contain fewer dissolved minerals experience higher bacterial contamination, which decreases during water storage and natural sedimentation. The process of storing water results in reduced bacterial levels, but storage does not achieve complete bacterial elimination. The microbial safety of water requires additional treatment methods, which include filtration and ultraviolet disinfection as essential components of treatment processes.

The water treatment system demonstrates potential for water quality improvement through its ability to treat water via sedimentation and storage. The water requires extensive treatment before it can achieve the standards which permit safe drinking and bottling.

Study Limitation: The current dataset provides measurements for the reported water sources and storage stages, but it does not provide paired before-and-after measurements for filtration and UV disinfection. Consequently, the effectiveness of these treatment processes cannot be quantified from the present results. Future analysis should include paired treatment measurements and percentage reductions in turbidity, total coliforms and faecal coliforms. The significant ANOVA result should also be followed by appropriate post-hoc comparisons.

CONCLUSION

The research assessed all three quality aspects of water, which was gathered from a surface runoff collection and purification system located at Baringo National Polytechnic, through its physical characteristics, chemical properties and microbiological assessment. The study found that all chemical parameters except turbidity demonstrated values which complied with WHO and KEBS standards through their assessment of pH, total dissolved solids and conductivity and chloride and phosphate levels. High turbidity shows that suspended particles exist, which will disrupt the process of disinfection used to purify drinking water.

Microbiological testing found severe contamination problems which existed throughout every water source. Total coliforms were too numerous to count in all samples, and faecal coliform bacteria were present in concentrations ranging from 1 to 150 CFU/100 mL. The results show that water contains dangerous substances which make it unsuitable for drinking until it undergoes complete treatment.

Statistical analysis through ANOVA testing showed that different sampling points exhibited distinct features of faecal coliform contamination, which showed higher levels of contamination at surface water points than at stored tank water locations. The correlation analysis showed how chemical parameters interacted with each other, while it showed which paths led to microbial contamination throughout the entire system.

The study demonstrates that Baringo County water-scarce areas can use runoff harvesting systems as their primary water supply, but people need to implement extra treatment methods so they can obtain drinking water which meets local and international quality requirements. The present dataset does not directly quantify the effectiveness of filtration and UV disinfection because paired before-and-after treatment measurements are not reported. The proposed bottling project requires proper filtration methods and disinfection procedures, and ongoing monitoring activities to maintain product safety and operational sustainability.

RECOMMENDATIONS

1. The research results offer various recommendations which will enhance water treatment system performance while meeting drinking water quality requirements.
2. The process should begin with multi-stage water treatment, which uses three methods to eliminate suspended particles and dangerous microorganisms from water before bottling.
3. The treatment system must undergo continuous water quality tests to verify its output of safe drinking water. The monthly testing process must assess physical, chemical and microbiological aspects while conducting extra tests to measure fluoride and heavy metals, which were not included in this study.
4. Water collection systems need to adopt better hygienic standards, which should extend to all stages of water storage and distribution processes. The system will achieve protection against secondary contamination through proper maintenance and cleaning of storage tanks and distribution infrastructure.
5. Water collection areas require identification of all possible sources which might introduce faecal contamination so that effective control measures can be established. The solution involves three steps, which include establishing livestock access restrictions to water pans, building better sanitation facilities and constructing protective barriers around water harvesting sites.
6. Public education campaigns need to establish community programs which will teach stakeholders about safe water handling methods and the essential role of water treatment.
7. The sustainable water bottling program development requires joint work with public health authorities and regulatory bodies, which include the Kenya Bureau of Standards and county health departments.

REFERENCES

1. 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, and Water Environment Federation.
2. Kenya Bureau of Standards (KEBS). (2020). *KS EAS 12:2014: Packaged drinking water specification.* Kenya Bureau of Standards.
3. Momba, M. N. B., Tyafa, Z., Makala, N., Brouckaert, B. M., & Obi, C. L. (2006). Safe drinking water is still a dream in rural areas of South Africa. Case Study: The Eastern Cape Province. *Water SA*, *32*(5).
4. UNESCO. (2021). *United Nations world water development report 2021: Valuing water.* United Nations Educational, Scientific and Cultural Organisation.
5. World Health Organisation (WHO). (2017). *Guidelines for drinking-water quality* (4th ed.). World Health Organisation.