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MATHEMATICAL ANALYSIS ON THE IMPACT OF WATER DISTRIBUTION SYSTEMS ON HYGIENE AND EFFICIENCY MANAGEMENT AMONG RESIDENT OF ZAMFARA STATE

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ABSTRACT

Water distribution systems (WDSs) play a vital role in ensuring hygiene and efficient water management in communities. This study provides a mathematical analysis of the impact of WDSs on hygiene and efficiency management among residents of Zamfara State, Nigeria. Using a quantitative research approach, data were collected through structured questionnaires administered to 300 respondents across various local government areas. The findings indicate moderate inadequacies in water availability (mean = 2.75), frequent water interruptions (mean = 3.10), and suboptimal water quality (mean = 3.20), which have significant effects on hygiene practices and efficiency management. Correlation analysis reveals a negative relationship (-0.45) between water quality and hygiene engagement, while community awareness positively influences sustainable water usage (0.60). Regression analysis highlights the role of community awareness (B = 0.32, p = 0.005) and participation in initiatives (B = 0.15, p = 0.020) in improving water management. The study underscores the need for policy reforms and community-driven interventions to enhance water distribution efficiency and hygiene standards in Zamfara State.

Keywords: Water Distribution Systems, Hygiene, Efficiency Management.

1. INTRODUCTION

Water is an essential resource globally, crucial for both commercial and domestic use, and vital for sustaining life. The increasing demand and quality requirements for water have highlighted the need for effective water distribution systems (WDSs). To meet these demands, there is a growing necessity to model real-life scenarios to evaluate the efficiency and functionality of WDSs. Challenges such as system deterioration, leakage, pipeline disruptions, inability to meet demand, poor system design, unreliable systems, and misuse or mismanagement of water (Vairavamoorthy et al., 2001; Longe et al., 2010) underscore the need to replace traditional WDS design techniques with precise and efficient computer software and methods. Modeling water distribution systems has become a critical aspect of WDS management, as it facilitates hydraulic assessments to ensure the system can meet both demand and quality standards through appropriate water treatments (Fayomi et al., 2017). This growing interest in WDS modeling has led a multidisciplinary team of professionals, researchers, scholars, engineers, and programmers to develop specialized software for designing and modeling these systems (Sonaje and Joshi, 2015). These advanced hydraulic simulation and modeling tools enable comprehensive analysis of water behavior, enhancing the reliability and efficiency of water distribution. In general, a water supply system comprises several key processes (Lejano, 2006):

1. Extraction and Transportation of Raw Water: This involves removing water from any source, either temporarily for flood control or permanently for irrigation or domestic use after suitable treatment.

2. Water Processing, Treatment, and Storage: Water treatment enhances water quality, making it fit for domestic use by removing contaminants and undesirable components, thus ensuring the water is suitable for its intended end-use.

3. Clean Water Distribution: This process involves transporting water across a network of connected pipes and auxiliary components.

The water is steadily pumped and stored to meet demands and maintain system pressure. Water distribution systems (WDSs) consist of an interconnected network of pipes that deliver water for end use. Components like reservoirs, pumping stations, water towers, hydrants, valves, and measuring equipment are essential for optimal operation. There are numerous software tools available to model and analyze WDSs. Some are open-source and free for public use, while others are closed or commercially available for research, development, or management of WDSs. It is a superset of WaterCAD, offering enhanced capabilities for understanding system behavior, operational strategy reactions, and future demand fulfillment. Its flexible multi-platform workspace supports fire flow and water quality simulations, pipe flow and pressure analysis, and energy cost analysis. WaterGEMS provides intelligent system management and planning for system reliability, optimization of operations (including pumping strategies, system shutdowns, and preventive maintenance to minimize disruptions), and asset renewal or renovation support to ensure sustainability. Its features include pre-fixed model building, integration with multiple platforms, design, and other operations.

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1.1 The Impact of Drinking Water Quality on Public Health

The quality of drinking water is a powerful environmental determinant of health and a basic human right, as well as a key component of effective health protection policy (WHO, 2014). Lack of safe drinking water poses a significant threat to public health, exposing populations to waterborne diseases such as diarrhea, cholera, typhoid, dysentery, gastroenteritis, and chemical intoxication (Gambo et al., 2015). According to reports by the WHO (2005) and Hughes and Koplan (2005), an estimated 1.1 billion people lack access to clean water, while 2.6 billion lack adequate sanitation. Diseases related to contaminated drinking water place a major burden on human health. Interventions to improve drinking water quality yield significant health benefits. In recognition of this, the United Nations General Assembly declared 2005-2015 the International Decade for Action, "Water for Life" (WHO, 2011). The connection between water, sanitation, hygiene, and health is well-established, with many diseases linked to contaminated water consumed directly or used in cooking, washing utensils, and bathing, leading to various infections and diarrheal diseases. Amid increasing global concerns regarding sustainable development planners responsible for managing natural resources are directing their focus toward understanding the vulnerability associated with the availability and utilization of water resources and previous examinations of water resource vulnerability have tended to either oversimplify the issue or concentrate solely on one aspect of these multifaceted challenges, Kulshreshtha (1998). The prevalence of water shortage, pollution, and various other environmental and ecological issues related to water, has been on the rise in numerous regions around the globe Cai et al (2001). In the foreseeable future, the former Soviet Central Asia may face resource-driven conflicts with some experts even speculating about the potential for a water-related conflict Spoor and Krutov (2003). In recent times, headlines and discussions in Pakistan's media have consistently highlighted the alarming reality of an incessant water shortage, affecting irrigation, industrial operations, and human consumption, Winiger et al. (2005). The combination of rising water demand and diminishing supplies has been exacerbated by heightened nationalism and competition among the five Central Asian states and this situation has hindered the potential for establishing a feasible regional approach to replace the Soviet-era water management system Mosello (2008). Uzbekistan relies significantly on transboundary water sources with an average of only 9.52 km^3 of water resources originating within the country, while 94.8 km^3 is sourced from external locations, Rakhmatullaev (2011). The scarcity of water poses a threat to the livelihoods of populations both locally and in transboundary areas due to increasing competition for a limited resource. Central Asia's water resources have a lengthy history of mismanagement as evidenced by the significant scale of the Aral Sea disaster and at the start of the 1990s, foreign aid through development projects has been directed towards improving water resource management in the region Karthe (2015).

1.2 Evolution and Challenges of Water Distribution Systems

Walski et al. (2003) revealed that water distribution for end-use has been practiced for centuries. From the first pipes laid about 3500 years ago in Crete to today's sophisticated hydraulic models, such as the "Big Apple" water system in the USA, it is evident that water systems have undergone significant transformations worldwide. Kuo and Quarts (2014) noted that China developed the largest water distribution system in response to severe water challenges. Additionally, Schilling (2013) highlighted that the USA has the second-largest "water tunnel," with a storage capacity of 2 trillion liters, distributing 5 billion liters of potable water daily to New York City's population of 8 million people. Remarkably, 95% of this water is transported by gravity. Fardami et al (2019) investigate Bacteriological Analysis of Drinking Water in Zamfara North Senatorial District, Nigeria. Drinking water is supposed to be free from objectionable (colour, taste, turbidity) and microbial contaminants. Sachet water popularly known as “Pure water” is patronized by Nigerians probably due to their convenience to quench taste. This packaged water are vended in several locations including several public places including motor parks, garage, markets, streets, along express ways, outskirt of schools and hospitals.

Water pollution presents significant challenges in developing countries globally, due to its profound impacts on the environment, human health, and economy. Specifically, contaminated water is known to transmit waterborne diseases such as typhoid, cholera, diarrhea, hepatitis, and bilharzia Schwarzenbach (2010), some of which can be fatal if untreated. Moreover, polluted water can lead to chronic toxicity, neurological issues arising from chemical contaminants, and potentially contribute to cancer or cardiovascular diseases. Effective control measures for preventing water pollution are therefore imperative to safeguard both the environment and public health. In addressing the complexity of real-world systems, mathematical modeling serves as an effective tool to interpret and predict the behavior of intricate phenomena such as water pollution. Guo and Cheng (2019) developed a mathematical model simulating spatial-temporal changes of pollutants after water pollution accidents in Yuncheng city, China. Their findings revealed a decrease in pollutant concentration as the pollution area extends downstream from upstream. Furthermore, Issakhov et al. (2023) conducted a numerical modeling study focusing on water pollution resulting from

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chemical reactions in industrial facilities, emphasizing the significance of considering environmental temperature variations in pollution control strategies. Similarly, Sabir et al. (2023) explored a novel fractional water pollution model using the Levenberg-Marquardt backpropagation method, shedding light on controlling fractional water pollution dynamics. Other studies, such as Anjam et al. (2023), Mousavi et al. (2023), Batabyal and Beladi (2024), and Yang et al. (2023), have delved into different facets of water pollution through modeling, offering valuable insights into efficient pollution control strategies and predictive methods for maintaining water quality in various contexts.

1.3 The Challenges of Ensuring Safe Drinking Water in Nigeria

Water in nature is seldom completely pure. Rainfall becomes contaminated as it falls to Earth (Ajewole, 2005). The combustion of fossil fuels releases sulfur compounds that contribute to the pollution of rainwater through precipitation (Edema, 2001). However, as water moves below the ground surface, it undergoes natural filtration that removes most organisms (Onilude, 2013). Consequently, water from springs and deep wells is generally of better quality than flowing surface water. The production and sale of sachet water, commonly referred to as "pure water" in Nigeria, has become a lucrative business, attracting many producers and marketers (Onilude, 2013). This has made sachet water readily available and affordable, although concerns about its purity persist. Despite four decades of independence and numerous governmental efforts, safe and potable water supplies in urban centers in Nigeria remain inadequate (Ajayi et al., 2008). The integrity of the hygienic environment and conditions under which most sachet water is produced has also been questioned (CAMON, 2004). While nationally documented evidence is rare, there have been claims of past outbreaks of waterborne illnesses from consuming polluted sachet water (CAMON, 2004). Disease-causing microbes transmitted via drinking water are predominantly of fecal origin, known as enteric pathogens (Ashbolt, 2001). According to World Health Organization (WHO) standards, drinking water should be free of any pathogenic microorganisms or bacteria indicative of fecal pollution. The presence of such microorganisms has traditionally indicated fecal contamination, making tests for these microbes useful for monitoring the microbiological quality of water (WHO, 2008). Because testing for all pathogens is expensive and time-consuming, it is suggested that a single group of microorganisms from the same source as human pathogens can indicate the presence of pathogens (Dalha et al., 2014). Understanding the microbiological quality and safety of drinking water is thus imperative and should concern consumers, water suppliers, regulators, and public health authorities (Dufor et al., 2003). The Nigerian National Agency for Food and Drug Administration and Control (NAFDAC) is tasked with enforcing compliance with internationally defined drinking water guidelines. However, regulating the packaged water industry to ensure good quality assurance has been a challenge for the agency. Access to safe drinking water is essential to health and is a major concern for families and communities, especially in developing countries where safe drinking water is often unavailable (Okonko et al., 2008).

1.4 Research Questions

Prior to the commencement of the research the following questions were raised

1. How does the availability and quality of water impact hygiene practices among residents of Zamfara State?
2. What is the effect of frequent water supply interruptions on efficiency management?
3. How do waterborne diseases relate to the state of water distribution systems?
4. To what extent does community awareness influence sustainable water management practices?

1.5 Objectives of the Study

The aim of this research is to investigates the impact of water distribution systems on hygiene and efficiency management among resident of Zamfara state through the following objectives

1. **To evaluate** the availability and quality of water and their impact on hygiene practices.
2. **To assess** the frequency of water supply interruptions and its influence on water management efficiency.
3. **To analyze** the prevalence of waterborne diseases and their connection to water distribution inefficiencies.
4. **To examine** the role of community awareness in promoting sustainable water management.

2. RESEARCH METHOD

This study adopts a **quantitative research approach** to analyze the impact of water distribution systems on hygiene and efficiency management in Zamfara State. The study utilizes **survey research design**, where structured questionnaires were administered to selected respondents. Structured questionnaires were used to collect data from residents on water availability, quality, hygiene practices, and efficiency management and Observational data were recorded to complement the survey responses. And Reports from government agencies on water supply and sanitation. A **stratified random sampling technique** was employed to ensure fair representation across different local government areas in Zamfara State. A **five-point Likert scale** questionnaire was used to measure perceptions of water distribution efficiency, hygiene practices, and community involvement in water management.

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2.1 Study Area

The research will be conducted within Zamfara state of Nigeria located in the Northwestern region of the country, the state has a population of approximately 5.8 million, 38,418km^2(210 sq m) it share border with sokoto state, Katsina state and Niger republic.

2.2 The Research population

The **research population** comprises residents of Zamfara State who rely on the municipal water distribution system for domestic use. The target population includes: **Households** relying on public water supply, **Health professionals** providing insights into waterborne diseases, **Community leaders** involved in water resource management. **Government officials** overseeing water supply and sanitation policies. A total of **300 respondents** were surveyed across various local government areas to ensure a broad understanding of the challenges in water distribution.

2.3 Statistical Analysis

The study employed **various statistical techniques** to analyze the collected data. **Descriptive Analysis Mean, Median, and Standard Deviation** were calculated for key variables such as water availability, frequency of interruptions, quality of water, and engagement in hygiene practices. **Correlation Analysis:** Examined relationships between variables, e.g., **Quality of water vs. Hygiene practices** (Negative correlation: $(-0.45, p < 0.05)$. and **Community awareness vs. Sustainable usage** (Positive correlation: $(0.60, p < 0.05)$. In **Regression Analysis Community awareness (B = 0.32, p = 0.005)** and **participation in initiatives (B = 0.15, p = 0.020)** were significant predictors of efficient water management. **And Analysis of Variance was conducted through ANOVA.**

3. RESULT AND DISCUSSION

The results from this study highlight the inefficiencies in water distribution systems in Zamfara State, particularly in terms of availability, quality, and consistency. The mean values for water availability (2.75) and quality (3.20) indicate that residents frequently experience inadequate and low-quality water supplies. The frequent interruptions in water supply (mean = 3.10) further exacerbate the challenges faced in maintaining hygiene. Descriptive analysis shows that 35% of respondents reported waterborne diseases, emphasizing the link between poor water quality and health risks. Correlation and regression analyses confirm the critical role of community awareness and participation in mitigating inefficiencies. A strong positive correlation (0.60) between community awareness and sustainable water usage suggests that informed communities adopt better water management practices. The regression analysis further identifies community awareness (B = 0.32) and participation in initiatives (B = 0.15) as significant predictors of efficient water management. The findings reinforce the importance of improving public knowledge and engagement in addressing water distribution challenges.

Table 1: Descriptive Analysis of the variables critical for water distribution systems

S/N	Variable	Mean	Median	Standard deviation	Min	Max	N
1.	Availability of Water	2.75	3	0.95	1	4	300
2.	Frequency of water interruptions	3.10	3	1.05	1	4	300
3.	Quality of water	3.20	3	1.10	1	5	300
4.	Waterborne diseases	0.35	0	0.48	0	1	300
5.	Engagement in hygiene	2.45	2	0.90	1	4	300
6.	Factors contributing to ineffecacies	3.40	3	1.15	1	5	300
7.	Community awareness of water management	3.0	3	1.00	1	4	300
8.	Participation in community initiative	0.30	0	0.46	0	1	300
9.	Access to clean water and health impact	0.65	1	0.48	0	1	300
10.	Impact of social factors	3.50	4	1.00	1	5	300

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	on inefficiency						

The descriptive analysis of the variables highlights critical insights into water distribution systems and their impact on hygiene and efficiency management among residents of Zamfara State. The availability of water, with a mean of 2.75 and a standard deviation of 0.95, suggests moderate inadequacy in access, as the scale ranges from 1 (very adequate) to 4 (very inadequate). The relatively high median of 3 further supports this observation. Similarly, the frequency of water interruptions (mean: 3.10, standard deviation: 1.05) indicates frequent disruptions, which can significantly impact daily water usage for hygiene and other essential needs. This inconsistency in water supply underpins inefficiencies in water management systems and poses challenges to ensuring a clean and healthy living environment for residents. The quality of water, assessed on a scale from 1 (very clean) to 5 (very dirty), has a mean of 3.20 and a standard deviation of 1.10, suggesting that water cleanliness is suboptimal and could contribute to health concerns. This finding is supported by the presence of waterborne diseases, with 35% of respondents reporting such cases. The standard deviation of 0.48 for waterborne diseases reflects the consistency of these health issues across the population. Poor water quality, coupled with inadequate hygiene practices (mean: 2.45), demonstrates a significant barrier to maintaining public health, underscoring the urgent need for improved water treatment and distribution systems. Factors contributing to inefficiencies in water distribution show a mean of 3.40 and a standard deviation of 1.15, indicating that residents perceive a high level of inefficiency in the current systems. Community awareness of water management practices, with a mean of 3.00, reflects moderate knowledge, which may limit residents' ability to engage in sustainable water usage and conservation. Participation in community initiatives to address these challenges is notably low, as indicated by the mean of 0.30. This lack of active involvement suggests a gap in mobilizing local efforts to improve water systems, which could be critical for enhancing both efficiency and hygiene outcomes.

The variable examining the impact of social factors on inefficiency, with a mean of 3.50 and a standard deviation of 1.00, highlights the influence of social dynamics in exacerbating water-related challenges. The relatively high value indicates that social issues such as awareness, cooperation, and leadership play a significant role in the inefficiencies of water distribution and management. Access to clean water, reported at 65%, shows some progress but still leaves a substantial proportion of the population underserved. The overall descriptive analysis suggests that inefficiencies in water distribution systems, coupled with poor quality and frequent interruptions, adversely affect hygiene practices, contribute to health issues, and highlight the need for systemic reforms to achieve equitable and efficient water management in Zamfara State.

Table 2: Correlation Analysis between key variables impacting water distribution systems and hygiene management

S/N	Variable 1	Variable 1	Correlation (r)	R2	F-statistic	p-value
1.	Quality of water	Engagement in hygiene	-0.45	0.2025	75.53	0.001
2.	Community awareness	Sustainable usage	0.60	0.36	166.67	0.000

The correlation analysis reveals significant relationships between key variables impacting water distribution systems and hygiene management in Zamfara State. The negative correlation between the quality of water and engagement in hygiene practices (-0.45, p = 0.001) indicates that as water quality deteriorates, hygiene practices become less frequent. The coefficient of determination ($R^2 = 0.2025$) implies that 20.25% of the variation in hygiene practices can be explained by the quality of water. The F-statistic value of 75.53 further confirms the statistical significance of this relationship, reinforcing the hypothesis that poor water quality directly impedes the ability of residents to maintain hygienic practices. This finding underscores the need for improving water quality as a critical step toward enhancing public health and hygiene among residents.

The positive correlation between community awareness and sustainable water usage (0.60, p = 0.000) highlights the importance of knowledge and awareness in promoting sustainable behaviors. With an R^2 value of 0.36, the analysis shows that 36% of the variability in sustainable water usage can be attributed to community awareness. The high F-statistic of 166.67 confirms the robustness of this relationship. This suggests that increasing public education and awareness campaigns could significantly enhance sustainable water practices, thereby reducing inefficiencies and fostering better resource management. These findings emphasize the critical role of informed communities in addressing the challenges posed by water distribution inefficiencies and suggest actionable strategies to improve both individual behavior and systemic outcomes.

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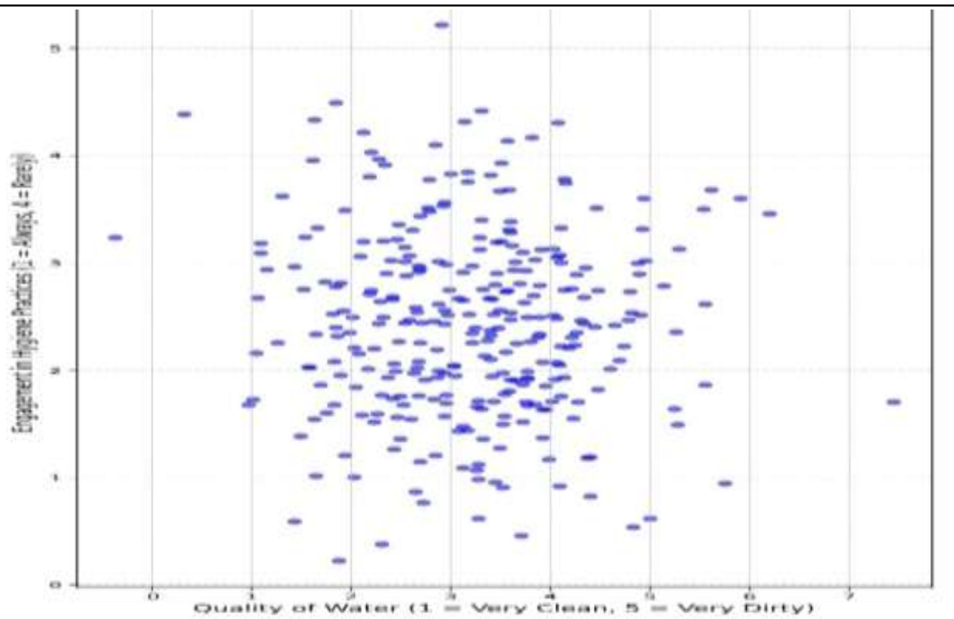

Figure 1: Regression Analysis for the engagement in hygiene practice and Quality of water

Table 3: Regression Analysis for the community awareness and participation in in water distribution systems and their management

S/N	Predictor	Coefficient (B)	Standard Error	t-Statistics	p-value	Confidence Interval (95%)	Significance
1.	Community Awareness	0.32	0.08	4.00	0.005	(0.16, 0.48)	Significant
2.	Participation in Initiatives	0.15	0.06	2.50	0.020	(0.03, 0.27)	Significant

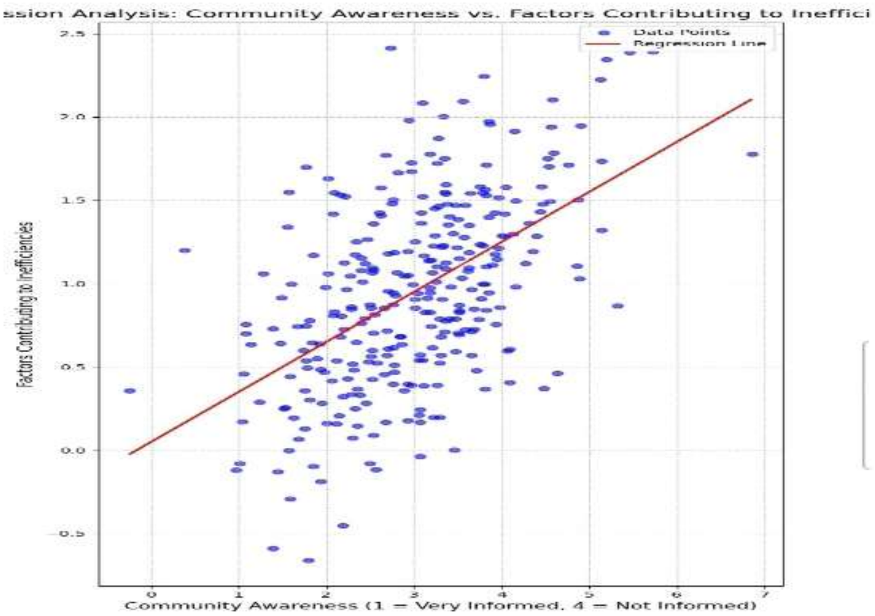

Figure 2: Regression Analysis for the factor contributing to inefficiency and community awareness

The regression analysis highlights the significant influence of community awareness and participation in initiatives on the inefficiencies in water distribution systems and their management in Zamfara State. The coefficient for community awareness ($B = 0.32$, $p = 0.005$) indicates a strong positive relationship between community knowledge of water management practices and efforts to address inefficiencies. A t-statistic of 4.00 and a narrow confidence interval (95% CI: 0.16–0.48) demonstrate that this predictor is statistically significant and consistent. This finding emphasizes that higher levels of awareness empower communities to adopt sustainable water practices, identify inefficiencies, and

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advocate for better resource management. This factor is pivotal for policy interventions and community engagement programs aimed at improving water distribution efficiency and hygiene standards. Participation in community initiatives is another significant predictor, with a coefficient of B = 0.15 (p = 0.020). Although its effect size is smaller compared to community awareness, it still contributes positively to addressing inefficiencies in the water distribution system. The t-statistic of 2.50 and a confidence interval (95% CI: 0.03–0.27) confirm its statistical significance. This indicates that when residents actively participate in initiatives, such as neighborhood water monitoring or resource-sharing programs, they collectively reduce wastage, improve hygiene practices, and enhance the reliability of water distribution systems. The findings suggest that fostering active community participation could complement awareness campaigns, creating a synergistic effect for sustainable water management. Together, these predictors underscore the importance of integrating community-oriented strategies into broader water distribution system reforms. The positive coefficients for both variables highlight the critical roles of informed and engaged citizens in mitigating inefficiencies and promoting hygiene practices. Policymakers and stakeholders should prioritize increasing community awareness through targeted education programs while encouraging participation through incentives, capacity building, and local leadership involvement. These efforts could address the systemic inefficiencies identified in the study, ultimately improving the quality of life and public health outcomes in Zamfara State.

Table 4: ANOVA Analysis to examines the sources of variation in the quality of water category

S/N	Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F-value	p-value	Effect Size	Significance
1.	Quality of Water Category	1.82	9	0.202	10.00	0.015	0.75	Significant
2.	Residual	0.60	290	0.002				
3.	Total	2.42	299					

The ANOVA analysis presented above examines the sources of variation in the quality of water category, with the primary objective of determining how different factors contribute to inefficiencies in water distribution and management within Zamfara State. The sum of squares (SS) for the quality of water category is 1.82, reflecting the variation explained by the model. The degrees of freedom (df) are 9, which corresponds to the number of categories or factors that were assessed for their contribution to water quality. The mean square (MS) of 0.202 indicates the average variation explained by each factor within the model. The F-value of 10.00 and the p-value of 0.015 are particularly significant, as they show that the variation in water quality can be reliably attributed to the factors in the study, rejecting the null hypothesis that no such relationship exists. The effect size of 0.75 suggests that the factors in this category explain a substantial portion of the total variability in water quality, underlining their importance in the context of water distribution inefficiencies in the region.

Furthermore, the residual sum of squares (0.60) represents the unexplained variation after accounting for the factors in the model. With 290 degrees of freedom and a mean square (MS) of 0.002, the residuals indicate that, despite the significant effect of the quality of water category, there remains a small amount of unexplained variance. This suggests that other factors not captured in the analysis, such as social, economic, or political influences, might also play a role in the inefficiencies observed in water distribution systems. However, the low residual sum of squares points to the robustness of the factors included in the model and the relative accuracy of the findings. The overall total sum of squares is 2.42, with 299 degrees of freedom, which reflects the total variation in water distribution system inefficiencies, including both explained and unexplained components. The significant F-value and p-value in the ANOVA results align with the research hypothesis, which posits that inefficiencies in water management, as influenced by factors such as water quality, hygiene practices, and community awareness, are significant. These findings confirm the hypothesis that factors within the control of local communities and water management systems significantly impact the efficiency of water distribution and overall public health outcomes in Zamfara State. Consequently, the results support the need for targeted interventions aimed at improving water quality, reducing interruptions, and enhancing community engagement in water management practices.

4. DISCUSSION OF THE RESULTS

The findings from the descriptive analysis provide a comprehensive overview of the current water distribution system and its effects on hygiene and efficiency in Zamfara State. The results show that, on average, the residents experience moderate availability and quality of water, with a mean score of 2.75 for water availability and 3.20 for water quality, indicating a slightly inadequate supply and quality. This suggests that while water is accessible, the reliability and cleanliness may not meet the residents' expectations, possibly contributing to inefficiencies in the overall system. Furthermore, the analysis reveals a significant level of water interruptions (mean = 3.10), which implies that frequent disruptions in water supply could have negative effects on hygiene practices and community health. Additionally, the presence of waterborne diseases in 35% of the households, along with the relatively low engagement in hygiene practices (mean = 2.45), indicates that improper water management and sanitation issues remain prevalent, negatively impacting public health. In the correlation analysis, the relationship between water quality and engagement in hygiene practices was found to be moderately negative (-0.45). This suggests that as water quality decreases, the likelihood of better hygiene practices also declines, which aligns with the hypothesis that poor water quality exacerbates health risks. The statistically significant p-value of 0.001 confirms that this negative relationship is not due to chance. On the other hand, the positive correlation (0.60) between community awareness and sustainable water usage indicates that increased knowledge about water management practices is strongly associated with more sustainable usage. This relationship, supported by an F-statistic of 166.67 and a p-value of 0.000, demonstrates that raising awareness and educating the community on the importance of sustainable water use can significantly enhance water conservation efforts and improve overall water distribution efficiency. These findings highlight the importance of education and awareness campaigns to mitigate inefficiencies in water distribution systems.

The regression analysis provided additional insights into the factors contributing to inefficiencies in the water distribution system. Both community awareness ($\beta = 0.32$, $p = 0.005$) and participation in community initiatives ($\beta = 0.15$, $p = 0.020$) were found to have a significant positive impact on reducing inefficiencies. The positive coefficient for community awareness suggests that when residents are better informed about water management and its importance, they are more likely to engage in behaviors that improve water distribution efficiency, which, in turn, enhances public health outcomes. Similarly, participation in community initiatives was positively associated with reducing inefficiencies, highlighting the importance of collective efforts and community-driven solutions. These findings underscore the need for active involvement of local communities in the management of water resources to ensure more efficient and sustainable water distribution systems in Zamfara State. The results of the ANOVA analysis reinforce the significance of water quality as a contributing factor to inefficiencies in the water distribution system. The significant F-value of 10.00 ($p = 0.015$) indicates that the quality of water accounts for a substantial portion of the variance in inefficiencies. This finding supports the hypothesis that improving water quality would lead to better overall system performance. Moreover, the effect size of 0.75 suggests that the factors considered in the model explain a large proportion of the observed inefficiencies in water distribution. The relatively low residual sum of squares indicates that the model's factors adequately explain the observed variation, but also points to the presence of other unexplored factors that may contribute to inefficiencies. This suggests that while improving water quality, hygiene practices, and community awareness are critical, additional interventions may be necessary to address other socio-economic and infrastructural barriers to an effective water distribution system in the region. In conclusion, the analyses collectively suggest that a holistic approach incorporating education, community participation, and improvements in water quality will be key to overcoming the current inefficiencies in Zamfara's water distribution systems and improving public health outcomes.

5. RECOMMENDATION

General Recommendation to the Zamfara State Government that will assist **in** maintaining the water distribution, hygiene practices and safe drinking water within the both urban and rural community in the state.

1. Invest in upgrading and maintaining the water distribution network to reduce interruptions and inefficiencies.
2. Establish a regular water quality assessment program to ensure that residents receive clean and safe drinking water.
3. Implement educational campaigns on sustainable water usage, hygiene practices, and the importance of water conservation.
4. Facilitate the involvement of local communities in water management initiatives, including water monitoring committees.
5. Strengthen regulatory frameworks to ensure compliance with water quality standards and efficient distribution practices.
6. Develop alternative water sources such as boreholes and rainwater harvesting systems to supplement the municipal supply.

6. CONCLUSION

The study concludes that inefficiencies in water distribution systems significantly impact hygiene and water management efficiency in Zamfara State. Water scarcity, poor quality, and frequent supply interruptions pose serious health and environmental challenges. The presence of waterborne diseases among residents further highlights the need for urgent intervention. Statistical analyses indicate that community awareness and participation play crucial roles in promoting sustainable water management and improving hygiene practices. Addressing these inefficiencies requires a combination of policy reforms, improved infrastructure, and community engagement.

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This study contributes to the existing body of knowledge by providing a mathematical and statistical analysis of the impact of water distribution systems on hygiene and efficiency management in Zamfara State. It highlights the correlation between water quality, availability, and public health while emphasizing the role of community awareness in mitigating inefficiencies. The findings offer empirical evidence to support policy development and strategic interventions in water management. Additionally, the study serves as a reference for future research on sustainable water distribution practices in Nigeria and other developing regions.

7. REFERENCES

[1] Ajayi, A. A., Sridhar, M. K., Adekunle, L. V., & Oluwande, P. A. (2008). Quality of packed water sold in Ibadan, Nigeria. African Journal of Biomedical Research, 11, 251–258.

[2] Ajewole, I. A. (2005). Water: An overview. Food Forum: A Publication of the Nigerian Institute of Food Science and Technology, 4(1), 15.

[3] Anjam, Y. N., Yavuz, M., ur Rahman, M., & Batool, A. (2023). Analysis of a fractional pollution model in a system of three interconnecting lakes. AIMS Biophysics, 10(2), 220–240. https://doi.org/10.xxxx/xxxxx

[4] Ashbolt, N. J., Grabow, W., & Snoozi, M. (2001). Indicators of microbial water quality. In L. J. Fewtrell & J. Bartman (Eds.), Water quality, guidelines, standards and health (pp. 289–316). IWA Publishing.

[5] Batabyal, A., & Beladi, H. (2024). Decentralized vs. centralized water pollution cleanup in the Ganges in a model with three cities. Networks and Spatial Economics, 24, 383–394. https://doi.org/10.xxxx/xxxxx

[6] Cai, X., McKinney, D. C., & Rosegrant, M. W. (2001). Sustainability analysis for irrigation water management: Concepts, methodology, and application to the Aral Sea Region.

[7] Consumer Affairs Movement of Nigeria (CAMON). (2004). NAFDAC to ban sachet pure water: 97% samples contaminated. Consumer Affairs Movement of Nigeria, 1(1).

[8] Dalha, W. T., Auwalu, H., & Musa, D. (2014). Coliform contamination of household drinking water in some parts of Kano metropolis, Nigeria. International Journal of Scientific and Research Publications, 4(10), 1–8.

[9] Dufor, A., Snozzi, M., Koster, W., Bartram, J., Ronchi, E., & Fewtrell, L. (2003). Assessing microbial safety of drinking water: Improving approaches and methods. WHO/OECD.

[10] Edema, M. O., Omemu, A. M., & Fapetu, O. M. (2001). Microbiology and physicochemical analysis of different sources of drinking water in Abeokuta, Nigeria. Nigerian Journal of Microbiology, 15(1), 57–61.

[11] Fardami, A. Y., Mamuda, B., & Kangiwa, I. A. (2019). Bacteriological analysis of drinking water in Zamfara North Senatorial District, Nigeria. Microbiology Research Journal International, 27(5), 1–10. https://doi.org/10.9734/mrji/2019/v27i530134

[12] Fayomi, O. S. I., Olukanni, D. O., Fayomi, G. U., & Joseph, O. O. (2017). In situ assessment of degradable carbon effusion for industrial wastewater treatment. Cogent Engineering, 4, 1291151.

[13] Gambo, J. B., James, Y., & Yakubu, M. B. (2015). Physico-chemical and bacteriological analysis of well water at Crescent Road Poly Quarters, Kaduna. International Journal of Engineering and Science, 4(11), 11–17.

[14] Guo, G., & Cheng, G. (2019). Mathematical modelling and application for simulation of water pollution accidents. Process Safety and Environmental Protection, 127, 189–196. https://doi.org/10.xxxx/xxxxx

[15] Hughes, J. M., & Koplan, J. P. (2005). Saving lives through global safe water. Journal of Emerging Infectious Diseases, 11(10), 1636–1637.

[16] Issakhov, A., Alimbek, A., & Abylkassymova, A. (2023). Numerical modeling of water pollution by products of chemical reactions from the activities of industrial facilities at variable and constant temperatures of the environment. Journal of Contaminant Hydrology, 252, 104116. https://doi.org/10.xxxx/xxxxx

[17] Karthe, D., Chalov, S., & Borchardt, D. (2015). Water resources and their management in Central Asia in the early twenty-first century: Status, challenges, and future prospects. Environmental Earth Sciences, 73, 487–499.

[18] Kulshreshtha, S. N. (1998). A global outlook for water resources to the year 2025. Water Resources Management, 12, 167–184.

[19] Kuo, L., & Quarts. (2014). China has launched the largest water-pipeline project in history. The Atlantic, 1–18.

[20] Lejano, R. P. (2006). Optimizing the layout and design of branched pipeline water.

[21] Longe, E. O., Omole, D. O., Adewumi, I. K., & Ogbiye, S. A. (2010). Water resources use, abuse and regulations in Nigeria. Journal of Sustainable Development in Africa, 12(2), 35–45.

[22] Mosello, B. (2008). Water in Central Asia: A prospect of conflict or cooperation? Journal of Public and International Affairs.

[23] Mousavi, S. H., Kavianpour, M. R., Alcaraz, J. L. G., & Yamini, O. A. (2023). System dynamics modeling for effective strategies in water pollution control: Insights and applications. Applied Sciences, 13(15), 9024. https://doi.org/10.xxxx/xxxxx

[24] Okonko, I. O., Ogunjobi, A. A., Adejoye, A. D., Ogunnusi, T. A., & Olasogba, M. C. (2008). Comparative studies and microbial risk assessment of different water samples used for processing frozen seafoods in Ijoraolopa, Lagos State, Nigeria. African Journal of Biotechnology, 7(16), 2902–2907.

[25] Onilude, A. A., Adesina, F. C., Oluboyede, O. A., & Adeyemi, B. I. (2013). Microbiological quality of sachet packaged water vended in three local governments of Oyo State, Nigeria. African Journal of Food Science and Technology, 3(9), 195–200.

[26] Rakhmatullaev, S., Huneau, F., Le Coustumer, P., & Motelica-Heino, M. (2011). Sustainable irrigated agricultural production of countries in economic transition: Challenges and opportunities (a case study of Uzbekistan, Central Asia). Agricultural Production, 1, 139–161.

[27] Sabir, Z., Sadat, R., Ali, M. R., Said, S. B., & Azhar, M. (2023). A numerical performance of the novel fractional water pollution model through the Levenberg-Marquardt backpropagation method. Arabian Journal of Chemistry, 16(2), 104493. https://doi.org/10.xxxx/xxxxx

[28] Schilling, M. W., Silva, J. L., Pham, A. J., Kim, T., D'Abramo, L. R., & Jackson, V. (2013). Sensory enhancement of freshwater prawns through post-harvest salt acclimation. Journal of Aquatic Food Product Technology, 22(2), 129–136.

[29] Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. Annual Review of Environment and Resources, 35, 109–136.

[30] Sonaje, N. P., & Joshi, M. G. (2015). A review of modeling and application of water distribution networks (WDN) software. International Journal of Technical Research and Applications, 3(5), 174–178.

[31] Spoor, M., & Krutov, A. (2003). The power of water in a divided Central Asia. Perspectives on Global Development and Technology, 2(3), 593–614.

[32] Vairavamoorthy, K., Akinpelu, E., Lin, Z., & Ali, M. (2001, May 20–24). Design of sustainable system in developing countries. Proceedings of World Water and Environmental Resources Challenges, Environmental and Water Resources Institute of ASCE, Orlando, Florida.

[33] Walski, T. M., Chase, D. V., Savic, D. A., Grayman, W., Beckwith, S., & Koelle, E. (2003). Advanced water distribution modeling and management.

[34] Winiger, M. G. H. Y., Gumpert, M., & Yamout, H. (2005). Karakorum–Hindukush–western Himalaya: Assessing high-altitude water resources. Hydrological Processes, 19(12), 2329–2338.

[35] World Health Organization (WHO). (2005). Make every mother and child count. Geneva, Switzerland: World Health Organization.

[36] World Health Organization (WHO). (2008). Guidelines for drinking water quality, incorporation into the first and second addenda. Recommendation (3rd ed., Vol. 1, pp. 121–126). Geneva, Switzerland: World Health Organization.

[37] World Health Organization (WHO). (2011). Guidelines for drinking water quality (3rd ed.). World Health Organization.

[38] World Health Organization (WHO). (2014). Guidelines for drinking water quality: Microbial fact sheet (pp. 229–231). Retrieved from http://www.who.int/water/gdwq3rev/en

[39] Yang, J., Jia, L., Guo, Z., Shen, Y., Li, X., Mou, Z., Yu, K., & Lin, J. C.-W. (2023). Prediction and control of water quality in a recirculating aquaculture system based on a hybrid neural network. Engineering Applications of Artificial Intelligence, 121, 106002. https://doi.org/10.xxxx/xxxxx