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ASSESSMENT OF PHYSICOCHEMICAL WATER QUALITY PARAMETERS ASSOCIATED WITH DRINKING WATER POTABILITY

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Abstract—*Safe drinking water is essential for public health, yet deterioration in physicochemical water quality continues to pose significant environmental and health challenges. Identifying key physicochemical predictors of water potability is important for improving water quality monitoring and management. This quantitative secondary data analysis utilized the publicly available Water Potability dataset from the Kaggle repository, comprising 1,000 water samples. Nine physicochemical parameters, including pH, hardness, solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity, were analyzed. Descriptive statistics, independent sample t-tests, correlation, variance inflation factor analysis, regression, and model performance evaluation were performed. Statistical significance was established at $p < 0.05$. Most physicochemical parameters showed comparable distributions among potable and non-potable water samples. Trihalomethanes emerged as the only significant independent predictor of water potability in the multivariable logistic regression model. Correlation and multicollinearity analyses indicated weak associations among predictor variables and the absence of substantial multicollinearity. The logistic regression model demonstrated moderate predictive performance, achieving an accuracy of 60.5%, specificity of 69.3%, sensitivity of 46.5%, and an area under the receiver operating characteristic curve of 0.582. Physicochemical assessment combined with multivariable logistic regression provides an interpretable approach for identifying important predictors of drinking water potability. Monitoring trihalomethanes alongside routine water quality parameters may strengthen drinking water surveillance and support evidence-based environmental management.*

Keywords: *Drinking water quality; Water potability; Physicochemical parameters; Logistic regression; Water quality assessment*

1. INTRODUCTION

Safe drinking water is fundamental to human health, the sustainability of the environment and socioeconomic development. Nevertheless, the situation is still threatened by the quick urbanization, industrialization, population growth, and environmental pollution in the world the abundance of drinkable water. Poisonous drinking water is one of the key causes of waterborne illnesses and negative health effects, and frequent water quality evaluation is essential to safeguard human health and adhere to the safety standards (Addisie, 2022). The physicochemical properties of water, such as pH, hardness, total dissolved solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity, are the major determinants of drinking water quality. These parameters contain the chemical composition of water and show the appropriateness of water to human consumption. They can differ based on natural geologic environments, industrial effluents, agricultural runoffs, and other human activities (Haftu & Sathishkumar, 2020). A balance between these parameters to acceptable ranges is thus necessary to keep the health risks to the minimum and safe water supplies (Fetrat & Islam, 2024). Water quality index-based assessments of groundwater have also proven that physicochemical parameters play a crucial role in assessing the overall quality of water and aiding environmental management (Abolli et al., 2022).

Some of the studies have indicated that diminished physicochemical water quality is usually associated with microbial contamination and health hazards. Evaluations of domestic and drinking water sources have highlighted that the constant check of physicochemical and bacteriological parameters is critical to prevent the outbreak of diseases and provide safe drinking water (Adesakin et al., 2020; Asionye et al., 2023). The same has been observed in Nigeria and Ethiopia, where combined assessments emphasized the need to conduct regular monitoring to protect the general health and ensure drinking water quality (Edeki et al., 2023; Atumo Ante et al., 2023). Traditional drinking water testing has been done using laboratory measurements and water quality indices to establish conformity to recommended standard. These methods incorporate various physicochemical variables in one indicator, which makes it easier to interpret and make environmental decisions (Abolli et al., 2024). In more recent times, multivariate statistical methods have enhanced the quality of water quality by determining how physicochemical variables are related to each other and how much the key factors contributing to water quality impact it (Fikret et al., 2021). The use of correlation analysis has also been extensive to analyze the relationship between water quality parameters (Kothari et al., 2021), whereas the combination of physicochemical and microbiological information through an integrated analytical method has also enhanced the evaluation and management of water quality (Maguvu et al., 2020).

Despite the fact that various studies have been carried out to determine the quality of drinking water based on its physicochemical parameters, majority of them have either concentrated on water quality indices, contamination analysis, microbiological analysis or regional environmental surveillance. Investigations in groundwater system and rural populations have shown spatial variability of physicochemical parameters but have not substantiated the independent contribution of each variable to potability of water (Gebresilasie et al., 2021; Lewoyehu, 2021). Similarly, integrated tests have focused on the combined effect of physicochemical and bacteriological properties and provided limited information on the predictive value of specific physicochemical parameters (Kassegne & Leta, 2020). Health risk assessment has also revealed that variations in physicochemical properties can raise the exposure risks between source and consumption (Luvhimbi et al., 2022) and cause negative health effects (Malakootian et al., 2020). In addition, the recent research has found important physicochemical parameters that influence the quality of drinking water but has primarily addressed the optimization of water treatment instead of predictive statistical modelling of potability (Koley et al., 2024). This means that there is still a necessity of an interpretable statistical model that can determine independent physicochemical predictors of drinking water potability.

By defining the physicochemical parameters that alone affect the potability of water, the drinking water may be more robustly monitored and evidence-based environmental management may be supported. Secondary data, especially those publicly accessible, provide a cost-effective way of analyzing water quality trends without having to collect primary data. Multivariate logistic regression is a statistically interpretable method to estimate the independent effect of a set of physicochemical parameters with a comparison of the overall model performance. Thus, a publicly accessible water quality data set was analyzed in this paper to determine the important physicochemical predictors of drinking water potability and the predictive efficiency of a logistic regression model. The results should inform the environmental monitoring agencies, water treatment authorities and the policy makers of the population about the bettering of the drinking water quality evaluation and management.

Objectives of the study

1.To evaluate the physicochemical characteristics of potable and non-potable water samples and examine the relationships among water quality parameters.

2.To identify independent physicochemical predictors of drinking water potability using multivariable logistic regression and evaluate the predictive performance of the model.

2. METHODOLOGY

2.1 Study Design

The research design used in this study was a quantitative secondary data analysis design to determine the relationship between physicochemical water quality parameters and drinking water potability. Available water quality records were evaluated to assess variations in potable and non-potable water samples and to determine important physicochemical predictors of water potability. The quantitative secondary data analysis methodology proved to be suitable since it allowed a thorough statistical assessment of an already existing dataset without having to collect primary data and offered credible evidence regarding the factors related to water potability.

2.2 Data Source and Study Population

The source of data for this research was secondary data obtained from an online dataset available on the Kaggle data repository (Kadiwal, 2021). The dataset was comprised of 1,000 water samples with measurements of physicochemical parameters and the potability status of the samples. The population of the study included potable and non-potable water samples that were fully measured in terms of pH, hardness, solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity. The fact that this research was solely carried out based on secondary data meant that all the records that were available in the data set were used in the analysis.

2.3 Study Variables

The dependent variable was water potability and it was either potable or non-portable as per the dataset. These independent variables were the pH, hardness, solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity. These physicochemical parameters were chosen as they are significant indicators of drinking water quality and were measured to identify how much they were associated with water potability and to show an independent predictive value of classifying water samples.

2.4 Data Processing

The dataset was checked to make sure that all data is present and is consistent and therefore is subject to statistical analysis. All the variables were kept in their measurement scales and water potability was kept as a binary outcome variable of potable and non-potable water samples. The completed dataset was formatted to undergo descriptive and inferential statistical tests, such as descriptive, independent sample t-tests, Pearson correlation analysis, variance inflation factor analysis, multivariate logistic regression and model performance analysis.

2.5 Statistical Analysis

To assess the physicochemical properties of the water samples and determine predictors of water potability, statistical analysis was carried out. The distribution of potable and non-portable samples was described in terms of frequency and percentage, whereas all physicochemical variables were summarized with the help of descriptive statistics. Potable and non-portable groups were compared using independent sample t-tests. The correlation and variance inflation factor (VIF) to test the relationship between variables and multicollinearity. Regression was used to find independent predictors of water potability, and accuracy, sensitivity, specificity, positive predictive value, negative predictive value, F1-score, area under the receiver operating characteristic (ROC) curve, and the Hosmer -Lemeshow goodness-of-fit test to assess model performance. The level of statistical significance was $p < 0.05$.

3. Results

3.1 Distribution of Water Samples According to Potability

A total of 1,000 water samples were included in the study. The study had all ten variables including nine physicochemical parameters and one binary outcome variable (potability). Water samples based on their potability status are shown in Figure 1. Out of the 1,000 water samples that were part of the study, the non-potable samples had a higher percentage as opposed to the potable water samples.

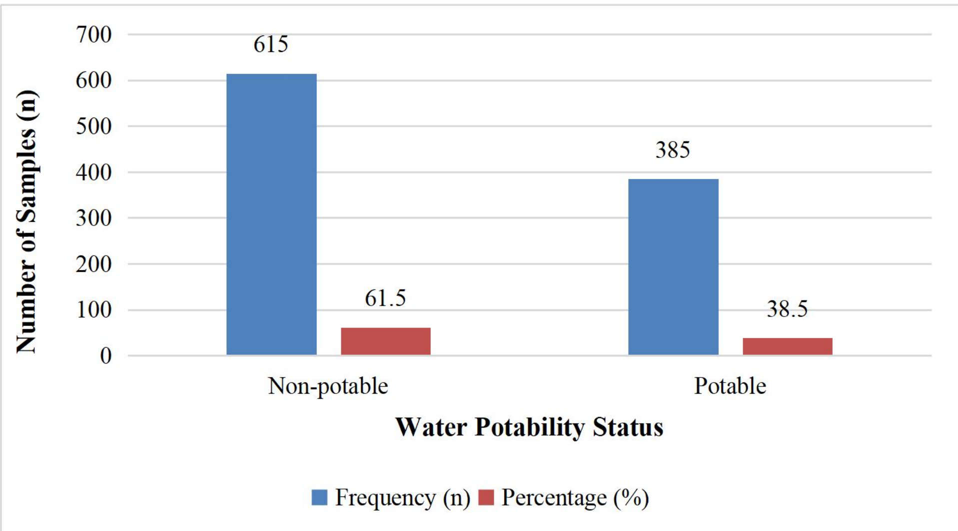

Figure 1. Distribution of water samples according to potability status

Figure 1 shows that 615 (61.5) of the water samples were categorized as non-potable, and 385 (38.5) as potable. The results demonstrate that the non-potable samples were more common than the potable samples in the research sample.

3.2 Descriptive Statistics of Physicochemical Water Quality Parameters

Table 1 summarises the overall descriptive statistics of the physicochemical parameters. The mean pH was 7.12 ± 1.57, while hardness averaged 196.21 ± 30.24 mg/L. Total dissolved solids demonstrated the greatest variability (21,997.40 ± 8,869.67 mg/L). The mean concentrations of chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity were 7.11 ± 1.64 mg/L, 331.27 ± 41.26 mg/L, 429.03 ± 80.58 µS/cm, 14.25 ± 3.35 mg/L, 66.97 ± 16.16 µg/L, and 3.94 ± 0.79 NTU, respectively. In general, the majority of variables were distributed fairly symmetrically with mild skewness.

TABLE 1. OVERALL DESCRIPTIVE STATISTICS OF PHYSICOCHEMICAL WATER QUALITY PARAMETERS

Parameter	Mean ± SD	Median	IQR	Minimum	Maximum
pH	7.12 ± 1.57	7.04	1.99	0.23	12.25
Hardness	196.21 ± 30.24	197.93	34.49	73.49	306.63
Solids	21,997.40 ± 8,869.67	21,065.07	11,662.02	1,372.09	56,488.67
Chloramines	7.11 ± 1.64	7.11	2.10	2.48	13.13
Sulfate	331.27 ± 41.26	330.47	48.90	129.00	476.54
Conductivity	429.03 ± 80.58	425.51	117.00	210.32	695.37
Organic carbon	14.25 ± 3.35	14.21	4.69	2.20	23.92
Trihalomethanes	66.97 ± 16.16	66.67	20.15	8.58	120.03
Turbidity	3.94 ± 0.79	3.96	1.09	1.50	6.49

3.3 Correlation Analysis and Multicollinearity Assessment

Correlation analysis showed weak correlations between the studied physicochemical parameters and none of the strong linear relationships. The values of variance inflation factor (VIF) were between 1.004 and 1.117 and tolerance between 0.895 and 0.996 indicating that there was no multicollinearity between the predictor variables.

The tolerance and Variance Inflation Factor (VIF) were used to assess the multicollinearity of the physicochemical predictor variables. Figure 2 depicts the findings and gives a graphical view of the level of multicollinearity between the variables of study.

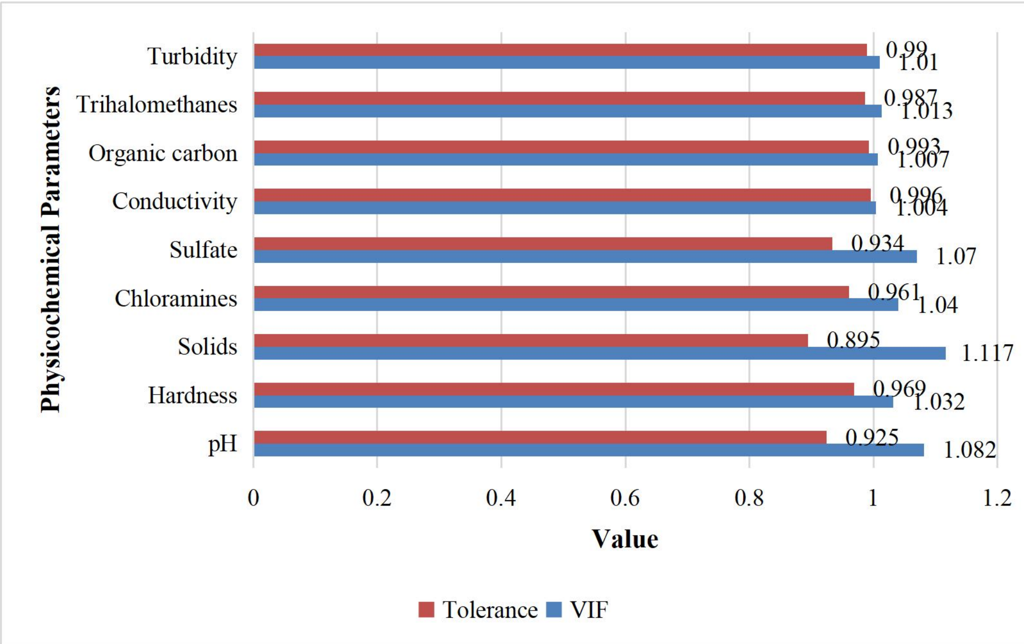

Figure 2. Assessment of Multicollinearity

All the variants of predictors are seen to have VIFs between 1.004 and 1.117 and tolerance between 0.895 and 0.996 as seen in Figure 2. Solids showed the highest VIF (1.117) and Conductivity had the lowest VIF (1.004). On the same note, the tolerance values were far above the accepted level of 0.20 of all variables. Such results suggest that there were no major multicollinearities between the physicochemical parameters and that all the predictors could be included in the multivariate logistic regression model.

3.4 Comparison of Physicochemical Parameters Between Potable and Non-potable Water

Table 2 shows the comparison of physicochemical parameters of potable and non-potable water samples. There was a significant difference in conductivity between the two groups, where potable water had lower conductivity than non-potable water ($p = 0.041$). Likewise, the concentration of trihalomethane was much higher in potable samples than non-portable ones ($p = 0.028$). Other physicochemical parameters, such as pH, hardness, solids, chloramines, sulfate, organic carbon, and turbidity did not show significant differences between the two groups.

TABLE 2. COMPARISON OF PHYSICOCHEMICAL PARAMETERS ACCORDING TO POTABILITY STATUS

Parameter	Non-potable (Mean ± SD)	Potable (Mean ± SD)	Statistical test	p-value
pH	7.08 ± 1.57	7.19 ± 1.57	Mann–Whitney U	0.292
Hardness	196.40 ± 27.40	195.90 ± 34.34	Mann–Whitney U	0.938
Solids	21,677.60 ± 8,774.99	22,508.25 ± 9,006.75	Mann–Whitney U	0.173
Chloramines	7.05 ± 1.48	7.21 ± 1.86	Independent t-test	0.153
Sulfate	333.15 ± 32.09	328.27 ± 52.61	Independent t-test	0.102
Conductivity	432.86 ± 79.47	422.90 ± 82.06	Mann–Whitney U	0.041
Organic carbon	14.37 ± 3.38	14.05 ± 3.30	Independent t-test	0.146
Trihalomethanes	66.08 ± 15.96	68.39 ± 16.40	Independent t-test	0.028
Turbidity	3.92 ± 0.79	3.98 ± 0.77	Independent t-test	0.242

3.5 Model Performance Evaluation

Even though the entire regression model was statistically significant, the goodness-of-fit test of Hosmer-Lemeshow showed that the model was not calibrated (2 = 32.05, p = 0.001). Also, the ROC analysis indicated an area under the curve (AUC) of 0.582, which indicated a poor discrimination between potable and non-potable water samples. The model provided a model accuracy, sensitivity and specificity of 60.5, 46.5 and 69.3 respectively at the optimal probability threshold.

Normal classification measures were used to assess the overall predictive performance of the multivariate logistic regression model. The performance of the model in terms of accuracy, sensitivity, specificity, positive predictive value, negative predictive value, and F1-score is shown in Figure 3.

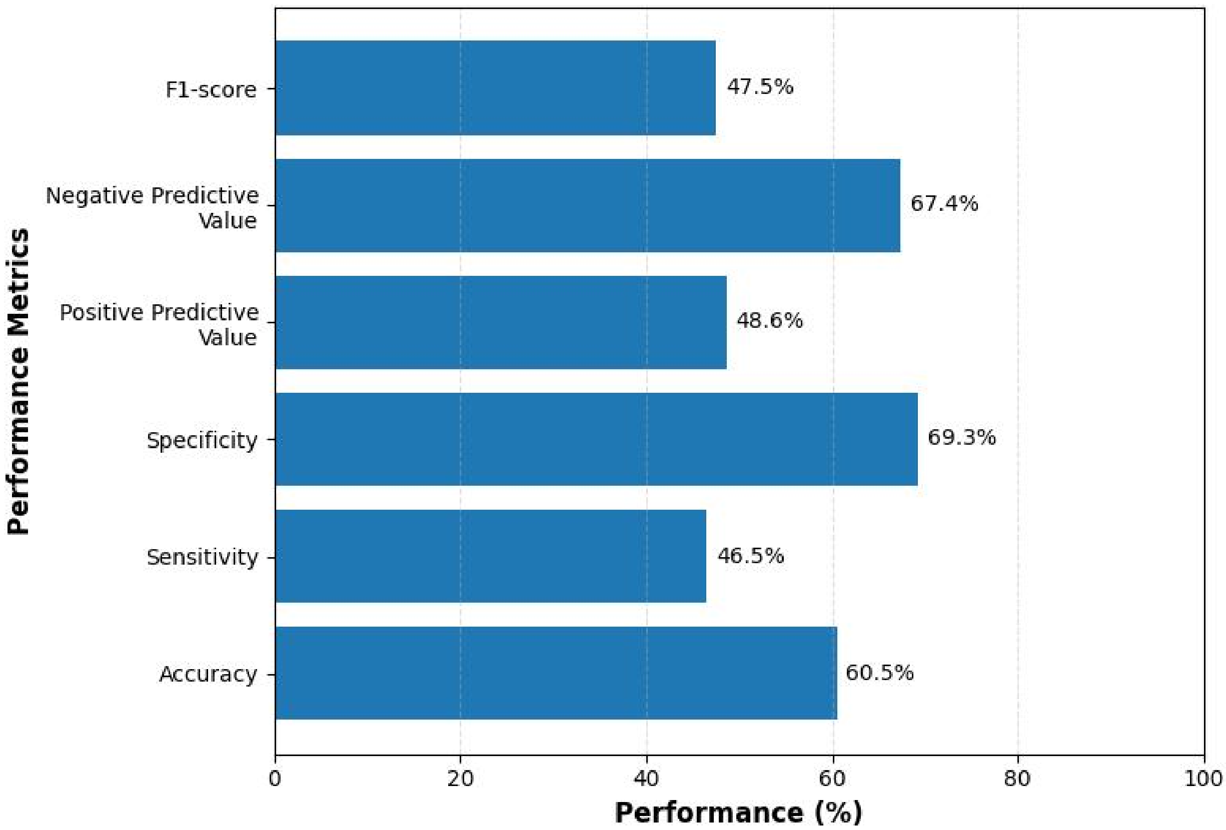

Figure 3. Performance of the Logistic Regression Model

Figure 3 demonstrates that the logistic regression model presented the best specificity (69.3%), negative predictive value (67.4%) and accuracy (60.5%). Sensitivity (46.5%), positive predictive value (48.6%), and the F1-score (47.5), on the other hand, were relatively lower, which suggests that the model was more efficient in correctly predicting non-potable water samples than the potable ones. In general, these results indicate average classification with more specificity than sensitivity.

3.6 Regression Analysis
All the physicochemical variables were entered into the multivariate logistic regression model. Table 3 demonstrates that trihalomethanes were the only statistically significant independent predictor of water potability, when all covariates were taken into account (Adjusted OR = 1.008, 95% CI: 1.0001.016; p = 0.049). The entire regression model was statistically significant (Likelihood Ratio 20.52 = 0.015, p = 0.015) but the explanatory power was low (McFadden pseudo-R 2 = 0.015).

TABLE 3. REGRESSION ANALYSIS

Predictor	Adjusted OR	95% CI	p-value
pH	1.074	0.986–1.170	0.103
Hardness	0.999	0.995–1.003	0.644
Solids	1.000	1.000–1.000	0.128
Chloramines	1.063	0.981–1.152	0.135
Sulfate	0.998	0.994–1.001	0.141
Conductivity	0.999	0.997–1.000	0.073
Organic carbon	0.975	0.938–1.013	0.192
Trihalomethanes	1.008	1.000–1.016	0.049
Turbidity	1.099	0.932–1.296	0.261

4. DISCUSSION

The current research tested the relationship between the physicochemical water quality parameters and drinking water potability under the descriptive statistics, comparative analysis, correlation analysis and multivariate logistic regression. The results revealed that the majority of the physicochemical parameters were relatively similar in the potable and non-potable water samples, and the single indicators of water quality may not be sufficient to give a clear indication of safe and unsafe drinking water. The comparative analysis showed that there were very few physicochemical variables which varied significantly between the two groups. In addition, trihalomethanes were the only meaningful independent predictors in the multivariate logistic regression model, suggesting that disinfection by-products can be more important in influencing the drinking water potability than a number of physicochemical characteristics that are regularly determined. The fact that there were weak correlations between predictor variables and low values of variance inflation factors further indicated that there was no multicollinearity, indicating that each variable provided distinct information to the regression model. Despite a moderate predictive accuracy of the logistic regression model, its specificity was higher than the sensitivity indicating that the model was more successful in predicting non-portable water samples than the potable ones.

The results of the current research align with those of earlier studies that have stressed the importance of using a holistic approach through physicochemical analysis to properly assess the quality of drinking water. The comparative study of bottled and well water revealed that a combination of various physicochemical variables was used to classify water quality, and using integrated statistical methods was more relevant than using single variables (Molefe et al., 2020). In the same vein, an overview of water quality monitoring revealed that the physicochemical analysis is still essential to determine the quality of drinking water and emphasize the trends of pollutants in various water sources (Nayar, 2020). Well-to-borehole comparisons also indicated significant differences in physicochemical properties between water sources based on the effect of local environmental factors on the quality of water (Odu et al., 2020). The Kenya-based household drinking water studies also revealed that the regular water quality monitoring should be supplemented by physicochemical analysis to guarantee the availability of safe drinking water sources (Ondieki et al., 2021). Groundwater investigations also revealed that the overall assessment of physicochemical parameters can offer valuable information on the quality of drinking water and contribute to the evidence-based environmental management (Qureshi et al., 2021). Moreover, the tests carried out in dry mountainous areas stressed that several physicochemical indicators must be used together to enhance the evaluation of the quality of drinking water and resource management (Saeed et al., 2022). Certainly, much the same has been found in Ethiopia, where, physicochemical assessment has been suggested in addition to other indicators of water quality to give a more credible picture of the safety of drinking water (Sitotaw et al., 2021).

The implications of the findings on environmental monitoring and the practice of the public health are significant. The finding that trihalomethanes is an independent predictor should emphasize the need to check the disinfection by-products as part of the regular water quality monitoring. Routine evaluation of the physicochemical parameters with interpretable statistical models can help the water treatment authorities to recognize key indicators related to the drinking water safety and facilitate evidence-based monitoring strategies. These approaches can enhance resource distribution, enable early warning of possible water quality decline, and enhance regulatory decision-making to protect the well-being of populations. Nevertheless, the current research was limited by a number of limitations. The study was conducted using a publicly available secondary data, which restricted the ability to control data collection processes and preclude the incorporation of other environmental, microbiological or geographical factors that could affect drinking water potability. More so, the dataset did not have seasonal variation and site-specific features, which could have influenced the predictive power of the model. The results may therefore only be understood in terms of the dataset provided and are not necessarily applicable to every drinking water system.

Microbiological, climatic, geographical, and land-use variables should also be included in future studies to come up with more predictive drinking water quality models. The comparative analysis of the traditional statistical methods and the new powerful machine learning algorithms can be improved further to enhance the accuracy of predictions and retain the interpretability of the model. Also, the predictive models would be more effective in terms of robustness and generalizability with validation by primary datasets collected in various geographical areas, which would facilitate more effective environmental monitoring and sustainable drinking water quality management.

5. Conclusion

The study compared physicochemical water quality parameters and drinking water potability with a publicly available secondary dataset and multivariate logistic regression analysis. The results indicated that the majority of the physicochemical parameters showed similar distributions in potable and non-potable water samples with only trihalomethanes as an important independent predictor of water potability after controlling other variables. The correlation and multicollinearity analyses identified that the predictor variables were measuring different variables of water quality and could be accurately incorporated into the regression model. Even though the logistic regression model showed moderate predictability, its specificity was higher than its sensitivity which showed that it was effective in predicting non-portable water samples than potable samples. The paper indicates the importance of using physicochemical evaluation together with multivariate statistical analysis to determine important predictors related to drinking water quality. The finding that trihalomethanes is a predictor on its own, highlights the need to test disinfection by-products as part of regular water quality monitoring. Although the physicochemical parameters are useful parameters used to assess the safety of drinking water, the results also indicate that other environmental and microbiological parameters ought to be included to enhance the predictability. On balance, this paper offers an interpretable and useful framework of determining the drinking water portability based on physicochemical data. The results could be used by environmental surveillance agencies, water treatment officials, and policymakers to enhance water quality measurement and formulate evidence-based policies on how to ensure safe and sustainable source of water to drink.

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