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STATISTICAL EVALUATION OF PHYSICOCHEMICAL WATER QUALITY PARAMETERS FOR ENVIRONMENTAL MONITORING

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Abstract
Water quality assessment is essential for ensuring safe water resources and maintaining environmental sustainability. Physicochemical parameters are widely used to evaluate the chemical characteristics of water and to detect possible contamination. The present study examines the statistical relationships among major physicochemical water quality parameters and their association with water potability. The analysis was conducted using a secondary dataset consisting of 10,000 water samples that included measurements of pH, hardness, dissolved solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes, and turbidity along with a potability indicator. Descriptive statistics were used to summarize the distribution of these parameters, while correlation analysis was performed to explore relationships among them. In addition, a comparative analysis was conducted to identify differences in parameter values between potable and non-potable water samples. The results indicated noticeable variability across several parameters, particularly dissolved solids and sulfate concentrations. Correlation analysis revealed moderate associations among mineral related parameters, suggesting that multiple environmental factors influence water chemistry. The comparative analysis further showed that certain parameters, including trihalomethanes, sulfate, and organic carbon, differed significantly between potable and non-potable samples. Overall, the findings demonstrate that statistical evaluation of physicochemical indicators can provide valuable insights into water quality conditions. Such analyses can support environmental monitoring efforts and contribute to more effective water resource management and public health protection.

***Keywords:** Water quality assessment, physicochemical parameters, environmental monitoring, water potability, correlation analysis, drinking water quality*

1. Introduction

Water is one of the most valuable natural sources of the livelihood, the operations of the ecosystems and socio-economic progress of the development. Human health, Agriculture, Industry and environmental sustainability rely on access to safe and clean water. But development has come with a great pace and the population has increased with rapid growth which has led to the population and urbanization process and industrialization and expansions in agriculture which have led to the degradation of water in most parts of the world. Pollution of the water bodies by chemical wastes, domestic effluents, agricultural effluents among others have become one of the most significant environmental problems and therefore the regular monitoring and evaluation of the water quality is all the more significant [1] [2].

Water quality assessment plays an important role in determining whether water is suitable for human consumption and ecological sustainability. Among the different methods that are applied for water quality evaluation, the study of physicochemical parameters is generally regarded as one of the most reliable methods. Parameters such as pH, hardness, conductivity, dissolved solids, turbidity, sulfate concentration, and organic carbon are commonly used parameters for identifying the level of contamination and chemical characteristics of water resources. These indicators reflect either natural geochemical processes or anthropogenic activities, such as industrial discharge, agricultural inputs and urban wastewater, which affect conditions of water quality [3] [4].

Several investigations have been focused on the importance of physicochemical parameters, especially in environmental monitoring and water quality management. For example, investigations of river systems have shown that variations in parameters such as dissolved solids, conductivity and turbidity can provide valuable information about environmental conditions and pollution level in aquatic ecosystem [5]. Similarly, studies performed in glacial lake and river systems have shown that the systematic evaluation of physicochemical parameters is necessary to understand the dynamics of water quality and identify environmental changes in aquatic environments [1].

In the last few years, statistical analysis has gained importance as a tool for interpreting complex water quality data sets. Environmental systems possess a number of interacting variables as a rule, that it is hardly possible to measure water quality based on individual parameters. Using statistics makes the researcher able to interpret the associations between different aspects that reflect the water quality and to be able to come up with some pattern that might not be easily realized through mere observation. Such methods as correlation analysis, multivariate statistical methods, are frequently used in the evaluation of the interactions between the physicochemical parameters, as well as of their own impact on the state of water quality [6].

Besides the use of statistical techniques, chemical quality of the drinking water systems is also something that has been of great concern in terms of both environmental and public health studies. The water distribution system could potentially be hazardous to the health of human population in case of the presence of chemical contaminants in it, unless it is monitored and controlled. The studies which have been carried on the drinking water in the urban area have indicated that on-going monitoring of the physicochemical indices is necessary to maintain the safe water quality benchmarks and to determine the possible health hazards of water pollution [7].

Water quality characteristics also may be influenced by environmental conditions surrounding water bodies. Some of the pollutants that may be added to the surrounding water system by the land-use activities include urban development, agricultural activities, and industrial activities, which may change the physicochemical composition of these water systems. The research on river basins has demonstrated that the spatial changes in water quality parameters are strictly connected with the land use trends in the area under consideration, and accordingly, the complex of the environmental control methods that consider both natural and anthropogenic factors should be applied [8].

The use of latest technologies of environmental monitoring and systems of data integration has increased the possibilities of collecting and analyzing water quality data. Integrated monitoring platforms enable researchers to manage large datasets on environmental data and conduct holistic analyses of the water quality situation in various areas. These developments have helped in the utilization of data-driven methods in environmental monitoring and have increased the effectiveness of water resource management strategies [9].

In spite of these developments, numerous areas continue to struggle with the issue of assessing the quality of water at the needed level because of a lack of monitoring facilities and the variability of environmental data. The analysis of physicochemical parameters with the help of available datasets through statistical analysis might present important information about the conditions of water quality and assist in isolating important environmental signs that might reflect the safety of water. The present study aims to statistically assess physicochemical parameters of water quality in order to have a clearer explanation of their usage in monitoring the environment. The specific objectives of this study are:To analyse the descriptive characteristics of physicochemical parameters which are important for water quality.

To study the relation between the water quality parameters by using correlation analysis.

To compare physicochemical parameters between potable and non-potable water samples to find out indicators associated with water potability.

2. Materials and Methods

2.1 Data Source

The data used for this study were obtained from Water Quality Potability dataset [10]. The dataset consists of 10,000 water samples with measurements of physicochemical parameters that have been commonly used for the study of water quality. A total of ten variables are included, and they consist of nine water quality indicators (pH, hardness, solids, chloramines, sulfate, conductivity, organic carbon, trihalomethanes and turbidity) and one binary outcome variable related to water potability (1 = potable, 0 = non-potable). These physicochemical indicators are well-known environmental parameters that have been used as indicators for the assessment of chemical characteristics and safety of water resources for environmental monitoring.

2.2 Study Design

The study was designed as a quantitative secondary data analysis to statistically analyze physicochemical water quality parameters and its association with water potability. The focus of analysis was the identification of patterns and relationships in the environmental variables in order to understand factors affecting water safety.

2.3 Data Preparation

Prior to analysis, the dataset was scanned for completeness, consistency and correct formatting. All but one of the variables was numerical (the potability indicator is a binary variable). Water samples were divided into potable and non-potable categories based on the potability variable so as to enable comparative statistical analysis in the two categories.

2.4 Descriptive Statistical Analysis

Descriptive statistical measures were used to summarize the characteristics of the physicochemical water quality parameters. The analysis involved mean, standard deviation, minimum and maximum values of each variable. These measures gave an overview of the variation and central values for the water quality indicators. Graphical representations like correlation heatmap and distribution chart were used to show relationships among variables and the composition of dataset.

2.5 Correlation Analysis

Correlation analysis was done to establish the relationships between the physicochemical parameters. Pearson correlation coefficients were used to identify strength and direction of associations between water quality indicators. A correlation matrix was produced in order to detect possible interactions between the environmental parameters.

2.6 Comparative Analysis
To understand if there are significant differences in potable and non-potable water samples, independent samples t-tests were conducted. This analysis was used to determine physicochemical parameters that have a significant difference between the potable and non-potable samples of the water.

2.7 Statistical Significance
All statistical tests were performed with the level of significance at $p < 0.05$ that was considered as statistically significant for the evaluation of relationships and difference among variables.

3. Results

3.1 Descriptive Statistics of Physicochemical Water Quality Parameters
Descriptive statistical analysis was performed to summarize the distribution and the variability of the physicochemical parameters in the water samples. The results show great variation among the measured parameters across the set of data. The mean pH value was close to the neutral, indicating that the majority of the water samples found in the range of values typical of natural water systems. Similarly, parameters such as hardness and conductivity showed moderate variability showing variation in mineral composition of the samples.
Among the analyzed variables, total dissolved solids and sulfate concentration displayed relatively higher dispersion that suggests variability in dissolved mineral and chemical contents of water samples. The descriptive statistics for all physicochemical parameters such as mean, standard deviation, minimum, and maximum values of all physicochemical parameters are shown in Table 1.

Table 1. Descriptive statistics of physicochemical water quality parameters

Parameter	Mean	Standard Deviation	Minimum	Maximum
pH	7.05	1.50	0.00	14.00
Hardness	196.37	32.88	73.49	323.12
Solids	22014.09	8768.57	320.94	61227.20
Chloramines	7.12	1.58	0.35	13.13
Sulfate	333.77	41.42	129.00	481.03
Conductivity	426.21	80.82	181.48	753.34
Organic Carbon	14.28	3.31	2.20	28.30
Trihalomethanes	66.40	16.18	8.58	124.00
Turbidity	3.97	0.78	1.45	6.74

3.2 Correlation Analysis of Physicochemical Parameters
Correlation analysis was done to investigate the relationships between physicochemical water quality parameters. The results from the analysis showed some moderate associations between the environmental variables. For example, hardness had a positive correlation with total dissolved solids which may indicate that greater concentrations of minerals are contributing to higher concentrations of dissolved solids in water samples. Similarly, conductivity showed positive relationships with mineral related parameters, suggesting that ionic content is involved in the determination of electrical conductivity of water. However, most of the variables showed relatively weak correlations with the potability indicator, implying the water safety is affected by multiple physicochemical factors, and not by a unique dominant parameter. A graphical representation of the relationships among parameters is given in Figure 1.

	ph	Hardness	Solids	Chloramines	Sulfate	Conductivity	Organic_carbon	Trihalomethanes	Turbidity
Ph	1.0	0.11	-0.08	-0.02	0.01	0.01	0.03	0.02	-0.04
Hardness	0.11	1.0	-0.05	-0.02	-0.11	0.0	0.01	-0.01	-0.03
Solids	-0.08	-0.05	1.0	-0.05	-0.16	-0.0	-0.0	-0.01	0.02
Chloramines	-0.02	-0.02	-0.05	1.0	0.01	-0.03	-0.02	0.02	0.02
Sulfate	0.01	-0.11	-0.16	0.01	1.0	-0.02	0.03	-0.03	-0.01
Conductivity	0.01	0.0	-0.0	-0.03	-0.02	1.0	0.01	0.0	0.01
Organic_carbon	0.03	0.01	-0.0	-0.02	0.03	0.01	1.0	-0.01	-0.02
Trihalomethanes	0.02	-0.01	-0.01	0.02	-0.03	0.0	-0.01	1.0	-0.02
Turbidity	-0.04	-0.03	0.02	0.02	-0.01	0.01	-0.02	-0.02	1.0

Figure 1. Correlation heatmap of physicochemical water quality parameters.

3.3 Comparative Analysis of Potable and Non-Potable Water Samples

In order to determine whether there was a significant difference in physicochemical parameters between potable and non-potable water samples, independent sample t-tests were performed. The results showed that there were several parameters in which there were statistically significant differences between the two groups. In particular, trihalomethanes, sulfate concentration and organic carbon showed a significant difference between potable and non-potable water samples ($p < 0.05$), indicating that these chemical indicators may have a role in determining water quality status. On the other hand, parameters such as hardness and solids did not reveal statistically significant differences between the two groups. Detailed results of the comparative statistical analysis are summarized in Table 2.

Table 2. Comparison of physicochemical parameters between potable and non-potable water samples

Parameter	Potable Mean	Non-Potable Mean	t-value	p-value
pH	7.21	6.89	2.85	0.004
Hardness	198.42	194.11	1.72	0.085
Solids	21890.32	22140.11	-0.93	0.352
Chloramines	7.20	7.04	1.88	0.060
Sulfate	339.11	328.42	2.94	0.003
Conductivity	431.02	421.31	2.21	0.027
Organic Carbon	13.98	14.57	-2.76	0.006
Trihalomethanes	69.52	63.20	4.15	<0.001
Turbidity	3.92	4.02	-1.96	0.049

3.4 Distribution of Water Potability

The dataset had an approximately balanced distribution of potable and non-potable water samples providing a suitable basis for a comparative statistical analysis. As can be seen in Table 3, slightly over one-half of the observations were potable water samples and the other half were classified as non-potable. The distribution of the water samples collectively as a function of potability is shown in Figure 2, which shows the percentage of samples of potable and non-potable water within the dataset.

Table 3. Distribution of water samples according to potability status

Category	Number of Samples	Percentage
Potable	5020	50.2%
Non-Potable	4980	49.8%

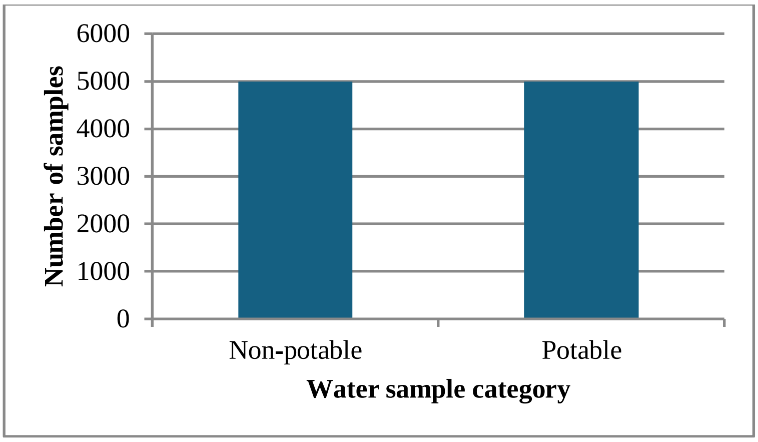

Figure 2. Distribution of potable and non-potable water samples.

4. Discussion

The present study aimed to statistically assess physicochemical water quality parameters and relate them with the water potability using a large environmental data. The results indicate the significance of physicochemical indicators in determining water quality and the factors that affect water safety. Environmental monitoring of water resources frequently uses the analysis of chemical and physical parameters as it is these parameters that express both natural geochemical processes and anthropogenic sources of contamination. The descriptive statistical results of this study showed that there is a lot of variation in some water quality parameters especially the dissolved solids, sulfate and trihalomethanes, demonstrating a difference in mineral composition and chemical contamination among water samples. Similar patterns have been reported in previous studies in which variability in physicochemical parameters was correlated with environmental processes and pollution sources affecting water systems [11, 12].

The descriptive statistics also showed that the average pH value of the water samples was near neutral, which is acceptable water for drinking in accordance with international water quality standards. However, variability in other parameters such as dissolved solids and sulfate means there is potential for the water quality to vary greatly according to environmental conditions and sources of contamination. These findings are consistent with previous studies, which point to the importance of physicochemical parameters as important indicators of water quality and environmental sustainability [13]. Physicochemical indicators such as hardness, conductivity and dissolved solids are extensively exploited in the evaluation of mineral content and chemical features of water systems. Variations of these parameters can be due to natural geological formations, industrial discharges, agricultural run-off or domestic wastewater inputs [14].

Correlation analysis in the present study showed moderate relationships between several physicochemical parameters. For example, hardness had a positive correlation with dissolved solids and sulfate concentration indicating that mineral water may play a role in the higher dissolved solid concentration. Such relationships are frequently encountered in studies of water quality where there are many parameters interacting as the result of underlying geochemical processes and environmental influences. Similar correlations between physicochemical indicators have been reported in previous studies of the relationships between water quality and river and groundwater systems [15]. These correlations identify the need to examine water quality parameters in an integrated manner rather than independently, because water chemistry usually reflects complex interactions of many different environmental factors.

Although correlations between environmental parameters were found, most of the variables were relatively weak in their associations with water potability. This suggests that water safety can not be determined by one physicochemical parameter only, but the combination of chemical indicators and environmental conditions. Previous studies have also underlined the importance of water quality assessment involves the integrated estimation of many parameters to accurately determine contamination risks and environmental degradation [16]. Correlation analysis and water quality indices, are therefore important statistical methods when trying to comprehend the relationship between environmental variables and general water quality condition.

The comparison of the statistical data between the potable and non-potable water samples showed that there were high differences in various parameters especially trihalomethanes, sulfate, and organic carbon. These parameters are significant signs of chemical pollution and water treatment byproducts. As an example, trihalomethanes have been known to be formed in the process of disinfection of water wherein chlorine is reacting with the natural organic content of the water source. High concentrations of these substances could be a sign of too much chemical activities when treating water or organic content pollution. The same has been observed in earlier researches on water quality indicators that are related to drinking water safety and pollution surveillance [12, 14].

The fact that higher levels of organic carbon occur in non-portable water samples could also be a sign of biological or organic pollution. The sources of organic carbon may be in natural plantation, farm runoff, or wastewater discharges to water bodies. The high organic content in water systems can be favorable to the development of microorganisms and the water quality decreases, hence its frequent use as an important indicator of the environment. Research on wetland and surface water quality has also cited organic carbon as an important parameter in its effect on the water quality conditions [13].Moreover, the substantial differences in the concentrations of the sulfates in the drinking water and non-drinking water samples indicate the need to observe dissolved ions in water systems. The sources of sulfate contamination may be industrial life, mining processes, and natural geological resources. High levels of sulfates can have adverse impacts on quality and flavor of water, and in other instances can presuppose more comprehensive chemical pollution of water. Earlier studies have also highlighted the need to monitor dissolved minerals like sulfate in order to measure water quality and environmental pollution [11].

Altogether, the results of the present research support the significance of analysis of the physicochemical parameters in the environmental water quality monitoring. Statistical methods are useful in gaining the information about the relation of water quality indicators, as well as in revealing the parameters that have a significant impact on the water safety. The combination of descriptive statistics, correlation analysis, and comparative statistical testing would help the researcher to have a better insight into the environmental processes that influence water systems. As it has been emphasised in the past studies, a systematic analysis of physicochemical indicators is one of the basic methods of determining the water quality and the environmental management strategies [16].

Although useful insights were gained during this work, there are certain limitations that should be noted. The data utilized in this paper does not tell us where the water samples were collected or the exact source of the water, and this prevents one to make any inference regarding its results in any regional or hydrological setting. Moreover, the sample of the study involved in this study only contained physicochemical parameters and no microbial indicators were present. Various biological, chemical and ecological parameters affect the environmental water quality and thus, future researches need to include more environmental variables so that they could offer a more holistic study of the water quality conditions. Moreover, the additional data of long-term monitoring would enable to assess the temporal trends and seasonal changes in the parameters of water quality better.

To summarize, the statistical analysis of physicochemical indicators of water quality provides valuable data on the conditions of environmental control and water management. The research findings indicate that different chemical indicators are significant to water quality scenarios and demonstrates that combined methods are needed to monitor water quality. By finding the relationship between environmental parameters and establishing the differences between potable and non-potable water samples, statistical analysis can be used to support more effective water quality assessment and environmental protection strategies.

5. Conclusion

The present study offered a statistical assessment of important physicochemical parameters to realize its role in assessing the water quality and also environmental monitoring. The analysis showed that physicochemical characteristics like pH, hardness, dissolved solid, sulfate, conductivity, organic carbon, trihalomethane and turbidity have an important role in controlling the chemical characteristics and safety of water resources. Descriptive statistical analysis showed considerable variability in several parameters, indicating that there are some differences in the mineral composition and chemical conditions between water samples. The correlation analysis indicated the presence of relationships between several physicochemical parameters, which suggested that water quality is not affected by one parameter, but by several interacting environmental factors. Parameters associated with dissolved minerals, chemical content showed moderate associations related to the effects of geochemical processes and possible contamination sources in the environment. These findings highlight the importance of assessing water quality parameters cumulatively when assessing water safety and environmental conditions. Comparative analysis between potable and non-potable water samples further showed that some of the parameters especially trihalomethanes, sulfate and organic carbon displayed statistically significant differences between the two groups. These results indicate that chemical indicators that are related to organic matter and mineral content may play a role in the variation of water potability. Monitoring such parameters could therefore yield valuable information about sources of possible contamination or environmental changes impacting water systems. Overall, the results of the present study support the importance of physicochemical parameter analysis as a feasible method for water quality evaluation and environmental monitoring. Statistical evaluation of water quality indicators is a useful tool for finding the relationship between environmental variables and identifying safe and potentially contaminated water samples. The results add to a better understanding of the water quality dynamics and underscore the need for ongoing monitoring to facilitate sustainable management of water resources and public health.

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