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Predicting Probable Number of Escherichia Coli from pH, Temperature and Turbidity to Indicate Water Quality in Gezira State, Sudan

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Abstract

Predicting water quality is crucial for distinguishing safe and unsafe water in under-equipped laboratory settings, especially in developing countries. In this study, we utilized a linear regression model to predict the probable number of Escherichia coli (E. coli) based on water temperature, pH and turbidity. The analysis was conducted on 185 water samples collected from diverse sources such as surface water and groundwater in Gezira state, Sudan. The biological quality of the water was assessed using a compartmental bag test (CBT), with the possible number of E. coli serving as an indicator of water quality. The findings indicate that 58.3% of water sources are deemed safe, 16.8% categorized as intermediate risk/probably safe, 16.2 were probably unsafe and 22.2% are considered unsafe. The regression model effectively processed the measured values and demonstrated a high level of prediction accuracy. Furthermore, the turbidity significantly contributed to the prediction ($p < .005$).

Keywords: Prediction; Water quality; E. coli; Gezira state; Sudan.

Highlights

- Investigating water quality is vital in differentiating safe and unsafe water.
- Simplifying testing methods of water is important for communities in low-resource settings.
- Developing the relationship between the physical and biological aspects of water quality is essential for determining its drinkability.
- Turbidity plays a significant role in predicting the presence of E. coli.

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Graphical abstract

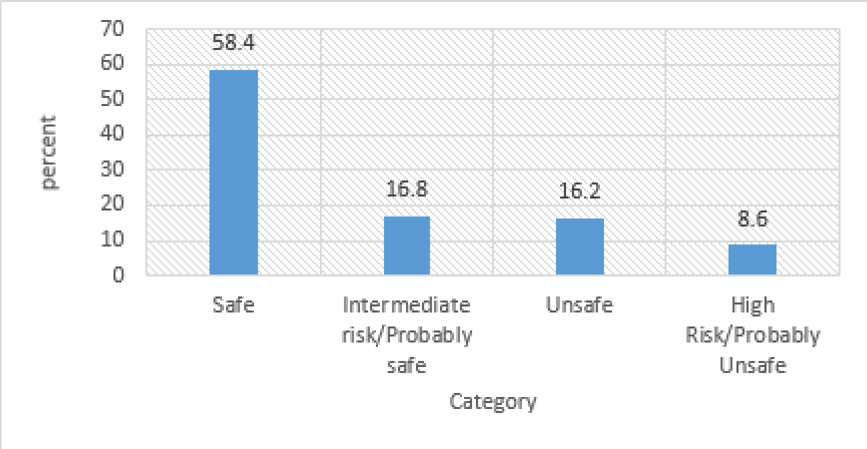

Figure 1

1. Introduction

Poor water quality is a global challenge due to its impact on human and animal lives. Water contamination poses a significant health risk [1]. Each year, over 2 million deaths from diarrheal diseases occur, primarily in developing countries where resources for water quality testing are limited [2]. Consumption of unsafe water remains a major cause of annual diarrheal disease deaths [3]. Approximately 26% of the global population lacks access to safely managed drinking water services [4].

E. coli is bacteria commonly found in the intestines of humans and animals. Most E. coli strains are harmless, but some can cause illness and infections. E. coli infections are a significant public health concern. Therefore, E. coli has long been recognized as an indicator of water quality [5,6].

The water temperature is one of the factors to consider when assessing water quality. Temperature affects chemical and microbiological processes within the storing distributing of water. Increased water temperatures will affect chemical reaction kinetics and, combined with deteriorations in water quality and freshwater ecological status [7]. Zlatanović, el al[8]) examined influence of water stagnation and temperature change on water quality in a full-scale domestic drinking water system and found that temperature and water stagnation affect both chemical and microbial quality in domestic drinking water system. Prommer, & Stuyfzand, [9] studied temperature-dependent water quality changes during a deep well injection and found that the reaction rates depended significantly on the spatially/temporally varying groundwater temperature. Water warming decreased dissolved oxygen [10].

The normal pH of water is about 7. which is considered neutral. However, the pH of water is affected by the presence of minerals or pollutants in water. The pH level in pure water is 7, but water can be acidic or alkaline depend on dissolved minerals. The pH of water is an important indicator of its quality. aquatic organisms have specific pH requirements for survival and reproduction. Deviation of pH from 7 pH considered harmful and affecting overall health the aquatic organisms. pH level of water play key role in chemical reactions as at low pH levels, metals become more soluble and toxic to aquatic life and high pH levels precipitates minerals. The pH of drinking water affects the taste of water and can cause health issues. The pH of water is an important parameter for determining water quality. It affects the health of the suitability of water for human consumption, ecological balance of aquatic ecosystems and aquatic life.

Turbidity is a measure of water cloudiness caused by suspended particles. High turbidity levels can impact factors like water clarity, light penetration, and the presence of contaminants. High turbidity may increase the presence of impurities that can cause bacterial diseases like cholera and typhoid [11]. High water turbidity in aquatic ecosystems is a global challenge due to its harmful effects [12]. Previous studies in Sudan [13, 14,15,16] have documented E. coli in different water sources, including surface and groundwater, as well as in household storage containers, boreholes, reservoirs, hand pumps, and dug wells [17,18,19]. However, none of these studies have developed a prediction model for indicating water quality.

It is necessary to evaluate water quality using appropriate techniques [20]. Countries worldwide have been striving to optimize techniques for assessing water quality more accurately [21]. Ensuring optimal water quality is essential for both humanity and the environment. A quick and accurate prediction of water quality based on water turbidity would be useful in avoiding unsafe water. Therefore, understanding the relationship between biological quality and physical quality of water is crucial for ensuring the safety and sustainability of water resources. This paper aims to predict probable number of Escherichia coli (E. coli) as an indicator of water quality using statistical modeling techniques such as linear regression.

2. Methodology

2.1. Study area

Gezira State is situated in Sudan, between latitudes 14°24′04″N and 33°31′11″E (Kogan 1990) (Figure 1). The average monthly temperature in the state ranges from 22 °C in January to 34 °C in May. The state's population is approximately 3.5 million people, with 53% residing in rural areas, 35% in urban areas, and 12% as nomads. The annual growth rate is 2.9% (Sudan Population Census 2008, 2010; Gezira Population Statistical Office). The soil in the region is mainly composed of clay [22], and the annual rainfall ranges from 150 mm to 250 mm. The Blue Nile is the primary source of groundwater recharge for Gezira and Nubian formations. The main sources of surface water in the state are the Blue Nile, Dinder, and Rahad rivers, as well as rainfall [23] and [24]. According to the 5th Sudan Population and Housing Census held in 2008, most of the rural populations are agro-pastoralists. Gezira State is surrounded by the White Nile and Dinder Rivers and crossed by the Blue Nile and Rahad Rivers. The state is divided into seven administrative subdivisions or localities. This study was conducted in the Greater Wad Medani locality, which includes Wad Medani city, the capital of the state.

Figure 2: location of Gezira State in Sudan

2.2. Data collection

A total of 185 samples were collected from various water sources, including rivers, water treatment plants, borehole wells, hand pumps, public water taps, public water coolers, public elevated water tanks, and household elevated water tanks (Table 1). The fieldwork was conducted from 6th June to 28th July 2016, primarily representing the beginning of Sudan's rainy season. A dataset was compiled, encompassing measurements of temperature, pH and turbidity and water quality indicators for Escherichia Coli (E. coli). The Compartment Bag Test (CBT) was utilized to assess E. coli presence in the water samples. CBT is a simple, portable, and self-contained water quality test that can be conducted in field environments. This test kit, developed by researchers at the University of North Carolina at Chapel Hill, determines if water contains E. coli bacteria and poses a health risk. For each water sample, the provided E. coli chromogenic medium was dissolved in 100 mL of the sample, which was then poured into a specially designed 100-mL compartment bag. The bag was subsequently incubated at 37 °C for 24 hours. Each compartment bag is divided into 1 mL, 3 mL, 10 mL, 30 mL, and 56 mL compartments. CBT calculates the most probable number (MPN) of E. coli per 100 mL of water. Results were recorded following WHO standards (Table 2). Temperature was measured in degree centigrade. Turbidity was measured in Nephelometric Turbidity Units (NTU) and pH for each sample was also measured.

Table 1: number of samples from different water sources

Source	Number of samples
Pots	61 (32.9%)
Taps	52 (28.1%)
Boreholes	37 (20.0%)
Public Tank	8 (4.3%)
Public cooler	10 (5.4%)
Hand pumps	4 (2.1%)
Treatment Plant	1 (0.5%)
Irrigation Canal	3 (1.6%)
River	1 (0.5%)
Plastic Container, *Hafaza*	5 (2.7%)
Household elevated tank	3 (1.6%)
Total	185 (100%)

Table 2: Health risk based on WHO guidelines for drinking water quality [4]

Health Risk Category	E. coli/100 mL
Low Risk/safe	0.0
Intermediate Risk/Probably Safe	01 -10
High Risk/Probably Unsafe	11-100
Very high risk/unsafe	>100

2.3. Data processing and analysis

Linear regression is a statistical modeling technique used to establish a relationship between probable number of of E. coli and temperature, pH and turbidity. Linear regression was used to predict water quality using temperature, pH and turbidity measures for the same water samples. Regression is determined and used to understand the relationship between water quality (indicated by probable number of E. coli) and physical parameters (temperature, pH and turbidity) of the water samples.

3. Results and discussion

3.1. Physical analysis of water samples

Temperature, pH, turbidity and the probable number of E. coli of 185 water samples were statistically analyzed as shown in Table 3. The lowest value of temperature is found to be 20.0 ^{0}C in water treatment plant and the highest value (20.0 ^{0}c) was in water pots source. Water pots are normally exposed to sunshine and located outside homes for all to drink. Increased water temperatures will affect chemical reaction kinetics and, combined with deteriorations in water quality and freshwater ecological status [7]. Zlatanović, [8] examined influence of water stagnation and temperature change on water quality in a full-scale domestic drinking water system and found that temperature and water stagnation affect both chemical and microbial quality in domestic drinking water system. In all water samples, the pH levels were more than 7. High pH levels can precipitate minerals and affects the overall water quality.

Turbidity varied between 0.0 and 5500 NTU. This is because of different sources including groundwater sources and surface water (river raw water). The lowest turbidity (0.0 NTU) mostly occurred in pots, household taps, boreholes, hand pumps and treatment Plant. These sources were relatively well covered and protected from pollutants. The greatest turbidity (5500 NTU) occurred in the Blue Nile water, which is exposed to sedimentation. All water sources showed maximum MPN of E. coli except household evaluated tanks and treatment plants. This result indicates elevated household tanks and treatment pants water were E. coli free.

Turbidity is a crucial factor in water quality. According to the WHO, turbidity should not exceed 5 NTU [25]. Turbidity refers to the presence of suspended materials in water, which give it a cloudy appearance. These suspended particles can be either inorganic or organic in nature. High turbidity levels of water can indicate the presence of sediment, organic substances, or other pollutants. Turbidity can also impact the appearance of water, making it appear dirty. García-Ávila, and his colleagues[26] have observed a strong correlation between turbidity, color, TDS, and total hardness of water. Furthermore, high turbidity promotes the growth of harmful bacteria and pathogens by reducing light penetration into the water, creating a favorable environment for bacterial growth. In the case of surface waters such as rivers and irrigation canals, turbidity levels have been recorded as high as 5500 and 58.7 NTU respectively. These high levels are likely due to the presence of various types of particulate matter, including attached microorganisms that pose a health risk [27,4].

It has been observed that there is no significant difference between the physical quality of water obtained from different sources. However, there are notable differences in the levels of turbidity and E. coli found in water from different sources. This suggests that open water sources such as irrigation canals, rivers, and open boreholes tend to have higher levels of turbidity compared to other elevated or covered sources.

Table 3: descriptive statistics

Water source	N	**Temperature ^{0}C**			**pH**			**Turbidity**			**E. coli**		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Pots (Zeer)	61	24.0	26.0	25.3	7.01	7.82	7.43	.00	40.00	6.30	.00	100.00	25.74
Household taps	52	23.9	26.7	25.3	7.01	7.85	7.44	.00	45.00	3.88	.00	100.00	8.61
Boreholes	37	24.9	25.8	25.3	7.08	7.80	7.41	.00	75.00	2.89	.00	100.00	7.21
Public elevated tank	8	25.0	25.6	25.2	7.11	7.40	7.27	.02	.23	.12	.00	100.00	12.68
Household elevated tank	3	25.0	25.7	25.3	7.59	7.81	7.66	.13	.14	.13	.00	.00	.00
Hand pumps	4	25.2	25.5	25.4	7.02	7.51	7.26	.00	.95	.34	.00	48.30	12.07
Irrigation Canal	3	25.1	25.7	25.4	7.24	7.43	7.33	33.00	50.00	42.50	100.00	100.00	100.00
Plastic Container (*Hafaza)*	5	22.3	25.0	23.7	7.54	7.76	7.65	.12	38.15	19.83	13.60	100.00	82.72
Blue Nile river	1	25.0	25.0	-	7.80	7.80	-	5500.00	5500.00	-	100.00	100.00	-
Public cooler	10	25.5	25.5	25.5	7.71	7.71	7.71	.08	23.00	2.49	.00	100.00	11.88
Treatment Plant	1	20.0	25.8	-	7.34	7.80	-	.00	.00	-	.00	.00	-

3.2. Categorization of water sources

The water samples were biologically categorized (Figure 2). Nearly, 58.5% of water sources contained 0.0 E. coli per 100 ml of water and classified as safe water. This result is in agreement with [28] who found that 44.50% of the water samples contained E. coli. in rural Barazil. Water sources, contained greater than 100 E. coli per 100 ml of water and categorized unsafe water constitute 16.2%. The high risk/ probably unsafe water sources, constitute 8.6% and Intermediate risk/ probably safe sources constitute 16.8%. Water sources of boreholes, hand pumps, taps, and elevated tanks, show relatively safe water. These water sources are protected from any external pollutants. River water and irrigation canals are considered surface open sources and not well protected from animal and human waste and therefore, they yield risky water. This result is in line with [29] who found that surface water had the highest mean of E. coli concentration compared to other sources. Irrigation canals and river water are exposed to sedimentation and weather effects and are considered raw water. Pollution in raw water poses increasing threats to safe water supply in many developing countries [30]. Unfortunately, some people in Gezira take water directly from the Blue Nile River and irrigation canals which are contaminated water. Contaminated drinking water may contain unsafe levels of microorganisms that pose a risk to human health [2]. Abdo and Salih, [31] found that 55% of the investigated water samples in north Bahri, Khartoum city, were affected by E. coli, while this study found that more than 30% of samples are affected by E. coli. The residents of Khartoum depend mostly on surface water sources which exposed to pollutants.

Table 4 shows the risk classification for each water source. The result showed that out of 61 pots, 27(44.3%) were E. coli-free, while 15(24.6%) of water pots contained unsafe water. Pots are made of clay for storing and serving water. Pots are normally covered but in most cases, left open vulnerable to pollution from dust, insects, or other contaminants. Pots are not regularly cleaned and sanitized and therefore, its water remains unsafe and full of contaminants.

It is investigated that 39(75.0%) of the taps water (N=52) are E. coli free and 4(7.7%) of taps contained unsafe water. Taps are connected to the water distribution network. Normally, the networks take water from the main sources of boreholes, hand pumps, elevated tanks, or treatment plants. All of these sources produce safe water

A number of 6 (60%) of public cooler samples contained safe water and 20% of the samples were classified as probably safe. Public water coolers are commonly found in public spaces, such as markets, Schools, hospitals, and public buildings. Public coolers are well protected from external pollutants because the cooler water containers are completely covered. Plastic containers are used to carry water from the main source of water and to store water at homes. Therefore, 80.0% of plastic containers showed unsafe water and the remaining 20% of the water samples of the plastic containers are possibly unsafe. River water and irrigation canals showed unsafe water. These sources contained raw water, exposed to wind, soil erosion, and different other pollutants.

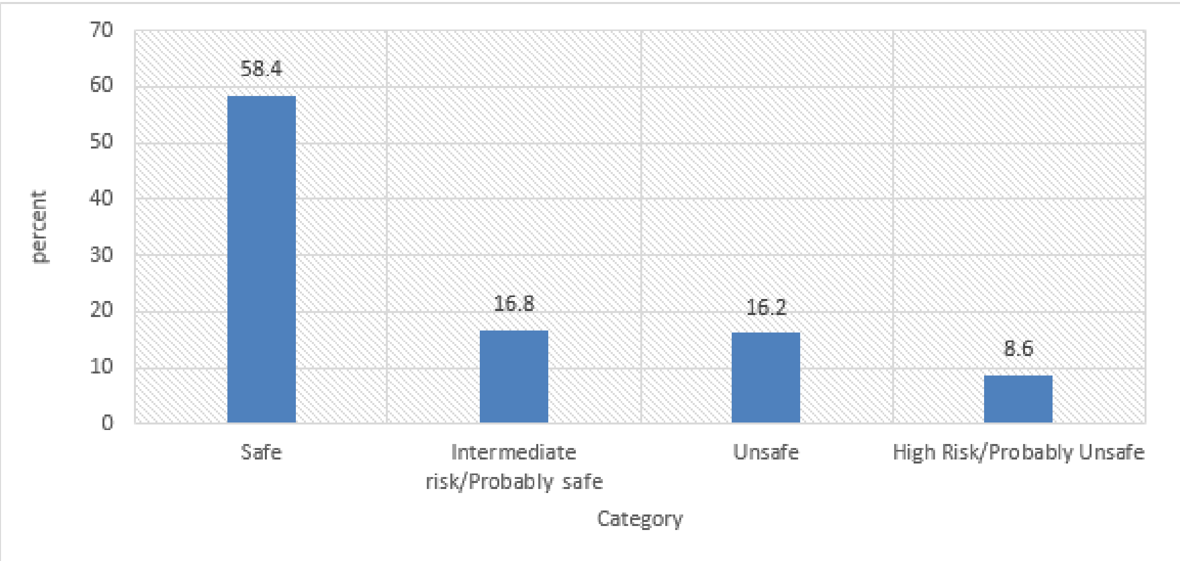

Figure 1: Categorization of water sources

Table 4: Categorization of water sources according to WHO

Water source	N	Safe	Intermediate risk/Probably safe	Unsafe	High Risk/Probably Unsafe
Pots	61	27(44.3%)	17(27.9%)	15(24.6%)	2(3.3%)
Taps	52	39(75.0%)	7(13.5%)	4(7.7%)	2(3.8%)
Boreholes	37	23(62.2%)	4(10.8%)	1(2.7%)	9(24.3%)
Public Tank	8	6(75%)	1(12.5%)	1(12.5%)	0(0.0%)
Public cooler	10	6(60%)	2(20.0%)	1(10.0%)	1(10.0%)
Hand pumps	4	3(75%)	0(0.0%)	0(0.0%)	1(25.0%)
Treatment Plant	1	1(100%)	0(0.0%)	0(0.0%)	0(0.0%)
Irrigation Canal	3	0(0.0%)	0(0.0%)	3(100%)	0(0.0%)
River	1	0(0.0%)	0(0.0%)	1(100%)	0(0.0%)
Plastic Container, *Hafaza*	5	0(0.0%)	0(0.0%)	4(80.0%)	1(20.0%
Household elevated tank	3	3(100.0%)	0(0.0%)	0(0.0%)	0(0.0%)
Total	185	108(58.4%)	31(16.8%)	30(16.2%	16(8.6%)

3.3. Statistical analysis

Regression analysis is used to understand and quantify the relationship between most possible number of E. coli and pH, temperature and turbidity. Regression analysis shows R 0.633, R^2 = .401 which indicates a good level of prediction. The regression model is a good fit of the data (Table 5). The result shows direct relationship between the E. coli and Turbidity and inverse relationship between E. coli and pH and temperature. The change in the most possible number of E. coli is directly proportional to the change in the turbidity. The analysis shows positive coefficient of turbidity which indicates a positive relationship between E. coli and Turbidity. However, the model shows negative confidents for PH and temperature. The model predicted MPN of E. coli from pH, temperature and turbidity. The pH, temperature and turbidity are statistically significantly predicted MPN of E. coli, $F = 40.465$, $p < .005$, $R = .633$, $R^2 = 0.401$. The variables added statistically significantly to the prediction, $p < .005$. The general form to predict MPN of E. coli from pH, temperature and turbidity is

$$Probable\ number\ of\ E.coli\ =\ 39.569 - (pH * 1.624) - (.771 * temperature) +\ (Turbidity * 1.87)$$

The model showed poor relationship between the expected cumulative values and the observed cumulative values which indicates random variation in the observed cumulative values. This variation might be the cause of discrepancies between the expected and observed cumulative values. This might be related to relatively small sample (N=185)

Table 5: regression analysis

N	185
R	.633[a]
R Square	.401
Adjusted R Square	.398
Sum of squires	98736.485
F Change	40.465**
	B
(Constant)	39.569
pH	-1.624
Turbidity	1.879**
Temperature	-.771

a. Dependent Variable: probable number of *E. coli*

b. Predictors: (Constant), PH, temperature and turbidity

4. Limitations

The study data was collected during the months of June and July, which marks the beginning of the rainy season in Sudan. It is possible that there could be seasonal variations that could affect both water quality and turbidity if the study was conducted in other seasons. It is important to note that the study was conducted on a sample size of 185 samples, the results could potentially influence if the study was repeated with a larger or smaller sample.

5. Conclusion

This study expands the knowledge on water quality under low resource setting in rural areas. CBT prove to be suitable tool to test water quality in free lab environment. The study approach facilitates predicting E. coli from PH, temperature and turbidity which can be easily measured under limited resources. The MPN of E. coli, showed accurate method to dedicate the level of water quality and alarming risky water. The surface water sources are relatively more polluted with E. coli compared to other water sources.

6.Author Contributions:

E. A, Designed the methodology carried out an analysis and wrote the first draft and final manuscript

A. M, Reviewed and edited and the manuscript

J. A, contributed to data collection and edited the manuscript

All authors have read and agreed to the final version of the manuscript.

7.Declaration of competing interest

The authors declared no conflict of interests

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