Assessment of Groundwater Quality Using Water Quality Indices in Illegal Mining Communities: A Case Study of the Atwima-Kwanwoma District and Obuasi East Metropolis, Ghana

ABSTRACT

This study investigated groundwater quality in illegal mining zones within the Atwima-Kwanwoma District and Obuasi East Metropolis of the Ashanti Region, Ghana, employing both the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) and Nemerow's Pollution Index (NPI). The analysis revealed severe contamination acrossmultiple parameters, including heavy metals, microbial indicators, and physicochemical parameters. The CCME-WQI values for the five towns consistently indicated "Poor" water quality, ranging from 26.8 to 31.1, reflecting significant deviations from acceptable water quality standards. Notably, Town A exhibited a cyanide concentration of 11.25 mg/L, while Town B recorded lead levels at 118.73 μg/L, both far exceeding permissible limits set by health authorities. The presence of Escherichia coli further exacerbates health risks, underscoring the urgent need for improved water treatment and management practices. This study demonstrates that the integrated use of NPI and CCME-WQI provides a comprehensive assessment of groundwater quality, revealing significant environmental and public health challenges. Immediate intervention, including regulatory enforcement, sustainable mining practices, and remediation strategies, is crucial to safeguard groundwater resources. The findings contribute uniquely to the understanding of water quality dynamics in mining-affected regions and advocate for a coordinated approach to mitigate environmental degradation.

Keywords: Groundwater quality,illegal mining zones, Ashanti region, CCME-WQI, Nemerow's Pollution Index.

1. INTRODUCTION

Water Quality Index (WQI) is an essential tool used globally to assess the overall quality of water resources, integrating multiple water quality parameters into a single index value. The WQI simplifies complex water quality data, making it more accessible to both scientific researchers and policymakers, while providing a basis for evaluating the suitability of water for various uses, including drinking, agriculture, and industry. Among the most widely recognized indices are the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) and Nemerow's Pollution Index (NPI). Both indices offer robust frameworks for analyzing water pollution and categorizing water quality, particularly in areas experiencing significant environmental stress.

In Ghana, illegal small-scale mining, referred to locally as “galamsey,” is a key contributor to environmental degradation, particularly in mining communities. Illegal mining refers to the unregulated extraction of minerals without appropriate permits and oversight, often conducted using unsustainable practices that ignore environmental regulations. This contrasts with sustainable mining, which follows established environmental, social, and economic standards to minimize adverse impacts. Illegal mining in the Atwima-Kwanwoma District and Obuasi East Metropolis predominantly focuses on gold extraction using hazardous chemicals, including mercury and cyanide, which can seep into the soil and contaminate groundwater resources [1]. Unlike coal or stone mining, which have their own distinct environmental consequences, gold mining in this region primarily leads to heavy metal contamination, compromising the quality of groundwater.

The environmental impacts of galamsey are multifaceted. Heavy metals such as lead, manganese, and iron are frequently released into the water table, heightening the risk of toxic exposure for nearby populations. Furthermore, the unregulated nature of galamsey increases the salinity and Total Dissolved Solids (TDS) in groundwater, diminishing its suitability for human consumption. Previous studies have established a strong link between these illegal mining activities and the degradation of water quality in the region [2].

Groundwater contamination from illegal mining poses significant health risks to communities reliant on these water sources for drinking and household purposes. Long-term exposure to heavy metals like lead and manganese can result in severe health conditions, including neurological disorders, kidney disease, and developmental issues in children [3]. Additionally, the presence of microbial contaminants, such as Escherichia coli (E. coli), which often accompany mining-induced pollution, can cause gastrointestinal diseases, diarrhea, and other life-threatening infections [4]. When compromised by such contaminants, groundwater may fall below acceptable health and safety standards, raising public health concerns.

Several studies have explored groundwater quality in mining-impacted regions both locally and globally. Yidana&Asiedu [2] examined groundwater contamination in Ghana's mining areas and found elevated levels of heavy metals, particularly lead and iron. Similar patterns have been observed internationally; for instance, research in South Africa’s mining communities revealed excessive manganese and cyanide concentrations, rendering the water unsafe for consumption [5]. Globally, countries such as India and China have experienced similar declines in groundwater quality due to illegal mining, with frequent instances of cyanide contamination [6].

This study aims to assess the groundwater quality in illegal gold mining communities within the Atwima-Kwanwoma District and Obuasi East Metropolis using both the Nemerow Pollution Index (NPI) and the CCME Water Quality Index (CCME-WQI). The specific objectives are to measure physicochemical parameters such as temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), salinity, Total Dissolved Solids (TDS), and cyanide; evaluate heavy metal concentrations including manganese, lead, zinc, and iron; and assess microbial contamination by

E. coli. The findings of this research will provide critical data to inform water management strategies, reduce public health risks, and contribute to the broader understanding of the environmental impacts of illegal mining on groundwater resources.

This research aims to fill this gap by focusing on groundwater quality in these illegal mining communities and offering a comprehensive assessment using both the Nemerow Pollution Index (NPI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI).

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Groundwater samples were collected from five selected locations: three in the Atwima-Kwanwoma District [Manso Wahaso (Town A), Manso Aponapong (Town B), Manso Ankam (Town C)] and two in the Obuasi East Municipality [Obuasi Dunkwaw (Town D), Obuasi Suanso (Town E)]. The Atwima-Kwanwoma District, located at longitude 1°56ˈW and latitude 6°24ˈN, spans approximately 1,141 km², with Manso Adubia as its capital. The Obuasi East Municipality lies at longitude 1.0114°W and latitude 6.6074°N, covering approximately 1,380 km². These areas are within Ashanti Region (Figure 1) which are predominantly known for small-scale mining activities ("galamsey"), which may influence groundwater quality.

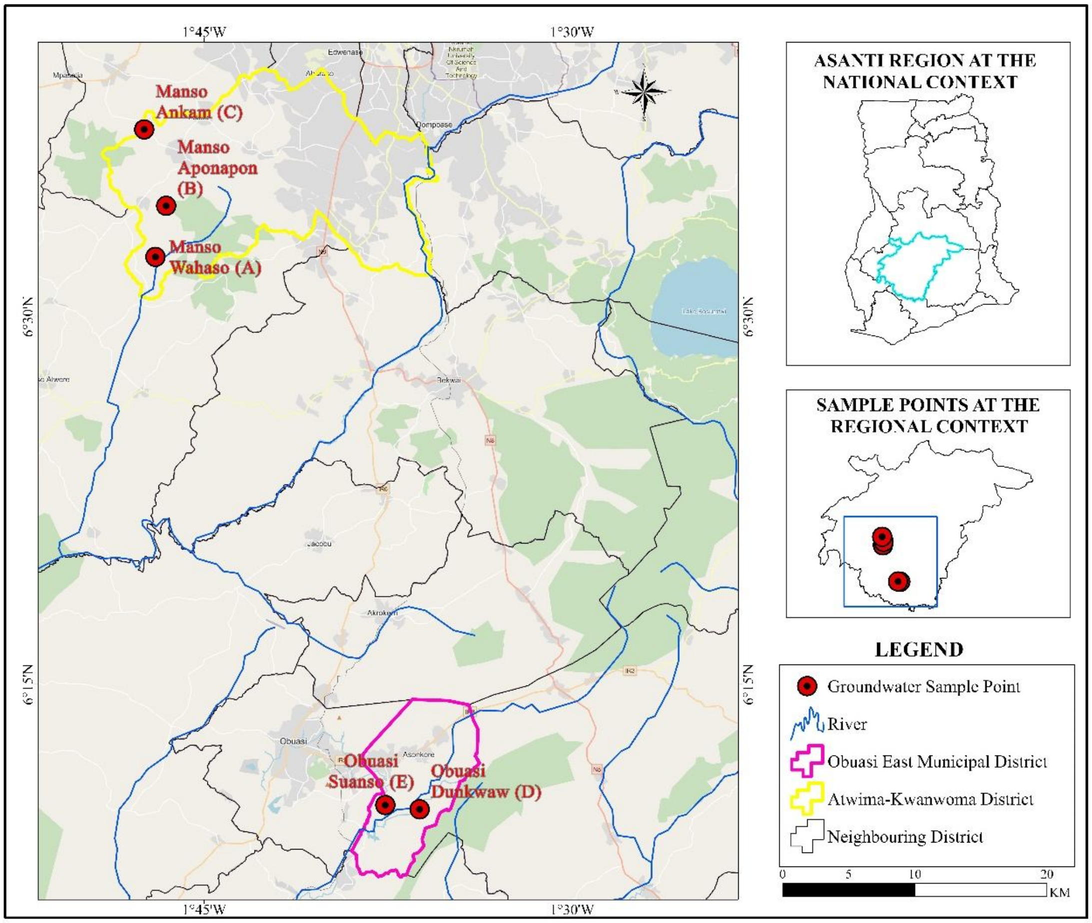

Figure 1: A Map of Ghana indicating the Ashanti Region with the Atwima – Kwanwoma and Obuasi East Districts capturedGeographic information on mining sites[7]

2.2 Study Design and Period

The study was conducted between May 2021 and April 2022 in the Atwima-Kwanwoma and Obuasi East Districts of the Ashanti Region, Ghana. Groundwater samples were collected throughout the year, from May 2020 to April 2021, ensuring that both dry and rainy seasons were included in the analysis. The collection period allowed the research to capture seasonal variations in groundwater quality, particularly as mining activities tend to intensify during the dry season when water levels are lower, increasing the concentration of pollutants. All laboratory analyses were performed at the Departments of Chemistry, Fisheries and Aquatic Sciences, and Water and Sanitation at the University of Cape Coast.

2.2.1 Chemical Reactions and Components Resulting from Mining Pollution

Mining activities significantly alter the chemical composition of water systems, leading to the formation of various pollutants and associated health and environmental risks. Below is an overview of the chemical reactions that occur, the resultant components, and their consequences.

1. Heavy Metal Leaching

Mining operations often expose sulfide minerals, resulting in the leaching of heavy metals such as lead, arsenic, mercury, and cadmium into groundwater. This leaching process can be summarized by Equations (1) & (2):

$$M_xO_y + H_2O \rightarrow M^{n+} + OH^{-} + H_2O \qquad (1)$$

where M represents the metal. The increase in heavy metal concentration in water bodies can be toxic to aquatic organisms and pose serious health risks to humans [2].

2. Cyanide Complex Formation

In Gold mining, cyanide is frequently utilized, leading to the formation of toxic cyanide complexes:

$$Au \quad + \quad CN^{-} \quad \rightarrow \quad Au\,(CN)^{2-} \qquad (2)$$

The presence of these complexes can be lethal to aquatic life and present significant health hazards to communities relying on contaminated water sources [5].

2.3 Sample Population

A total of 100 groundwater samples were collected from the study areas, with 20 samples taken from each location. Samples were drawn from three wells within each area, including control samples from wells located at least 2 km away from mining sites to assess background water quality unaffected by mining[8].

2.4 Sample Collection and Sampling Technique

Groundwater samples were collected using a method described by [8] where a total of 240 water samples were obtained for physicochemical, heavy metal, and microbial analyses. Each well was sampled over a one-year period. The samples were collected in sterilized polyethylene bottles and immediately treated with 1 ml of concentrated nitric acid to prevent metal leaching [9].

2.5 Sample Preservation and Transportation

To ensure the integrity of the samples, they were preserved in ice chests with ice blocks and transported to the laboratory following[9] guidelines. Upon arrival, samples were stored in a refrigerator at 4°C until analysis.

2.6 Physicochemical & Heavy Metal Analysis

2.6.1 Physicochemical Analysis

In situ measurements of pH, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were taken using the Eutech PC 700 multi-parameter checker. The pH meter was calibrated using buffer solutions of pH 4 and 7, while electrodes were rinsed with deionized water between readings [10].

2.6.2 Heavy Metal Analysis

Samples for heavy metal analysis were digested using aqua regia (a 5:2 ratio of HCl to HNO□) in a fume hood. A 100 ml aliquot of each water sample was heated for 2 hours, reducing the volume to 20 ml before filtration into a 100 ml volumetric flask. The digested samples were analyzed for cadmium, cyanide, iron, lead, manganese, and zinc using a SHIMADZU AA-7000 Atomic Absorption Spectrophotometer (AAS) [11]. Calibration curves were prepared for each metal, and concentrations in the samples were calculated accordingly.

2.7 Pesticide Analysis Using GC-MS & Cyanide Determination

2.7.1 Pesticide Analysis Using GC-MS

Water samples for pesticide residue analysis were collected in amber bottles pre-washed with detergent and rinsed with solvents according to US EPA Method 1699 United States Environmental Protection Agency (US EPA)[12]. The samples were stored below 6°C and transported to the laboratory in iced coolers. Pesticide residues were extracted and analyzed using a Shimadzu QP2020 Gas Chromatography-Mass Spectrometry (GC-MS) system [13].

2.7.2 Cyanide Determination

Cyanide concentrations were measured using the alkaline titration method described by [14]. A 5% potassium iodide (KI) solution was used as the indicator, and titration was carried out with 0.02 M silver nitrate (AgNO□). Sodium hydroxide (6 M) was added to the samples before titration, and the endpoint was noted when the solution turned faint yellow.

2.8 Microbial Analysis& Bacterial Identification

2.8.1 Microbial Analysis

For microbial analysis, media preparation, sterilization, and bacterial culture were conducted using standard microbiological techniques. Petri dishes were sterilized in an autoclave at 121°C for 15 minutes at 15 psi. Water samples were then inoculated onto Plate Count Agar, Eosin Methylene Blue (EMB) Agar, and Sulphur Indole Motility (SIM) Agar. The plates were incubated at 37°C for 24-48 hours, and colonies were enumerated using the plate count method [15].

Bacterial Enumeration

$$\text{CFU/milliliters} = \frac{NUMBER\ OF\ COLONIES\ per\ ml}{TOTAL\ DILUTION\ FACTOR}$$

2.8.2 Bacterial Identification

Bacteria isolated from the plates were identified using Gram staining and biochemical tests. Pure cultures were Gram stained, and cell shapes were examined under oil immersion (X100 objective lens) [16]. Sub-cultures of *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa* were confirmed through biochemical tests using SIM Agar, which was incubated aerobically at 35-37°C for 18-24 hours.

2.9 Determining the (CCME-WQI)&Nemerow's Pollution Index (NPI)

2.91 CCME-WQI

The Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) is a comprehensive tool used to summarize and communicate water quality data[17]. The index is calculated based on three primary factors:

1. **Scope**: This factor measures the extent of water quality guideline exceedances. It reflects how many of the parameters exceed the acceptable limits set by water quality guidelines[17].
2. **Frequency**: This factor considers the number of times the measured values exceed the water quality guidelines. It provides insight into how often the water quality issues occur [17].
3. **Amplitude**: This factor evaluates the magnitude of exceedances. It reflects how significantly the measured values exceed the guidelines [17].

To determine the CCME-WQI, water quality indicators are first selected based on the parameters of interest, such as pH, temperature, dissolved oxygen, and the presence of contaminants [17]. The data collected is then compared against established water quality guidelines or standards.

The index produces a score between 0 and 100, with higher scores indicating better water quality. Scores are interpreted as follows:

- **0-44**: Poor water quality
- **45-74**: Marginal water quality
- **75-94**: Good water quality
- **95-100**: Excellent water quality [17].

This index provides a single value that summarizes complex water quality data, making it accessible for stakeholders and policymakers [17].

F1 (Scope) was the proportion of indicators, relative to the total number of variables monitored, that did not satisfy their aims at least once in the time period being examined also known as "failed variables" (Equation (3)).

$$\mathbf{F_1} = \left(\frac{Number of failed variables}{\text{Total of variables}}\right) x\ 100 \quad (3)$$

F2 (Frequency) indicated the percentage of individual tests also known as "failed tests"that fail to satisfy their respective objectives (Equation (4)):

$$\mathbf{F_2} = \left(\frac{Numberoffailedvariables}{\text{Total of variables}}\right)\boldsymbol{x}\ \mathbf{100} \qquad \mathbf{(4)}$$

F3 (Amplitude) was the value that indicated the degree to which failed test values fall short of their respective targets. F, was calculated in three steps.

i) The term "excursion" referred to the number of times that an individual concentration was larger than (or lower than, when the target was a minimum) the target, and it was characterized as follows. When the value being tested must not be greater than the objective (Equation (5)):

$$\mathbf{excursion}_i = \left(\frac{FailedTestValue_i}{\text{Objective}_j}\right)\mathbf{-1} \qquad \mathbf{(5)}$$

In the circumstances in which the value of the test cannot be allowed to be lower than the objective (Equation (6)):

$$\mathbf{excursion_i} = \left(\frac{Objective_i}{Objective_j}\right) - 1 \qquad (6)$$

ii) The total amount that individual tests as a whole are found to be in violation of the standards was determined by adding up the distances that each test deviates from its goals and then dividing that total by the entire number of tests (both those meeting objectives and those not meeting objectives). This quantity, which was computed as follows and was known as the normalised of excursions, or nse for short (Equation (7)):

$$\mathbf{nse} = \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ tests} \qquad (7)$$

iii) After that, the value of F3 was determined by applying an asymptotic function to the normalised sum of the excursions from objectives (nse), which results in a range which could be anywhere from 0 to 100(Equation (8)).

$$\mathbf{F_3} = \left(\frac{nse}{0.01nse + 0.01}\right) \qquad (8)$$

After obtaining the factors, the index may be computed by adding up the three variables in the same manner as if they were vectors. This will result in the index value. As a result, the square of the index is equal to the sum of the squares that are contributed by each element.

This method views the index as a three-dimensional space, with each factor occupying a position along one axis of the space. The index shifts in a manner that is directly proportional to shifts in the other three parameters when using this model[17].

The CCME-WQI is calculated using the following formula(Equation (9)):

$$\textbf{CCME - WQI = 100 -} \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1732} \right) \tag{9}$$

2.9.2 Nemerow's Pollution Index (NPI)

Nemerow's Pollution Index (NPI) (Equation (10))is a comprehensive tool used to assess the overall pollution level of water bodies based on multiple water quality parameters. This index evaluates the combined effect of various pollutants, providing a single measure of water quality [18].

$$\textbf{NPI = Ci / Li} \tag{10}$$

where, Ci is the revealed concentration of ith parameter, and Li is the allowable limit of ith parameter. In Equation (8), the unit of Ci and Li must be the same.

The value of the NPI represents the total pollution that a single parameter contributes to the environment. If the value of NPI is greater than 1.0, this shows the presence of impurities in the water, which means that the water will require some sort of treatment before it can be used.

Numerous indices have apparently already been devised for the purpose of evaluating the quality of the water. In the work that is being presented here, the Nemerow's Pollution Index (NPI) has been utilised for the purpose of determining the physicochemical parameters that are responsible for the pollution of water as well as the evaluation of the current status of the water quality. Major pollutants of a certain water quality parameter can be identified after doing an analysis and performing the calculations necessary to calculate the NPI values for that particular water quality parameter. Therefore, utilising NPI has the potential to deliver quick and easy assessment results of the current state of the water's quality, which is an advantage [18].

For this study, NPI was calculated using specific physicochemical parameters including Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids

(TDS), and Cyanide, along with heavy metals such as Manganese, Lead, Zinc, and Iron. These parameters are crucial in assessing the quality of groundwater, particularly in areas impacted by illegal mining activities

The NPI yields a single value that reflects the overall pollution level, with higher values indicating greater pollution. The index is typically categorized as follows:

- **NPI < 1.0:** Low pollution
- **1.0 ≤ NPI < 2.0:** Moderate pollution
- **2.0 ≤ NPI < 3.0:** High pollution
- **NPI ≥ 3.0:** Very high pollution [18].

The NPI offers an integrated measure of groundwater quality by accounting for the combined effects of multiple physicochemical parameters, which is essential for understanding the overall impact of pollutants in areas affected by illegal mining [18].

3. RESULTS AND DISCUSSION

The statistical summary of water quality parameters across the five towns reveals several key insights into the conditions of the groundwater in the region (Table 1). Table 2 gives a summary of the five mining locations and corresponding distances to the illegal mining sites.

Table 1.0: Statistical Summary of all the Five Towns

Statistics	pH	DO	EC	Sal	TDS	CN	Mn	Pb	Zn	Fe
Mean	7.014	5.421	195.525	13.282	18.938	1.024	0.147	0.937	0.024	1.115
Std	0.658	0.694	85.383	0.679	8.517	0.790	0.089	0.484	0.015	0.622
Median	7.025	5.475	182.330	13.243	17.672	0.765	0.142	0.702	0.023	1.004
%CV	9.383	12.802	43.668	5.116	44.975	77.167	0.573	51.594	60.027	55.766
Max	8.320	7.290	501.790	15.940	47.635	2.410	0.315	1.806	0.066	2.543
Min	5.645	4.075	101.100	11.665	10.305	0.128	0.028	0.398	0.003	0.232
SE	0.040	0.042	5.197	0.041	0.518	0.048	0.005	0.029	0.001	0.038

Kurtosis	-0.697	-0.507	6.994	1.685	5.049	-1.008	-1.253	-0.998	-0.175	0.188
Skewness	0.101	0.219	1.642	0.925	2.167	0.726	0.243	0.834	0.445	1.013

Table 2.0: Illegal mining sites from sampling sites

Town	Name of Town	Distance (meters) to Illegal Mining Sites
A	Manso Wahaso	1241
B	Manso Aponapon	482
C	Manso Ankam	5722 (238 to a stream)
D	Obuasi Dunkwaw	15
E	Obuasi Suanso	1,374

Source:[7]

3.1 Comparative Assessment of Groundwater Quality using (CCME-WQI) &Nemerow's Pollution Index (NPI)

3.1.1 CCME-WQI

Table 3 displays the CCME WQI values for the small-scale (galamsey) towns in the Ashanti Region of Ghana and Table 4 stands as input data for computation of CCME-WQI in Table 3, namely Town A (Manso Wahaso), Town B (Manso Aponapon), Town C (Manso Ankam), Town D (Obuasi Dunkwaw), and Town E (Obuasi Suanso).

The CCME WQI values are numerical scores representing the overall water quality of each town's groundwater system. Based on the provided CCME-WQI values, we can assess the water quality category for each town using the given CCME-WQI rank and description.

In Town A, the CCME WQI value is 26.8, indicating poor water quality. This suggests that the water quality in Town A is virtually always in danger or deteriorating, with conditions that almost never conform to what would be considered normal or optimal.

Similarly, Town B has a CCME WQI value of 27.3, falling under the poor water quality category. This implies that the water quality in Town B is also virtually always in danger or deteriorating, with conditions that rarely meet the desired standards.

For Town C, the CCME WQI value is 31.1, still categorizing it as having poor water quality. Although the water quality conditions in Town C may occasionally deviate from their natural or optimal values, they predominantly indicate a state of imperilment or deterioration.

Town D, with a CCME WQI value of 28.2, falls within the poor water quality category as well. The water quality conditions in this town consistently suggest a state of danger or deterioration, with deviations from natural or optimal values.

Lastly, Town E has a CCME WQI value of 29.5, classifying it as having poor water quality. The conditions in Town E exhibit a regular imperilment or deterioration, with water quality that almost never meets the expected standards.

These results highlight the concerning water quality status in all five small-scale (galamsey) towns in the Ashanti Region. The poor water quality categories indicate an ongoing risk of degradation or deterioration, with conditions that frequently deviate from natural or optimal values. Immediate attention and appropriate measures are required to improve the water quality and ensure a safer water supply for the communities in these towns.

CCME-WQI (Canadian Council of Ministers of the Environment - Water Quality Index): The CCME-WQI provides an overall assessment of water quality and is based on various water quality parameters. The health implications associated with poor CCME-WQI rankings [19],[20]such as Fair, Marginal, or Poor can include:

Contaminant Exposure: Poor water quality indicated by lower CCME-WQI values suggests a higher likelihood of exposure to various contaminants, including heavy metals, chemicals, or pathogens. Prolonged exposure to these contaminants may lead to health issues such as gastrointestinal illnesses, skin problems, or respiratory conditions [20].

Increased Health Risks: Water with poor quality may not meet regulatory standards or recommended guidelines for safe drinking water. Consuming water with inadequate quality can result in the ingestion of harmful substances and an increased risk of waterborne diseases, affecting the gastrointestinal system, immune system, and overall well-being[20].

Long-Term Health Effects: Continuous exposure to poor water quality may have long-term health effects. Chronic exposure to contaminants, including heavy metals, may lead to cumulative health impacts over time, such as organ damage, neurological disorders, or an increased risk of certain cancers [20].

Table 3.0: CCME-WQI Results for the Five Towns

Station	Town A	Town B	Town C	Town D	Town E
F1	62.5	62.5	62.5	62.5	62.5
F2	54.2	54.2	43.5	52.3	51.4
F3	96.2	95	91.8	93.9	91.4
CCME WQI	**26.8**	**27.3**	**31.1**	**28.2**	**29.5**
WQI Category	**POOR**	**POOR**	**POOR**	**POOR**	**POOR**
Sum of Failed Tests	10849.1	8249.3	4853.7	6609.2	4585.5
Normalized Sum of Excursion	25.1	19.1	11.2	15.3	10.6
Total Samples	54	54	54	54	54
Total Variables	8	8	8	8	8
Actual Variables Tested	8	8	8	8	8
Total Tests	432	432	432	432	432
Number of Failed Tests	234	234	188	226	222
Number of Passed Tests	198	198	244	206	210
Number of Less than Detected	0	0	0	0	0

Source:[21]

Table 4.0: Standards and Parameter Used for CCME-WQI

Parameter_	Lower_Limit	Upper_Limit
pH	6.5	8.5

Total Dissolved Solids (mg/L)	0.6
Iron (mg/L)	0.3
Lead (ug/L)	0.01
Zinc (mg/L)	5
Manganese (mg/L)	1
Cyanide (mg/L)	0.2
Electrical Conductivity (µs/cm)	1000

Source:[22],[20]

Similar studies conducted in other countries, such as [5] in South Africa, [6] in India, and [23]in China, have observed comparable patterns of groundwater contamination, especially in areas with extensive mining operations.

Yidana& Asiedu [2] investigated the contamination of groundwater in Ghana's mining regions, revealing that illegal mining activities significantly degrade water quality through the release of toxic substances such as mercury and heavy metals.Also, [24] carried out a similar study on illegal mining and water Pollution, a case study in Fena River in the Ashanti Region of Ghana.

Other studies on surface water quality using (CCME-WQI) and Weighted Arithmetic Water Quality Index (WAWQI) are available in literature. Babatunde et. al. [25]studied water quality index on Nigerian Port Authority waterway in Port Harcourt with the following range of values: 3192.635 – 5061.35; while [26] carried out WQI for typical community pond water in Imo State, Nigeriawith range of values: 1338.71 - 3322.81. These range of values underscore the margin of difference between surface water and ground water quality index and it becomes relevant when we compare it World Health Organization standard for drinking water standard and other domestic uses.

3.1.2 Nemerow's Pollution Index (NPI)

Table 5 showcases the input data for the computation of Nemerow’s Pollution Index (NPI), while Table 6summarizes the (NPI) computed values for groundwater quality assessments in five small-scale (galamsey) towns in the Ashanti Region of Ghana. The table provides concentrations of various water quality parameters, such as Cyanide, Manganese, Lead, Zinc, and Iron, for each town.

Nemerow's Pollution Index (NPI) is a simple index proposed by Nemerowto measure pollution index[27]. It is commonly used to assess the pollution levels of different water quality parameters. The NPI value for a particular parameter is determined by Equation (8), [27]. Considering the context of the table, it represents the assessment of groundwater quality in the small-scale (galamsey) towns of the Ashanti Region in Ghana. The NPI values indicate the level of pollution contributed by each parameter in the groundwater of the respective towns. A value greater than 1.0 suggests the presence of impurities in the water, indicating the need for treatment before use.

Table 5.0: Standards and Parameter Used for NPI

Parameter	Standard
Iron (mg/L)	0.3
Lead (mg/L)	0.01
Zinc (mg/L)	5
Manganese (mg/L)	1
Cyanide (mg/L)	0.2

Source: [22],[20]

Table 6.0: NPI Results for the Five Towns

Metals / Towns	Town A	Town B	Town C	Town D	Town E
Cyanide	11.25	5.416665	1.845	2.71	4.375
Manganese	0.162	0.233333	0.056	0.230333	0.051
Lead	170.4	118.7333	61.4	69.3667	48.8
Zinc	0.0044	0.002133	0.0066	0.003689	0.007633
Iron	4.56	6.94889	1.82	3.28111	1.976667

Source: [21]

Analyzing the table, variations were observed in the NPI values across the different towns and parameters. For example, Town A (Manso Wahaso) shows an NPI value of 11.25 for Cyanide, indicating a high level of pollution beyond the allowable limit. Similarly, Town B (Manso Aponapon) exhibits an NPI value of 118.7333 for Lead, signifying a significant pollution level surpassing the acceptable limit. On the other hand, Towns C, D, and E (Manso Ankam, Obuasi Dunkwaw, and Obuasi Suanso) generally demonstrate NPI values below 1.0 for most parameters, suggesting relatively lower pollution levels within acceptable limits.

These results highlight the diverse groundwater quality in the assessed small-scale (galamsey) towns of the Ashanti Region. It is evident that immediate action is required to address the high pollution levels observed in Town A for Cyanide and in Town B for Lead. Implementing appropriate treatment measures is crucial to ensure the safety and usability of the groundwater in these towns. Additionally, continuous monitoring and effective management of water quality parameters are essential for maintaining environmental health in these small-scale mining communities.

The NPI is a pollution index that helps assess the level of pollution based on the concentrations of specific parameters. High NPI values indicate a higher level of pollution.

4. CONCLUSION

This study evaluated groundwater quality in illegal mining zones within the Atwima-Kwanwoma District and Obuasi East Metropolis in the Ashanti Region, Ghana, using an integrated approach with the Nemerow Pollution Index (NPI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI). The results reveal significant contamination across multiple parameters, particularly heavy metals, microbial indicators, and physicochemical properties. These findings highlight the severe impact of illegal mining on groundwater resources, with implications for public health and environmental sustainability.

The CCME-WQI results for all five towns consistently indicated "Poor" water quality, with values ranging from 26.8 to 31.1, signifying that the groundwater in these communities fails to meet basic water quality standards for human consumption and other uses. The high sum of failed tests and elevated excursions from permissible limits, especially in dissolved oxygen

(DO), electrical conductivity (EC), salinity, and total dissolved solids (TDS), underscore the vulnerability of the groundwater system to pollution from illegal mining activities.

The NPI results further confirmed significant contamination, particularly with heavy metals such as lead, iron, and manganese, alongside the presence of cyanide. Lead concentrations, for instance, were notably higher than acceptable limits in all five towns, with Town A recording the highest concentration of 170.4 µg/L, far exceeding WHO guidelines. The presence of cyanide, a common byproduct of illegal mining, also poses a serious risk, with Town A showing the highest concentration at 11.25 mg/L. These toxic substances, coupled with the microbial contamination by *Escherichia coli*, present a substantial threat to the health of local populations reliant on groundwater for drinking and other domestic uses.

The integrated use of NPI and CCME-WQI provided a comprehensive assessment of water quality, combining both physicochemical and biological parameters. This approach offers critical insights into the cumulative effects of illegal mining activities on groundwater resources in the region. The overall findings emphasize the urgent need for intervention, including stronger regulatory enforcement, sustainable mining practices, and the development of remediation strategies to safeguard groundwater resources.

In effect, this study underscores the detrimental impact of illegal mining on groundwater quality in the Ashanti Region of Ghana. The poor water quality observed across all sites highlights a public health crisis, necessitating immediate attention from both local and national authorities. Future efforts should focus on continuous monitoring, community education, and the promotion of alternative livelihoods to mitigate the environmental degradation caused by illegal mining. Moreover, this study contributes to the growing body of evidence that integrated water quality indices like NPI and CCME-WQI are effective tools for assessing the multifaceted nature of water contamination in mining-affected areas.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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