



Assessment of Heavy Metal Content of the Groundwater of Basilan Province, Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), Philippines

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(Received: 16 January 2025

Revised: 20 February 2025

Accepted: 31 March 2025)

| KEYWORDS | ABSTRACT: |
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| Heavy metals Groundwater quality Basilan BARMM | This study evaluates the groundwater quality in various municipalities of Basilan, focusing on the concentrations of heavy metals and overall water safety. Sampling wells were analyzed for parameters including mercury (Hg), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), nickel (Ni), chromium (Cr), lead (Pb), and barium (Ba). Results indicate that most wells showed acceptable levels for these parameters, with notable exceptions: localized iron exceedances in wells SW4, SW1, and SW3, and consistently high arsenic levels 5.00 across all municipalities, raising significant health concerns. The Compound Pollution Index (CPI) values were generally below 1, suggesting that the groundwater is safe for drinking. However, the Heavy Metal Pollution Index (HPI) revealed slight contamination in certain areas, while Sumisip, Moh. Ajul and Lamitan City reported no contamination. The Excellent Water Quality Index (EWQI) further confirmed that the groundwater is classified as excellent across all sampled sites. These findings highlight the necessity for regular monitoring and investigation into sources of contamination, particularly concerning arsenic levels, to safeguard public health and maintain water quality in the study area. |

1. Introduction

Life on Earth fundamentally depends on water, a finite and vital resource essential for survival. Groundwater and surface water are intricately interdependent, forming a critical hydrological system that sustains ecosystems and human activities [1]. Groundwater is particularly important as it provides water for drinking, agriculture, and industry, serving over half of the global population and accounting for approximately 13–30% of the world's freshwater resources [2-3]. Access to clean groundwater is crucial for sustainable development, food security, and public health [4-6].

To protect these groundwater resources, it is imperative to test and analyze the chemical composition of groundwater periodically. Such chemical assessments are necessary to identify hazardous substances, including heavy metals, and evaluate overall water quality. Heavy metals can infiltrate groundwater and surface water,

posing serious health risks to humans and wildlife [7]. These toxic metals often enter groundwater through various pathways, including rainfall, agricultural runoff, sewage discharge, industrial waste, and the use of pesticides [8].

Heavy metals like lead, mercury, arsenic, and cadmium are particularly concerning due to their toxicity, environmental persistence, and potential for bioaccumulation in humans, animals, and plants. Even trace amounts of these metals can lead to severe health consequences, including cancer, cognitive impairments, and organ damage, as noted by [9]. While trace levels of certain metals are necessary for biological functions, excessive exposure can pose risks to health [10].

Given the significant risks associated with groundwater contamination, numerous studies emphasize the urgent need for the rigorous monitoring of water quality,



especially when used for drinking purposes [11,12]. Contamination often stems from human activities such as industrial expansion, urban development, and agricultural practices, which can introduce pollutants that disrupt the natural balance of groundwater systems and compromise water quality. This underscores the importance of proactive measures to safeguard groundwater resources, ensuring their availability for future generations.

As the challenges of groundwater contamination continue to escalate, there is an increasing global awareness of the urgent need to address this issue, particularly regarding heavy metals. The detrimental effects of heavy metal pollution on public health and the environment necessitate sustained monitoring and proactive measures to mitigate pollution sources [13]. Recognizing the significance of these challenges, the present study aims to comprehensively evaluate the heavy metal pollution indices and assess groundwater quality using the entropy method. Additionally, this research seeks to identify correlations among various groundwater parameters, thereby providing valuable insights into the interactions and potential sources of contamination. Through enhancing our understanding of these dynamics, we can better inform strategies for effective groundwater management and pollution prevention.

2. Methods

2.1 The Study Area

Basilan Province, as illustrated in Figure 1, encompasses an area of 137,900 hectares. It is geographically situated between latitudes $6^{\circ}16'48''$ and $6^{\circ}45'56''$ North, and longitudes $121^{\circ}26'00''$ and $122^{\circ}24'38''$ East. The province comprises two component cities and 11 municipalities, totaling 255 villages. The landscape features rolling hills, with flat terrain primarily along the coastal regions. The dominant soil type in Basilan is Bulaon clay, with some areas of Bancal clay loam. Agriculture plays a significant role in the local economy, with the majority of land cultivated with coconut, rubber, and various fruit trees. The island experiences a Type III climate, characterized by less distinct seasons relatively dry from November to April, followed by a wet season for the remainder of the year [14]. The average annual temperature is 26.6°C , with total annual precipitation averaging 1,100 mm [14].

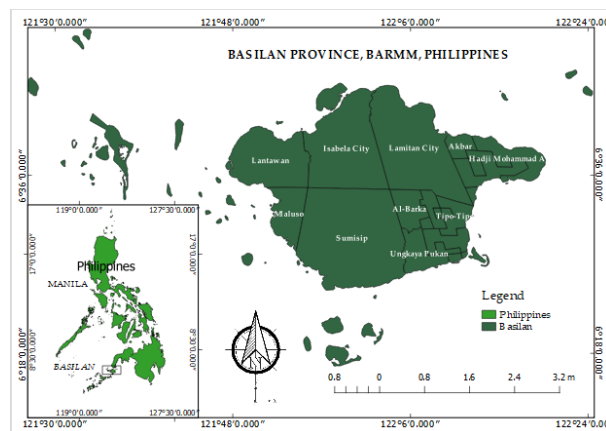


Figure 1. Map of the study area

2.2 Test method

Table 1 presents the analytical methods employed to assess various groundwater parameters, highlighting the rigorous techniques used to ensure accurate and reliable results. Parameters such as cadmium, copper, iron, zinc, manganese, nickel, chromium, and lead were analyzed using the 3030 F method for nitric acid-hydrochloric acid digestion, followed by the 3111 B procedure utilizing Direct Air-Acetylene Flame Atomic Absorption Spectroscopy (AAS). This combination allows for the effective extraction and quantification of these metals from the groundwater samples.

In contrast, barium and arsenic concentrations were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), a method known for its sensitivity and ability to detect low concentrations of metals. This technique is particularly valuable for elements like arsenic, which pose significant health risks even at trace levels.

Mercury analysis was conducted using the cold vapor AAS technique, which is specifically designed to minimize interference from other elements and improve detection limits for this highly toxic metal. Lead, on the other hand, was analyzed through the combination of 3030 E nitric acid digestion and the 3111 B Direct Air-Acetylene Flame AAS method, ensuring a thorough assessment of its concentration in the groundwater.



Table 1. Method of Analysis of Heavy Metals Employed in the Study

| Parameters | Units | Method of Analysis |
|------------|-------|-----------------------------------------------------------------------------------------|
| Mercury | mg/L | Cold Vapor AAS |
| Arsenic | mg/L | ICP-OES |
| Cadmium | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Copper | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Iron | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Zinc | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Manganese | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Nickel | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Chromium | mg/L | 3030 F. Nitric Acid-Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Lead | mg/L | 3030 E. Nitric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AAS |
| Barium | mg/L | ICP-OES |

2.3 Heavy Metal Pollution Indices

2.3.1 Risk calculation of heavy metal pollution

There were two types of risk assessment methods of trace heavy metal pollution degree used to assess the heavy metal pollution in the groundwater in the study area, which is shown below:

2.3.1.1 Single-Factor Pollution Index (Ii)

The Single-factor pollution index (Ii) evaluates how a single heavy metal pollutes groundwater at a sampling well. The [15] was used to evaluate the parameters. When Ii is >1, the content of that heavy metal exceeds the standard [16]. This single-factor index was assessed using this equation.

$$I_i = \frac{C_i}{S_i}$$

The Ci measured the content of contaminant Ii in groundwater water (mg/L) and the Si standard of pollutant i in groundwater (mg/L).

2.3.1.2 Compound pollution index (CPI)

The Compound Pollution Index (CPI) assessed the levels of heavy trace metal pollution in water. A CPI value of less than 1 indicates no heavy metal contamination in the water samples, while a CPI value of 1 or greater signifies the presence of heavy metal contamination [16]. The CPI is calculated using the following equation:

$$CPI = \sum_{i=1}^m \frac{I_i}{m}$$

The Ii is a single-factor index of heavy metal, and m is the number of heavy metal types.

2.3.1.3 The degree of contamination (Cd)

The degree of contamination (Cd) is adopted from [17] and is calculated using the following equation. This parameter is essential for assessing the cumulative impact of various contaminants in groundwater, providing a comprehensive measure of overall water quality and potential risks.

$$Cd = \sum_{i=1}^n Cfi$$

$$Cfi = \frac{CAi}{CN1} - 1$$

The Cfi is the contamination factor for each heavy metal in a particular groundwater sample, and Cai is the analytical concentration of a specific heavy metal.



C_{ni} is the permissible concentration limit for the heavy metal or the maximum allowed concentration (MAC)

2.3.1.4 Heavy Metal Pollution Index (HPI)

The Heavy Trace Metal Pollution Index (HPI) model assesses water quality by assigning weights (W_i) to various parameters. Each parameter is rated on a scale from 0 to 1, reflecting its impact on overall water quality, with the rating inversely proportional to the recommended standard (S_i) for that parameter [18,19]. Concentration limits, including the maximum permissible value for drinking water (S_i) and the maximum desirable value (I_i), are based on [15]. An HPI value below 100 indicates non-contaminated water, while a value above 100 signifies contamination by heavy metals. The HPI utilizes these ratings to compute an overall score, as described in the equation below.

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i}$$

The W_i is the unit weight, and Q_i is the sub-index of the ith parameter.

$$W_i = \frac{K}{S_i}$$

$$K = \frac{1}{\sum_{i=1}^n \frac{1}{S_i}}$$

The K is the proportionality constant, and S_i is the standard permissible limit in water for the ith parameter

$$Q_i = \sum_{i=1}^n \frac{|M_i - I_i|}{(S_i - I_i)} \times 100$$

The M_i is the monitored value of the ith parameter, I_i is the ideal value of the ith parameter, and S_i is the standard value of the ith parameter.

2.4 Groundwater quality

The Water Quality Index (WQI) is an effective method widely employed to assess groundwater quality for drinking purposes, taking into account hydro-geochemical parameters and heavy metal pollution [20]. In addition, some researchers have utilized the Entropy Water Quality Index (EWQI) to evaluate groundwater quality [21-23]. The EWQI is an innovative tool that analyzes multivariable water quality data against user-defined standards, allowing for a comprehensive assessment of water quality [23], as outlined by [24-28].

The first is to construct the performance matrix. The initial matrix x compiles the chemical analysis data for m

monitored wells (1, 2,...,m) used to evaluate water quality. Each well contains n-measured parameters (1, 2,...,n). The matrix x is structured as follows:

$$X = \begin{pmatrix} X_{11} & X_{12} & X_{13} & \dots & X_{1n} \\ X_{21} & X_{22} & X_{23} & \dots & X_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ X_{m1} & X_{m2} & X_{m3} & \dots & X_{mn} \end{pmatrix}$$

Secondly, normalization of the performance matrix is crucial for minimizing errors arising from differing units of measurement across various parameters and their quantities [29]. To achieve this. The normalized matrix x_{ij} value is divided by the sum of the values in its respective column:

$$V_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}}$$

Thirdly, the entropy value. The entropy for the jth measured parameter is determined using the following formula [30]

$$z_j = - \frac{1}{\ln(m)} \sum_{i=1}^n V_{ij} \ln(V_{ij})$$

where z_j represents the entropy value of the jth parameter, and fourth is to calculate the objective weights for each parameter using the following formula:

$$W_j = \frac{1 - z_j}{\sum_{i=1}^n 1 - z_j}$$

where W_j is the weight for the jth parameter. Another quality scaling factor, according to [31], is:

$$q_j = \left[\frac{V_j - Vid}{S_j - Vid} \right] \times 100$$

The q_j represents the quality rating for the jth water parameter, V_j is the measured value of the jth parameter, S_j is the standard permissible value for that parameter as set by WHO [15], and Vid is the ideal value for the jth parameter in pure water.

The overall water quality index can be estimated by combining the quality scaling factor for the jth parameter with the corresponding unit entropy weight, as described in the formula. Furthermore, Table 2 presents the range of values obtained from these computations, including the classification of water types.



$$EWQI = \sum_{i=1}^n W_j x_{qj}$$

Table 2. Classification of groundwater quality according to the entropy-weighted groundwater quality index (EWQI) range

| Range Values | Type of Water |
|--------------|-------------------------|
| <50 | Excellent Water |
| 50-99.99 | Good Water |
| 100-199.99 | Poor Water |
| 200-299.99 | Very poor |
| >300 | Unsuitable for drinking |

3. Results and Discussion

3.1 Single-factor and Compound pollution indices

The single-factor pollution index evaluation, presented in Table 3, reveals a generally positive assessment of groundwater quality across the studied areas. Parameters such as mercury, cadmium, iron, copper, zinc, manganese, nickel, chromium, lead, and barium were all found to have values of one (1) or less. This indicates that these parameters are within acceptable limits, demonstrating compliance with established safety standards in all sampling wells examined.

However, iron levels showed localized exceedances in wells SW4, SW1, and SW3, which are situated in Akbar, Lantawan, and Lamitan, respectively. These exceedances highlight the need for targeted monitoring and potential remediation efforts.

In contrast, arsenic levels were slightly elevated, with a consistent value of 5.00 recorded across all sampling wells in the municipalities of Tuburan, Akbar, Tipo-Tipo, Al-Barka, Maluso, Lantawan, and Ungkaya Pukan. This widespread presence of arsenic poses significant health risks and underscores the urgency of addressing this contamination issue.

Despite these concerns, the compound pollution index indicates that the overall groundwater quality remains safe for drinking, with values below 1 across all sampling locations. This finding is reassuring; however, it also emphasizes the necessity for ongoing monitoring to ensure that localized issues, particularly with iron and

arsenic, do not compromise public health or the integrity of this vital water resource.

Table 3. Single and compound factors of groundwater parameters

| Mun | SW | Hg | As | Cd | Cu | Fe | Zn | Mn | Ni | Cr | Pb | Ba | CPI |
|---------------|----|------|------|------|------|------|------|------|------|------|------|------|------|
| Tuburan | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 0.40 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.77 |
| | 4 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| Akbar | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 0.20 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.75 |
| | 4 | 0.17 | 5.00 | 0.67 | 0.01 | 2.20 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.94 |
| Tipo-Tipo | 1 | 0.17 | 5.00 | 0.67 | 0.02 | 0.06 | 0.20 | 0.08 | 0.14 | 0.60 | 1.00 | 0.01 | 0.72 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.02 | 0.06 | 0.20 | 0.08 | 0.14 | 0.60 | 1.00 | 0.01 | 0.72 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.02 | 0.06 | 0.20 | 0.08 | 0.14 | 0.60 | 1.00 | 0.01 | 0.72 |
| | 4 | 0.17 | 5.00 | 0.67 | 0.02 | 0.06 | 0.20 | 0.08 | 0.14 | 0.60 | 1.00 | 0.01 | 0.72 |
| Al-Barka | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.20 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.75 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 1.00 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.83 |
| Maluso | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 0.16 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.75 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 0.10 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 4 | 0.17 | 5.00 | 0.67 | 0.01 | 0.30 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.76 |
| Lantawan | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 1.80 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.90 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.20 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.75 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.25 | 0.14 | 0.60 | 1.00 | 0.01 | 0.76 |
| | 4 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| Ungkaya Pukan | 1 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 2 | 0.17 | 5.00 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.74 |
| | 3 | 0.17 | 5.00 | 0.67 | 0.01 | 1.00 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.83 |
| Sumisip | 1 | 0.17 | 1.00 | 0.67 | 0.01 | 0.12 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.38 |
| | 2 | 0.17 | 1.00 | 0.67 | 0.01 | 0.20 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.39 |
| | 3 | 0.17 | 1.00 | 0.67 | 0.01 | 0.40 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.41 |
| | 4 | 0.17 | 1.00 | 0.67 | 0.01 | 0.16 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.39 |
| | 5 | 0.17 | 1.00 | 0.67 | 0.01 | 0.10 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.38 |
| Moh. Ajul | 1 | 0.17 | 0.50 | 0.67 | 0.01 | 0.80 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.40 |
| | 2 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.33 |
| | 3 | 0.17 | 0.50 | 0.67 | 0.01 | 1.00 | 0.40 | 0.10 | 0.29 | 0.60 | 1.00 | 0.01 | 0.43 |
| | 4 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.03 | 0.33 |
| Lamitan | 1 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.25 | 0.14 | 0.60 | 1.00 | 0.06 | 0.35 |
| | 2 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.14 | 0.60 | 1.00 | 0.01 | 0.33 |
| | 3 | 0.17 | 0.50 | 0.67 | 0.01 | 1.60 | 0.40 | 0.10 | 0.29 | 0.60 | 1.00 | 0.01 | 0.48 |
| | 4 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.43 | 0.60 | 1.00 | 0.01 | 0.36 |
| | 5 | 0.17 | 0.50 | 0.67 | 0.01 | 0.06 | 0.40 | 0.10 | 0.71 | 0.60 | 1.00 | 1.00 | 0.47 |

3.2 Degree of Contamination and Heavy Metal Pollution Index (HPI)

Table 4 reveals that the overall degree of contamination indicates that groundwater throughout the province of Basilan is predominantly pure and free from significant contamination. This assessment suggests that the water quality in most areas is suitable for consumption and supports the health of the local ecosystem.

However, using the Heavy Metal Pollution Index (HPI). The groundwater in the municipalities of Tuburan, Akbar, Tipo-Tipo, Al-Barka, Maluso, Lantawan, and Ungkaya Pukan exhibits slight contamination with HPI



values exceeding 100, indicating a level of concern that warrants attention. These elevated HPI values suggest the presence of heavy metals, which could pose health risks if not properly managed.

In contrast, the groundwater in Sumisip, Moh. Ajul and Lamitan City present a more favorable condition, with HPI values below 1, indicating that the groundwater from these areas is free from contamination. This variation highlights the importance of targeted monitoring and intervention strategies, particularly in areas experiencing high heavy metal concentrations.

Table 4. Degree of Contamination and Heavy Metal Pollution Index (HPI) Values

| Mun | S W | Long | Lat | HPI | Cd |
|---------------|--------|--------------|-------------|------------|-----------|
| Tuburan | 1 | 122.189 2 | 6.6173 3 | 114.9 4 | - 2.85 |
| | 2 | 122.191 6 | 6.6101 3 | 114.9 5 | - 2.85 |
| | 3 | 122.188 9 | 6.6150 4 | 115.0 4 | - 2.51 |
| | 4 | 122.200 9 | 6.6117 6 | 114.9 5 | - 2.85 |
| Akbar | 1 | 122.195 1 | 6.6657 9 | 114.9 5 | - 2.85 |
| | 2 | 122.185 1 | 6.6649 2 | 114.9 5 | - 2.85 |
| | 3 | 122.183 1 | 6.6498 6 | 114.9 8 | - 2.71 |
| | 4 | 122.183 5 | 6.6224 5 | 115.5 1 | - 0.71 |
| Tipo- Tipo | 1 | 122.124 1 | 6.5131 8 | 114.9 4 | - 3.06 |
| | 2 | 122.200 7 | 6.5349 1 | 114.9 4 | - 3.06 |
| | 3 | 122.155 4 | 6.5580 1 | 114.9 4 | - 3.06 |
| | 4 | 122.174 2 | 6.5750 3 | 114.9 4 | - 3.06 |

| | | | | | |
|------------------|---|--------------|-------------|------------|-----------|
| Al-Barka | 1 | 122.150 6 | 6.4973 1 | 114.9 5 | - 2.85 |
| | 2 | 122.149 9 | 6.4742 | 114.9 8 | - 2.71 |
| | 3 | 122.133 3 | 6.4601 6 | 115.2 0 | - 1.91 |
| Maluso | 1 | 121.891 1 | 6.5588 9 | 114.9 7 | - 2.75 |
| | 2 | 121.889 8 | 6.5192 9 | 114.9 5 | - 2.84 |
| | 3 | 121.914 6 | 6.5070 8 | 114.9 6 | - 2.81 |
| | 4 | 121.913 4 | 6.4863 2 | 115.0 1 | - 2.61 |
| Lantawan | 1 | 121.927 1 | 6.5968 2 | 115.4 1 | -1.11 |
| | 2 | 121.855 8 | 6.6037 5 | 114.9 9 | - 2.70 |
| | 3 | 121.840 7 | 6.6362 3 | 115.0 0 | - 2.69 |
| | 4 | 121.876 9 | 6.6466 3 | 114.9 5 | - 2.84 |
| | 5 | 121.876 9 | 6.6466 3 | 114.9 5 | - 2.84 |
| Ungkaya Pukan | 1 | 122.106 5 | 6.4600 4 | 114.9 5 | - 2.85 |
| | 2 | 122.117 1 | 6.4912 6 | 114.9 5 | - 2.85 |
| | 3 | 122.126 5 | 6.5214 7 | 115.1 9 | - 1.91 |
| Sumisip | 1 | 122.053 6 | 6.4459 1 | 62.38 | - 6.79 |
| | 2 | 122.029 7 | 6.4349 4 | 62.40 | - 6.71 |
| | 3 | 122.009 1 | 6.4270 5 | 62.46 | - 6.51 |
| | 4 | 121.977 5 | 6.4319 7 | 62.39 | - 6.75 |
| | 5 | 121.955 2 | 6.4495 6 | 62.38 | - 6.80 |



| | | | | | |
|-----------|---|----------|---------|-------|-------|
| Moh. Ajul | 1 | 122.2548 | 6.64675 | 55.99 | -6.61 |
| | 2 | 122.2569 | 6.64575 | 55.79 | -7.35 |
| | 3 | 122.2666 | 6.64065 | 56.31 | -6.27 |
| | 4 | 122.2704 | 6.64077 | 55.80 | -7.33 |
| Lamitan | 1 | 122.035 | 6.69555 | 55.85 | -7.15 |
| | 2 | 122.0627 | 6.67717 | 55.79 | -7.35 |
| | 3 | 122.0786 | 6.6972 | 56.47 | -5.67 |
| | 4 | 122.1215 | 6.64986 | 56.33 | -7.07 |
| | 5 | 122.1461 | 6.66176 | 57.05 | -5.79 |

3.3 Entropy Water Quality Index (EWQI)

Table 5 provides the minimum and maximum values of the analyzed groundwater parameters from mainland Basilan, along with the mean and weight values for each parameter. This comprehensive analysis highlights the variability in groundwater quality across all the study areas.

This illustrates that the computed Overall Water Quality Index (EWQI) (Table 6) values are all below 100, indicating that the groundwater in the province of Basilan is classified as pure and of excellent quality. This suggests that the groundwater is safe for consumption and meets the necessary health and environmental safety. The findings underscore the importance of ongoing monitoring to maintain the quality of this vital resource.

Table 5. Minimum, Maximum, and Weight of each Groundwater Parameter.

| Chem | Min | Max | Mean | WHO | Wj |
|------|-------|-------|-------|-------|--------|
| Hg | 0.001 | 0.001 | 0.001 | 0.006 | 0.0041 |
| As | 0.005 | 0.05 | 0.035 | 0.01 | 0.0674 |

| | | | | | |
|----|-------|-------|-------|-------------|--------|
| Cd | 0.002 | 0.002 | 0.002 | 0.003 | 0.0041 |
| Cu | 0.01 | 0.04 | 0.013 | 2 | 0.0494 |
| Fe | 0.03 | 1.1 | 0.165 | 0.5 | 0.2304 |
| Zn | 0.01 | 0.02 | 0.019 | 0.01 - 0.05 | 0.0082 |
| Mn | 0.03 | 0.1 | 0.042 | 0.4 | 0.0151 |
| Ni | 0.01 | 0.05 | 0.012 | 0.07 | 0.0351 |
| Cr | 0.03 | 0.03 | 0.030 | 0.05 | 0.0041 |
| Pb | 0.01 | 0.01 | 0.010 | 0.01 | 0.0041 |
| Ba | 0.005 | 0.7 | 0.025 | 0.7 | 0.5780 |

Table 6. Entropy Water Quality Index and Type of Water of each Sampling Well in all Municipalities

| Mun | SW | EWQI Values | Type of Water |
|-----------|----|-------------|-----------------|
| Tuburan | 1 | 32.45 | Excellent Water |
| | 2 | 32.7 | Excellent Water |
| | 3 | 32.26 | Excellent Water |
| | 4 | 32.7 | Excellent Water |
| Akbar | 1 | 32.7 | Excellent Water |
| | 2 | 32.7 | Excellent Water |
| | 3 | 32.42 | Excellent Water |
| | 4 | 33.75 | Excellent Water |
| Tipo-Tipo | 1 | 30.3 | Excellent Water |
| | 2 | 30.3 | Excellent Water |
| | 3 | 30.3 | Excellent Water |
| | 4 | 30.3 | Excellent Water |
| Al-Barka | 1 | 32.7 | Excellent Water |
| | 2 | 32.42 | Excellent Water |
| | 3 | 32.33 | Excellent Water |
| Maluso | 1 | 32.48 | Excellent Water |
| | 2 | 32.3 | Excellent Water |
| | 3 | 32.51 | Excellent Water |



| | | | |
|---------------|---|-------|-----------------|
| | 4 | 32.14 | Excellent Water |
| Lantawan | 1 | 32.93 | Excellent Water |
| | 2 | 32.01 | Excellent Water |
| | 3 | 31.18 | Excellent Water |
| | 4 | 32.3 | Excellent Water |
| Ungkaya Pukan | 1 | 32.7 | Excellent Water |
| | 2 | 32.7 | Excellent Water |
| | 3 | 32.43 | Excellent Water |
| Sumisip | 1 | 17.31 | Excellent Water |
| | 2 | 17.42 | Excellent Water |
| | 3 | 17.64 | Excellent Water |
| | 4 | 17.36 | Excellent Water |
| | 5 | 17.1 | Excellent Water |
| Moh. Ajul | 1 | 16.8 | Excellent Water |
| | 2 | 15.14 | Excellent Water |
| | 3 | 17.2 | Excellent Water |
| | 4 | 14.84 | Excellent Water |
| Lamitan | 1 | 13.83 | Excellent Water |
| | 2 | 15.24 | Excellent Water |
| | 3 | 18.62 | Excellent Water |
| | 4 | 15.54 | Excellent Water |
| | 5 | 16.97 | Excellent Water |

3.4 Correlation

There are positive correlations (Table 7) between mercury and cadmium with chromium and lead. This suggests that as the levels of mercury and cadmium increase, so do the levels of chromium and lead. Such correlations may imply a potential shared source of contamination or similar contact route, highlighting the importance of monitoring these heavy metals in environmental and health studies. Further investigation is warranted to understand the underlying mechanisms and implications of these correlations.

Table 7. Correlation Among the Listed Groundwater Parameters

| Chem | Hg | As | Cd | Cu | Fe | Zn | Mn | Ni | Cr | Pb |
|------|---------|---------|-------|--------|-------|-------|--------|--------|-------|-------|
| Hg | 1 | | | | | | | | | |
| As | -7E-16 | 1 | | | | | | | | |
| Cd | 1 | -7E-16 | 1 | | | | | | | |
| Cu | 6.1E-16 | 0.2027 | 6E-16 | 1 | | | | | | |
| Fe | 3.6E-17 | -0.0205 | 4E-17 | -0.188 | 1 | | | | | |
| Zn | 3E-15 | -0.244 | 3E-15 | -0.985 | 0.174 | 1 | | | | |
| Mn | 1.6E-15 | -0.1322 | 2E-15 | -0.174 | -0.08 | 0.293 | 1 | | | |
| Ni | 3.6E-16 | -0.405 | 4E-16 | -0.101 | 0.022 | 0.093 | -0.041 | 1 | | |
| Cr | 1 | -7E-16 | 1 | 6E-16 | 4E-17 | 3E-15 | 2E-15 | 4E-16 | 1 | |
| Pb | 1 | -7E-16 | 1 | 6E-16 | 4E-17 | 3E-15 | 2E-15 | 4E-16 | 1 | 1 |
| Ba | 3.4E-17 | -0.2463 | 3E-17 | -0.056 | -0.09 | 0.061 | 0.0139 | 0.8477 | 3E-17 | 3E-17 |

4. Conclusion

In conclusion, evaluating groundwater quality in Basilan reveals mixed results. Most parameters, including mercury, cadmium, and others, fall within acceptable limits, but iron levels exceeded standards in specific wells, and arsenic levels were alarmingly high at 5.00, posing significant health risks.

While the compound pollution index indicates that overall groundwater is safe for drinking, slight contamination is noted in several municipalities, with Sumisip, Moh. Ajul and Lamitan City remain uncontaminated. The Excellent Water Quality Index (EWQI) supports that groundwater is generally pure and suitable for consumption, but ongoing monitoring is crucial. Additionally, the observed correlations between mercury, cadmium, chromium, and lead necessitate further investigation into contamination sources. These findings emphasize the importance of proactive measures to ensure water quality and public health.

Acknowledgment

We would like extend our heartfelt gratitude to the National Research Council of the Philippines (NRCP) under the Department of Science and Technology (DOST) for approving and funding our research project. Their unwavering support and commitment have been instrumental in making this study possible and have greatly contributed to its success.



References

- [1] Zakir, H. M.; Sharmin, S.; Akter, A.; Rahman, M. S. Assessment of Health Risk of Heavy Metals and Water Quality Indices for Irrigation and Drinking Suitability of Waters: A Case Study of Jamalpur Sadar Area, Bangladesh. *Environ. Adv.* **2020**, *2* (September), 100005. <https://doi.org/10.1016/j.envadv.2020.100005>.
- [2] Dragoni W, Sukhija BS. Climate change and groundwater: a short review. *Geol Soc London Spec Publ* 2008(1); 288: 1-12. doi: 10.1144/sp288.1.
- [3] Hofmann J, Watson V, Scharaw B. Groundwater quality under stress: contaminants in the Kharaa River basin (Mongolia). *Environ Earth Sci* 2015; 73(2): 629-48. doi: 10.1007/s12665-014-3148-2.
- [4] Rao, K.N.; Latha, P.S. Groundwater quality assessment using water quality index with a special focus on vulnerable tribal region of Eastern Ghats hard rock terrain, Southern India. *Arab. J. Geosci.* 2019, 12, 1–16. [CrossRef]
- [5] Maharjan, A.K.; Kamei, T.; Amatya, I.M.; Mori, K.; Kazama, F.; Toyama, T. Ammonium-Nitrogen (NH₄⁺-N) Removal from Groundwater by a Dropping Nitrification Reactor: Characterization of NH₄⁺-N Transformation and Bacterial Community in the Reactor. *Water* 2020, 12, 599. [CrossRef]
- [6] Nurtazin, S.; Pueppke, S.; Ospan, T.; Mukhitdinov, A.; Elebessov, T. Quality of drinking water in the Balkhash District of Kazakhstan's Almaty Region. *Water* 2020, 12, 392. [CrossRef]
- [7] Wang P, Zhao Z-Z, Wang J-G, Zhang Z-W, Zhang Z-C (2011) Distribution characteristic and potential ecological risk assessment of heavy metals in latosol in the Western area of Hainan Island. *Journal of Anhui Agricultural Sciences* 9: 5210-5339.
- [8] Liu L, Lv J, Xu G (2013) uniformly dispersed CdS nanoparticles sensitized TiO₂ nanotube arrays with enhanced visible light photocatalytic activity and stability. *Journal of Solid-State Chemistry* 208:27-34.
- [9] Hosseinpour, M. M., Lashkaripour, G. R. & Debghan, P. 2014 Assessing the effect of heavy metal concentrations (Fe, Pb, Zn, Ni, Cd, As, Cu, Cr) on the quality of adjacent groundwater resources of Khorasan steel complex. *International Journal of Plant, Animal and Environmental Sciences* 4(2), 511–518.
- [10] Elumalai, V., Brindha, K., & Lakshmanan, E. (2017). Human exposure risk assessment due to heavy metals in groundwater by pollution index and multivariate statistical methods: A case study from South Africa. *Water (Switzerland)*, 9(4). <https://doi.org/10.3390/w9040234>
- [11] Momot, O., & Synzynyns, B. (2005). Toxic aluminium and heavy metals in groundwater of Middle Russia: Health risk assessment. *International Journal of Environmental Research and Public Health*, 2(2), 214–218. <https://doi.org/10.3390/ijerph2005020003>
- [12] Ravindra, K. & Mor, S. 2019 Distribution and health risk assessment of arsenic and selected heavy metals in groundwater of Chandigarh, India. *Environmental Pollution* 250, 820–830
- [13] Adeyemi, A. & Ojekunle, Z. O. 2021 Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun state, Nigeria. *Scientific African* 11,1–11.
- [14] Bangsamoro Development Agency (2016). Comprehensive Capacity Development Project for the Bangsamoro Development Plan for the Bangsamoro Final Report Sec.
- [15] WHO (2011) Guidelines for Drinking-Water Quality. 4th ed. Geneva: World Health Organization https://www.who.int/water_sanitation_health/
- [16] Zhong S, Geng H, Zhang F, Liu Z, Wang T, et al. (2015) Risk Assessment and Prediction of Heavy Metal Pollution in Groundwater and River Sediment: A Case Study of a Typical Agricultural Irrigation Area in Northeast China. *Int J Anal Chem* 921539.
- [17] Backman B, Bodis D, Lahermo P, Rapant S, Tarvainen T (1997) Application of a groundwater



- contamination index in Finland and Slovakia. *Environ Geol* 36: 55-64.
- [18] Mohan SV, Nithila P, Reddy SJ (1996) Estimation of heavy metal in drinking water and development of heavy metal pollution index. *J Environ Sci Health A31*: 283-289.
- [19] Bhuiyan M, Bodrud-Doza M, Islam, ARM, Rakib M, et al. (2016) Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis. *Environmental Earth Sciences* 75: 23.
- [20] Liu, F.; Zhao, Z.; Yang, L.; Ma, Y.; Li, B.; Gong, L.; Liu, H. Phreatic Water Quality Assessment and Associated Hydrogeochemical Processes in an Irrigated Region Along the Upper Yellow River, Northwestern China. *Water* 2020, 12, 463. [CrossRef]
- [21] Bhardwaj, K.S.P.R. Water quality index and fractal dimension analysis of water parameters. *J. Environ. Sci. Technol.* 2013, 10, 151–164.
- [22] Rabeiy, R.E. Assessment and modeling of groundwater quality using WQI and GIS in Upper Egypt area. *Environ. Sci. Pollut. Res.* 2018, 25, 30808–30817. [CrossRef]
- [23] Gnanachandrasamy, G.; Dushiyanthan, C.; Jeyavel Rajakumar, T.; Zhou, Y. Assessment of hydrogeochemical characteristics of groundwater in the lower Vellar river basin: Using Geographical Information System (GIS) and Water Quality Index (WQI). *Environ. Dev. Sustain.* 2020, 22, 759–789. [CrossRef]
- [24] Area, S.; Maskooni, E. K.; Naseri-rad, M.; Berndtsson, R.; Nakagawa, K. Use of Heavy Metal Content and Modified Water Quality Index to Assess Groundwater Quality in A. 2020.
- [25] Amiri, Vahab, Mohsen Rezaei, and Nasim Sohrabi. "Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran." *Environmental Earth Sciences* 72 (2014): 3479-3490.
- [26] Adimalla, Narsimha. "Application of the entropy weighted water quality index (EWQI) and the pollution index of groundwater (PIG) to assess groundwater quality for drinking purposes: a case study in a rural area of Telangana State, India." *Archives of environmental contamination and toxicology* 80.1 (2021): 31-40.
- [27] Unigwe, Chinanu O., and Johnbosco C. Egbueri. "Drinking water quality assessment based on statistical analysis and three water quality indices (MWQI, IWQI and EWQI): a case study." *Environment, Development and Sustainability* 25.1 (2023): 686-707.
- [28] Yang, Yongqiang, et al. "Groundwater quality assessment using EWQI with updated water quality classification criteria: a case study in and around Zhouzhi County, Guanzhong Basin (China)." *Exposure and Health* 15.4 (2023): 825-840.
- [29] Amiri, V.; Rezaei, M.; Sohrabi, N. Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environ. Earth Sci.* 2014, 72, 3479–3490. [CrossRef]
- [30] Li, H.; Wang, W.; Fan, L.; Li, Q.; Chen, X. A novel hybrid MCDM model for machine tool selection using fuzzy DEMATEL, entropy weighting and later defuzzification VIKOR. *Appl. Soft Comput.* 2020, 91, 1–14. [CrossRef]
- [31] WHO. Guidelines for Drinking-Water Quality, 4th ed. Available online: http://www.who.int/water_sanitation_health/publications/dwq_guidelines/en/# (accessed on 30 March 2016).