

Water Quality Index (WQI) of Nabaa El Tasseh Spring, Nabatiyeh, Lebanon

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Abstract

Despite the abundant water resources available in Lebanon, it still faces a water shortage. Pollution is one of the main stresses on Lebanon's water resources. This study was carried out in Nabaa El Tasseh Spring, the main water supply source in the Nabatiyeh Region. The aim of this study is to assess water quality of the spring of Nabaa El Tasseh during winter and spring seasons to determine the Water Quality Index (WQI). At the Environmental Laboratory of Lebanese University, Faculty of Agronomy, water was tested physiochemical parameters including temperature, hydrogen potential (pH), electrical conductivity (EC), total dissolved solids (TDS), anions (NO_3^- , Cl^- , SO_4^{2-}), and cations (Mg^{2+} , Ca^{2+} , Na^+ , K^+ and Fe^{2+}). The majority of the physical and chemical parameters under investigation fell below the international and Lebanese norms, including WHO recommendations. Additionally, fecal Streptococcus, total coliforms, and fecal coliforms were determined using microbiological testing. Due to its proximity to agricultural activities, the Nabaa El Tasseh Spring water was contaminated by total coliforms. Fecal Coliforms and Fecal Streptococcus, on the other hand, are a sign of animal or human sewage contamination in groundwater. WQI was calculated using the Weighted Arithmetic Index approach. This study has shown that water quality in Nabaa El Tasseh Spring was not acceptable for consumption without treatment in February 2019 with WQI values equal to 88.608, but it became 31.51 acceptable during April and 18.22 in December 2022. An index is a useful tool for conveying water quality information to the public and legislative decision-makers. Although the WQI is

excellent in the spring, there is microbiological pollution, thus water treatment is required. The results indicated that Principal Component Analysis (PCA) could clearly explain the pollution trends in the spring over several months. The study's findings indicate that before the water of Nabaa El Tasseh Spring can be used for drinking or residential purposes, it must first undergo extensive treatment.

Keywords

Water Resources, Chemical Parameters, Statistical Analysis, Water Quality, Treatment

1. Introduction

Water quality, an essential element affecting plants, animals, and human well-being, can be altered by natural and human-related factors. These factors include unregulated industrial wastes, climate change, and erosion, leading to changes in the quantity and quality of surface water and groundwater. Evaluating the insufficiency of water resources at a local level requires considering some variations in freshwater levels and quality, including snow, surface water, and groundwater (Abou Abbass et al., 2024; Barbieri and Watts, 2021; Pearson and Aitchison-Earl, 2022).

Groundwater sources are crucial components of the global water supply system. They provide a significant portion of the world's freshwater, particularly in areas where surface water is scarce or unreliable. Springs are one of the most common types of groundwater sources naturally rises to the surface, usually as a result of geological structures pushing the water out. Springs are natural flows of groundwater from rocks or sediment and their characteristics vary depending on the type rock. Springs are divided into multiple categories, primarily based on geography, aquifer type, discharge, flow direction, chemical properties, and temperature. Thus, Lebanon has five main types of springs. These are: contact springs, karstic springs, fault springs, artesian springs and thermal springs (Shaban, 2020). As a result, groundwater travels erratically through these underground passages, complicating the delineation of the flow patterns in karstic springs. This type of spring is predominantly found in Lebanon, where an estimated 50% to 60% of the springs are karstic (Shaban, 2020). This is particularly significant given that a large part of Lebanon's geological makeup consists of carbonate rocks (Shaban, 2017). Therefore, unlike other spring types where groundwater seeps as diffusion flow among porous and permeable rocks, the flow of karstic springs, or pipe flow, exhibits rapid changes in the opposite direction (Shaban, 2020).

Growing urbanization, industrialization, and population growth all contribute to the presence of contaminants, which in turn degrades freshwater quality and puts the ecosystem at severe risk. These compounds can persist unbroken in any environment due to their complicated structure, which makes them challenging to neutralize. In freshwater ecosystems, the majority of contaminants build up in

minute concentrations in the bottom sediments. Aquatic environments and related biota are permanently impacted by the presence of these pollutants (Mush-taq et al., 2020). Notably, 80% of infections have been related to poor sanitation and water quality, and in underdeveloped nations, waterborne illnesses claim the lives of almost 1.8 million people each year (Batterman et al., 2009). Moreover, pollution is widespread across Lebanon, where pristine water sources are scarce. Rivers suffer from contamination, and many aquifers exhibit elevated pollution levels (Nehme & Haydar, 2018; Nehme et al., 2019; Nehme et al., 2020; Haydar et al., 2022).

Underdeveloped in the Mediterranean region, Lebanon faces a number of difficulties, including poor infrastructure, a dire economic crisis, political confusion, and widespread pollution. Lebanon is thought to be relatively water rich when compared to other nations in the Middle East and North Africa (MENA) area (Daou et al., 2018). Unfortunately, Lebanon's water resources have been mismanaged for a long time, in part because the nation lacks a national policy for integrated water resources management, which keeps Lebanon from taking full advantage of this priceless resource (Lebanon Crisis 2017-2020 Response Plan, 2021). In addition, there is a growing risk of pollution to Lebanon's water supply because of three main factors: 1) population growth, which includes the influx of approximately 1.5 million refugees (or one for every four natives) since 2011; 2) improper management of solid waste and wastewater; and 3) a lack of monitoring and surveillance programs (Jaafar et al., 2020; Kassem and Jaafar, 2020).

As Lebanon faces environmental challenges such as water scarcity, climate change and pollution, Nabaa El Tasseh Spring represents a crucial natural resource that needs protection and conservation efforts especially for Nabatieh region. This spring has been a vital water source for centuries, providing water for agriculture, drinking, and sustaining communities in the region. Researching the quality of water, especially in places like Nabaa el Tasseh Spring in Lebanon, is crucial for several reasons: The quality of water directly impacts public health. The study can identify potential contaminants or pollutants in the water that may pose health risks to people who use it for drinking or agriculture. The research can reveal sources of pollution or degradation affecting the spring and its surrounding ecosystem.

Depending on the informative objectives, sample type, and sampling area size, there are several approaches to assess water quality. Using the appropriate indices is one of the best ways to disseminate information about trends in water quality. The WQI is a widely used tool for describing water quality, based on physical, chemical, and biological factors. It involves parameter selection, data transformation, weighting, and sub-index value aggregation. To expand, WQIs should be linked to scientific breakthroughs and sophisticated statistical methods.

An effective approach to educating the public about the WQI, involves consolidating data from multiple water quality parameters into a single mathematical formula. This formula then assigns a numerical rating to each parameter. The

primary purpose of the WQI is to simplify complex water quality data into easily understandable information for the general public.

This study aimed to evaluate the Nabaa El Tasseh Spring water quality for potable abstractions by shedding light on a novel approach established for the water quality index. The development of the Nabaa El Tasseh Spring water quality index involved the use of unique data and techniques, such as the availability of data on water quality, statistical correlations, and criteria for water quality. The findings could provide a foundation for formulating future policies and conservation efforts to rehabilitate the ecological health of Nabaa El Tasseh Spring. Consequently, a comprehensive analysis of Nabaa El Tasseh Spring water quality is crucial. Research outcomes can raise awareness among local communities about the importance of water quality and encourage participation in conservation efforts. It promotes community involvement in monitoring and safeguarding their water resources. Continuous research ensures that water quality monitoring is ongoing and adaptive to changes over time. It supports efforts to maintain the sustainability of water resources for future generations. To our knowledge, this is the first study that assessed water quality of Nabaa El Tasseh Spring in Lebanon as none has been published previously.

2. Materials and Methods

2.1. Study Area

Lebanon, covering a land area of 10,452 km², faces various management and technological challenges in its water sector. With its renewable water resources of roughly 900 m³/hab/year, Lebanon is able to stay just below the 1000 m³/hab/year water deficit criterion. At the moment, Lebanon is likewise experiencing unfavorable environmental conditions that is causing serious harm to its aquatic ecosystems (Nehme et al., 2021a). El-Fadel et al. (2010) pointed out, significant socio-economic issues exacerbate the depletion of water supplies, that issues such as population growth, economic development, and inequalities in resource distribution can all contribute to increasing pressure on water supplies. Lebanon is experiencing a growing water shortage as a result of ineffective management, quick deforestation caused by quarries and wildfires. Trees play a critical role in maintaining the hydrological cycle by regulating rainfall and reducing runoff. When forests are removed, the natural water retention capacity of the soil decreases, leading to reduced groundwater recharge and increased erosion, which in turn impacts water availability (Abou Abbass et al., 2024).

Nabatiyeh Governorate with an area of 1052 km² and covered about 10% of Lebanon's total area. It includes four districts: Nabatiyeh, Bint-Jbeil, Hasbaya and Marjeyoun. Nabatiyeh district, where about 89,000 population is bounded by Jezzine and Mount Rihan from the north and by the Litani River from the south and east (Nehme et al., 2021b). One of the most known springs in this region is Nabaa El Tasseh Spring.

The Nabaa El Tasseh Spring (Figure 1), which is a karstic spring is situated in

the uppermost portion of the Zahrani River, approximately one kilometer southwest of the village Louaize and one kilometer northeast of the village Jarjouaa. It is characterized by the largest discharge of groundwater from a single conduit, typically taking the form of a cave-like structure. The flow of groundwater in karstic springs follows sub-surface conduits and galleries, often spanning several kilometers. In contrast to other types of springs karstic springs (referred to as pipe flow) exhibit abrupt changes (Shaban, 2020).



Figure 1. Nabaa El Tasseh Spring.

A primary catchment consisting of two emergences griffon sources conveys water through a canal to a reservoir where three additional emergences are also gathered. Four canals for supplying water are submerged beneath the water's surface and possess the following characteristics: The first has 20" pipe, reduced to 16" after 3 m, to supply the Nabatieh Region. The second has 16" pipe reduced to 10" for supply to the Iklim el Toufah Region. The third has 7" pipe to supply Arab Salim Reservoir, whereas the fourth has 16" conduit that is currently out of service and was dedicated to supplying the Jezzine sector (BTD, 2019).

Outside the catchment there are four boreholes that are located on the same side of the valley as the catchment. They have been used to supply the villages Mlikh and Jarjoua'a located upstream from the spring. The characteristics of these boreholes are as follows: The first Borehole has depth: 15 m; borehole discharge rate 15 l/s; water level drop to 6 m. The second Borehole has depth: 15 m; borehole discharge rate 13 l/s; water level drop to 6 m. The third Borehole has depth: 30 m; borehole discharge rate 13 l/s; water level drop to 10 m, whereas the fourth Borehole has depth: 40 m; borehole discharge rate 12 l/s; water level drop to 10 m (BTD, 2019).

Flooding causes excess water discharge into the river, determining total flow. Gauging sections are established downstream of the catchment building to measure water discharge. Applications like flood forecasting, water resource management, environmental monitoring, and infrastructure design rely on discharge measurements. When the river's primary course is active, a measuring section is established and the resulting flow is subtracted from the overall river flow. Measurements were taken at intervals of 0.2 hours, 0.6 hours, and 0.8 hours, these intervals to understand flow variations over time. This can help in identifying

trends, such as changes in discharge due to flooding (BTD, 2019). Flow measurement can be improved by thorough preparation, execution, and constant monitoring. Researchers ensure accurate measurements by choosing the right instrument, ensuring proper installation and maintenance, and considering environmental factors. In high flooding, advanced techniques like probe measurements and chemical gauging are used to measure velocity profiles. Even under difficult circumstances, the data from these probes can be used to determine flow rates. A water level curve is then established by conducting regular flow measurements and continuously recording the water level every six hours. Throughout the measurement campaigns, the operational status and flow rates of the boreholes were recorded for future reference (Shaban, 2003; Shaban et al., 2004; BTD, 2019).

2.2. Water Sampling

Water sample was collected from the main source of Nabaa El Tasseh Spring shown in **Figure 2** to determine the pollution levels, providing 2000 ml of water. The sample was duplicated to ensure accuracy from the site. The samples were stored in polyethylene bottles and collected manually from Nabaa El Tasseh Spring. A sterile cup was utilized for the microbiological tests. No detergents were used on the bottles before or for the chemical characterization, the samples were kept in 2 L polyethylene plastic bottles, and after sampling to maintain purity. To prepare the bottle for sampling, it was treated with 2% nitric acid to achieve an acidified condition ($\text{pH} < 2$), water samples that require the addition of modest volumes of acid to stabilize dissolved components as a typical additional treatment, and were kept in portable coolers. For the microbiological analysis, 500 ml of water was gathered in borosilicate glass bottles, to avoid contamination. The sampling occurred over two seasons: winter (February 2019), spring (April 2022) and winter (December 2022) to make a comparison in different season. Every time, a precise water sample was taken from the same location to guarantee that it was representative of the entire spring. Accessibility, variability in flow rate, and closeness to possible contaminants are factors to take into account.

2.3. Methodology

The comprehensive methodological flowchart that illustrates the several stages in the assessment of water quality of Nabaa El Tasseh is shown in **Figure 3**. The flow chart displays the methodology for water quality, water evaluation, and statistical analysis as well as the results.

2.3.1. Physicochemical and Microbiological Tests

The parameters studied included T, pH, EC, TDS, salinity, turbidity, total hardness, bicarbonate, and concentrations of chlorides, sulfates, nitrates, calcium, magnesium, sodium, potassium, ammonium, iron, nitrites, phosphates, as well as total Coliforms, Fecal Coliforms, Fecal Streptococcus, and *Pseudomonas Aeruginosa*. The temperature, pH, EC, and turbidity parameters were examined in the laboratory, using a thermometer, a digital pH meter, an EC meter, and a turbidity

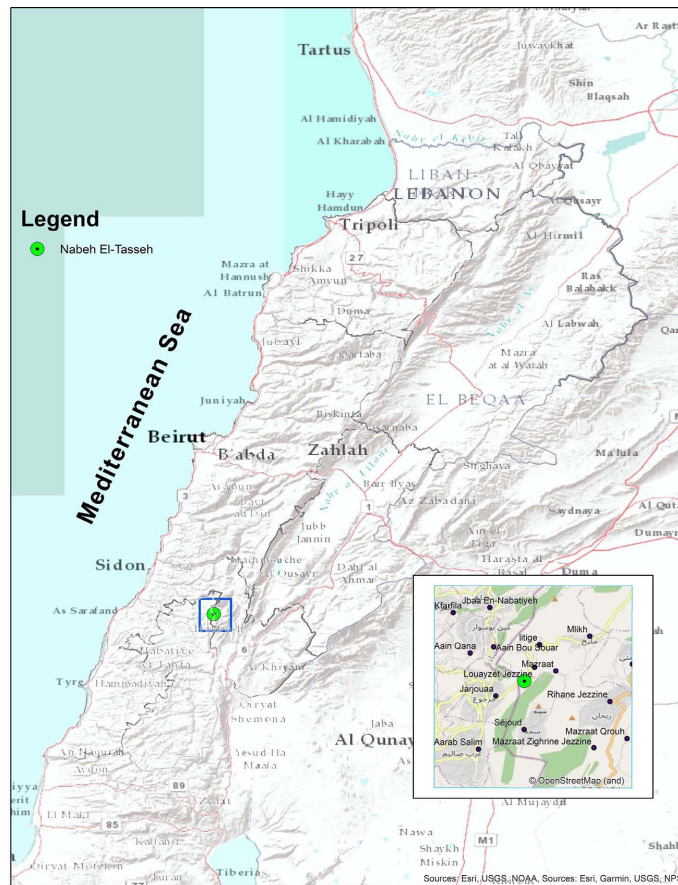


Figure 2. Location map of the water sampling sites (Source: CNRS, 2024).

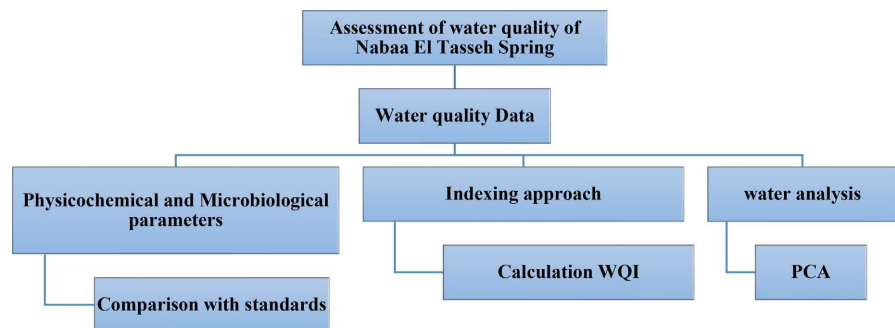


Figure 3. Methodology flow chart of this study.

meter according to the standard procedures. The additional physicochemical tests were performed with a Jenway UV 6100 spectrophotometer, following standard methods. Microbial counts of total and Fecal Coliforms, Fecal Streptococcus, and Pseudomonas Aeruginosa were measured by the membrane filtration technique (Abou Abbass et al., 2023), 100 ml of water is filtered through a membrane that retains bacteria with a pore size of 0.45 mm. Membrane is then put on a selective medium that stops other bacteria from growing and encourages the growth of specific bacteria at a determined temperature and time of incubation shown in Table 1 for each microorganism. Colonies are counted after incubation.

Table 1. Show the average temperature of incubation and time of incubation for each microorganism.

| Microorganisms | Agar | Temperature of incubation | Time of incubation (per hours) |
|-------------------------------|---------------------|---------------------------|--------------------------------|
| <i>Total Coliforms</i> | Mac Conkey | 37°C | 24 |
| <i>Fecal Coliforms</i> | Mac Conkey | 45°C | 45 to 48 |
| <i>Fecal Streptococcus</i> | M-Enterococcus agar | 37°C | 24 |
| <i>Pseudomonas aeruginosa</i> | Pseudomonas CN agar | 37°C | 48 |

Data were compiled and organized in Microsoft Excel for analysis. Data compiled in Microsoft excel was analyzed by using the statistical program, R program. R is a language and environment for visual design and statistical computing. R's simplicity of use in producing publication-quality charts, complete with mathematical symbols and formulas where necessary, is one of its many advantages. R is a GNU (GNU stands for Gnu's Not Unix). Although the user still has complete flexibility, consideration has been given to the defaults for the small graphic design decisions (Abou Abbass et al., 2023). The water quality results for all parameters mentioned before were then evaluated against both Lebanese and international standards, including WHO guidelines (WHO, 2018). A risk analysis was also carried out based on the range found in the microbiological assessments.

2.3.2. Water Quality Index

1) History of water quality concept

The WQI, which condenses a large amount of data into a single number between 0 and 100, is one of the most efficient methods to characterize the quality of water. It has been used to describe the acceptability of water sources for human use.

Numerous water control organizations employed the water quality indices in the final decade of the 20th century to evaluate the quality of the water (Paun et al., 2016). To evaluate the quality of the water in rivers, the water quality indices were introduced in the 1960s (Hamlat et al., 2017).

In an effort to lessen water pollution, Horton (1965) developed a system for ranking the quality of water using index numbers. Ten variables, including sewage treatment, dissolved oxygen, pH, coliforms, electroconductivity, carbon chloroform extract, alkalinity, chloride, temperature, and evident pollution, are chosen for the system, and a scale value and relative weighting factor are assigned for each.

Brown et al. (1970) developed a new water quality index (WQI) using nine variables, based on arithmetic weighting and arithmetic mean, to assess water quality. The final weight of each variable is then obtained by dividing each temporary weight by the total of all the temporary weights (Kachroud et al., 2019; Shah &

Joshi, 2017). According to Brown et al. (1970), a geometric aggregation is preferable than an arithmetic one for aggregating variables because it is more sensitive when a variable deviate from the norm. This work was funded by the National Sanitation Foundation (NSF) (Kachroud et al., 2019; Shah & Joshi, 2017).

Steinhart et al. (1982) created an environmental quality index (EQI) for the Great Lakes ecosystem, assessing biological, physical, chemical, and toxic factors. The final score ranged from 0 (poor quality) to 100 (best quality). Dinius (1987) developed a Water Quality Index based on multiplicative aggregation, which was introduced to Canada in the mid-90s. The Watershed Enhancement Program (WEPWQI) in Dayton Ohio in 1996 included water quality variables, flow measurements, and water clarity, incorporating pesticide and PHA contamination.

Liou et al. (2004) developed a Water Quality Index in Taiwan region, downsizing thirteen variables to nine based on environmental and health significance. Said et al. (2004) implemented a new WQI in Florida, focusing on logarithmic aggregation, reducing the number of variables and adjusting the aggregation method. The ideal WQI ranged from 0 to 3, with the ideal value being 3. Both studies highlight the importance of reducing ambiguous values in water quality assessments.

The Malaysian Water Quality Index (MWQI) was developed in 2007 and includes six variables: DO, BOD, COD, Ammonia Nitrogen, suspended solids, and pH. The MWQI uses a curve to transform actual values into non-dimensional sub-indices, with weighting determined by experts' opinions. The Hanh and Almeida indices were established in 2010 and 2012 on surface water in Vietnam and Argentina, respectively. The West Java Water Quality Index (WJWQI) was developed in 2017 to reduce uncertainty in other water quality indices, focusing on thirteen crucial variables in the Java Sea.

The weighted arithmetic water quality index (WAWQI) is used to calculate the treated water quality index, in other terms, this method classifies the water quality according to the degree of purity by using the most commonly measured water quality variables (Kizar, 2018; Paun et al., 2016). This procedure has been widely used by scientists (Singh et al., 2013). The goal of this study was to determine the quality of Nabaa El Tasseh water Spring and its appropriateness for drinking, using the WAWQI including thirteen parameters: pH, electrical conductivity, TDS, Turbidity, Chloride, Sulfates, Nitrates, Calcium, Magnesium, Sodium, Potassium, Nitrites and Phosphates.

2) WQI calculation

Although the WQI is a useful tool for assessing water quality, these limitations must be addressed through standardizing data collection, adapting to local conditions, choosing parameters carefully, and communicating effectively. The validity and usefulness of WQI results are maintained through ongoing study and methodological upgrades. The first step is collecting of data for the relevant physico-chemical water quality parameters. This data should include the different parameters that are relevant to the body of water being studied. As second step it can be calculation of the proportionality constant "K". This constant is used to give

weightage to the individual factors that are used to calculate the WQI. The equation is showing the calculation of K is:

$$k = \left[\frac{1}{\sum_1^n \frac{1}{S_n}} \right] \quad (1)$$

where S_n = standard permissible value for the n^{th} parameter. Calculation of the quality rating for each parameter will be the third step. The quality rating for a parameter is a measure of how close the measured value is to the ideal value. The formula for calculating the quality rating for the n^{th} parameter is:

$$q_n = \left[\frac{(V_n - V_{id})}{(S_n - V_{id})} \right] \times 100 \quad (2).$$

where, V_n = Estimated value of n^{th} water quality parameter at a given sample location.

V_{id} = Ideal value for n^{th} parameter in pure water. (V_{id} for pH = 7 and 0 for all other parameters).

S_n = Standard permissible value of n^{th} water quality parameter.

Calculation of the unit weight for each parameter will be the fourth step. The unit weight for a parameter is a measure of its importance to the overall water quality.

The formula for calculating the unit weight for the n^{th} parameter is:

$$W_n = \frac{K}{S_n} \quad (3)$$

The last step will be calculation of the WQI. The WAWQI is calculated by averaging the weighted quality ratings for all of the parameters.

The formula for calculating the WQI is:

$$\text{WQI} = \frac{\sum q_n W_n}{\sum W_n} \quad (4)$$

Given the small size of Lebanon and the similar climatic conditions for several springs and water resources, this study can be applied to other springs. An important instrument for determining and sharing the state of water quality in different ecosystems is the WQI. As a streamlined composite metric, it reduces complicated water quality data to a single, intelligible value that a broad spectrum of stakeholders, including environmental experts, decision-makers, and the general public, can understand.

2.3.3. WQI and Status

The ranges of WQI, the corresponding status of water quality and their possible use are summarized in **Table 2**.

2.4. Principal Component Analysis (PCA)

PCA was used to do a multivariate analysis of the water samples. The massive

Table 2. WQI and corresponding water quality status (Source: Chatterjee & Raziuddin, 2002).

| S.No | WQI | Status | Possible usages |
|------|-----------|---------------------|-----------------------------------------|
| 1 | 0 - 25 | Excellent | Drinking, Irrigation and Industrial |
| 2 | 25 - 50 | Good | Domestic, Irrigation and Industrial |
| 3 | 51 - 75 | Fair | Irrigation and Industrial |
| 4 | 76 - 100 | Poor | Irrigation |
| 5 | 101 - 150 | Very Poor | Restricted use for Irrigation |
| 6 | Above 150 | Unfair for Drinking | Proper treatment is required before use |

amount of data is also reduced using PCA into some useful, simpler data that can then be used to identify the key variables causing the variation in the water quality attributes. PCA is chosen for water quality studies due to its ability to simplify complex datasets, identify patterns, reduce noise, and enhance data visualization. These advantages make it a powerful tool for analyzing and interpreting water quality data effectively (Wright & Fielding, 2010). Various procedures must be completed before a dataset is subjected to PCA: First, the data must be cleaned to eliminate any missing values or outliers from the dataset. Next, the data must be standardized by scaling each feature to have a mean of 0 and a standard deviation of 1. Lastly, any redundant or irrelevant features must be removed by feature selection. In addition, correlation analysis was used to select the features; verify the linearity PCA infers a linear relationship between the features. PCA was then applied to the pre-processed data when these procedures were finished. Three groups, however, appeared when it is used k-means clustering, indicating a more complex structure in the data.

3. Results and Discussion

3.1. Physicochemical Characteristics

It can be noticed that the different water quality parameters showed seasonal variation over the period of study. All these physicochemical parameters are discussed here.

3.1.1. pH

Springs' water is almost neutral to slightly alkaline, with a narrow pH range of 7.30 to 7.75 as shown in **Figure 4**. In February 2019, the pH value peaked at 7.75, which is below the maximum acceptable level of 8.5. By April 2022, it dropped to its lowest at 7.3, and in December 2022, the pH was recorded at 7.51. These fluctuations may result from seasonal changes in the alkalinity of the surrounding areas around spring sources, as well as recharge from rain full. The pH values obtained fall within the acceptable ranges set by the WHO and Lebanese guidelines, indicating that the water's pH-related quality is satisfactory.

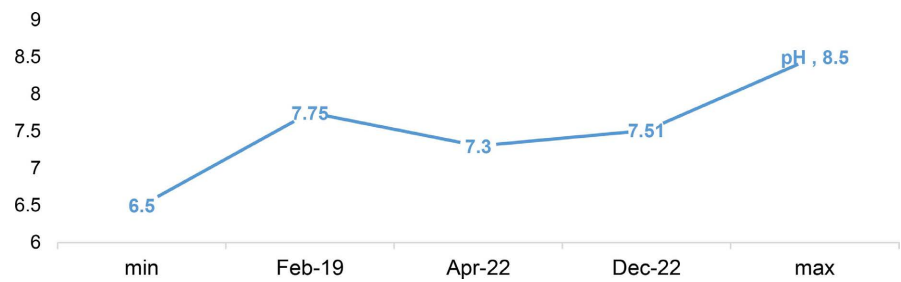


Figure 4. pH value of sampled water in February 2019, April 2022 and December 2022.

3.1.2. Total Dissolve Solids (TDS)

TDS is a parameter that measures all the minerals dissolved in water. According to Lebanese standards, the maximum level of TDS for natural drinking water should be 750 mg/L. The level of TDS in Nabaa El Tasseh Spring ranged from a minimum of 257 mg/L in February 2019 to a maximum of 275 mg/L in April 2022, and 260 mg/L in December 2022, as shown in **Figure 5**. These levels include the necessary minerals required to ensure the water is of good quality and has a taste suitable for human consumption.

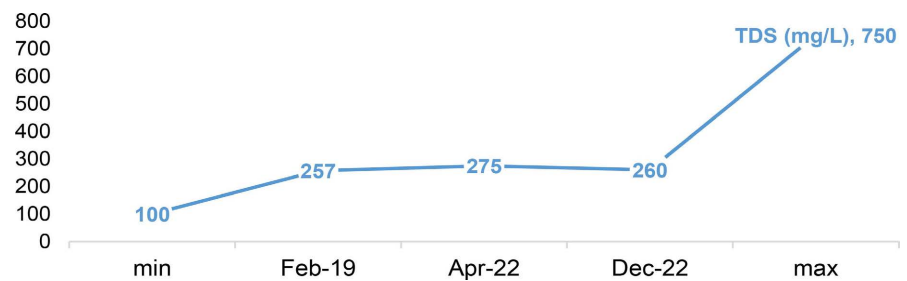


Figure 5. TDS value of sampled water in February 2019, April 2022 and December 2022.

3.1.3. Turbidity

With a mean value of 1.3033 NTU, the obtained turbidity fell between the range of 0.46 and 2.83 NTU as shown in **Figure 6**. February 2019 shows the highest value ever recorded. This suggests that natural colloids such as silt and clays, as well as suspended debris, are contaminating springs. This could be explained by the way surface water interacts with springs, particularly during periods of intense precipitation or spring runoff.

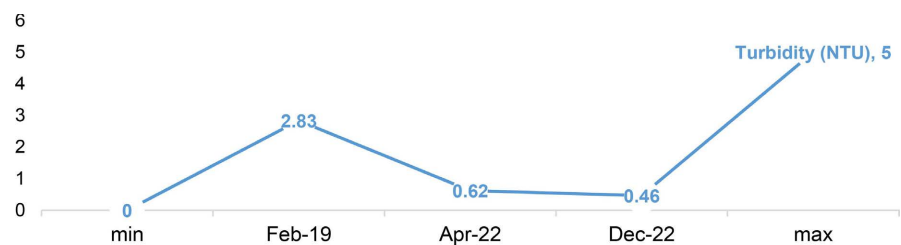


Figure 6. Turbidity value of sampled water in February 2019, April 2022 and December 2022.

3.1.4. Electrical Conductivity

The electrical conductivity values were 434.333 $\mu\text{S}/\text{cm}$ on average, with a range of

402 - 472 $\mu\text{S}/\text{cm}$ as shown in **Figure 7**. These results are explained by variations in the study area's soil composition, agricultural practices, and geological composition and structure. The normal range of EC that has been observed is a sign of the normal concentration of dissolved salts, including potassium and sodium chloride. *Marmontel et al. (2018)* assert that the notable variation in EC values can be attributed to the spatial distribution of spring locations, differing land uses, and the conservation status of vegetation.

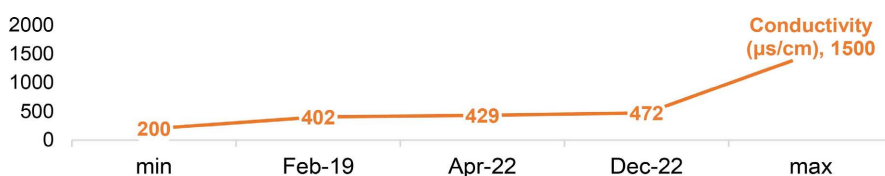


Figure 7. Conductivity value of sampled water in February 2019, April 2022 and December 2022.

3.1.5. Total Hardness

The mean total hardness value for Nabaa El Tasseh Spring was 205.333 mg/L, with measurements ranging from 180 mg/L to 230 mg/L. The highest recorded value of 231 mg/L was observed in winter (February 2019), a value of 205 mg/L was noted in spring (April 2022), and the lowest, 180 mg/L, was measured in December 2022, as shown in **Figure 8**. Water quality was classified according to total hardness, as detailed in **Table 3**. The classification of the obtained values of total hardness for water from the spring ranged from moderately hard to hard.

Table 3. Water quality classification for various ranges of hardness by *Sawyer (1960)*.

| Total hardness in mg/L | Degree of hardness |
|------------------------|--------------------|
| 0 - 75 | Soft |
| 75 - 150 | Moderately hard |
| 150 - 300 | Hard |
| >300 | Very hard |

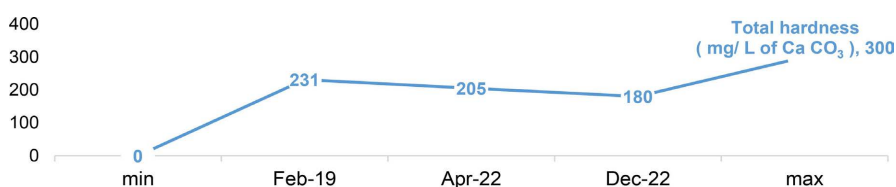


Figure 8. Total hardness value of sampled water in February 2019, April 2022 and December 2022.

3.1.6. Chloride Content

The chloride content in the water ranged from 7.5 mg/L to 25 mg/L, with a mean value of 13.60 mg/L. The maximum value of 25 mg/L was recorded in April 2022, while the minimum value of 7.5 mg/L was recorded in February 2019, as shown in **Figure 9**. It is worth noting that the maximum value did not exceed the permissible limit of 250 mg/L set by Lebanese standards and the WHO.

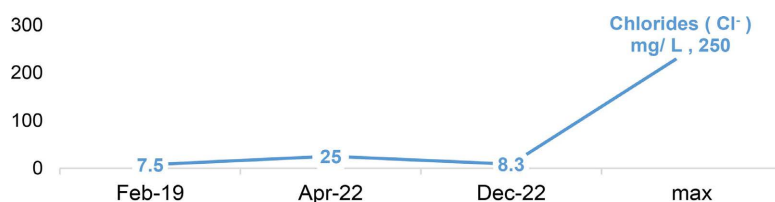


Figure 9. Chloride value of sampled water in February 2019, April 2022 and December 2022.

3.1.7. Nitrite Content

The measured nitrite concentration ranged from 0.009 to 0.049 mg/L, with a mean value of 0.026 mg/L. In the winter of February 2019, the nitrite concentration reached the permissible limit, as shown in **Figure 10**. In contrast, the nitrite levels were 0.009 mg/L in December 2022 and 0.02 mg/L in April 2022. Most nitrogen-containing compounds in natural water, including nitrites, tend to be converted into nitrates. This conversion is likely due to the infiltration of nitrites from sewage and other waste sources. Water contaminated with nitrites is unsuitable for domestic use as it can cause diseases and health problems in both humans and animals.

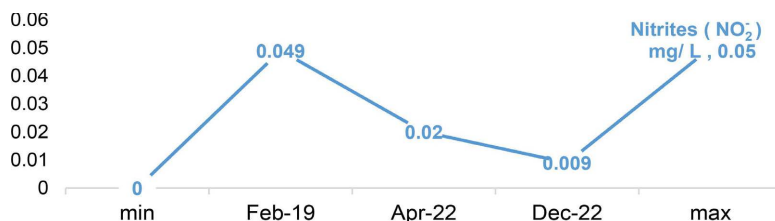


Figure 10. Nitrite value of sampled water in February 2019, April 2022, and December 2022.

3.1.8. Nitrates Content

The measured nitrate concentration ranged from 1.1 to 4.1 mg/L, with a mean value of 2.9666 mg/L. During the winter season, the nitrate concentrations were closely matched, recording 4.1 mg/L in February 2019 and 3.7 mg/L in December 2022, as illustrated in **Figure 11**. Meanwhile, the nitrate concentration dropped to 1.1 mg/L in April 2022, as shown in **Figure 11**. All of these levels fall under the permissible limit of 45 mg/L. In all water samples, the measured concentration of nitrates is much higher than nitrites. This is because nitrate is a more stable ion compared to nitrite.

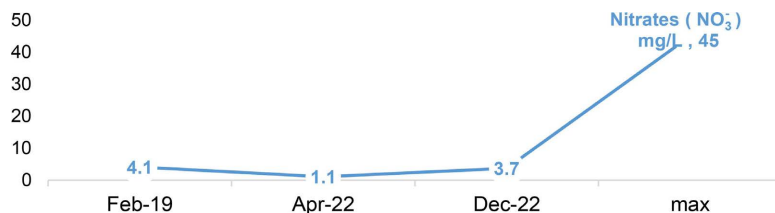


Figure 11. Nitrate value of sampled water in February 2019, April 2022 and December 2022.

3.1.9. Phosphates Content

The measured phosphate concentration ranged from 0.07 to 0.49 mg/L, with a mean value of 0.2333 mg/L.

In February 2019, the phosphate concentration matched the permitted limit (0.5 mg/L), as shown in **Figure 12**. However, it remained below the minimum value in April 2022 and December 2022, measuring 0.07 mg/L and 0.14 mg/L, respectively.

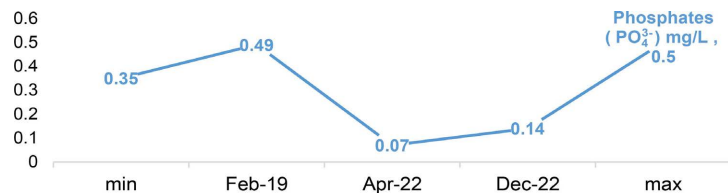


Figure 12. Phosphate value of sampled water in February 2019, April 2022 and December 2022.

3.1.10. Cations Content

The concentrations of the cations calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), potassium (K⁺), and iron (Fe²⁺) all surpass the permissible limits set by both the WHO and Lebanese standards, as shown in **Figures 13-17**. Thus, the spring and well of Naba El Tasseh are deemed uncontaminated and suitable for use in domestic, human, and agricultural sectors.

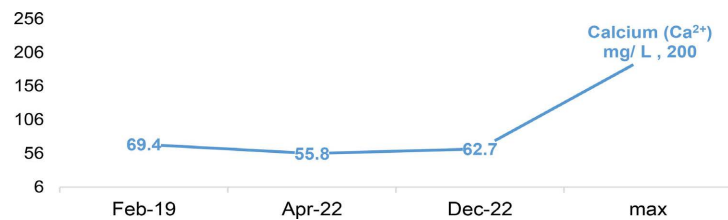


Figure 13. Calcium value of sampled water in February 2019, April 2022 and December 2022.

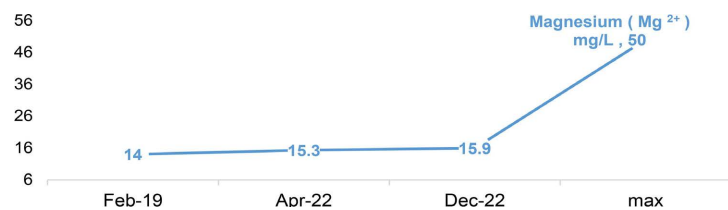


Figure 14. Magnesium value of sampled water in February 2019, April 2022 and December 2022.

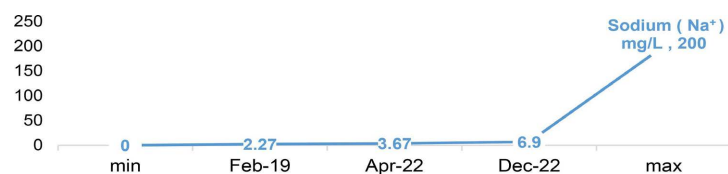


Figure 15. Sodium value of sampled water in February 2019, April 2022 and December 2022.

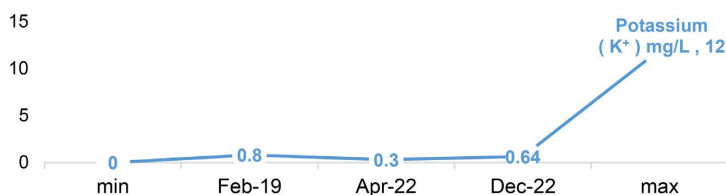


Figure 16. Potassium value of sampled water in February 2019, April 2022 and December 2022.

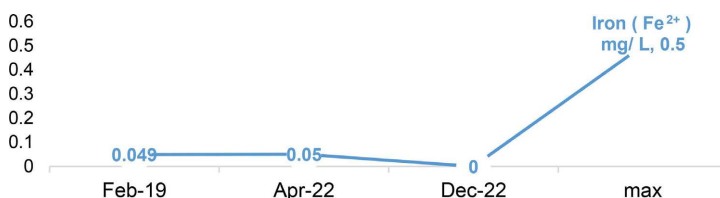


Figure 17. Iron value of sampled water in February 2019, April 2022 and December 2022.

3.2. Microbiological Characteristics

Table 4 presents the obtained analytical findings of the microbiological parameters, summarizing the water quality characteristics of the spring in this study. The table also outlines the corresponding permissible limits according to both Lebanese standards and WHO standards. The total coliform counts were measured at 38 CFU/100ml in February 2019, 110 CFU/100ml in April 2022, and 20 CFU/100ml in December 2022. The highest total coliform count was observed in April, whereas lower counts were recorded in other months. Significantly, *Pseudomonas Aeruginosa* was not detected. While fecal coliforms were measured at 20 CFU/250ml during the spring season and 1 CFU/250ml in December at the Nabaa El Tasseh Spring.

Table 4. Microbiological parameters for Nabaa El Tasseh Spring during Feb 2019, April 2022 and December 2022.

| Microbiological Parameter | February 2019 | April 2022 | December 2022 |
|--------------------------------------------------|----------------|----------------|----------------|
| Total Coliforms (UFC/100ml) | 38 | 110 | 20 |
| Fecal Coliforms (UFC/250ml) | 10 | 20 | 1 |
| Fecal Streptococcus (UFC/250ml) | 3 | 8 | 1 |
| <i>Pseudomonas Aeruginosa</i> (UFC/250ml) | 0 | 0 | 0 |
| Compliment or not with Lebanese Standards | Not Compliment | Not Compliment | Not Compliment |

The sampled water showed microbial contamination with total coliforms, fecal coliforms, and fecal *Streptococcus* in both winter and spring seasons as shown in **Figure 18**. Nabaa el Tasseh Spring shows a high number of total coliform bacteria

in comparison to other microbiological parameters. The potential sources of total coliform contamination such as nearby anthropogenic activities, it is a sign of recent fecal infection. This renders the water to be incompatible for drinking and potentially problematic for handwashing (Verbyla et al., 2019). The water's quality can change when these organisms are present. A possible health risk for those exposed to this spring is indicated by the presence of fecal coliform bacteria.

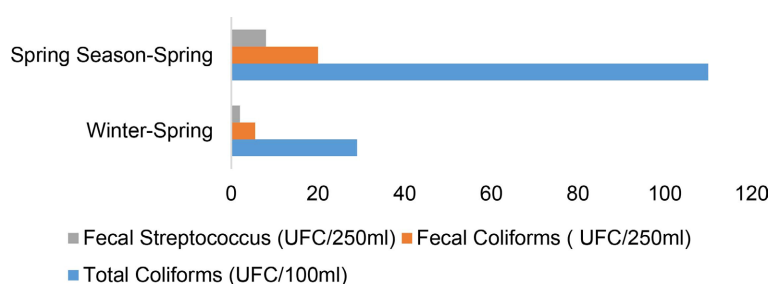


Figure 18. Microbiological parameters of sampled water in winter and spring 2022.

3.3. Water Quality Index (WQI)

WQI facilitates a comprehensive analysis of water quality in various aquatic systems. It also assesses the capacity of the aquatic system to host aquatic life while helping to identify potential threats associated with the diverse uses of water within the river system (Mamun & An, 2021; Shah & Joshi, 2017).

In the present study, thirteen water quality parameters, namely, pH, electrical conductivity, TDS, Turbidity, Chloride, Sulfates, Nitrates, Calcium, Magnesium, Sodium, Potassium, Nitrites and Phosphates were considered for computing WQI and the unit weight.

Table 5 summarizes the result obtained during the analysis of the physicochemical parameters of the water sampled at the study site. After calculating the overall WQI using the physicochemical parameter results and comparing them to the Lebanese standard values, the WQI values for the Nabaa El Tasseh Spring were determined to be 88.608 in February 2019, 31.51 in April 2022, and 18.22 in December 2022, as depicted in **Figure 19**.

Table 5. Calculation of the relative weight (W_n), quality rating (q_n) standard of the studied physicochemical parameters during February 2019.

| Parameters | S_n | Ideal Value* | Value February 2019 | Value April 2022 | Value December 2022 |
|------------------------------------------|-------|--------------|---------------------|------------------|---------------------|
| pH | 8.5 | 7 | 7.75 | 7.3 | 7.51 |
| Conductivity ($\mu\text{s}/\text{cm}$) | 1500 | 0 | 402 | 429 | 472 |
| TDS (mg/L) | 750 | 0 | 257 | 275 | 260 |
| Turbidity (NTU) | 5 | 0 | 2.83 | 0.62 | 0.46 |
| Chlorides [Cl^-] (mg/L) | 250 | 0 | 7.5 | 25 | 8.3 |
| Sulfates [SO_4^{2-}] (mg/L) | 250 | 0 | 5 | 3 | 8.3 |

Continued

| | | | | | |
|----------------------------------------------------|------|---|---------------|---------------|---------------|
| Nitrates [NO ₃ ⁻] (mg/L) | 45 | 0 | 4.1 | 1.1 | 3.7 |
| Calcium [Ca ²⁺] (mg/L) | 200 | 0 | 69.4 | 55.8 | 62.7 |
| Magnesium [Mg ²⁺] (mg/L) | 50 | 0 | 14 | 15.3 | 15.9 |
| Sodium [Na ⁺] (mg/L) | 200 | 0 | 2.27 | 3.67 | 6.9 |
| Potassium [K ⁺] (mg/L) | 12 | 0 | 0.8 | 0.3 | 0.64 |
| Nitrites [NO ₂ ⁻] (mg/L) | 0.05 | 0 | 0.049 | 0.02 | 0.009 |
| Phosphates [PO ₄ ³⁻] (mg/L) | 0.5 | 0 | 0.49 | 0.07 | 0.14 |
| $\sum_1^n q_n W_n$ | | | 99.763 | 99.598 | 99.678 |
| $\sum_1^n W_n$ | | | 1.126 | 3.161 | 5.4696 |
| WQI | | | 88.608 | 31.51 | 18.22 |

*Ideal value for *n*th parameter in pure water, ideal value for pH is equal to 7 and 0 for all other parameters).

As a result, the water quality of the spring in April 2022 was classified as good, making it suitable for drinking, domestic use, and irrigation. In December 2022, the water quality was categorized as excellent, and suitable for drinking, domestic use, and irrigation. However, in February 2019, the water quality was deemed poor, suitable only for irrigation, despite the presence of microbiological contamination. In addition to endangering aquatic life, high concentrations of chemicals like pesticides, heavy metals, or industrial pollution can also be dangerous to people who use the water for drinking, pleasure, or farming. This affects biodiversity and can disrupt the aquatic food chain. Restoring the spring’s water quality will require setting some policies in place, like stopping the discharge of solid waste and reducing the amount of raw domestic sewage that enters the system, meaning that this water needs to be treated before being utilized for any of these purposes.

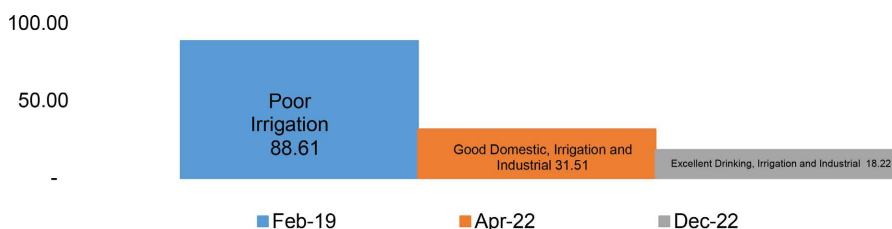


Figure 19. WQI for Nabaa El Tasseh Spring during February 2019, April 2022 and December 2022.

3.4. Correlation Analysis of Water Parameters

The Spearman Correlation was utilized to assess the factors of water quality (Table 6). Total coliforms, fecal coliforms and fecal streptococcus are directly correlated to total dissolved solids, Bicarbonates, chlorides, nitrates, calcium, potassium and iron. This indicates strong effect of water physicochemical parameters and bacteria growth.

Table 6. Correlation between Bacteria and physicochemical parameters.

| Parameters | pH | EC | TDS | NTU | Total Hardness | HCO ₃ ⁻ | Cl ⁻ | SO ₄ ²⁻ | NO ₃ ⁻ | Ca ²⁺ | Mg ²⁺ | Na ⁺ | K ⁺ | Fe ³⁺ | NO ₂ ⁻ | P ₂ O ₅ ³⁻ |
|---------------------|----|-----|-----|-----|----------------|-------------------------------|-----------------|-------------------------------|------------------------------|------------------|------------------|-----------------|----------------|------------------|------------------------------|---------------------------------------------|
| Total Coliforms | S* | Av* | S | Av | W* | VS* | VS | VS | VS | S | W | Av | S | S | W | Av |
| Fecal Coliforms | Av | S | VS | W | Av | VS | VS | VS | VS | S | Av | S | S | S | Av | W |
| Fecal Streptococcus | S | Av | VS | W | Av | VS | VS | VS | VS | S | W | Av | S | S | W | Av |

***VS**: Very Strong; ***S**: Strong; ***Av**: Average; ***W**: Weak.

3.5. Principal Component Analysis

To determine the relationship between the variables and determine how close or far apart these parameters are in water, a correlation analysis of the examined parameters from the Nabaa El Tasseh Spring was conducted (**Figure 20**).

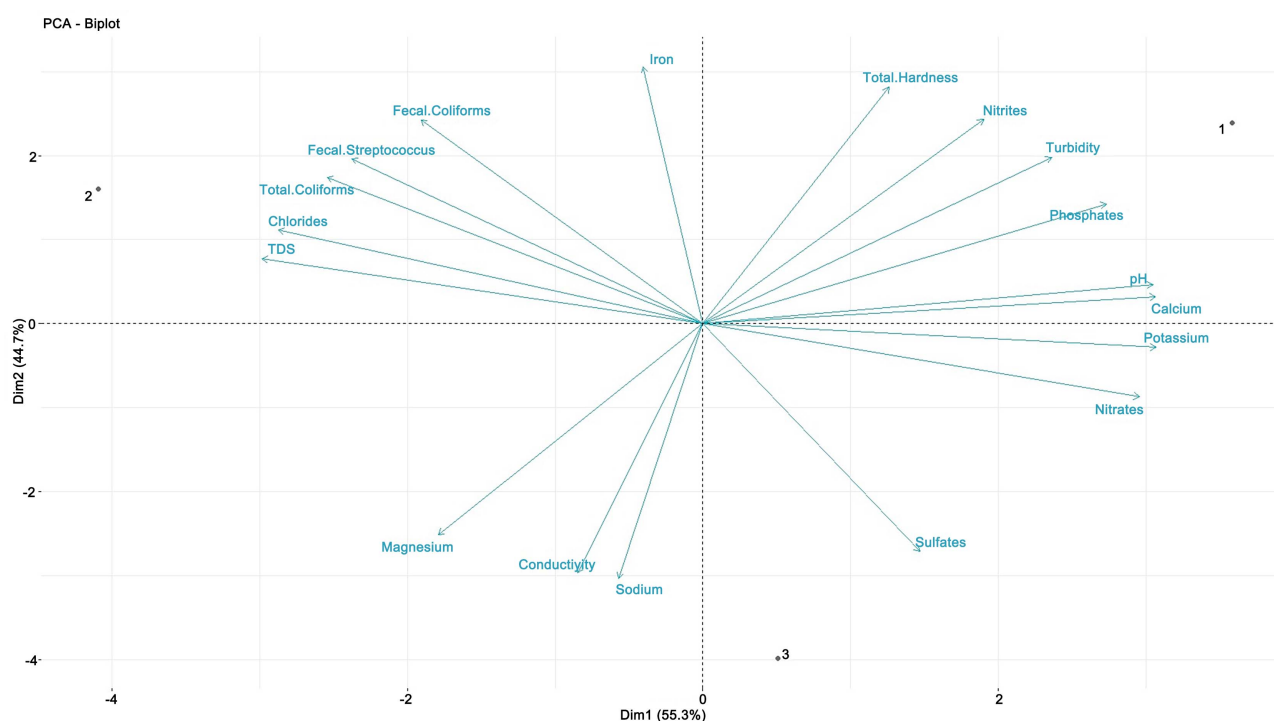


Figure 20. Principal Component Analysis (PCA) biplot of the water quality data.

Out of the overall variance in the data, the first two PCA axes explained 55.3% and 44.7% of the variation, respectively as shown in **Figure 20**. In the biplot of the first season, February 2019, results show that sulfates, nitrates, potassium, calcium, pH, phosphates, turbidity, nitrites and total hardness are dominants, which are defined as natural factors, which is, related to rock-forming minerals and water-rock interactions.

During the second season in April 2022, elevated levels of TDS, chlorides, total coliforms, fecal coliforms, and fecal streptococcus are observed, indicating anthropogenic influences. However, in December 2022, magnesium, conductivity, and sodium are closely clustered in the biplot, suggesting natural influences. These

findings indicate that the factors influencing water quality are both anthropogenic and natural.

4. Conclusions and Recommendations

This study aimed to evaluate the quality and accessibility of water for consumption in the Nabatiyeh region, focusing on the area from Nabaa El Tasseh Spring. The study assessed water quality during winter and spring seasons of 2019 and 2022 through physicochemical analysis (pH, electrical conductivity, salinity, total dissolved solids, magnesium, calcium, sodium, potassium, nitrites, nitrates, chlorides, and sulfates) and microbiological analysis (total coliforms, fecal coliforms, and fecal streptococcus). The results showed that the water quality was not affected by physicochemical parameters, and all these parameters are found to be below the maximum permissible limits of WHO. The examined water samples from the main source were found to be dangerous and unsafe due to the high level of total coliforms, fecal coliforms and fecal streptococcus. The findings of the microbiological examination of water samples taken from the spring have demonstrated that industrial and agricultural waste effluents are a significant cause of pollution to the environment when they are released into bodies of water. Nabaa El Tasseh Spring is vulnerable to pollution, as some of the microbiological water quality parameters exceeded their standard acceptable limits. The public and legislative decision-makers can both benefit from knowing about water quality through the use of an index.

The water quality of the spring as assessed by WQI values, was classified as “Poor” in February 2019, “Good” in April 2022, and “Excellent” in December 2022. This indicates a notable seasonal variation in WQI values. Infections and injuries are possible when swimming, fishing, and other recreational activities are conducted in unsafe settings due to poor water quality. In this study PCA were used to determine the factors controlling quality and sustainability of this spring. The first two PCA axes explained 55.3% and 44.7% of the variance in data. Natural factors dominate in February 2019, with sulfates, nitrates, potassium, calcium, pH, phosphates, turbidity, nitrites, and total hardness. In April 2022, anthropogenic influences were observed, while in December, natural influences were observed. The PCA results showed how the water is classified according to how human activity and natural processes affect it. Based on these findings, PCA was determined to be an appropriate method for evaluating the quality of water. In conclusion, low WQI values indicate generally good water quality, but they should be taken cautiously because they may not fully account for localized or emergent difficulties. Significant risks are indicated by high WQI values, and these include temperature fluctuations, pathogen presence, chemical contamination, nutrient pollution, sedimentation, and sedimentation. All of these have detrimental effects on aquatic ecosystems and human health. Effectively tackling these dangers requires thorough and frequent monitoring.

According to the results of this study, the water of Nabaa El Tasseh spring needs

to be thoroughly treated before it can be utilized for residential or drinking purposes. As is, it is not suitable for human consumption. It is necessary to take action to restore the spring's water quality, such as limiting the amount of raw residential sewage that enters into the system and eliminating the disposal of solid debris. It is strongly advised that unhealthy waste disposal methods be discontinued, contemporary techniques be implemented, and Spring water quality be regularly monitored. The study also shows how helpful WQI is in determining Spring's drinking water quality. Future developments and regional adaptation will be crucial to enhancing WQI's efficacy as a water quality management tool in an increasingly complicated environmental environment.

The baseline data collected for this study may be able to assist environmental managers and policymakers in making important decisions in order to protect all springs, especially Nabaa El Tasseh Spring. As a recommendation, numerous actions can be taken to better manage this socioeconomically significant spring system. Implementing strategies like upgrading infrastructure, enhancing household systems, promoting public awareness, enforcing regulations, providing incentives, and encouraging technological innovation can help limit residential sewage, promote sustainable management, and protect water resources. Implementing a comprehensive strategy for solid debris disposal, including strengthening waste management infrastructure, promoting public education, enforcing regulations, encouraging recycling, and leveraging technology, can protect the environment and improve public health.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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