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"Gheorghe Asachi" Technical University of Iasi, Romania

APPLYING WATER QUALITY INDEX TO EVALUATE GROUNDWATER QUALITY IN TWO PALESTINIAN GOVERNORATES

Issam Al-Khatib[1]*, Fathi Anayah[2], Nidal Mahmoud[1], Hamed Hamayel[3]

[1]*Institute of Environmental and Water Studies, Birzeit University, Birzeit, West Bank, Palestine*
[2]*Faculty of Engineering and Technology, Palestine Technical University - Kadoorie, Tulkarm, West Bank, Palestine*
[3]*Universal Institute of Applied and Health Research, Nablus, West Bank, Palestine*

Abstract

Groundwater is considered the main freshwater source for all uses in Palestine due to rapidly increasing demand and growing sanitation pressure. However, the quantity and quality of groundwater resources are deteriorating due to these anthropogenic pressures. Groundwater contamination can be harmful to human health and the environment. This intensified the need to evaluate and later control the groundwater quality. This research aims to characterize groundwater quality and to examine its compliance to be used as a potable water using the Water Quality Index (WQI) in Bethlehem and Hebron Governorates of Palestine. The 135 groundwater samples used in this research were collected by the Palestinian Water Authority in 15 combinations: 5 groundwater wells during 2020, and 5 groundwater wells during 2021 and 2022. The tested parameters were turbidity, pH, EC, Cl^-, NO_3^-, and hardness. The results show that the WQI values were less than 0.5 (Excellent) in 10 combinations, between 0.5 and 1 (Good) in four combinations, and greater than one (Poor) in only one combination. It also indicates that most measured parameters complied with the World Health Organization requirements of drinking water quality. It is essential to monitor and assess groundwater quality for a proper resources management, particularly in water-scarce countries such as Palestine.

Key words: groundwater, Palestine, water quality, water quality index

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1. Introduction

Groundwater accounts for 20% of the worldwide freshwater, and supplies 91% of the world's drinking water demand (Alsalme et al., 2021). The rapid increase in population, combined with increasing demand for anthropogenic activities, have exacerbated the potential contamination and vulnerability of groundwater resources (Hagan et al., 2022). Human activities such as pollution from agriculture and industry and overexploitation of groundwater have greatly impacted groundwater quantity and quality (Zango et al., 2021). Such situation is expected to degenerate due to climate change.

The climate of Palestine varies from semiarid to arid, and the water resources are scarce (Daghara et al., 2019). Some West Bank communities, particularly those in rural areas, depend on alternative water resources such as rainwater collection in rainwater harvesting cisterns. Water supply is, indeed, among the most pressing issues in the Middle East. Scarcity of water and deterioration of its quality are looming and growing. The Jordan River is the primary source of surface water in the West Bank. Surface water assets in Palestine are scarce, limited, and more importantly under Israeli control (Daghara et al., 2019).

Thus, for the Palestinians, groundwater is the main resource of freshwater in the West Bank (Daghara et al., 2019). It constitutes more than 90% of available resources due to the political and technical limitations (Bridges, 2016; EQA, 2016; PWA, 2012). The main basin system in the West Bank is divided

* Author to whom all correspondence should be addressed: e-mail: ikhatib@birzeit.edu; Phone: +970-22982120; Fax: +970-22982120

into three mountain aquifers; the Western, the Eastern, and the Northeastern (Anayah and Almasri, 2009; Bridges, 2016; PWA, 2012). The Western aquifer is considered the most important aquifer based on its quality and quantity (Anayah and Almasri, 2009; Bridges, 2016). The Israelis control the majority of the mountain aquifers' renewable water, leaving the Palestinians with less than 15% (about 22 million m^3 per year) (Bridges, 2016).

Pollution is seriously endangering the West Bank's available freshwater resources (Mahmoud et al., 2022). The disposal of untreated or inadequately treated wastewater from industrial and domestic sources, agricultural activities, and unsanitary dumpsites sites are the main sources of groundwater pollution throughout the West Bank (Mahmoud et al., 2022). Only about 30% of the Palestinian population in the West Bank are served with sewerage networks, while the other 70% of them use cesspits (Mahmoud et al., 2022). These figures are likely to result in septage infiltration through into soil jeopardizing groundwater quality. Moreover, less than 30% of the collected wastewater in sewerage networks ends up in wastewater treatment plants, and the rest is discharged randomly untreated into agricultural areas and wadis, creating line pollution sources (Mahmoud et al., 2022).

The potential physicochemical parameters of groundwater quality include Potential of Hydrogen (pH), Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Free Carbon Dioxide (CO_2), Alkalinity, Dissolved Oxygen (DO), Hardness, Chloride (Cl^-), Fluoride Ion (F^-), and Sodium Ion (Na^+) (Daghara et al., 2019). Human and animal waste, plant residues, industrial discharges and chemicals, all contribute to Nitrate (NO_3^-) contamination (Aryal et al., 2012). Turbidity in groundwater indicates water pollution caused by both improper disposal of solid and liquid wastes as well as deterioration of organic matter (Daghara et al., 2019). Electrical Conductivity (EC) is a measurement of dissolved salts in water that conduct electric current (Qureshi et al., 2021). Total Hardness is the sum of the concentrations of the magnesium and calcium ions (Daghara et al., 2019). High levels of water Hardness can cause heart disease and form kidney stone (Rao et al., 2022).

Due to its great impact on public health, water quality should be systematically and periodically monitored and assessed (Ekbal and Khan, 2022). Several water quality indices have been used in different parts of the world to assess water quality. These water quality indices include: Canadian Council Ministers of Environment Water Quality Index, Weighted Arithmetic Water Quality Index, Irrigation Water Quality Index, Groundwater Quality Index, Groundwater Screening Values, and Water Quality Index (Abdelaziz et al., 2020; Deekshitha et al., 2020; Ghazaryan et al., 2020; Khatri et al., 2020; Munagala et al., 2020; Shooshtarian et al., 2018; Swartjes and Otte, 2017). Water Quality Index (WQI) has become one of the dominant methods used to evaluate water quality. Due to its ability to transfer complex water quality information to the public, the WQI was routinely utilized by early-related studies (Walsh and Wheeler, 2013). Groundwater quality in Palestine is deteriorating according to previous studies (Al-Khatib and Arafat, 2009; Da'as and Walraevens, 2013). The parameters that are usually tested in groundwater quality are: TDS, turbidity, pH, EC, Cl^-, alkalinity, Fl, and DO (EPA, 2001; Hanjaniamin et al., 2023; Health Canada, 2015; Zafar et al., 2022).

The present study is of significant value due to physical and financial limitations in collecting water quality data in a developing country such as Palestine. Water quality data can be sparse, incomplete, and inconsistent in many cases, making relevant studies more challenging and uncertain. It is essential, however, to check and validate data quality and accessibility from reliable sources. It is worth to mention that physicochemical characteristics of groundwater quality are considered in the present study due to data limitation. Therefore, the present study aims at characterizing groundwater quality and inspecting its compliance to drinking water guidelines using the WQI in Bethlehem and Hebron Governorates of Palestine.

2. Study area

This study focuses only on five groundwater wells in each of the Bethlehem and Hebron Governorates, located in the southern West Bank (Fig. 1). Although Well no. 1 lies within the Jerusalem Governorate, yet it is administratively considered within the authority of Bethlehem. According to the Palestinian Central Bureau of Statistics projections in 2023, Bethlehem's population is 244,704 inhabitants and Hebron's population is 822,435 inhabitants (PCBS, 2021). Bethlehem is known for its religious tourism and some industries like stone quarries, and Hebron is known for its light and heavy manufacturing activities as well as trading and merchandise. In both Governorates, the main freshwater resources are local groundwater wells in addition to water purchased from the Israeli Water Company "Mekerot". There is a deficiency in meeting water demands because of the weak infrastructure in both Governorates. Hence, water supplies are reduced, water losses are increased, and water pollution indicators are rising (ARIJ, 2008, 2009; Hanieh et al., 2014; UN, 2016).

3. Methodology

The data were collected by the Palestinian Water Authority (PWA) technicians, and all parameters were analyzed by the PWA team. The PWA team measured only the following parameters: pH, Turbidity, EC, Cl^-, NO_3^-, and Hardness due to financial limitations and as these parameters reflect the quality of the well groundwater. A total of five groundwater wells in Bethlehem Governorate and five groundwater wells in Hebron Governorate were tested as shown in Table 1.

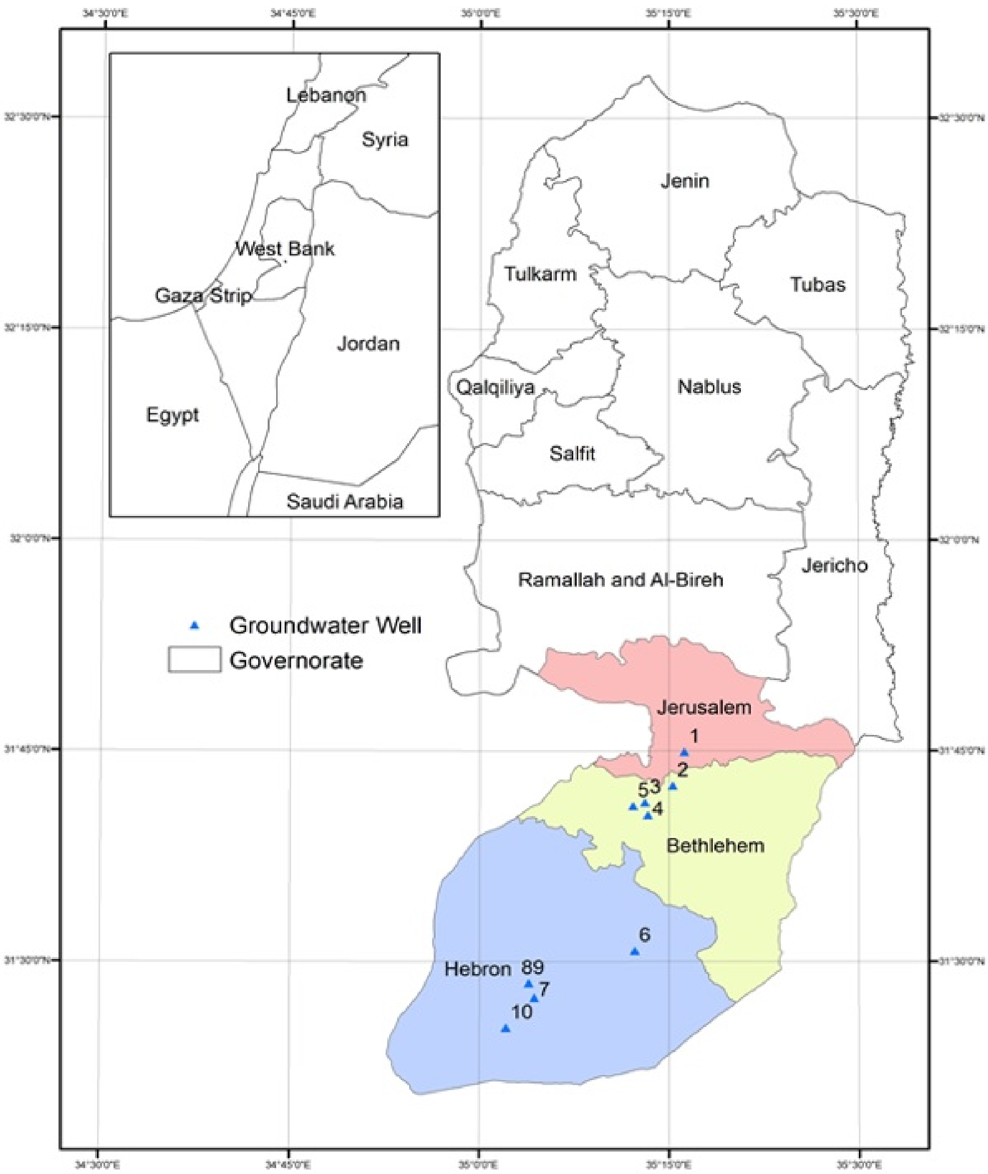

Fig. 1. The distribution of groundwater wells in the study area

Table 1. The groundwater wells considered in the present study

No.	*Well*	*Well ID*	*Governorate*	*Year*	*Number of samples collected*
1	Al 'Eizariya 3	17-12/011	Bethlehem	2021 & 2022	16
2	Al 'Eizariya 1A	17-12/010	Bethlehem	2021 & 2022	19
3	JWC-4	17-12/008	Bethlehem	2021 & 2022	16
4	PWA No. 3	17-12/007	Bethlehem	2021 & 2022	16
5	Hundaza	16-12/004	Bethlehem	2021 & 2022	10
6	Bani Na'im No. 2	16-10/005	Hebron	2020	12
7	Ar Rihiya	15-09/013	Hebron	2020	12
8	Al Fawwar HM No. 3		Hebron	2020	10
9	Al Fawwar HM No. 1 C		Hebron	2020	12
10	As Samu' No. 1	15-09/000	Hebron	2020	12

The water samples were collected from groundwater boreholes in Bethlehem and Hebron Governorates. EC and pH measurements were taken in situ using portable EC and pH meters as well as a field titration kit. To measure the anions (Cl^- and NO_3^-) and Hardness, Dionex ICS 90 ion chromatography system in the water quality laboratory of the PWA was used. The groundwater samples were filtered using 0.45 µm membranes and stored in preconditioned polyethylene bottles (1% volume/volume HNO_3) to determine the major cations (e.g., Na^+).

Table 2. Water quality parameters with their WHO standards, WQI weights, and normalized weights

Parameter	***Unit***	***WHO Standard (S_i)***	***Weight (W_i)***	***Normalized Weight (w_i)***
Turbidity	NTU	5	3	0.167
pH	–	6.5–8.5	3	0.167
EC	µS/cm	1500	2	0.111
Cl^-	mg/L	250	3	0.167
NO_3^-	mg/L	50	5	0.277
Hardness	ppm	300	2	0.111
Total			18	1.000

The PWA adopted the standard procedure of collection for water quality data. The procedure that was followed to ensure the accuracy of results started with soaking bottles and other glassware in 5% nitric acid solution, calibrating and validating the instruments with standard reference materials, and duplicating the samples. In addition, accuracy check was insured by checking the anion-cation balance.

The water quality for the 10 groundwater wells was evaluated based on the WQI. To calculate the WQI, first we had to assign weights for the selected parameters and then made normalization for the weights. The weights for the parameters, namely Turbidity, pH, EC, Cl^-, NO_3^-, and Hardness, are given in Table 2. The scale of weights ranges from 1 to 5 according to the importance of the parameter (El Baba et al., 2020). For example, Nitrate concentration was given the highest weight because it is an important indicator in order to assess the overall water quality. The EC was given low weight because it does not cause real problems to human health. The values of the water quality parameters were compared to the World Health Organization (WHO) standards (WHO, 2011) as shown in Table 2. The normalized weights can be calculated by Eq. (1).

$$w_i = W_i / \sum_{i=1}^{n} W_i \quad (1)$$

where: w_i is the parameter's *i* normalized weight, W_i is the parameter's assigned weight, and *n* is the total number of parameters.

The observed water quality is then standardized by dividing the values by the corresponding water quality standard of the WHO as shown in Eq. (2):

$$q_i = C_i / S_i \quad (2)$$

where: q_i symbolizes the partial WQI score for the parameter *i*, C_i symbolizes the measured concentration for the parameter *i*, and S_i is the water quality standard for the parameter *i* based on the WHO guidelines of drinking water (WHO, 2011) (see Table 2). The total WQI score (Eq. 3) is calculated by adding the scores of each parameter and multiplying them by their corresponding normalized weights (Eq.3).

$$\text{WQI} = \sum_{i=1}^{n} w_i \, q_i \quad (3)$$

If the WQI score is less than one, it means that groundwater can be used without any treatment. If the WQI score is higher than one, it means that groundwater has a low quality and needs to be treated. The WQI scores classify the water quality into categories which are unsuitable for use, very poor, poor, good, and excellent (El Baba et al., 2020) as illustrated in Fig. 2.

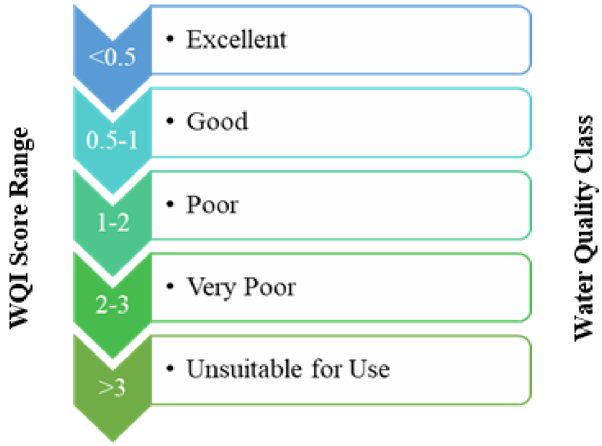

Fig. 2. Classification of the water quality according to the WQI score

4. Results and discussion

4.1. Groundwater quality analysis in Palestinian Governorates

The application of the methodology outlined facilitated comprehensive assessments across 10 groundwater wells spanning two distinct Palestinian Governorates. The thorough examination encompassed various critical physicochemical parameters including Turbidity, pH, EC, Cl^-, $NO3^-$, and Hardness, subsequently enabling the computation of the Water Quality Index (WQI) and the corresponding water quality classifications for each individual well.

Through meticulous computations, both the average value and the standard deviation (SD) were derived for these six key physicochemical parameters alongside the computed WQI scores. The findings, showcased in Table 3 and Table 4, delineate the intricacies of the physicochemical characteristics observed in groundwater samples from Bethlehem Governorate for the years 2021 and 2022, respectively. Similarly, Table 5 meticulously outlines the corresponding physicochemical traits identified in groundwater samples from Hebron Governorate during the year 2020.

These detailed analyses not only provide a snapshot of the diverse physicochemical makeup of the groundwater, but also pave the way for a comparative understanding of the quality variations over different periods and geographical regions. The nuances observed within these parameters underscore the imperative nature of continued monitoring and proactive measures to ensure the preservation and enhancement of groundwater quality in these regions.

4.2. Evaluation of key physicochemical parameters

4.2.1. Turbidity

In both the Bethlehem and Hebron Governorates, all groundwater well samples exhibited turbidity values well within the permissible limit for drinking water, set at 5.0 NTU according to WHO standards (2011). Turbidity, defined as the haziness or cloudiness within a liquid, often stems from an array of microscopic particles typically unseen by the naked eye (Nguiamba et al., 2019). Activities like construction, mining, and farming can trigger stormwater runoff, impacting the soil and leading to heightened sediment influx into water bodies.

Elevated turbidity levels pose health risks, particularly increasing the likelihood of gastrointestinal illnesses. The measurement of turbidity is commonly quantified in Nephelometric Turbidity Units (NTU) (Nguiamba et al., 2019). The compliance of the sampled groundwater with established drinking water turbidity standards is encouraging, suggesting a relatively lower risk of health-related issues associated with turbidity in these regions. However, continuous monitoring and management of potential sources impacting turbidity remain imperative to sustain and safeguard the quality of drinking water sources in these Governorates.

4.2.2. pH

The pH levels observed in the examined groundwater samples from both Bethlehem and Hebron Governorates fell comfortably within the recommended thresholds. The pH, denoting the acidity or alkalinity of a liquid, operates on a scale ranging from 0.0 (highly acidic) to 14.0 (highly alkaline), measured without units. WHO guidelines (2011) stipulate that drinking water should ideally maintain a pH level within the 6.5 to 8.5 range.

It is crucial to note that even when pH levels are within the acceptable range, slight deviations toward the extreme ends can result in undesired effects. Variations in pH can adversely impact the taste, odor, and appearance of drinking water (WHO, 2007). Elevated pH levels may impart a taste akin to baking soda and lead to appliance staining, while lower pH levels with a metallic or bitter taste can contribute to fixture corrosion and affect disinfection efficacy (WHO, 2007).

Although the analyzed samples conform to the recommended pH standards for drinking water, these nuances in pH underscore the importance of vigilance. Minor fluctuations, even within permissible limits, could affect the overall quality and user experience of the supplied water, emphasizing the necessity of consistent monitoring and management of pH levels in maintaining optimal drinking water quality.

4.2.3. Electrical conductivity

The analysis of electrical conductivity (EC) in groundwater samples from Bethlehem and Hebron Governorates indicates levels below the WHO guideline limit of 1500 μS/cm (WHO, 2011). The EC measures the water's ability to conduct electrical current due to the presence of ions. These ions originate from dissolved salts and various inorganic compounds such as sulfides, alkalis, chlorides, and carbonate species (Zafar et al., 2022). The adherence of EC levels within acceptable limits, as per WHO guidelines, suggests a favorable aspect of the overall groundwater quality in these Palestinian Governorates, contributing positively to their suitability for various purposes including drinking water supply and agricultural usage.

4.2.4. Chloride

The chloride (Cl^-) concentrations observed in the tested groundwater samples spanned from 24 to 44 mg/L, significantly below the WHO's set limit of 250 mg/L (WHO, 2011). This lower concentration range suggests a positive outlook for groundwater quality within the studied Palestinian Governorates. The Cl^- levels serve as an indicator of potential pollutants or human wastewater discharges. Natural rainwater-derived groundwater typically exhibits Cl^- concentrations below 10 mg/L.

The rise in Cl^- concentrations, often attributed to the leaching of chemical fertilizers on agricultural lands or wastewater discharge, can elevate levels to 20 or 30 mg/L and beyond. While these concentrations might not noticeably affect water taste, they serve as valuable indicators of contamination sources. Common sources contributing to chloride contamination encompass animal waste, fertilizers, and septic systems. Consequently, deteriorating groundwater quality, often intensified by extensive land use or excessive effluent discharge, generally correlates with increased Cl^- concentrations (Khalid et al., 2018). By monitoring Cl^- concentrations in groundwater, researchers can glean insights into potential contamination sources and assess the impact of various landuse practices. These findings underscore the importance of continued vigilance and comprehensive monitoring to preserve groundwater quality and mitigate potential risks posed by various sources of contamination in these Palestinian Governorates.

4.2.5. Nitrate

The nitrate (NO_3^-) levels in the majority of scrutinized groundwater samples fell below the 30 mg/L threshold, meeting standard safety guidelines. However, the exceptions were observed in two wells within the Hebron Governorate, specifically Al Fawwar HM No. 3 and Al Fawwar HM No. 1 C, which recorded concentrations of 106 and 90 mg/L, respectively. These concentrations notably exceeded the acceptable limit of 50 mg/L as prescribed by WHO standards (2011). The presence of elevated NO_3^- levels often serves as an indicator of potential groundwater pollution originating from sources like human excrement due to the high mobility of nitrogen in subsurface environments (Graham and Polizzotto, 2013).

The ramifications of heightened NO_3^- concentrations are alarming, considering the associated health risks and the complex and costly treatment required for its removal. Beyond NO_3^-, nitrite also poses health hazards (Anayah and Almasri, 2009; Mahmoud et al., 2022). Instances of elevated nitrite levels might stem from the use of sodium nitrite, common in preserving meats and pickling. However, regulations have restricted its widespread use (Kevil and Lefer, 2010). Additionally, improper practices during boiler cleaning, involving nitrous acid, can sporadically lead to nitrite contamination in building water sources (Kevil and Lefer, 2010).

The elevated NO_3^- and nitrite levels detected in specific wells highlight the pressing need for continual monitoring and management strategies. Addressing the sources contributing to these contaminants is essential in safeguarding the groundwater quality and mitigating potential health hazards posed by excessive nitrogenous compounds. Efforts to curtail such contamination sources are pivotal in ensuring the safety and purity of drinking water sources in these Governorates.

4.2.6. Hardness

The hardness concentrations of the groundwater samples from Bethlehem Governorate were less than the standard limit of 300 ppm (WHO, 2011). The measurements showed that the concentration of hardness in the groundwater of Hebron Governorate exceeded the recommended limit in four wells with a maximum value of 446.2 mg/L in Al Fawwar HM No. 3 well. The geological composition of the aquifer has a significant impact on hardness, and often, regions with limestone formations have hard water (Khan and Jhariya, 2017), as in the Hebron Governorate.

The negative impacts of magnesium and calcium in drinking water are linked to hardness (WHO, 2011). High concentrations of calcium and magnesium are present in hard water, which is determined by these two minerals (WHO, 2011). Hard water has no harmful effects on health, but it can lead to scale buildup in pipelines, treatment facilities, and storage tanks (Mahmoud et al., 2022). Additionally, when the hardness of water is higher than 200 mg/L, it creates deposits of calcium carbonate when heated (Mahmoud et al., 2022). Most of the parameters measured in the wells are within the WHO standards, and all wells have accepted WQI score except Al Fawwar HM No. 3 which has a poor classification.

5. Conclusions

In this study, the application of the Water Quality Index (WQI) served as a pivotal tool in assessing groundwater quality across 10 wells within the Bethlehem and Hebron Governorates of Palestine. Through meticulous analysis, various physicochemical parameters including Turbidity, pH, EC, Cl^-, NO_3^-, and Hardness were evaluated, alongside the computation of the WQI and subsequent water quality classifications for each individual well.

Table 3. The physicochemical characteristics of the groundwater samples in Bethlehem Governorate in 2021

Well	*Turbidity (NTU)*	*pH*	*EC (µS/cm)*	*Cl⁻ (mg/L)*	*NO₃⁻ (mg/L)*	*Hardness (ppm)*	*WQI Score*	*Water Quality Class*
Al 'Eizariya 3	3.0	7.96	493	22	5	280.0	0.46	Excellent
Al 'Eizariya 1A	1.0	7.46	528	25	8	279.2	0.41	Excellent
JWC-4	1.5	7.34	552	30	7	250.0	0.41	Excellent
PWA No. 3	2.0	7.50	543	30	15	249.0	0.48	Excellent
Hundaza	1.0	7.46	508	30	16	249.3	0.54	Good
Average	1.69	7.54	524.8	27.4	10.2	261.5	0.46	
SD	0.84	0.24	24.4	3.7	5.0	16.5	0.06	

Table 4. The physicochemical characteristics of the groundwater samples in Bethlehem Governorate in 2022

Well	*Turbidity (NTU)*	*pH*	*EC (µS/cm)*	*Cl⁻ (mg/L)*	*NO₃⁻ (mg/L)*	*Hardness (ppm)*	*WQI Score*	*Water Quality Class*
Al 'Eizariya 3	2.0	7.40	554	44	14	279.2	0.49	Excellent
Al 'Eizariya 1A	0.9	7.71	482	24	6	279.2	0.39	Excellent
JWC-4	0.8	7.69	489	29	14	249.3	0.43	Excellent
PWA No. 3	2.0	7.70	509	24	8	249.3	0.43	Excellent
Hundaza	0.9	7.86	524	34	16	289.1	0.58	Good
Average	1.32	7.67	511.6	31.0	11.6	269.2	0.46	
SD	0.62	0.18	28.9	8.4	4.3	18.6	0.07	

Table 5. The physicochemical characteristics of the groundwater samples in Hebron Governorate in 2020

Well	***Turbidity (NTU)***	***pH***	***EC (µS/cm)***	***Cl^- (mg/L)***	***NO_3^- (mg/L)***	***Hardness (ppm)***	***WQI***	***Water Quality Class***
Bani Na'im No. 2	1.00	7.46	508	30	16	292.0	0.46	Excellent
Ar Rihiya	0.89	7.49	545	49	5	320.1	0.42	Excellent
Al Fawwar HM No. 3	1.25	7.32	996	81	106	446.2	1.15	Poor
Al Fawwar HM No. 1 C	0.87	7.42	764	91	90	436.5	1.02	Good
As Samu' No. 1	0.82	7.34	854	95	43	407.4	1.02	Good
Average	1.69	7.54	524.8	27.4	10.2	261.5	0.46	
SD	0.84	0.24	24.37	3.71	4.97	16.53	0.05	

The research drew upon a dataset comprising 135 groundwater samples collected by the Palestinian Water Authority (PWA) throughout the years 2020, 2021, and 2022. This comprehensive analysis utilizing the WQI framework offers valuable insights into the overall groundwater quality within these specific regions, laying the groundwork for informed management strategies and interventions to safeguard and enhance water resources in these Palestinian Governorates.

The assessment of groundwater samples from the Bethlehem and Hebron Governorates reflects generally good water quality across the 10 wells, aligning well with WHO standards for physicochemical parameters in drinking water. Most of the examined wells in the southern West Bank exhibit acceptable water quality, ranging from good to excellent, except for the “Al Fawwar HM No. 3” well, which displayed poorer quality based on the WQI score.

To ensure sustainable groundwater management in Palestine, various strategies could be considered. These include risk mitigation measures, optimizing water usage, exploring non-conventional water resources, bolstering groundwater quality management protocols, implementing pollution prevention strategies, integrating groundwater considerations into land use planning, activating systems for groundwater use rights, and establishing comprehensive groundwater databases. The PWA should prioritize regular monitoring of groundwater wells and undertake thorough analyses to safeguard human health and environmental integrity.

The findings underscore the importance of proactive measures in safeguarding groundwater quality and emphasize the necessity for ongoing vigilance and strategic interventions to ensure the sustained availability of safe and reliable drinking water resources in these Palestinian Governorates. Regular monitoring and comprehensive analyses remain integral to preserving both environmental health and the well-being of local populations.

There was noted absence of a clear policy for sampling from artesian wells and an incomplete examination of all quality indicators in their water. Hence, it is recommended to prioritize scheduling a comprehensive examination of artesian well water, following a clear and defined timeline. This approach ensures ongoing water quality monitoring and safeguards public health.

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