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GIS-Based Spatiotemporal Mapping of Groundwater Potability and Palatability Indices in Arid and Semi-Arid Areas

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Abstract: This paper aims to assess groundwater potability and palatability in the West Bank, Palestine. It combines the adjusted weighted arithmetic water quality index method (AWAWQIM), a close-ended questionnaire, and step-wise assessment ratio analysis (SWARA) to develop groundwater potability (PoGWQI) and palatability (PaGWQI) indices. Both a geographic information system (GIS) and the kriging interpolation method (KIM) are employed to create spatiotemporal mapping of PoGWQI and PaGWQI. The research is based on data from 79 wells, which were provided by the Palestinian Water Authority (PWA). Data include fecal coliform (FC), nitrate (NO_3), pH, chloride (Cl), sulfate (SO_4), bicarbonate (HCO_3), total dissolved solids (TDS), turbidity, and hardness. Results indicate that 2% and 5% of water samples were unpotable and unpalatable, respectively. Unpotable samples were found in areas with poor sewer networks and intensive use of agrochemicals. All groundwater samples (100%) in the eastern part of the West Bank were unpalatable because of seawater intrusion. Unconfined aquifers were more vulnerable to potability and palatability contamination. It was noticed that PoGWQI is sensitive to FC and NO_3, while PaGWQI is sensitive to HCO_3, TDS, and Cl. Consequently, these quality parameters should be monitored well. The proposed method is of great interest to water decision-makers in Palestine for establishing strategies to protect water resources.

Keywords: groundwater; potability; palatability; assessment; quality index; SWARA; GIS

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1. Introduction

Groundwater forms a major source of potable water for many countries in the world [1,2]. It has been naturally purified by the infiltration process. Therefore, it is usually of excellent quality and requires no more than slight monitoring and treatment [3–5]. Unluckily, excellent quality is no longer assured due to human activities [3,6–8]. Indeed, urban (e.g., use of cesspits for wastewater disposal), agricultural (e.g., intensive use of fertilizers and pesticides), and industrial (e.g., unmanaged solid waste disposal) activities increase the soluble contaminants reaching groundwater [9–15]. Scholars have confirmed the increasing health risk associated with groundwater contamination [16,17], which could cause different diseases (e.g., hepatitis, dysentery, poisoning, blue baby syndrome, and cancers) and lead to death [11,13,14,18–20].

Accordingly, assessment of groundwater quality is of great interest for evaluating its suitability for human usage. Traditionally, researchers adopted a single parameter assessment to characterize groundwater quality [21]. They compared the parameter' concentration to the drinking water standards [21]. However, this traditional approach missed the multi-contaminant effect on drinking water [21]. Thus, researchers embraced the groundwater quality index (GWQI) as a strategic tool for characterizing groundwater quality [22–24]. It considers physical, chemical, and biological water characteristics according to drinking water standards. GWQI identifies the groundwater quality using a single score [22–24]. The score can be transformed into excellent, good, satisfactory, poor, and undrinkable water. Decision–makers and end-users [22–24] could easily understand this. GWQI is widely applied in many countries such as Mexico [25], Portugal [26], Hungary [27], India [28], Malaysia [29], Algeria [30], Egypt [31], and United Arab Emirates [22].

Various methods were used worldwide to develop the water quality index (WQI) for groundwater resources, such as the Horton model of WQI [32], Modified National Sanitation Foundation WQI [33], Scottish Research Development Department WQI [34], Oregon WQI [35,36], Martínez de Bascarón WQI [34], Bhargava's WQI [37], Canadian Council of Ministers of the Environment WQI [38], Liou's WQI [34,39], fuzzy-based WQI [40], Vaal WQI [34] and universal WQI [41,42]. Unlike most methods, the weighted arithmetic water quality index (WAWQI) method has flexibility in the input parameters [27,34]. It estimates the GWQI considering the most common contaminants wherever adopted [43]. Hence, it is considered an ideal approach for groundwater quality assessment at the national scale.

As stated by Aleem et al. (2018), the combination of GWQI and spatial analysis has proved to be a robust tool for assessing groundwater quality [44,45]. The geographic information system (GIS) enables the use of various interpolation methods for GWQI spatial analysis, such as proximity interpolation, inverse distance weighted interpolation, and the kriging interpolation method (KIM) [46,47]. Compared to other interpolation methods, the KIM method employs statistical approaches to eliminate spatial trends in data. It also characterizes the spatial data autocorrelation by defining the optimal experimental variogram model [46,47].

The groundwater quality in the West Bank, Palestine, has deteriorated due to the weak sewer infrastructure, unmanaged human practices, and weak quality monitoring systems [2,48]. Various studies confirmed the groundwater contamination using descriptive and statistical methods [48–50]. However, such methods are less comprehensive than the GWQI in assessing groundwater contamination [43]. GWQI considers the combined influence of contaminants which in turn provides decision-makers with informative results [43].

This paper presents an adjusted WAWQI method (AWAWQIM) to develop groundwater potability (water suitability for drinking) and palatability (water acceptability in terms of taste, odor, color . . . , etc.) indices (PoGWQI and PaGWQI) in the West Bank. The GWQI method is used for the first time to assess the groundwater quality in the West Bank. The paper discusses an unparalleled adjustment of the WAWQI method for developing the GWQI method. The adjusted method combines experts' opinions, step-wise assessment ratio analysis method (SWARA), and the conventional WAWQI method. The proposed approach can help decision-makers to develop strategies for protecting water resources in the West Bank.

2. Materials and Methods

2.1. Methodology

Figure 1 shows the methodology adopted in this research. It includes four phases: development of PoGWQI and PaGWQI, mapping of water quality indices, performing a sensitivity analysis, and constructing causal-effect analysis for understanding and prioritizing the factors affecting PoGWQI and PaGWQI.

2.1.1. Development of Potability and Palatability Groundwater Quality Indexes (PoGWQI and PaGWQI)

This paper proposes a new approach for developing PoGWQI and PaGWQI (Figure 2). It relies on the conventional WAWQI method for developing both indices. This method has no restriction in selecting the water quality parameters included in the calculation [51,52]. It is based on the selection of the most widespread parameters that threaten water quality. The conventional WAWQI can be used according to the following steps [53,54].

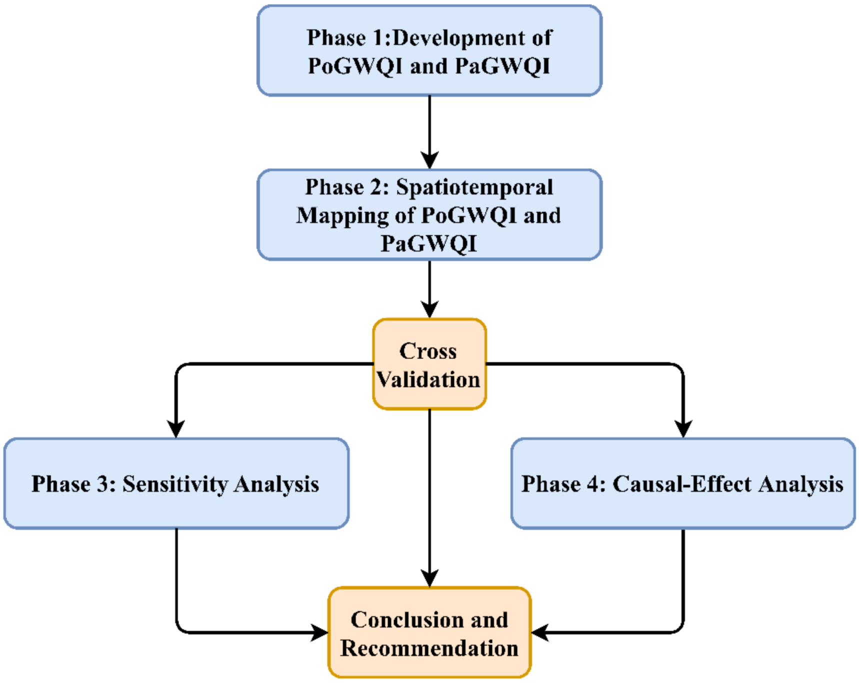

Figure 1. Overall methodological framework.

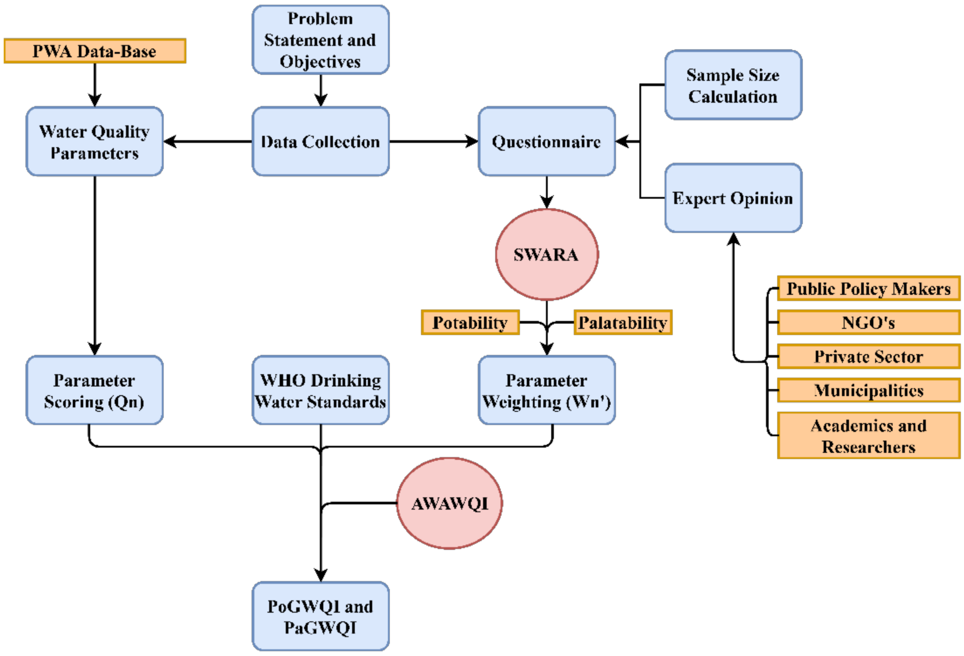

Figure 2. Development of potability and palatability groundwater quality indexes (PoGWQI and PaGWQI).

The first step concerns selecting the quality parameters for water potability and palatability. The second step consists of estimating the quality scores (Q_n) for the water quality parameters using the following expression:

$$Q_n = 100 \left(\frac{Vn - Vi}{Vs - Vi} \right) \tag{1}$$

where, V_n is the measured amount of the nth parameter in the analyzed water, V_i is the ideal amount nth parameter in pure water, and V_s is the standard permissible amount for the nth parameter according to the World Health Organization (WHO) [53,55,56].

The third step corresponds to estimating the weights (W_n) for water quality parameters using the following formulas:

$$K = \frac{1}{\sum(1/Vs)} \tag{2}$$

$$Wn = \frac{K}{Vs} \tag{3}$$

where k, is the proportionality constant.

The last concerns estimating PoGWQI and PaGWQI using the WQI formula:

$$\text{WQI} = \frac{\sum \text{Qn}\, Wn}{\sum Wn} \tag{4}$$

The conventional WAWQI' weighting system uses the standard permissible parameter (V_s) to assign the importance of the water quality parameters. Since this method does not consider the impact of the water quality parameters on human health and water acceptability, it could lead to inaccurate quality indices. In some cases, water quality indices could show excellent water potability, while some of the water quality parameters that significantly affect water potability exceed the WHO standards. Alternatively, this research proposes the use of AWAWQIM that considers experts' opinions to develop a comprehensive weighting system for the water quality parameters. The new system assigns the permeameters' weights considering the effect of quality parameters on the water potability and palatability. A close-ended questionnaire is used to assess the importance of quality parameters concerning water potability and palatability. Experts assess each parameter using the Likert scale (1, Not important, and 5, Extremely important). The questionnaire was addressed to water experts in the selected case study. The SWARA method was used to determine the weights of quality parameters ($W_n{}'$) using the following formulas [43]:

$$sj = \sum_{j}^{n} \frac{Aj}{n} \tag{5}$$

$$kj = \begin{cases} 1, & j = 1 \\ sj + 1, & j > 1 \end{cases} \tag{6}$$

$$qj = \begin{cases} 1, & j = 1 \\ \frac{qj-1}{kj}, & j > 1 \end{cases} \tag{7}$$

$$Wn\prime = \frac{qj}{\sum_{k=1}^{n} qj} \tag{8}$$

where Aj is the Likert scale score given by expert i.

n is the total number of experts.

sj, kj and qj are intermediary parameters used in the method.

Accordingly, the AWAWQIM was used to develop PoGWQI and PaGWQI in this research:

$$Adjusted\ \text{WQI} = \frac{\sum \text{Qn}\, Wn\prime}{\sum Wn\prime} \tag{9}$$

Five potability and palatability groundwater quality statuses (PoGWQS and PaGWQS) and grades (PoGWQG and PaGWQG) were identified according to Brown et al. 1970 [57]. Except for grade "E", all grades were considered potable and palatable but with gradual quality (See Table 1).

Table 1. Identification of potability and palatability groundwater quality statuses (PoGWQSs, PaGWQSs), and grades (PoGWQGs, and PaGWQGs) [57].

PoGWQI/PaGWQI	PoGWQS	PaGWQS	PoGWQG/PaGWQG
≤25	Excellent	Excellent	A
25.01–50	Good	Good	B
50.01–75	Satisfactory	Satisfactory	C
75.01–100	Poor	Poor	D
>100	Undrinkable	Unpalatable	E

The proposed weighting system considers the degree of severity of each water quality parameter on health in the local context. However, the proposed method could be combined with other methods for water quality assessment.

The proposed method is convenient for spatial water quality mapping. It could be used by decision-makers to scan the water quality at a large scale and to develop strategies for water resource protection.

2.1.2. Potability Groundwater Quality Index (PoGWQI) and Palatability Groundwater Quality Index (PaGWQI) Mapping

Q_n values were imported into Arc GIS and then were interpolated using the KIM method, which KIM is highly recommended. In this method, the input data are biased and spatially correlated [46]. The KIM method relies on statistics and spatial autocorrelation. Therefore, it is widely used in soil science, geology, and groundwater contamination research [47]. GIS-based raster calculator was used to processing the interpolated Q_n and Wn' values to develop spatiotemporal PoGWQI and PaGWQI mapping.

Water quality data from unconsidered groundwater wells are used to perform cross-validation for the resulted PoGWQI and PaGWQI maps. Such validation examines the ability and accuracy of KIM in predicting groundwater quality.

2.1.3. Mapping Sensitivity Analysis

Sensitivity of PoGWQI and PaGWQI toward the input quality parameters is performed using the map removal sensitivity approach (MRSA) [58–60]. The mean absolute error (MAE) in PoGWQI and PaGWQI was calculated by removing each of their input quality parameters separately.

2.1.4. Causal-Effect Analysis

Causal-effect descriptive analysis was used to understand how PoGWQI and PaGWQI changed within the different classes of influencing factors (land-use, soil texture, aquifer, well' depths, and rainfall). Then, the relative importance of each influencing factor was estimated using the random forest algorithm (RFA) and factor importance analysis. RFA is widely applied in life science for classifying the importance of influencing factors [60]. It can characterize features' importance at all multivariate interactions included in algorithm [2].

2.2. Application to the West Bank

2.2.1. Study Area

The West Bank, Palestine, is an arid to a semi-arid area located to the West of Jordan (Figure 3). It has a total extent of 5860 km^2 with around 3.1 million inhabitants [61,62]. The maximum (1022 m above MSL) and minimum (410 m below MSL) ground surface elevation are located in Hebron and Jericho, respectively [63]. The land-use map shows three main classes: rough grazing, agricultural areas, and built-up areas (urban and rural), which occupy 63%, 32%, and 5% of the study area, respectively [64]. Soil textures range from clay (47%), clay loam (31%), loamy (9%), sandy loam (8%) to bare rock (5%) [64]. The

West Bank is characterized by a Mediterranean climate with a high seasonal deviation [64]. The average rainfall is about 450 mm/year [65].

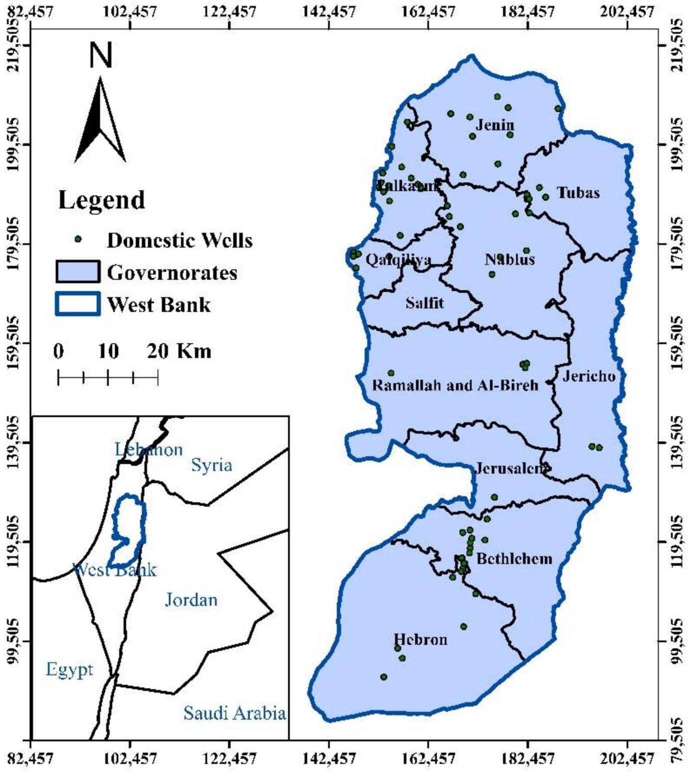

Figure 3. Regional location of the West Bank.

Five out of the 11 West Bank governorates are under high to very high domestic water poverty [64]. This is reflected through the water shortage conditions, and the inability to meet domestic water needs [66]. In 2018, a deficit of around 58 MCM (40%) was recorded to satisfy the domestic water demand (146.1 MCM) [67]. Moreover, political status limits the upgrading of existing water resources or the finding of new ones [62]. It also restricts the Palestinians' accessibility to water resources [62]. The water supply in the study area is obtained mainly from groundwater (63%) [68]. The remaining 37% are purchased from water companies located in neighborhood countries [68].

Groundwater is pumped from 79 domestic wells located in three main basins: Western Basin (WB), Eastern Basin (EB), and North-Eastern Basin (NEB) [69]. These basins contribute 29%, 48%, and 23% of the supplied groundwater, respectively [69]. Except for the Salfit governorate (which relies on purchased water), all governorates are partially or totally supplied by groundwater [68].

2.2.2. Data Collection and Application

According to various research works, the relevant water quality parameters in the West Bank concern turbidity, chloride (Cl), pH, electrical conductivity (EC), nitrate (NO_3), hardness, sodium (Na), total coliform (TC), fecal coliform (FC), total dissolved solids (TDS), magnesium (Mg), calcium (Ca), potassium (K), bicarbonate (HCO_3), and sulfate (SO_4) [21,49,50]. Due to a lack of data, this research will focus on nine parameters, including pH, HCO_3, Cl, SO_4, NO_3, TDS, FC, hardness, and turbidity. Data was collected from the Palestinian Water Authority (PWA) database [56]. Collected records are distributed among 79 domestic wells in the West Bank over the period 2001–2016. Quality parameters were divided into two groups according to WHO guidelines and experts' opinions [43]. The first group included parameters affecting water potability, such as FC and NO_3. The second one concerned water palatability such as pH, HCO_3, Cl, SO_4, Hardness, TDS, and Turbidity.

V_n, V_i, and V_s of the selected water quality parameters are illustrated in Table 2 [53,55,56].

Table 2. V_n, V_i, and V_s values of water quality parameters [53,55,56].

Water Quality Parameter	V_n (Range)	V_i	V_s	Unit
fecal coliform (FC)	0–120	0	10	CFU/100 mL
nitrate (NO_3)	0–128	0	50	mg/L as NO_3
chloride (Cl)	12–2573	0	250	mg/L
total dissolved solids (TDS)	33–5288	0	600	mg/L
Turbidity	0–13	0	5	NTU
pH	6.8–8.6	7	6.5–8.5	-
sulfate (SO_4)	0–600	0	250	mg/L
Hardness	168–1110	0	500	mg/L
bicarbonate (HCO_3)	76–431	0	120	mg/L

A close-ended questionnaire was addressed to 42 water-related bodies in the West Bank. These bodies are defined as the targeted population (*Pop*) (See Table 3). Accordingly, the sample size for infinite population (*SSIP*) and the required sample size (*SS*) were calculated according to the Cochran formula [70].

Table 3. Targeted water-related bodies for the groundwater quality survey.

Group	Total No. of Water-Related Institutions (Pop)	No. of Surveyed Institutions	No. of Respondents
Policymakers and related public bodies	7	6	13
Municipalities (in cities)	11	6	6
Non-governmental organizations (NGOs)	5	4	4
Private sector	10	5	5
Universities and water Institutes	9	9	13

$$SSIP = \frac{Z2p(1-p)}{e2} \tag{10}$$

$$SS = \frac{SSIP}{1 + \left(\frac{SSIP-1}{Pop}\right)} \tag{11}$$

where, Z value (given 95% confidence interval), population proportion (p) and margin of error (e) were equal to 1.96, 0.5 and 0.1 respectively. Accordingly, a *SSIP* of 96 and a *SS* of 29 were recorded. However, this questionnaire was filled out by 41 water experts from 30 water-related institutions to ensure more accuracy.

Accordingly, and by employing SWARA, two weighting systems were developed concerning water potability and palatability (See Table 4).

AWAWQIM treats the scores and weights illustrated in Tables 3 and 4 to develop PoGWQI and PaGWQI in the West Bank.

Table 4. Groundwater potability and palatability weighting systems in the West Bank.

Parameter	Potability W_n'	Palatability W_n'
FC	55.1	-
NO_3	44.9	-
Cl	-	19.0
TDS	-	17.1
Turbidity	-	15.6
pH	-	14.0
SO_4	-	12.8
Hardness	-	11.5
HCO_3	-	10.0

3. Results

3.1. Groundwater Potability and Palatability in the West Bank

Figure 4 illustrates the distribution of PoGWQGs and PaGWQGs in the West Bank. It shows that 49%, 33%, 13%, and 3% of the tested samples among all wells had A, B, C, and D-PoGWQGs, respectively. Around 2% of the tested samples were found to be unsafe for drinking (E-PoGWQG). The undrinkable samples were found in 4 wells (5.1% of all wells) in the West Bank (See Figure 5). Those wells are located in the northern and middle of the West Bank and have different rates of unpotable samples. Figure 5 shows that 67% of the samples taken from Well #1 were unpotable. Well #2, Well #3, and Well #4 have 13%, 11%, and 10% probability of providing unpotable water.

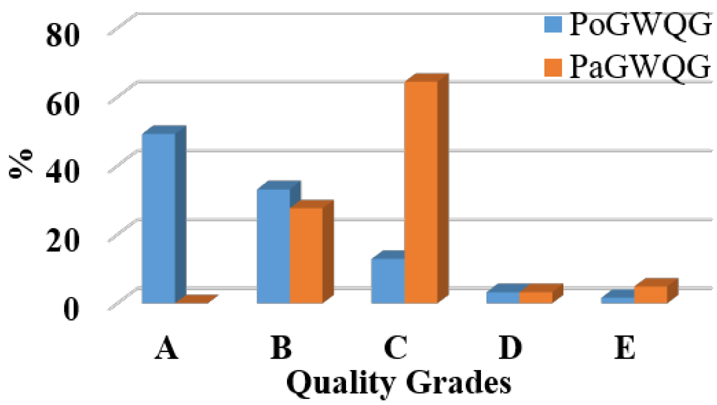

Figure 4. PoGWQGs and PaGWQGs in the West Bank.

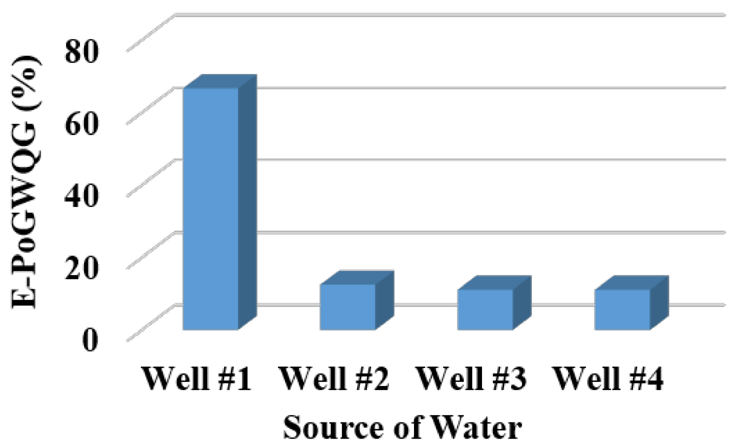

Figure 5. Un-potability rate over four contaminated groundwater wells in the West Bank.

On the other hand, none of the West Bank wells had A-PaGWQG; 28%, 64%, and 3% of the tested samples had B, C, and D-PaGWQGs, respectively (see Figure 4); 5% of unpalatable samples were recorded in two wells in the Eastern part of the study area. However, all samples (100% probability) taken from both wells were found to be unpalatable.

3.2. Spatiotemporal Mapping of PoGWQI and PaGWQI

GIS and KIM were used to establish a spatiotemporal mapping for both PoGWQI and PaGWQI. Cross-validation for the PoGWQI and PaGWQI mapping was conducted. Table 5 shows the validation results for two groundwater sources (wells) located in the middle and northern parts of the West Bank during the period 2001–2016. It is found that 14 out of the 17 PoGWQGs were correctly predicted (82.4% prediction accuracy). On the other hand, only one PaGWQG was incorrectly predicted (94.1% prediction accuracy). Figure 6 shows the PoGWQI and PaGWQI maps over the period 2001–2016. During the years 2001, 2007, 2010, 2011, 2015, and 2016, PoGWQG ranged from A, B to C. In 2003, 2004, 2009, and 2012, D and E grades appeared in the far north of the West Bank. Only in 2005 did the middle part of the West Bank experience groundwater potability contamination. This spatiotemporal variation in PoGWQI refers to the flash biological groundwater contamination (mainly due to FC). Such flash contamination could be caused by a direct seepage of the wastewater (mainly from cesspits) to shallow groundwater wells. On the other hand, the southern part of the West Bank was free of groundwater potability contamination.

Table 5. Cross-validation results for PoGWQGs and PaGWQGs among two groundwater wells in the West Bank.

Groundwater Source	Year	Actual PoGWQG	Interpolated PoGWQG	Actual PaGWQG	Interpolated PaGWQG
Source #1	2003	A	A	B	B
Source #1	2004	A	A	C	C
Source #1	2005	A	C	B	B
Source #1	2007	A	A	B	B
Source #1	2009	A	A	C	C
Source #1	2010	A	A	C	C
Source #1	2011	A	A	B	B
Source #1	2012	A	B	B	B
Source #2	2001	C	C	C	C
Source #2	2003	C	C	C	C
Source #2	2004	C	C	C	C
Source #2	2005	C	C	C	C
Source #2	2007	B	B	C	C
Source #2	2010	D	C	C	C
Source #2	2011	C	C	C	C
Source #2	2012	C	C	C	B
Source #2	2016	C	C	C	C

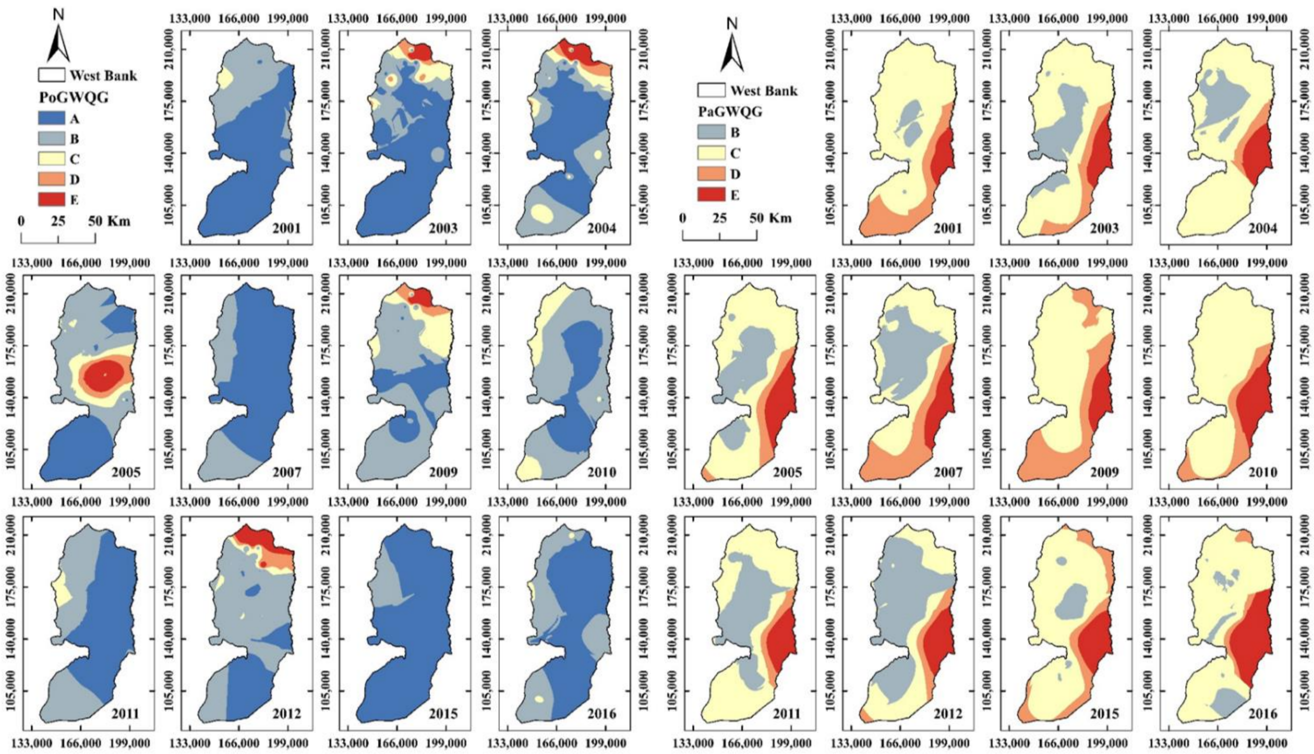

Figure 6. Spatiotemporal mapping of PoGWQI and PaGWQI in the West Bank between 2001 and 2016.

Figure 6 indicates that PaGWQI had a more consistent trend. The eastern part of the West Bank was characterized by permanent unpalatable groundwater. PaGWQG ranges from D to E. Moreover, grade D frequently appeared (in 6 non-successive years) in the far south of the study area. This stability of PaGWQI could be related to the permanent high salinity near the Dead Sea (the Eastern part of the study area). The middle, eastern and northern parts provide almost palatable water.

Figure 7 indicates that Jerusalem and Bethlehem governorates had the best potable water with almost 100% A-PoGWQG. It is also found that PoGWQGs range from A to D in Hebron, Qalqiliya, and Tulkarm governorates. Jenin governorate recorded the worst water potability with an E-PoGWQG of about 9%. This was followed by Tubas and Ramallah and Al Bireh, with an E-PoGWQG of about 5% and 3%, respectively. This could be related to the use of cesspits for wastewater disposal. It could also be referred to as the intensive use of agrochemicals.

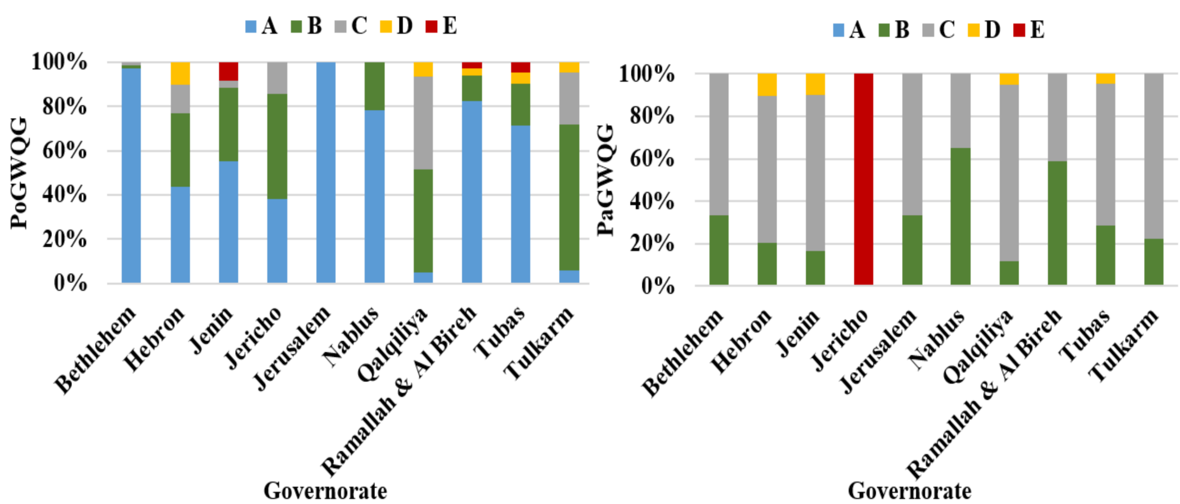

Figure 7. PoGWQGs and PaGWQGs cross the West Bank governorates.

Except for Jericho (with 100% E-PaGWQG), all governorates had zero E-PaGWQG. Generally, the palatability grades from B to D. The unpalatable water in Jericho could be caused by the saltwater intrusion from the Dead Sea. In this area, the TDS increased up to around 5300 mg/L.

3.3. Analysis of Indices' Sensitivity

The sensitivity of indices stems from the scores (values) and weights of their input parameters. Figure 8 indicates that PoGWQI was highly sensitive to the NO_3 concentrations with a MAE of 23–37 units. FC also had a significant influence on PoGWQI with a MAE between 19–30 units.

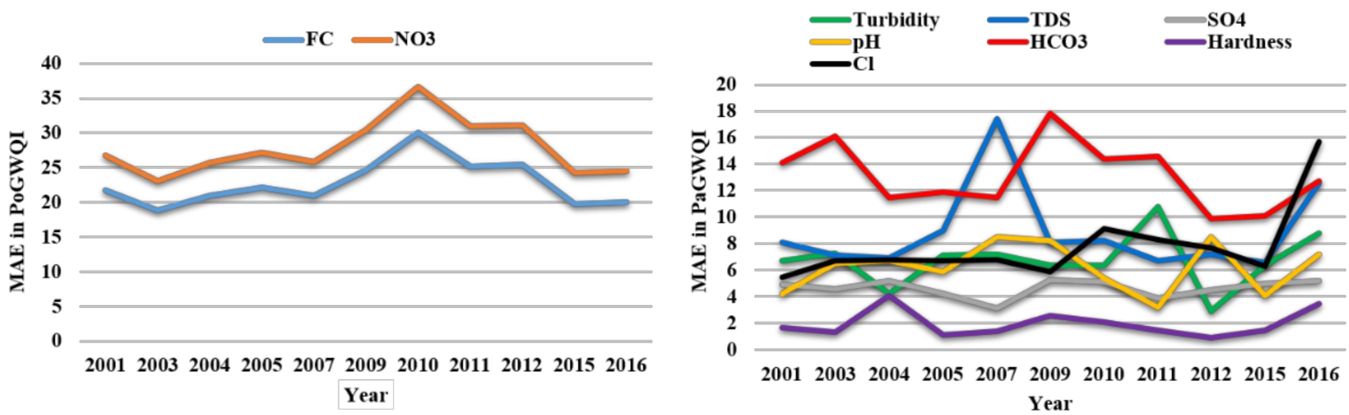

Figure 8. Sensitivity analysis of PoGWQI and PaGWQI.

Results show that HCO_3 was the most influencing parameter in estimating PaGWQI. This result contrasted with the experts' opinion, who considered HCO_3 as the lowest influencing parameter. This high importance of HCO_3 could be related to its high concentration. TDS and Cl follow it with MAE between 7–18 and 6–16 units, respectively.

4. Discussion

This section presents an analysis of the influence of various factors on PoGWQI and PaGWQI (e.g., land-use, soil texture, aquifer types, well depths, and the long-term average rainfall). Figure 9 indicates that urban areas have the worst water potability status (with 20% of E-PoGWQG) compared to the other land-use classes. This result could be attributed to the poor sewage network in this area. Around 54% of the urban areas are unserved by the sewer network [71]. Most citizens rely on cesspits for wastewater disposal [71]. Such cesspits cause a significant wastewater seepage to the groundwater aquifers, leading to high FC and NO_3 concentrations. Agricultural areas have around 1% of E-PoGWQG. Agrochemical applications could be the main reason for groundwater contamination [72]. Farmers extensively use agrochemicals to enhance their food production and to maximize their profits [2]. The best water potability was recorded under rough grazing. PoGWQGs under this land-use class ranged from A (80%), B (18%) to C (2%). Residential, agricultural, and industrial human-made activities are limited in this land-use class. The worst PaGWQGs status was observed in agricultural areas (with around 13% of E-PaGWQG). This result is due to the intensive use of agrochemical with significant SO_4 and TDS concentrations.

Despite the fact that clay soil has the highest water holding capacity and the lowest infiltration rate compared to other soil textures, it recorded the worst PoGWQGs. However, clay soil is the dominant soil texture in the West Bank, and it has a significant intersection with the residential and agricultural areas [73]. By contrast, groundwater wells under sandy loam were extremely unpalatable (with E-PaGWQG of 100%). This soil texture is distributed in the Eastern part of the West Bank with direct intrusion from the Dead Sea. Consequently, the saltwater infiltrates easily to over-pumped wells [74].

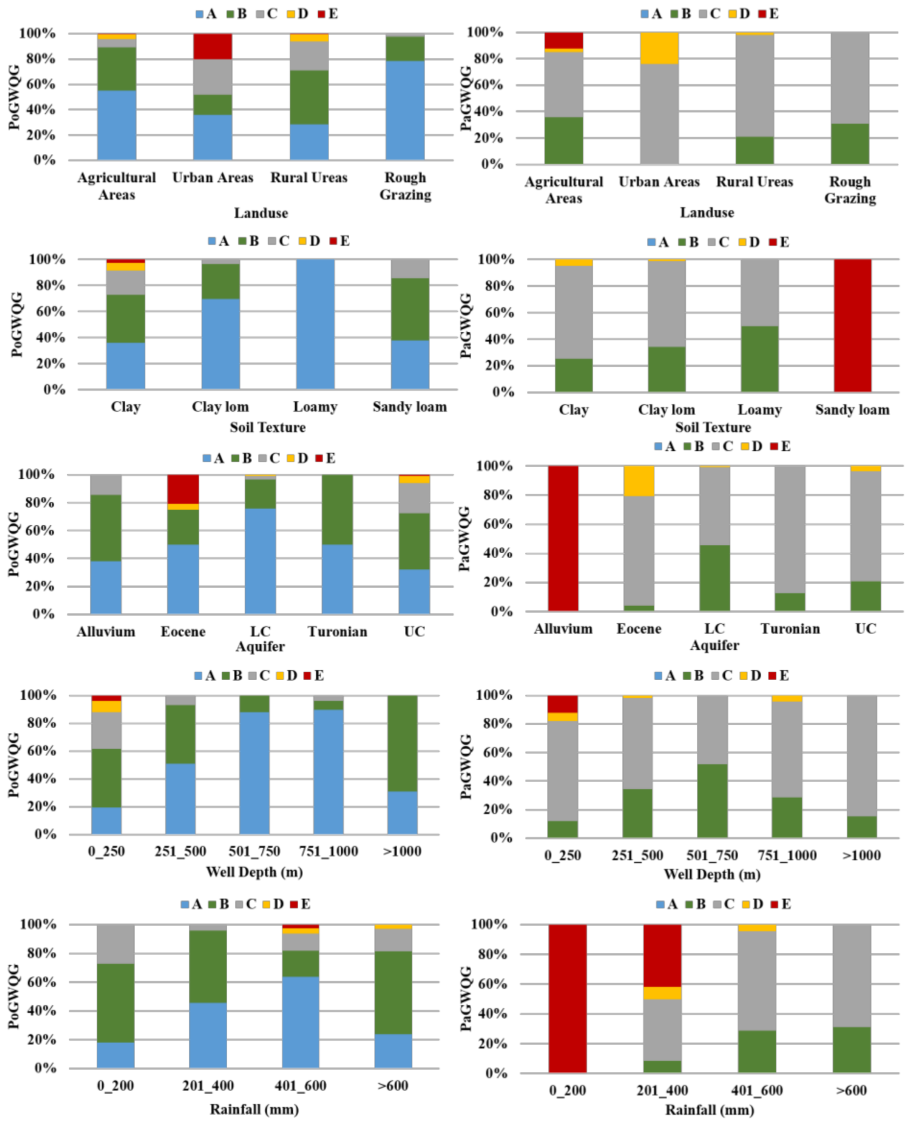

Figure 9. Factors affecting PoGWQI and PaGWQI in the West Bank.

Figure 9 shows that almost all the unpotable water samples were found in the Eocene Aquifer (20% with E-PoGWQG). Moreover, the Alluvium Aquifer was dominated by unpalatable water (100% with E-PaGWQG). This contamination could be related to the unconfined character of the aquifers. Indeed, unconfined aquifers are vulnerable to contamination due to their direct connection with the ground surface [48]. Other aquifers were almost free of water contamination.

All E-PoGWQG and E-PaGWQG samples were found in shallow wells (Below 250 m). Deeper wells were more potable and palatable. This observation indicates that well depth and groundwater contamination were negatively proportional. Various research works confirmed and discussed this negative outcome [48]. On-ground contaminants are easily infiltrated and leached to the shallow wells, whereas deep wells are more protected [2]. Infiltrated contaminated water follows mixing processes through its way to deep wells. Moreover, both microorganisms and soil particles degrade and filtrate contaminants before leaching into the deep wells [2].

Wells with D and E-PoGWQGs were located in areas with high average annual long-term rainfall (above 400 mm). A relatively high recharge rate characterizes those areas. Therefore, contaminants are infiltrating and leaching groundwater more easily [2]. Moreover, high rainfall could cause contaminants' wet deposition (e.g., NO_3) that reaches the ground surface and leaches to groundwater [2]. By contrast, unpalatable groundwater was found under rainfall-poor areas (mainly below 200 mm). However, those areas were located in the West Bank's eastern coastal and directly affected by the Dead Sea salinity.

The relative importance of the different factors affecting PoGWQI and PaGWQI was estimated using RFA (See Figure 10). Results showed that factors' relative importance concerning PoGWQI deviated more compared to PaGWQI. Wells' depths and land-use had the main influence on PoGWQI with a relative importance of about 35% and 22%, respectively. This result reflects the high vulnerability of shallow wells to NO_3 and FC contamination (specifically in urban areas). Both contaminants can directly reach shallow wells through wastewater seepage from cesspits.

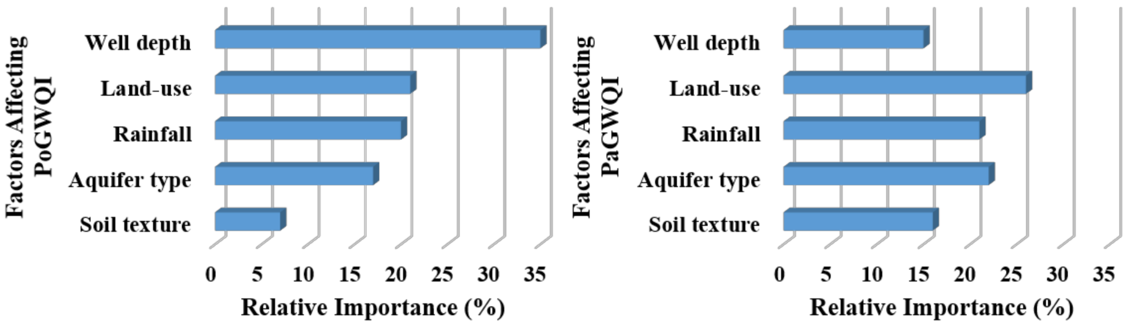

Figure 10. Relative importance analysis for the main factors affecting PoGWQI and PaGWQI.

On the other hand, all factors have a close relative influence (15–25%) on PaGWQI estimation. This influence could be referred to as the multi-causes for the high values in PaGWQI input parameters. These unaccepted values in some of the input parameters, such as (pH, TDS, and HCO_3) are caused by human activities (associated with land use), aquifer, or soil characteristics (e.g., mineralized formations).

5. Conclusions

An adjusted weighted arithmetic water quality index method (AWAWQIM) was proposed in this research to assess the groundwater quality in the West Bank. This enhances the conventional WAWQIM method by considering the experts' opinions through a close-ended questionnaire and SWARA method. AWAWQIM, GIS, and KIM were combined for the first time for the spatiotemporal mapping of PoGWQI and PaGWQI. This combination enabled an in-depth analysis of groundwater contamination, its causes, and potential consequences. Results showed that (i) around 5% of the wells in the West Bank had experienced potability-related contamination, (ii) deep wells had better PoGWQI and PaGWQI than shallow ones, (iii) water contamination was observed in areas with improper practices such as the use of cesspits, fertilizers, and pesticides. The protection of water resources in these areas requires urgent intervention to reduce (i) wastewater infiltration by installing sanitation systems, septic tanks, and sealed cesspits, and (ii) the use of chemicals and pesticides in areas impacting the groundwater resources.

The proposed method is relevant for decision-makers. It allows a large-scale scan of the water quality to be conducted as a first step to developing a strategy to protect water resources. The proposed method could be combined with other water-quality control methods to control the water quality.

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