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Assessment of Groundwater Quality Using Multivariate and Spatial Analysis in Gaza, Palestine

تقييم جودة المياه باستخدام التحليل المتعدد المتغيرات والتحليل المكاني في غزة فلسطين

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Abstract

Gaza strip suffers from the deterioration of ground water in both quality and quantity. Groundwater is one of the most precious natural resources in the Gaza Strip as it is the only source of drinking water for the majority of the population. This study assessed the quality of groundwater resources in Gaza governorate, using multivariate and spatial analysis. R Mode Factor analysis was used to extract factors that control the groundwater quality in the study area where as Cluster analysis was adopted to detect spatial similarities among sampling sites. The R mode factor analysis revealed three dominant factors, affecting the hydrochemistry of water. The biggest main factor with 64 % of variance indicates that the contamination of groundwater was mainly influenced by seawater intrusion. The cluster analysis distinguished three main spatial clusters from the data with most values exceeded the guidelines of the World Health Organization (WHO) at different levels for each cluster. The value of the Ground Water Quality Index ranged from 43 % and 63 %, indicating that the overall quality of the water in the study area was extremely low. The present study recommends the use of Geographical information system (GIS) and its applications in generating maps to reveal the deteriorating groundwater condition to the governorate.

Keywords: Ground water, Multivariate, spatial analysis, Water Quality Index.

ملخص

يعاني قطاع غزة من تدهور في المياه الجوفية من حيث الجودة والكمية، المياه الجوفية في القطاع هي احدى أغلى المصادر الطبيعية لأنها المصدر الوحيد لمياه الشرب في القطاع بالنسبة لغالبية السكان في الوقت الحاضر هنالك أزمة مياه في القطاع، تلوث المياه الجوفية أصبح مصدر قلق كبير في السنوات الأخيرة. هذا الدراسة عملت على إجراء تقييم شامل لجودة المياه الجوفية في قطاع غزة وذلك باستخدام تحليل متعدد المتغيرات والتحليل المكاني. التقييم يبدأ باستخدام التحليل العاملي لاستخراج العوامل ومن ثم استخدام التحليل العنقودي للكشف عن التشابه المكاني لمواقع الآبار وأخيراً تم استخدام تقنيات نظم المعلومات الجغرافية لعمل مؤشر لجودة المياه الجوفية يعمل على تصنيف المياه الجوفية بطريقة شاملة وبشكل واضح ويسهل فهمه. التحليل العاملي كشف ثلاثة عوامل مهيمنة تؤثر على جودة المياه وأكبر عامل وبنسبة 64% يرجع إلى تسرب مياه البحر إلى خزان المياه الجوفية، التحليل العنقودي ميز وجود ثلاث مجموعات للآبار، كل هذه المجموعات لديها قيم تحليل الجودة أعلى من القيم الإرشادية لمنظمة الصحة العالمية ولكن بمستويات مختلفة تبعا لكل مجموعة. انحصرت قيمة مؤشر جودة المياه بين 43% و63% وهذا يدل على أن جودة المياه في منطقة الدراسة منخفضة بشكل كبير والنطاق الضيق للمؤشر يدل على أنه لا خلاف جوهري بين منطقة وأخرى. من أهم التوصيات لهذه الدراسة هي استخدام أدوات وتطبيقات نظم المعلومات الجغرافية من أجل إعداد خرائط توضيحية لإيصال ومخاطبة العالم حول وضع المياه المتدهور في منطقة الدراسة وكذلك الحث على استخدام مؤشرات جودة المياه سواء بطريقة يدوية أو تلقائية من أجل فهم الجودة الكلية للمياه.

كلمات مفتاحية: المياه الجوفية، تحليل متعدد المتغيرات، التحليل المكاني، مؤشر جودة المياه.

1. Introduction

Groundwater is one of the most precious natural resources in the Gaza Strip as it is the only source of drinking water for the majority of the population. Groundwater contamination has become a major concern in the recent years. Groundwater aquifer is considered the main and the only water supply source for all kinds of human usage in Gaza Strip (domestic, agricultural and industrial).

The low level of rainfall, growing urban areas, decrease the recharge of the aquifer quantity and increasing population are main reasons of deterioration of the ground water.

The concept of water quality is complex because it depends on many factors. In particular, this concept is intrinsically tied to the different intended usages of the water; as different uses require different criteria. Water quality is one of the most important factors that must be considered when evaluating the sustainable development of a given region (Cordoba *et al.*, 2010, p.1049).

The multivariate statistical techniques are the appropriate tools for the interpretation of multi constituent chemical and physical measurements. The multivariate techniques have been widely used as unbiased methods for the analysis of water quality data to draw meaningful conclusions (Yilmaz *et al.* 2010, p.1). These methods have been employed to extract significant information from hydrochemical datasets in compound systems (Chenini I & Khemiri S., 2009, p.509). The necessity and usefulness of multivariate statistical techniques for evaluation and interpretation of large complex data sets with a view to get better information about water quality and design of monitoring network for effective management of water resources.

The application of different multivariate statistical techniques helps in the interpretation of complex data matrices for a better understanding of water quality and ecological status of the study region. These techniques allow the identification of the possible sources of pollution that influence water systems and offer a valuable tool for reliable management of water resources (Kazi *et al.* 2009, p.301).

Indicators and indices of the condition of the environment are used to summarize a multitude of attributes thereby providing decision makers with an integrated and more informative overview than would otherwise be attainable (Smajgl *et al.* 2010, p.1). Unlike water quantity, which can be expressed in precise terms, water quality is a multi-parameter attribute. The utility of water quality index (WQI) relies on the aggregation of information about water-quality parameters at different times and in different places and translating this information into a single score that represents the time period and the spatial unit under consideration (Terrado *et al*. 2010, p.1). In (Bengraine K & Marhaba T., 2003, p.179) study, Chemical, biological and physical data monitored at 12 locations along the Passaic River, New Jersey, during the year 1998 are analyzed. Principal component analysis (PCA) was used: (i) to extract the factors associated with the hydrochemistry variability; (ii) to obtain the spatial and temporal changes in the water quality. Solute content, temperature, nutrients and organics were the main patterns extracted. The spatial analysis isolated two stations showing a possible point or non-point source of pollution. The study shows the importance of environmental monitoring associated with simple powerful statistics to better understand a complex water system.

(Zhou *et al*. 2007, p.1), demonstrated that the multivariate statistical methods are useful for interpreting complex data sets in the analysis of temporal and spatial variations in water quality and the optimization of regional water quality monitoring network.

(Irabor *et al.* 2008, p.666) subjected the chemical data set to Principal Component Analysis (PCA)/Factor Analysis (FA) and Hierarchic Cluster Analysis (HCA). The aim of this study was to determine the nature and spatial distribution of chemical pollutants in surface and groundwater in the western Niger Delta region.

This research used multivariate and spatial techniques to assess groundwater quality in Gaza governorate. Factor analysis was used to extract factors that control the groundwater quality in the study area. Also, the research developed a robust water quality index - weighted for the essential parameters in domestic water quality assessment to classify groundwater in the study area into spatial water quality types.

1.1 Objectives

This research focuses on providing all the concerned stakeholders with clear and comprehensive perspective regarding the overall groundwater quality. The objectives of this research are:

- To determine and rank the sources of variation in the hydrochemistry of Gaza wells.
- To identify groups or clusters of similar sites of Gaza wells on the basis of similarities within a class and dissimilarities between different classes.
- To develop a robust water quality index (WQI) weighted for the essential parameters in domestic water quality assessment.

1.2 Study area

Gaza Governorate as shown in Figure (1) is a part of the Gaza strip was divided into five Governorates: North, Gaza, Middle, Khan Younis and Rafah. Gaza Strip area is part of Palestine. It is a narrow, low-lying stretch of sand dunes bordering the Mediterranean Sea. It forms the foreshore that slopes gently up to an elevation of 105 m. It is a small area of about 365 km2 located at the eastern coast of the Mediterranean, about 35 km long and between 6 and 12 km wide. The Gaza Strip forms a transitional zone between the semi-humid coastal area in the north and the semi-arid Sinai desert in the south. The area consists of a littoral zone, a strip of dunes from the Quaternary era situated on the top of a system of older Pleistocene beach ridge, and more to the east, gently sloping alluvial and loess plains. The climate in the area is typical of that of the eastern Mediterranean with mild wet winters and hot dry summers. Monthly average temperature reaches a maximum of 35^{o} C and a minimum of 4^{o} C. Gaza Governorate occupies an area of 73.35 km^2, and its population was estimated at 507,448 people. It comprises Gaza City, the main city in Gaza Strip and one of the main refugee camps which is Beach Camp (PCBS, 2014).

Figure (1): Gaza Governorate area.

1.3 Domestic wells in Gaza Governorate

The wells considered in this research in Gaza governorate are shown in Figure (2) below which includes 52 domestic wells in Gaza governorate.

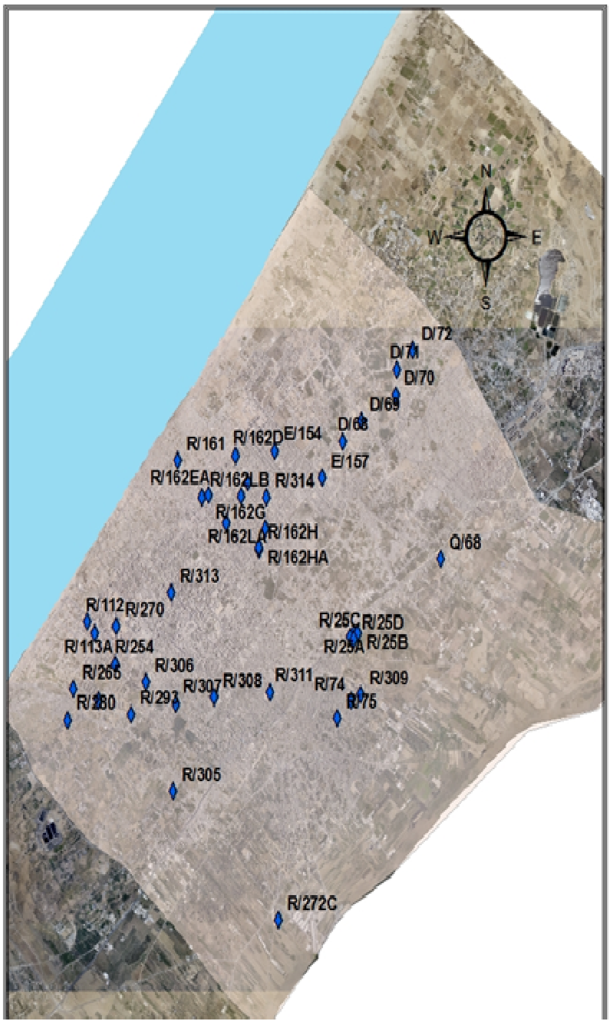

Figure (2): Selected domestic wells in the study area.

2. Methodology

In order to achieve the objectives of this research, which aim to conduct assessment of the quality of groundwater resource in Gaza governorate using Geographic Information Systems (GIS) analysis multivariate techniques, the following steps was implemented and Figure (3) shows the flowchart of the methods used in this research.

2.1. Data Collection and processing

Water quality Data was obtained from the Gaza municipality and Palestinian Water Authority (PWA). Some needed data were collected from the published reports of related institutions. The collected data for the 52 domestic wells for the year 2009 is checked and interpolation was used to estimate the missing data. The collected data were for the following parameters: electrical conductivity (EC) ,total dissolved solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl), Nitrate (NO_3), Sulfate (SO_4), Alkalinity and hardness. The mean value were took for each quality parameter in the 52 wells for the sporadic measurement of (PWA) taken in 2009.

2.2. Check of Normality

After checking data normality, the data was not normally distributed, data transformation was needed, so that the next statistical tests can be done, different transformation models were used to normalize the data, and the log transformation of data gives the best results, which is preferred for optimal results and reliable interpretations of the results, (Yidana et al., 2010, p. 220).

Data was standardized to have a zero mean and a variance of 1. The equation below used for this purpose:

$$\mathbf{Z} = \underline{x \quad \mu} \qquad (1)$$

Where: x is the data;μ is the mean; s is the standard deviation of the datasets.

2.3. R mode Factor Analysis

R mode Factor Analysis was also applied to the data to determine and rank the sources of variation in the hydrochemistry. In the factor analysis, 'principal components' was selected as the solution method. The total number of factors generated from a typical factor analysis indicates the total number of possible sources of variation in the data. The first factor or component has the highest eigenvector sum and represents the most important source of variation in the data. The last factor is the least important process contributing to the chemical variation. R mode Factor Analysis was done using Statistical Package for the Social Sciences (SPSS) release 15.

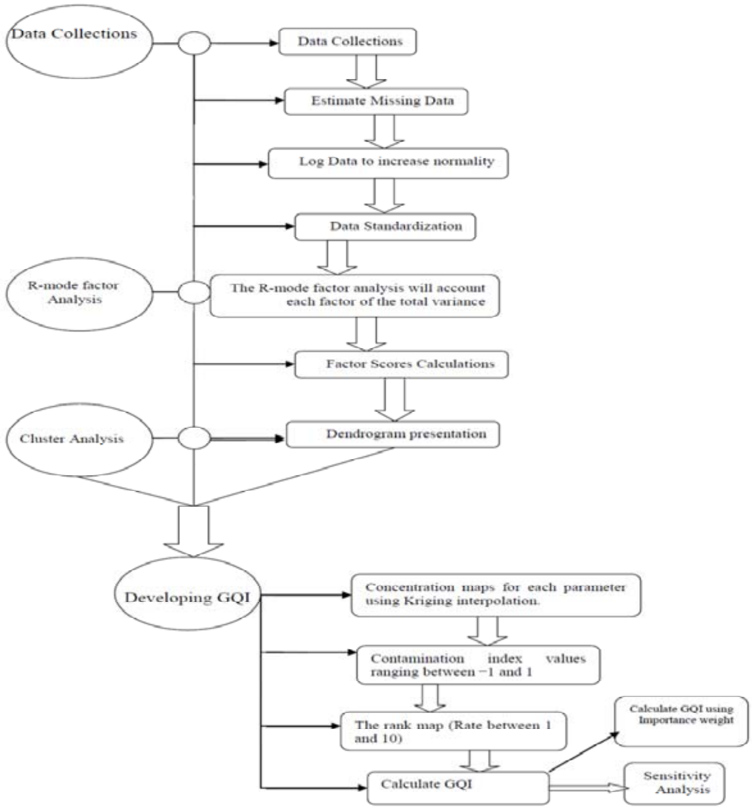

Figure (3): Chart of methodology**.**

2.4. Cluster Analysis

Hierarchical cluster analysis (HCA) is the most popular method of cluster analysis. It divides datasets into hierarchies based on similarity or dissimilarities in the field. In this study, the Q-mode HCA groups of wells locations into clusters. The method used for clustering is Squared Euclidean Distance which is the distance between two wells, x and y, is the sum of the squared differences between the values for the items.

$$\textbf{Squared Euclidean Distance } (x,y) = \Sigma_i (x_i - y_i)^2 \qquad (2)$$

The HCA resulted in a dendrogram, which is a presentation of the groundwater associations in the area. Samples with similar spatial characteristics and relationships are clustered together at low linkage distances, whilst dissimilar samples are linked at higher linkage distances. Cluster analysis and dendrogram were done by using (SPSS) release 15.

2.5. Developing Water Quality Index

Water quality index was developed using (Babiker *et al*. 2007, p.699) method. The following sub-sections summarise the steps used to formulate the WQI. All the steps were conducted using ESRI ArcMap 9.3: First, concentration maps representing the "primary map I" were constructed for each parameter from the point data using Kriging interpolation. The parameters used the ones which have WHO guidelines.Second, in order to relate the data to universal norm, the measured concentration, X′, of every pixel in the "primary map I" was related to its desired WHO standard value, X, using a normalized difference index:

$$C = (X' - X) / (X' + X) \qquad (3)$$

The normalized difference index used here provides fixed upper and lower limits for the contamination level. Table (1) shows the WHO guideline for the parameters used in the index.

Table (1): WHO Guidelines for drinking water, WHO (2011).

Parameter	WHO Guideline (mg/l)
TDS	600
Cl	250
Na	200
SO4	250
NO3	50
Hardness	500

Third, the contamination index (primary map II) was then rated between 1 and 10 to generate the “rank map”. Rank 1 indicates minimum impact on groundwater quality while Rank 10 indicates maximum impact. The following polynomial function was used to rank the contamination level

$$\mathbf{r = 0.5 * C^2 + 4.5 * C + 5} \quad (4)$$

C stands for the contamination index value for each pixel, r stands for the corresponding rank value.

Finally, the GQI(Ground Quality Index) is calculated as follows:

$$\mathbf{GQI = 100 - ((r_1w_1 + r_2w_2 + \ldots + r_nw_n) / N)} \quad (5)$$

Where r stands for the rate of the rank map (1–10); w stands for the relative weight of the parameter which corresponds to the “mean” rating value (r) of each rank map (1–10) and to the “mean r + 2” ($r \leq 8$) in the case of parameters that have potential health effects (e.g. nitrate); and N is the total number of parameters used in the suitability analyses.

The “100” in the first part of the formula was incorporated to directly project the GQI value such that high index values close to 100 reflect high water quality and index values far below 100 (close to 1) indicate low water quality.

2.6. Computing WQI using water importance weight

In order to validate the results from the above methodology, it is important to calculate GQI using a different approach. So, interpolation maps and equations above are used to compute GQI but by using water quality parameters importance which is put by water quality experts, weights was put from 1 to 10 to express how this water parameter is important in general water quality and the most factor affect the parameter is health aspects. Parameters importance used in this research is the same as in (Shivasharanappa *et al*. 2011, p.2). These values are very close in other papers and it is the same as in (Ramakrishnaiah et al., 2009, p.523). The parameter importance ranges from 1 to 10, as seen in Table (2). NO_3 has the highest importance weight as expected due to its significant adverse effect.

Table (2): importance weight for water quality parameters.

Parameter	Weight
TDS	8
Cl	6
Na	4
SO_4	8
NO_3	10
Hardness	6

2.7. The Sensitivity Analysis

Map removal sensitivity tests the sensitivity of the output index to the removal of one or more of the rank maps from the analyses expressed in terms of a variation index:

$$V(\%) = (|GQI_p - GQI'_p| / GQI_p) * 100 \qquad (6)$$

Where V (%) is the variation index, GQIp and GQI′p are the unperturbed and perturbed ground water quality indexes respectively, and GQI′p is the water quality index when removing one parameter each time.

3. Results and discussion

3.1. Results of Factor Analysis

3.1.1. Pretests

KMO (Kaiser-Meyer_Olkin Measure of Sampling Adequacy) is an index for comparing the magnitude of the observed correlation coefficients to the magnitude of the partial correlation coefficients. (Williams et al. 2012, p.1). The Closer the KMO measure to 1 indicate a sizeable sampling adequacy (0.8 and higher are great, 0.7 is acceptable, 0.6 is mediocre, less than 0.5 is unacceptable). Reasonably large values are needed for a good factor analysis. Small KMO values indicate that a factor analysis of the variables may not be a good idea.

Table (3) KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.758
Bartlett's Test of Sphericity	Approx. Chi-Square	1235.335
	df	66
	Sig.	.000

Since the measure in Table (3) is 0.758, the sampling size is adequate and the correlation between parameters is generally accepted.

Principal component analysis requires that the probability associated with Bartlett's Test of sphericity be less than the level of significance. The probability associated with the Bartlett test (Sig = 0) is <0.001, which satisfies this requirement.

Communalities represent the proportion of the variance in the original variables that is accounted for the factor solution. The factor solution should explain at least half of each original variable's variance, so the communality value for each variable should be 0.50 or higher.

Since the communality for pH equal 0.248 in Table (4) and is below 0.5 so this parameter was removed from the next iteration of the factor analysis test.

Table (4) Communalities

	Initial	Extraction
EC	1.000	.986
TDS	1.000	.868
PH	1.000	.248
calcium	1.000	.928
magnisum	1.000	.945
Sodium	1.000	.968
Potassium	1.000	.719
Chloride	1.000	.973
Nitrate	1.000	.799
Sulphate	1.000	.906
Alkalinity	1.000	.890
Hardness	1.000	.957

Extraction Method: Principal Component Analysis.

In Table (5), after the pH removal, the measure of adequacy is 0.78 so this indicates that the sampling size is adequate and the correlation between parameters is generally accepted.

Table (5) KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.780
Bartlett's Test of Sphericity	Approx. Chi-Square	1203.087
	df	55
	Sig.	.000

Then in Table (6) All the Communalities are above 0.5 so it is accepted. So from the checks above for iteration two it is clear that reliable result of the test is obtained so it will be valid with the results shown in this research.

Table (6) Communalities

	Initial	Extraction
EC	1.000	.986
TDS	1.000	.869
calcium	1.000	.948
magnisum	1.000	.960
Sodium	1.000	.970
Potassium	1.000	.720
Chloride	1.000	.973
Nitrate	1.000	.800
Sulphate	1.000	.920
Alkalinity	1.000	.904
Hardness	1.000	.974

Extraction Method: Principal Component Analysis.

3.1.2. Factors extraction

The examination of the Scree plot shown in Figure (4) provides a visual of the total variance associated with each factor, the steep slope shows the biggest factors.

It is clear from figure (4) that there are three dominant factors of the total variance of the hydrochemistry of water.

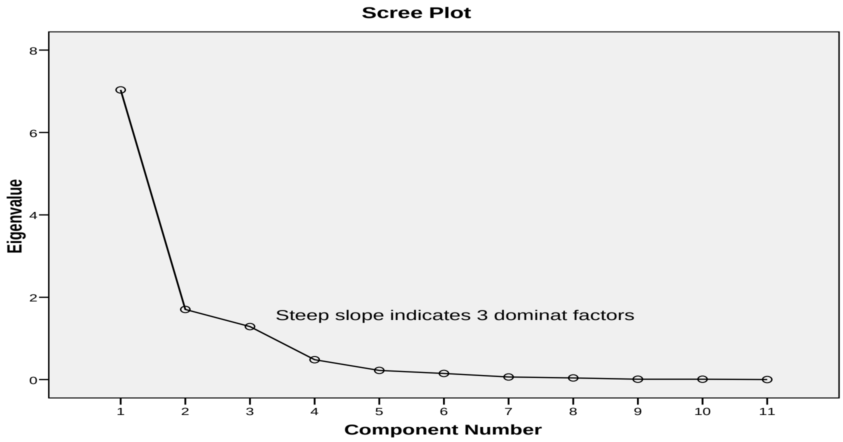

Figure (4): Scree plot.

The R-mode factor analysis resulted in three factors accounting for 91.1 % of the total variance in the hydrochemistry of the study area as shown in Table (7). Factor one accounted for about 63.9 %, Factor two accounted for about 15.48 %, Factor three accounted for about 11.7 %.

Table (7) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.034	63.948	63.948	7.034	63.948	63.948
2	1.703	15.481	79.429	1.703	15.481	79.429
3	1.287	11.700	91.129	1.287	11.700	91.129
4	.484	4.400	95.530			
5	.224	2.034	97.564			
6	.148	1.348	98.912			
7	.064	.584	99.496			
8	.039	.356	99.852			
9	.008	.075	99.927			
10	.008	.072	99.999			
11	.000	.001	100.000			

Extraction Method: Principal Component Analysis.

Table (8) presents the loading of each variable under each of the three factors. The first factor which accounts for about 64% of the variance has high positive loadings for EC, TDS, Ca, Mg, Na, Cl, SO_4 and the hardness could be related due to seawater intrusion.

The Second factor accounts for about 15% in the hydrochemistry and has high positive loading for Alkalinity. This factor could be related to alkalinity of groundwater due to bicarbonate ions.

The third factor accounts for about 12% in the hydrochemistry and has high positive loadings for NO3 and K, this could be related to domestic waste and agricultural activities.

Table (8) Component Matrix [a]

	Component		
	1	2	3
EC	.973	.178	-.090
TDS	.912	.099	-.164
calcium	.872	-.434	.002
magnisum	.902	-.380	.036
Sodium	.894	.392	-.129
Potassium	.587	.076	.608
Chloride	.958	.167	-.164
Nitrate	.242	-.227	.831
Sulphate	.869	.390	-.114
Alkalinity	-.016	.877	.366
Hardness	.898	-.409	.025

a. 3 components extracted.

3.2. Results of Cluster analysis

3.2.1. Dendrogram

Three main spatial Clusters were distinguished from the Cluster analysis of data in the study area. Figure (5) presents the dendrogram from the HCA. Table (9) shows the average of parameters for each Cluster.

Table (9): The average concentration for each Cluster.

Parameter	Cluster No.		
	Cluster 1	**Cluster 2**	**Cluster 3**
EC	3146.8	11875.0	1194.6
TDS	2147.1	7362.5	742.5
Cl	679.9	3568.8	187.2
Hardness	560.5	2308.8	379.1
Na	442.5	1636.3	113.8
Alkalinity	416.2	285.6	289.6
SO_4	167.0	704.6	43.5
NO_3	152.9	153.1	101.5
Ca	112.8	475.4	77.8
Mg	67.5	272.1	44.7
K	9.8	16.4	3.9
pH	7.4	6.8	7.1

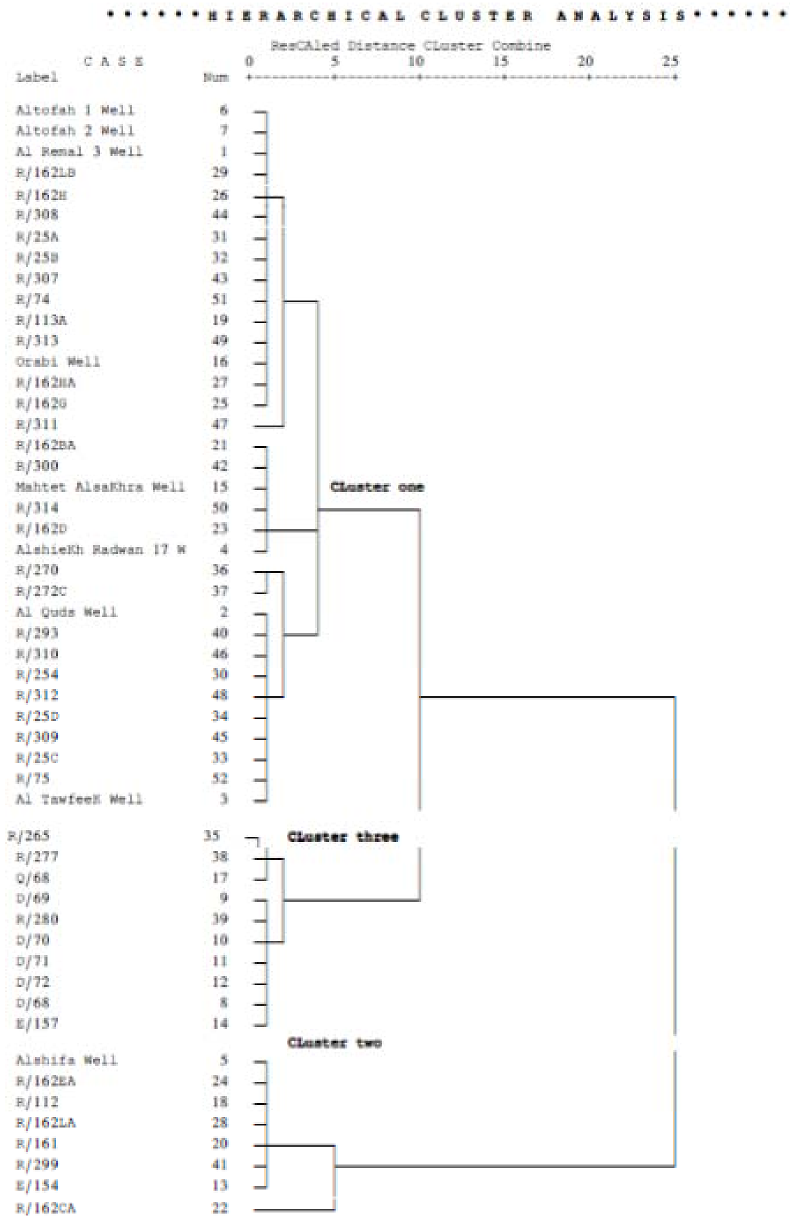

Figure (5): Dendrogram shows three Clusters.

From Table (9) it can be noted that the 34 well in Cluster one have extremely high concentration values, and highly exceeded the WHO guidelines. Also it can be noted that the 8 wells in Cluster two have the extremist concentrations and the most contaminant wells, so it is too far from the WHO Guidelines. However, the 10 wells in Cluster three have values around or a little above the WHO guidelines except for the NO3 which is extremely high and far from the WHO guidelines in the three Clusters.

3.2.2. Schoeller Diagram for the three Clusters

Since choosing the number of Clusters in Cluster analysis is subjective so we used this diagram to help us to choose the best number of Clusters. From Schoeller Diagram shown in Figure (6), three Clusters were the best choice.

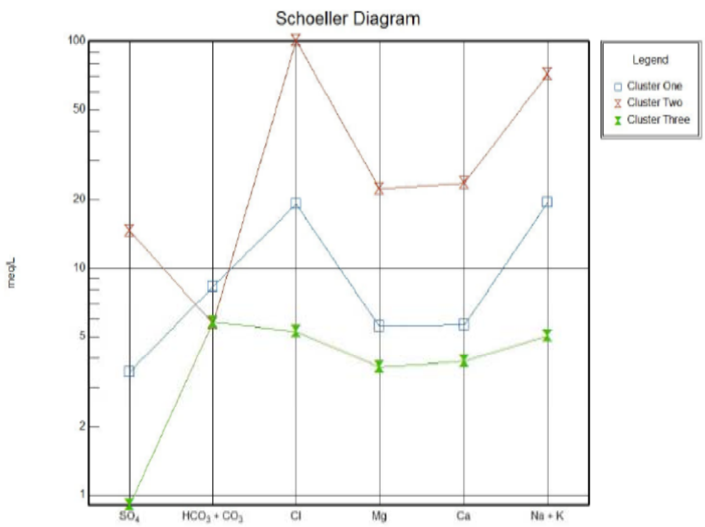

Figure (6): Schoeller Diagram for the three Clusters.

It is seen that Cluster 2 has the highest values for cations and anions, cluster 3 has the lowest values, cluster two has values between cluster one and cluster three.

3.2.3. Stiff Diagram

In this research, the average concentration of the major ions was used to describe the different groundwater associations depicted by the three different clusters.

Stiff diagrams of cluster one and two in Figures (7) and (8) show that the Na cation is the highest among the cations whilst the CL is the predominant anion. This means that the most predominant water type in cluster two is the Na–Cl water type. In cluster three in Figure (9), the Na cation is the highest among the cations but the HCO_3 is the predominant anion. This means that the most predominant water type in cluster 3 is Na-HCO_3. Water in cluster 3 is the least saline water of the three clusters.

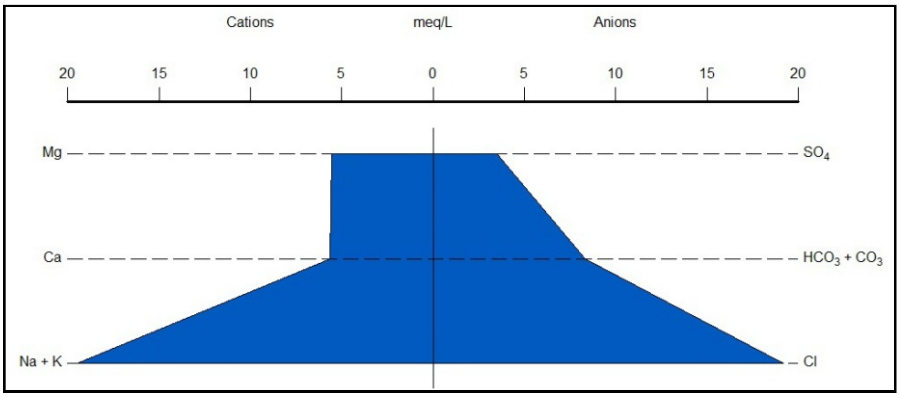

Figure (7): Stiff diagram for Cluster one.

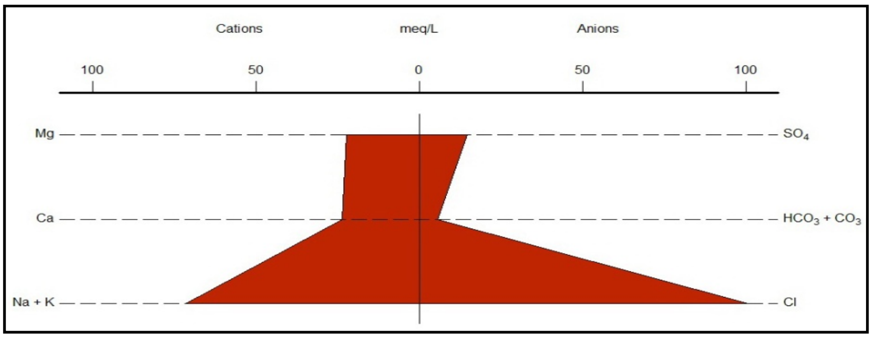

Figure (8): Stiff diagram for Cluster two.

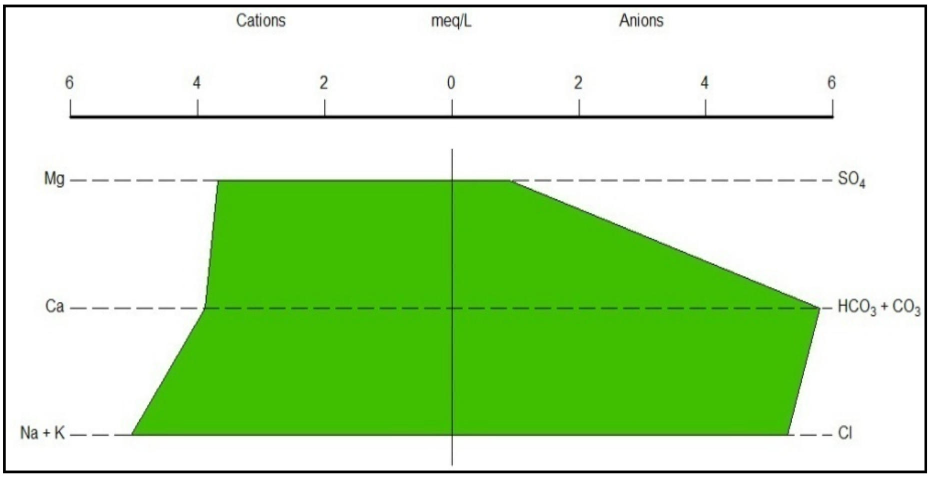

Figure (9): Stiff diagram for Cluster three.

3.3. Results of water Quality Index

Figure (10) presents the interpolation maps for the parameters which used in calculating Water Quality Index (WQI). It is noticed that concentrations increases as the area is close to shoreline, decreases in the north, and increases at it goes south. Interpolation maps show clearly that most of the area exceeded the WHO guidelines.

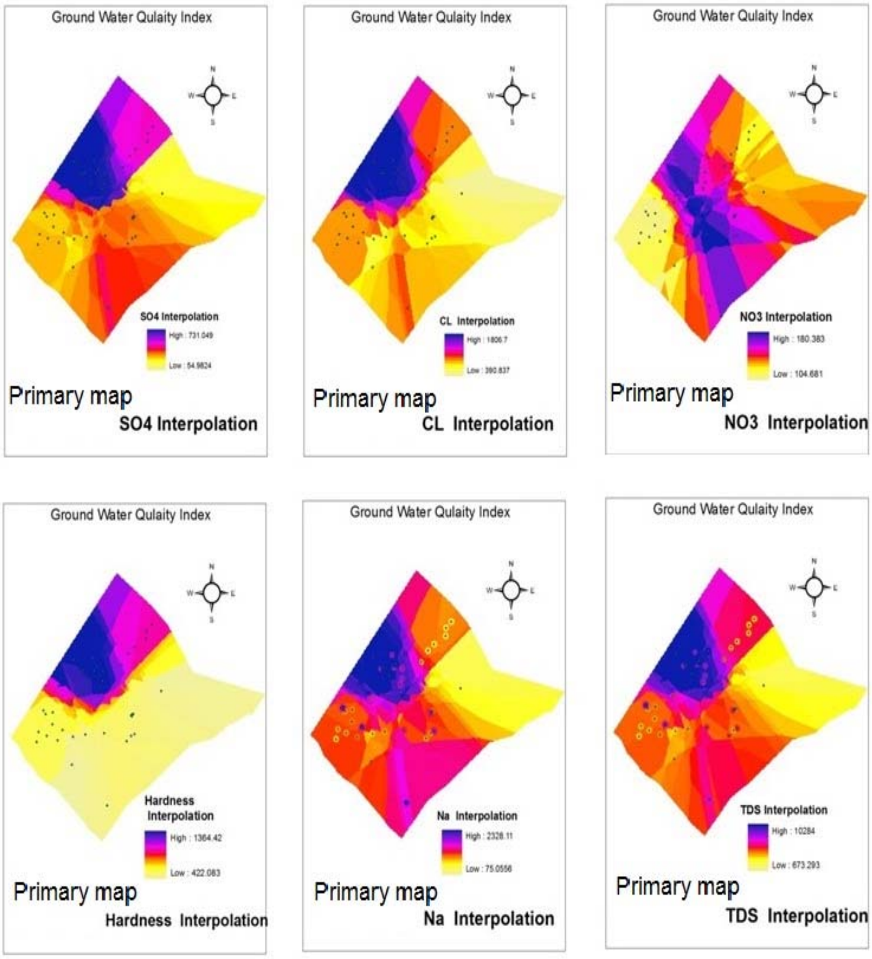

Figure (10): Interpolation maps for parameters (primary map I).

The statistics in Table (10) of the six rank maps (parameters) used to compute the WQI. Table (10) indicates that parameters such as TDS (7.62), Cl (7.4), NO_3 (7.23) and Na (6.75) have high mean rank values. This means that these parameters indicate a significant impact on groundwater quality. Hardness and SO_4 also have the significant impact but less than the four parameters which mentioned first.

Table (10): Summary of statistics of the rank maps.

Parameter	Min	Max	mean	SD
TDS	5.26	9.40	7.62	0.53
Cl	6.01	8.69	7.40	0.63
Na	3.06	9.14	6.75	0.69
SO_4	2.33	7.33	4.53	0.77
NO_3	6.65	7.71	7.23	0.21
Hardness	4.62	7.19	5.47	0.83

3.3.1 Groundwater Quality Index

From Figure (11, left) of the GQI, the index is between 43 % and 63 %. This indicates that the quality of the water in the study area was extremely low. This narrow range of the indicator shows that the quality in the area is close to each other in its low. This index shows that two gradients of groundwater quality can be observed in the study area. These two areas are: the first area is near to the shoreline and the second area is next of the first area. The first area near to the shoreline is lower than the second area in the quality. This is an expected result since the seawater intrusion factor has 64% variance effected of the water quality. The second area is obviously higher quality than the first area in the narrow range as mentioned above, the north of the area has the best quality in the study area and the quality decrease as it goes south. The index shows also that the area of the beach camp is the worst in the index due to its nearness to the sea and the effect of the seawater intrusion. From the overall study area it is clear that the middle of the area is relatively worse than the quality of the sides of the area.

3.4 Water quality index using water quality importance weight

When the WQI is calculated using the expert opinions about the importance weight of the parameters which used in calculating the WQI. In Figure (11, right), Values of the index are between 63.6 and 43.2. The result of the original index above is between 63.2 and 43.5. This gives good impression and reputation because the results are nearly the same value, which gives an indication of perfect water quality index, appeared in this research.

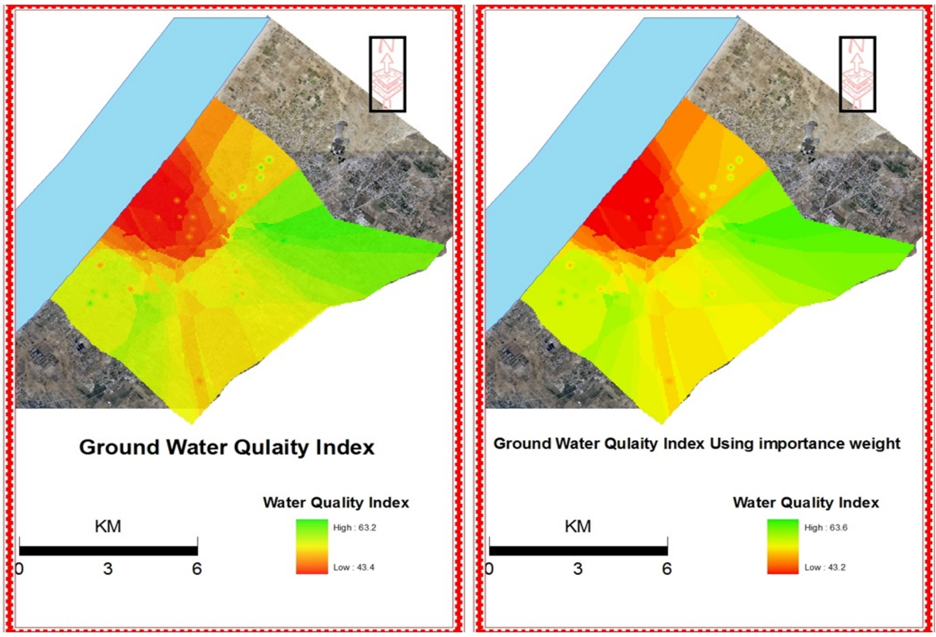

Figure (11): Water Quality Index using two approaches.

3.5 Results of sensitivity analysis

The removal of each parameter from the computation in Table (11) seems to cause close and high variations for SO_4 and NO_3 and little lower for hardness; NO_3 has high mean rank and high variation index when removed. So NO_3 is the most important and the most affected parameter and can be used for the assessment of water quality.

SO_4 and NO_3 have relative lower mean rank values but have high variations index when they are removed. In contrast, Na has high mean rank value but a low variation index. This ensures that these parameters are desired to be among the parameters used in the computation of the index. In general, it is obvious that the GQI was rather insensitive to the removal of any of the input parameter maps probably because the index was generated by averaging. This ensures the stability of the index and the comparability of the results from different locations using different data sets.

Table (11): Statistics of Variation Index (%).

Parameter Removed	Min	Max	mean	SD
TDS	0.53	7.52	**4.52**	0.54
Cl	1.75	5.83	**3.30**	0.71
Na	0.00	5.91	**0.60**	0.42
SO_4	6.06	12.41	**9.42**	0.74
NO_3	5.17	9.52	**7.65**	0.76
Hardness	1.29	8.68	**5.94**	0.94

4. Conclusions

- Gaza Governorate suffers from the deteriorating in both of quality and quantity of the groundwater which is the only source of drinking water in the area.
- Three factors affect the hydrochemistry of groundwater of Gaza governorate, the most important factor with 64% could be due to the sea water intrusion into groundwater, the second factor with 15% could be due to the existence of bicarbonate ions in the water, the third factor with 12% could be due to wastewater and agriculture activities.
- The wells in the study area can be categorized according to the parameters of water quality into three groups (clusters), the three groups exceeded the WHO guidelines but in different levels except for the NO3 which is extremely high and far from the WHO guidelines in the three clusters.

- The most predominant water type in the study area is the NA–CL water, while some locations have NA-HCO3 water type.
- Water Quality Index indicates clearly that the parameters TDS, CL , NO3 and NA have high mean rank value, This means that these parameters indicates significant impact on groundwater quality. Hardness and SO4 also have significant impact but less than the four parameters mentioned first.
- So4 and No3 have relative lower mean rank values but have high variations index when it is removed. In contrast Na has high mean rank value but low variation index, this ensure that these parameters is desired to be of the parameters used in the computation of the index.
- The multivariate statistical techniques such as cluster analysis and factor analysis, has been approved in this study to an intelligent methods in analysis of water quality data for drawing meaningful information.
- Water quality index has been approved in this study to be user friendly, easy communication tool and more trustful as it express about the water quality for composite of parameters not for isolated one.

5. Recommendations

- The overall quality of groundwater is low and this situation needs urgent and strategic solutions.
- As sea water intrusion has the highest effect on groundwater quality, short term and long term solutions must be implemented in order to reduce this effect, over pumping from the aquifer should stop through water conservation and providing additional water sources to satisfy the domestic demands of Gaza. These additional sources could include desalination and imports from other areas.
- Programs should be implemented to monitor the wells exceeded the WHO guidelines especially in cluster two which is highly exceeded

the WHO guidelines.

- Since domestic waste and agricultural activities has factor effect in the hydrochemistry, it is an important issue to: Complete and improve the sanitation services in the governorate and implement Monitoring programs to ensure the proper use in of fertilizers and pesticides.
- Since the area near to the shoreline is the most contaminant area so this area should benefit as the first priority from any desalination project.
- Since the parameters TDS, Cl, Na ,SO4 ,NO3 and Hardness have high mean rank value and have significant spatial variability imply larger impacts on the GQI ,so it and must be carefully and accurately mapped.
- Water quality indexes should be used in automated or manual way in order to understand the overall water quality and the trends the quality tends to.
- It is highly recommended to use GIS tools and its application to produce maps to communicate our tragic water situation in the governorate.

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