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Groundwater Quality Evaluation for Irrigation Suitable Using Geostatistical Algorithms

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Abstract

The groundwater is the primary source for irrigation and other purposes in the Gaza Strip. The low irrigational water quality effects on the soil quality, which interrupts the growth of plants impacting agricultural yield and can cause risk to human health. Thus, it is essential to evaluate the water quality for irrigation uses. Therefore, it is a need to understand irrigation water quality better. This study mainly focuses on the assessment of the suitability of water for irrigation. Water quality indices, known as sodium adsorption ratio, exchangeable sodium per cent (SSP or %Na), residual sodium carbonate (RSC), Kelly's rate (KR), permeability index (PI), chloroalkaline indices (CAI1 and CAI2), potential salinity (PS), magnesium hazard (MH), total dissolved solids (TDS) and total hardness (TH), have been calculated for several wells. The majority of the wells are falling under the wrong category of water for irrigation purposes.

Keywords: Irrigation indices, Sodium adsorption ratio, Wilcox diagram, Geostatistical modeling, Kriging.

1. Introduction

Groundwater has turned out the primary source of water utilized in the agricultural activities in many countries where river and drainage systems have not adequate. Therefore, low groundwater quality for irrigation activities has a matter of anxiety in recent years. Under over chemical pesticides and fertilization have caused in groundwater pollution (Nemčić-Jurec, Singh, Jazbec, Gautam, & Kovač, 2019). Groundwater quality-related on the nature of recharging water, rainfall, subsurface and surface water and hydro-geochemical procedures in aquifers (Das, Munoz-Arriola, Singh, Jha, & Kumar, 2017), land use and land cover modification, mining performances, temporal modification in the constitution and sources of the water recharged. Human activities frequently result in periodic changes in groundwater quality (Rawat, Singh, & Gautam, 2018).

Groundwater quality reduction depended on, firstly, geochemical reactions in the aquifers and soils and, secondly, the time when it has supplied through undue canals for irrigation. Therefore, it is vital to execute a regular evaluation of irrigation and drinking water quality (Gautam, Evangelos, Singh, Tripathi, & Singh, 2018). Irrigation needs suitable water supplying of utilized quality. Index depended on composition and concentration of dissolved particles in water can utilize in determining its applicability for agricultural using (S. K. Singh et al., 2015). Suitability of groundwater for irrigation related to the nature of the mineral elements in the water and their influences on both the soil and plants (S. Singh, Singh, Kumar, Gupta, & Mukherjee, 2009).

Generally, water quality factors main cations like K^+, Ca^{2+}, Mg^{2+}, Na^+ and anions as Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3^- and heavy metals have indicators of drinking water usable. In contrast, water quality indices like sodium adsorption ratio (SAR), sodium percentage (SSP and % Na), residual sodium carbonate (RSC), residual alkalinity (RA), Kelly's rate (KR) or Kelly's index (KI), permeability index (PI), chloroalkaline indices (CAI2 and CAI1), magnesium hazard (MH), potential salinity (PS), total dissolved solids (TDS) and total hardness (TH) depend on water quality factors have frequently used to define the quality of water for irrigation (Gautam et al., 2015).

The relation between irrigation and groundwater resources has highly connected. This paper illustrates the groundwater quality situation for irrigation intent utilizing the water quality indexes (SAR, %Na, RSC, PI, MH, CAI2 and CAI1 CR, TDS, TH) depends on the main parameters like as (NO_3^-, SO_4^{2-}, HCO_3^-, Cl^-, K^+, Ca^{2+}, Na^+, and Mg^{2+}). However, the aim of this study is to determine the suitability of groundwater for irrigation purpose.

2. Study area

The area which will study in this study is Gaza Strip which section of the Palestinian coastal plain placed in an arid to semi-arid region. Egypt borders it from the south, the green line from the North, the Mediterranean Sea from the West and Negev desert from the East, so The Gaza Strip is placed on the Mediterranean Sea on the south-eastern coast, between latitudes 31° 16" and 31° 45" north and longitudes 34° 2" and 34° 25" east, Figure (1). The Gaza Strip is 360 km total surface area (Naciri & Ttlich, 2001). where about 1,961,406 Palestinian people live and work (PCBS, 2018), this figure showed the Gaza Strip areas as one of the most densely populated in the world. The Gaza Strip is geographically divided into five Governorates: Northern, Gaza, Mid Zone, Khan Younis and Rafah. The annual average precipitation directly varies from 400 mm in the north to about 200 mm in the south of the strip. Most of the precipitation happens in the period from October to March, the rest of the year being dry (S. S. Gharbia, Aish, & Pilla, 2015).

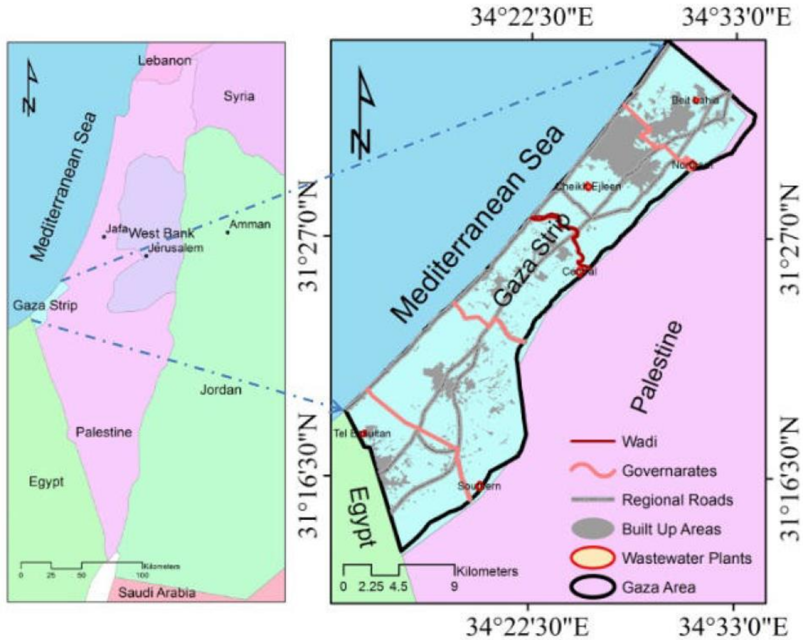


Figure 1: The Gaza strip Location map (S. S. Gharbia et al., 2015).

3. Materials and methods

Groundwater samples have collected and analyzed by the Palestinian Water Authority (PWA) and the Ministry of Health (MOH). The samples have collected from 240 groundwater wells during the year 2019. The research work defined here used this data set, which was provided by PWA and MOH.

3.1 Irrigation water quality parameters:

The poor irrigational water quality influences on the plant's growth, agriculture yields, soil quality and human health, it is essential to assess the water quality for irrigation utilize in the agriculture areas. Irrigation indexes as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), per cent sodium (%Na), Kelly's rate (KR), permeability index (PI), magnesium hazard (MH), potential salinity (PS), chloroalkaline indices (CAI2 and CAI1) and corrosivity ratio (CR), these factors used to determine the suitability of groundwater for irrigation

3.1.1 Sodium Adsorption Ratio (SAR)

SAR is the ratio of Na^+ ions to $Mg^{2+,}$ and Ca^{2+} ions represent in the water samples. SAR used to predict the potential of Na^+ which initially accumulate in the soil by water transport at the expense of Ca^{2+}, Mg^{2+} and K^+ as a result of regular utilize of sodic water. It has formulated as Eq. (1)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \text{ ----- (Richards, 1968)} \qquad (1)$$

Where: Na^+, Ca^{2+} and Mg^{2+} in meq/l.

Based on SAR range, irrigation water can classify into four classes: SAR < 10 considered as (Excellent), SAR range between 10–18 considered as (Good), SAR range between 18–26 considered as (Doubtful), SAR > 26 considered as (Unsuitable). SAR also influences the percolation time of water in the soil. Therefore, the lower value of SAR of irrigation water is desirable.

3.1.2 Per cent Sodium (%Na) or Sodium Hazard

The %Na has also used in classifying water for irrigation purpose. Na^+ is an important parameter and helps in the categorization of any source of water for irrigation uses. Na^+ makes chemical bonding with soil to decline the water transport capacity (Ayers & Westcot, 1985). Percent % Na^+ concentration is a parameter to evaluate the suitability for irrigation used (Wilcox 1948). while Na^+ and CO_3^{2-} reaction produce alkaline mean, while Na^+ reaction with chloride produce saline soils. Sodium soil (alkaline/saline) retards crop growth (Todd & Mays, 2004). If the concentration of Na^+ in irrigation water is high, then the ions tend toward the clay, by removing Ca^{2+} and Mg^{2+} ions through the base-exchange reaction. This process in soil reduction water transport capacity. In this situation, water and air cannot move freely or restricted during wet conditions, and such grounds have become stiff when dry (Collins & Jenkins, 1996). The %Na values have calculated as Eq. (2):

$$\% Na = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100 \text{ ----- (Richards, 1968)} \qquad (2)$$

The classification of water based on %Na as excellent (< 20%), good (20–40%), permissible (40–60%), doubtful (60–80%) and unsuitable (> 80%) (Khodapanah, Sulaiman, & Khodapanah, 2009).

3.1.3 Kelly's Ratio (KR) or Kelly's Index (KI)

(Kelly, 1940) introduced factor to assess the quality and classification of water for irrigation purpose based on the concentration of Na^+ against Ca^{2+} and Mg^{2+}. It can calculate using Eq. (3)

$$KR/KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \text{ ----- (Kelly, 1940)} \qquad (3)$$

KR/KI > 1 indicatation an excess level of Na^+ in waters. Therefore, water with a KI ≤ 1 has recommended for irrigation, while water with KI ≥ 1 have not suitable for irrigation due to alkali hazards (Ramesh & Elango, 2012).

3.1.4 Permeability Index (PI)

Water trasport capability in soil (permeability) has influenced by the long-term use of irrigation water (with a high concentration of salt) as it has influaced by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- ions of the soil. PI formula has developed by Doneen (1964)to assess water movement capability in the ground as the suitability of any source of water for irrigation, and it formulated as Eq. (4):

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100 \text{ ----- (Doneen, 1964)} \quad (4)$$

According to Doneen (1964), PI categorized in three classes: class I (> 75%, suitable), class II (25–75%, good) and class III (< 25%, unsuitable). Water underclass I and class II sutabile for irrigation used.

3.1.5 Magnesium Hazard (MH) or Magnesium Adsorption Ratio (MAR)

Alkaline soil (Ca^{2+} and Mg^{2+}) are in an equilibrium state in groundwater. Both Ca^{2+} and Mg^{2+} ions connected with soil friability and aggregation, but both are also important nutrients for the crop. The sigenficant values of Ca^{2+} and Mg^{2+} in water can increase soil pH (therefore soil converting it to saline nature of the ground. Szabolcs (1964) projected MH values for irrigation water and calculated using Eq. (5):

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \text{ ----- (Szabolcs, 1964)} \quad (5)$$

MH > 50 has not suitable for irrigation used (Khodapanah et al., 2009).

3.1.6 Potential Salinity (PS)

PS is water quality parameter-based index (Doneen, 1964) for classifecation of water for agriculture used. PS < 3 meq/l an indication of the suitability of water for irrigation, and it formulated as Eq. (6):

$$PS = CL^{-} + 0.5 * SO_4^{\ 2-} \text{ ----- (Doneen, 1964)} \quad (6)$$

3.1.7 Chloroalkaline Indices (CAI1 and CAI2)

Information about coming changes in the chemical composition of the groundwater during underground travel is also vital (Sastri, 1994). The chemical reaction which has ion exchange between the groundwater and the aquifer occurs during the movement and rest condition of the water. It analyzed through the chloroalkaline indices. The CAI1 and CAI2 have assessed (Schoeller, 1977) and expressed by Eqs. (7 and 8):

$$CAI1 = \frac{CL^{-} - (Na^{+} + K^{+})}{CL^{-}} \text{ ----- (Schoeller, 1977)} \quad (7)$$

$$CAI2 = \frac{CL^{-} - (Na^{+} + K^{+})}{(SO_4^{\ 2-} + CO_3^{\ 2-} + HCO_3^{\ -} + NO_3^{\ -})} \text{ ----- (Schoeller, 1977)} \quad (8)$$

CAI1 and CAI2 indices can be negative or positive depending on the exchange procedures of Na^+ and K^+ from rocks with Mg^{2+} and Ca^{2+} present in water. If a direct exchange process (DEP) occures between Na^+ and K^+ in water with Mg^{2+} and Ca^{2+} in rocks, then CAI ratio be positive. If a reverse exchange process happens (Na^+ and K^+ in water with Mg^{2+} and Ca^{2+} in rocks), then CAI ratio be negative.

3.1.8 Corrosivity Ratio (CR)

The corrosivity ratio is giving information about the water supply. While CR < 1 has recommended to the transport of any source of water in any pipes, whereas CR > 1 present erosion of the water nature, means not to be transported through metal pipes (Aravindan, Manivel, & Chandrasekar, 2004) The CR can be estimated using an Eq. (9):

$$CR = \frac{\left(\frac{CL^-}{35}\right)+2*\left(\frac{SO_4{}^{2-}}{96}\right)}{\left(\frac{CO_3{}^{2-}+HCO_3{}^-}{100}\right)} \quad (9)$$

The rate of corrosion depends on physical parameters as pressure, temperature and water flow rate. In addition to the high values of Cl^- and SO_4^{2-} also rise the erosion rate.

3.1.9 Total Dissolved Solids (TDS)

For irrigation classified, if TDS < 450 mg/l and is preferred for irrigation and TDS > (450–2000) mg/l is little to moderate and TDS > 2000 mg/l is unsuitable for agricultural using (FAO, 2006).

3.1.10 Total Hardness (TH)

Water hardness is a result of the existence of divalent metallic cations (Ca^{2+} and Mg^{2+}), and it can calculate as the sum of Ca^{2+} and Mg^{2+} concentration as meq/l equivalent to $CaCO_3$ (Todd & Mays, 2004) and expressed by (Eq. 10):

$$TH = 2.5 * Ca^{2+} + 4.1 * Mg^{2+} \quad (10)$$

(EPA, 1986) classified TH as soft (0–60 mg/l), moderately hard (60–120 mg/l), hard (120–180 mg/l) and very hard (> 180 mg/l).

4. Result and discussion

4.1 Hydrochemical characterization of the groundwater

The water quality chemical data have plotted on the Piper diagram, to understand the hydrochemical facies and associated procedures in the groundwater of the Gaza Strip area. AquaChem 2014.2 software has used for planning the Piper diagram (Figure 2). As shown from the figure 2, the water type which dominated was Calcium Chloride and Sodium Chloride types that considered as permanent hardness and saline water from the presentation of groundwater parameters.

4.2 Suitability for irrigation uses

The groundwater samples have categorized according to its irrigation usage (Table 1), which resent the descriptive statistics for irrigation indices and the classification of it. A soil property loses its life when the dissolved ions are in excess, and it affects the fertility of the soil. Infertility of the soil affects the growth of plants or crops. Excess amount of salt content in water modifies the osmotic pressure in the root zone. As a consequence of the limited absorption of water, the growth of plant or crops gets terminated (Hanson, Grattan, & Fulton, 1999). When Salt concentration is high in the soil, it limits the growth of plant or yields due to the change in its metabolic processes (Peiyue, Qian, & Jianhua, 2011).

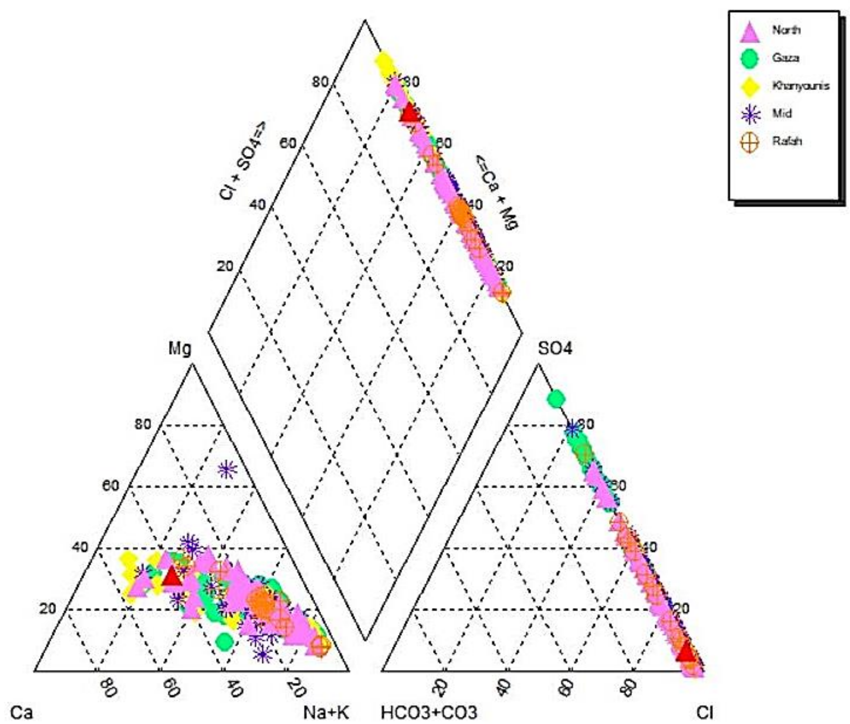


Figure 2: Gaza Strip Groundwater Quality Piper Diagram

Table 1: a descriptive analysis of irrigation indicates

	SAR	%Na	KR	PI	MH	PS	CAI1	CAI2	CR	TDS	TH
No.	240	240	240	240	240	240	240	240	240	240	240
Min.	0.0	0.0	0.0	22.9	0.00	98.0	-27.9	-3.9	1.4	338.0	128.0
Max.	43.3	91.2	10.8	184.4	86.3	11712.0	0.9	26.5	127.5	19406.0	5067.0
Mean	10.4	63.4	2.6	77.9	41.5	1186.4	-0.6	1.0	14.1	2526.0	870.6
STD.	7.9	17.9	2.0	15.7	10.5	1494.3	2.8	3.1	17.4	2531.2	898.7
Skewness	1.6	-0.9	1.6	0.9	-0.4	3.9	-5.1	4.3	3.7	3.4	2.7

According to the table 1 descriptive analysis the classification of groundwater quality depend on the irrigation indices was: SAR gives Good indication, % Na gives Doubtful indication, KR gives not recommended for irrigation due to alkali harmful, PI gives Class I that means is suitable, MH provides a good signal, PS gives unsuitability indication, CR gives unsuitability indication, TDS gives unsuitability indication and TH gives hard water for irrigation. Generally, the groundwater quality has high saline, alkali harmful and very hard behaviours from irrigation indices which give unsuitability indication for irrigation purpose.

4.3 Graphical interpretation of USSL diagram, Wilcox diagram, Doneen diagram and Gibbs diagram

The US Salinity Laboratory's diagram (USSL, 1954) used for the suitability appraisal of irrigation water quality, which expresses the sodium hazard concerning salinity hazard. The % Na versus EC values for groundwater samples has plotted in the USSL diagram (Figure 3), which illustrates that generally, most of the samples locate on permissible to doubtful, doubtful to problematic and unsuitable areas that give to unsuitable using of water to irrigation purpose.

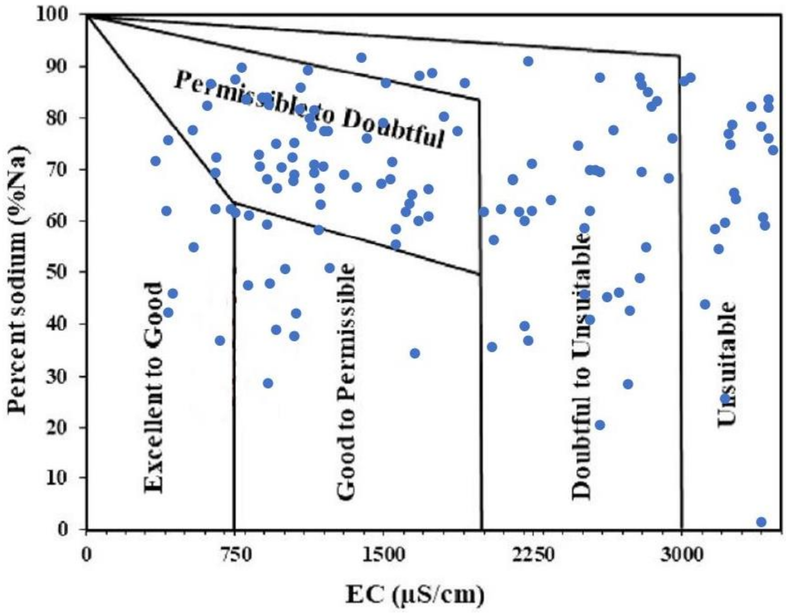


Figure 3: USSL Diagram Indicating the Suitability of Groundwater for Irrigation.

Wilcox diagram (Wilcox, 1955) is a critical graphical method extensively used to understand the combination of EC and SAR for the irrigation suitable evaluation which divided to areas on X-axis and Y-axis depend on the EC and SAR. Figure 4 presents the groundwater samples that fall in the fields of C4S3 and C4S2. However, C4S3 have extraordinarily high salinity control with high sodium hazard and some pieces locate on C4S2 which consider very high salinity control with medium sodium hazard that believe unsuitable for irrigation used.

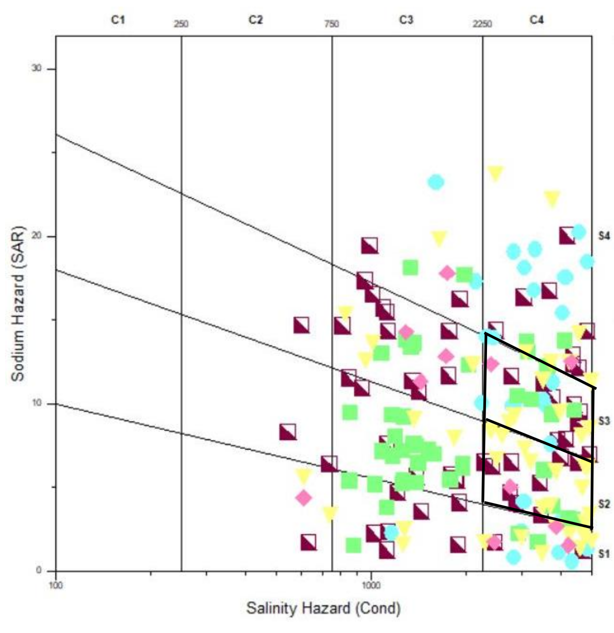


Figure 4: Wilcox Diagram Indicating the Suitability of Groundwater for Irrigation

Figure 5 SAR versus salinity plot illustrates the relationship between salinity and sodicity and infiltration rate of groundwater. Generally, the samples locate at no reduction in the quality of infiltration and slight to moderate decrease in the rate of infiltration zone' indicating the suitability of the groundwater for irrigation.

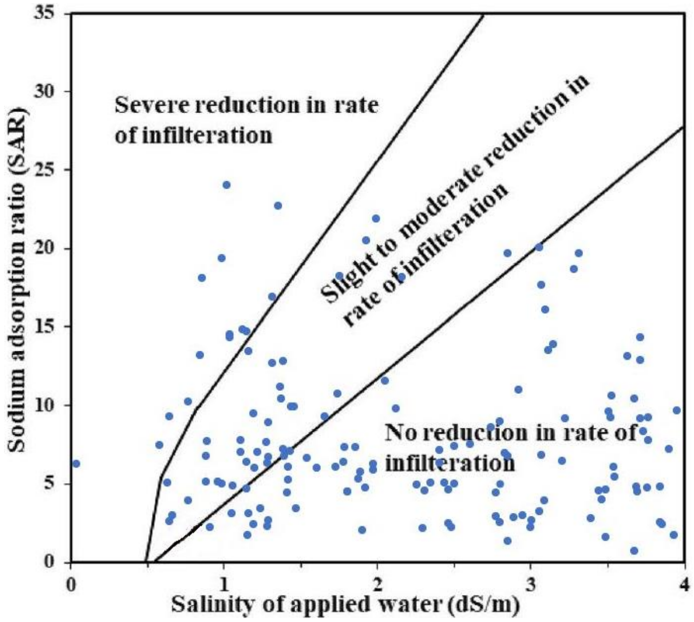


Figure 5: SAR versus Salinity Diagram Indicating the Suitability of Groundwater for Irrigation

Doneen developed a criterion to evaluate irrigation water suitability based on the permeability index as expressed in Eq. 4; accordingly, water is classified as Class I, Class II or Class III. Figure 6 illustrates the samples locate on Class II categorized as useful for irrigation with 75% of maximum permeability and Class III classified as unsuitable for irrigation.

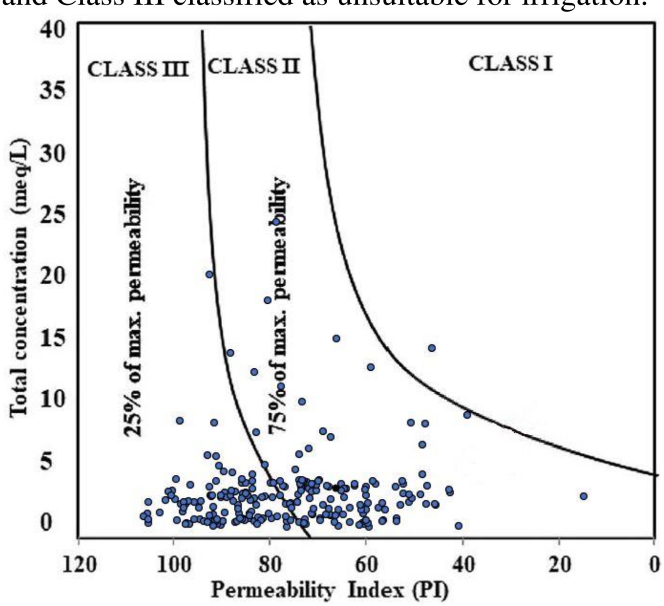


Figure 6: Doneen irrigation water classification diagram based on the permeability index

Figure 7 shows the Gibbs diagram, which presents water-rock/soil interaction that responsible for the chemical composition of the groundwater. The predominant samples fall in the rock–water interaction dominance and evaporation dominance field of the Gibbs diagram (Fig. 7). The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolated waters under the subsurface.

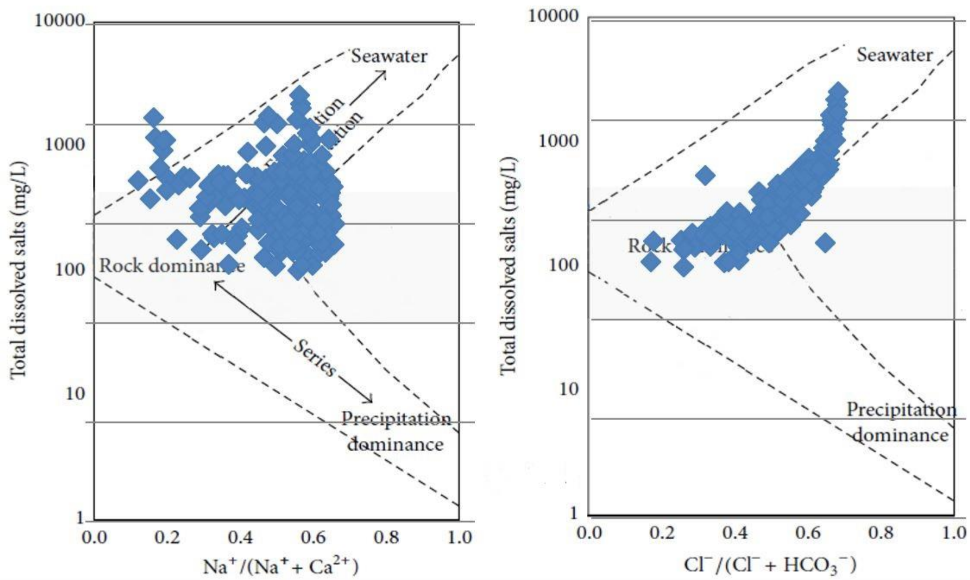


Figure 7: Gibbs Diagram Indicating the Suitability of Groundwater for Irrigation

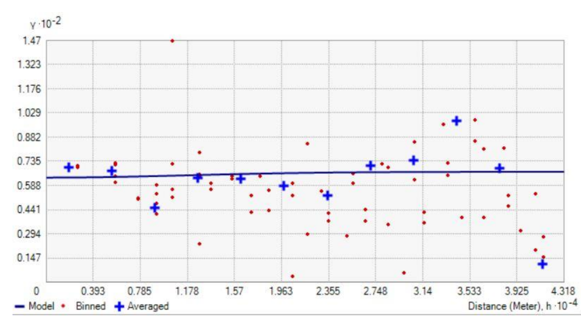
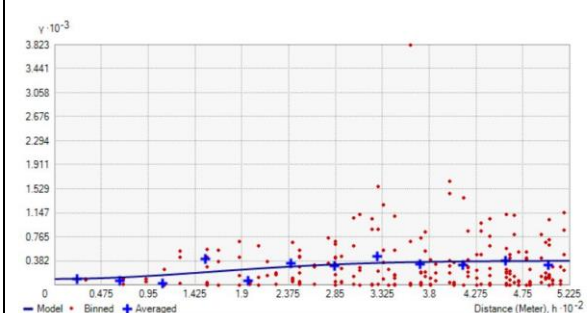
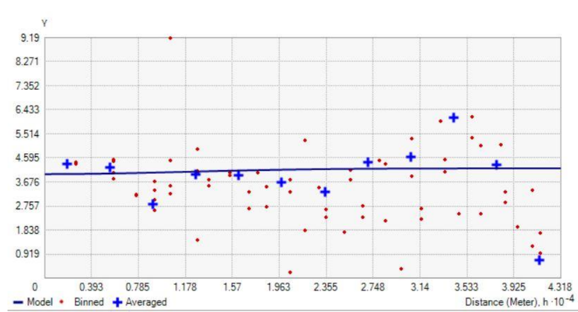
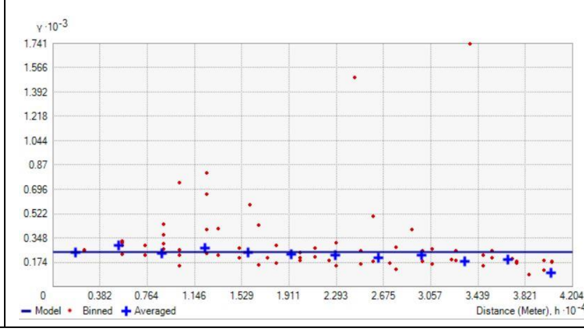
1.1 Geostatistical modelling for irrigation indices

Many interpolation methods are available in the literature for Kriging methods are the best way for standard distribution data. As such, Kriging used in this study for spatial variation analysis (A. S. Gharbia et al., 2016). Kriging method has three steps. Firstly exploratory data analysis was executed to explore data and to check data consistency and uniformity, removing outliers and identifying statistical distribution. Secondly, spatial correlation or dependence quantified with semivariograms (variograms). Applying the Kriging approach with semivariograms model is related to the expected squared difference between paired data values to the distance by which locations have separated and finally, prediction (A. S. Gharbia et al., 2016). There are four types of semivariogram models (Stable, Hole effect, J-Bessel, Exponential, and Gaussian,) have tested for each groundwater quality irrigation indication for the selection of the best one. Predictive performances of the fitted models checked based on spatial cross-validation tests. The magnitudes of (ME) mean error, (MSE) mean square error, (RMSE) root mean error, average standard error (ASE) and root mean square standardized error (RMSSE) were pridected to test the performance of the developed models that present on table 2. If the predictions are unbiased, the ME should be near zero. However, this statistic has some important drawbacks: it depends on the scale of the data and is insensitive to inaccuracies in the variogram. So, usually, the MSE is used to standardize the ME, being ideally zero, i.e., an accurate model would have an MSE close to zero. In addition predictions, each of the Kriging techniques gives the Kriging variances which estimate the variability of the forecasts from the known values of the probability Kriging. If the RMSE is close to the ASE, the prediction errors have correctly assessed. If the RMSE is lower than the ASE, then the variability of the predictions is overestimated; conversely, if the RMSE is higher than the ASE, then the variability of the predictions is underestimated. The same deduced from the RMSSE statistic. It should be close to one. If the RMSSE is more significant than one, the variability of the predictions has underestimated; likewise, if it is lower than one, the variability is overestimated. (A. S. Gharbia et al., 2016). The corresponding sill, nugget, and range magnitudes of the best fitted theoretical models have observed and reported in Table 2. The best-fitted variogram models have shown in Table 3.

Table 2: Characteristics parameters of variogram models.

	Model type	Nugget	Sill	variance	Lag size	Range	ME	RMSE	ASE	MSE	RMSSE
SAR	Stable	0.029	0.634	5%	702.3	610.8	-0.12	7.97	9.80	-0.012	0.815
% Na	Gaussian	0.094	2.873	3%	4354.1	3876.7	-0.26	17.22	19.41	-0.014	0.903
KR	Hole effect	0.002	0.031	5%	702.5	659.4	-0.05	2.06	2.32	-0.022	0.886
PI	Gaussian	0.101	2.308	4%	2495.6	2210.1	0.04	15.79	18.72	-0.002	0.849
MH	J-Bessel	0.060	0.503	12%	3351.2	2013.5	0.12	10.71	10.71	0.011	0.980
PS	Gaussian	0.024	0.829	3%	536.7	492.7	-1.64	11.99	33.99	-0.004	0.387
CAI1	Stable	0.001	0.066	1%	3190.4	2758.9	0.045	2.73	2.13	0.005	1.187
CAI2	Stable	0.008	0.516	1%	519.4	455.1	-0.04	2.69	7.95	-0.005	0.381
CR	Stable	0.150	1.155	13%	1200.9	483.25	-0.17	14.36	37.34	-0.003	0.422
TDS	Gaussian	0.766	5.60	14%	512.55	475.57	-1.09	20.73	59.65	-0.005	0.375
TH	Exponential	0.003	1.17	0%	588.1	6767.2	1.15	24.16	41.87	0.011	1.186

Table 3: Best-fitted semivariograms models for irrigation indices parameters.

SAR		%Na	
KR		PI	

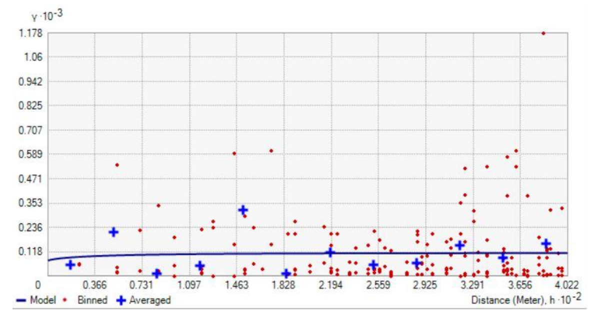
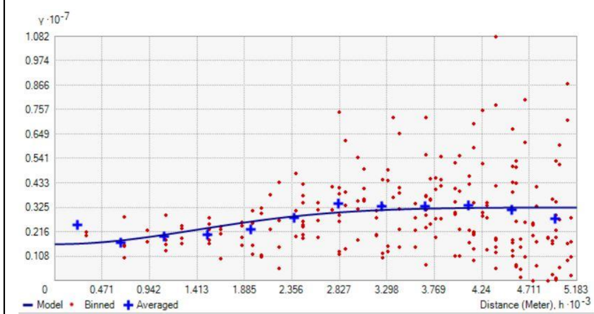
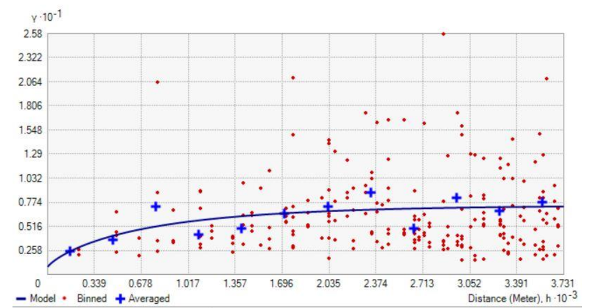
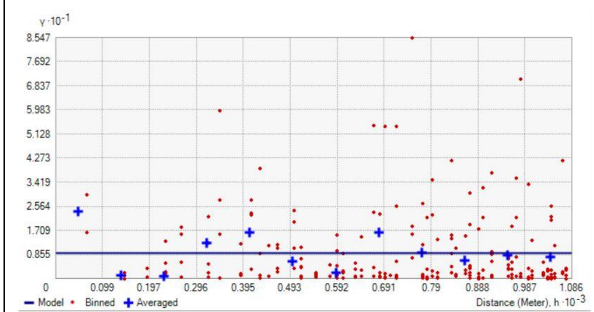
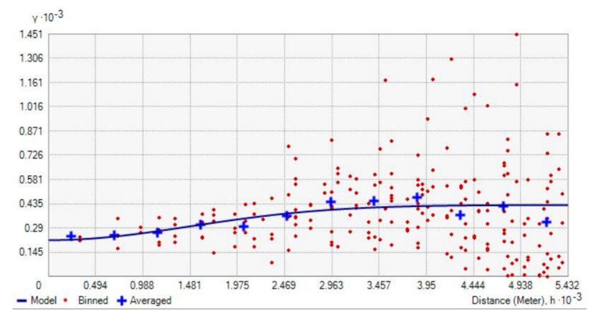
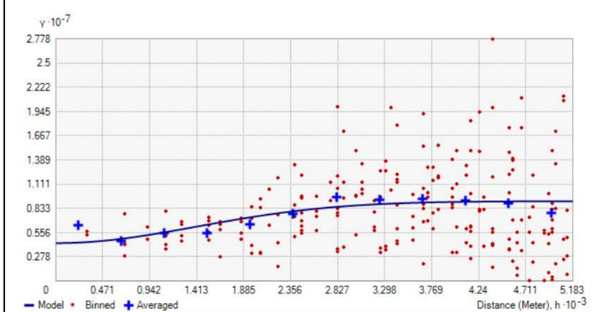
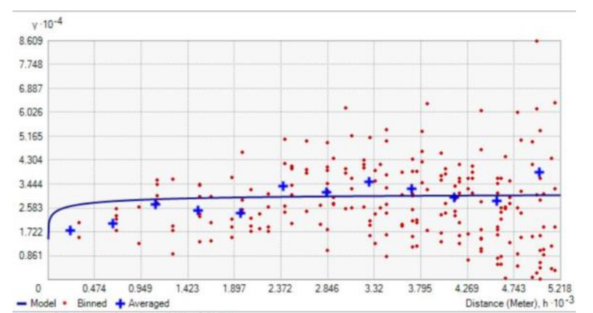
MH		PS	
CAI1		CAI2	
CR		TDS	
TH			

Table 3 shows the best-fitted model for each parameter for prediction of SAR, %Na, KR, PI, MH, PS, CAI1, CAI2, CR, TDS and TH. The ratio of nugget variance to sill delicated in percentages (Table 2) used as a criterion for classified the spatial dependence of irrigation factors. If this ratio is lower than 25%, then the variable has strong spatial support; if the rate is between 25% and 75%, the variable has a moderate spatial dependence and greater than 75%, the variables show only weak spatial dependence. All parameters of groundwater quality irrigation indices have significant spatial structure. The MSE values are close to zero, and their corresponding to RMSSE values relative to one represents a good prediction model.

2. Conclusions

Agriculture activities are the primary source of income to a high number of population on Gaza Strip. Gaza Strip is agriculturally productive and also facing adverse effects of excessive agricultural activites due to the overdraft of groundwater, quality impairment and salinity of the area. This study provides essential information on groundwater quality for irrigational use in the Gaza Strip by using irrigation indexes as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), per cent sodium (%Na), Kelly's rate (KR), permeability index (PI), magnesium hazard (MH), potential salinity (PS), chloroalkaline indices (CAI2 and CAI1) and corrosivity ratio (CR) for assessment process, generally according to the index results the groundwater consider as unsuitable for using in irrigation. The geostatistical analysis for all irrigation models all parameters of groundwater quality irrigation indices have significant spatial structure. The MSE values are close to zero, and their corresponding to RMSSE values relative to one represents a good prediction model. In general, all irrigation indices give that the groundwater which using of irrigation process on Gaza strip is unsuitable for agriculture activities which suffering from high salinity which harm plants production.

3. Declarations

3.1 Availability of data and materials

The datasets generated and analysed during the current study are not publicly available, groundwater samples have collected and analyzed by the Palestinian Water Authority (PWA) and the Ministry of Health (MOH), due to this data is related to Gazastrip area and used for sesonal reports and resarchs, but are available from the corresponding author on reasonable request depending on the resarch used. The research work defined here used this data set, which was provided by PWA and MOH.

3.2 Competing interests

Not applicable.

3.3 Funding

Not applicable.

3.4 Authors' contributions

This research is team work between autors that depend on using the data and examin it to the aim of the study, all authers organized and reviewed the work.

3.5 Acknowledgements

Not applicable.

4. References

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Figures

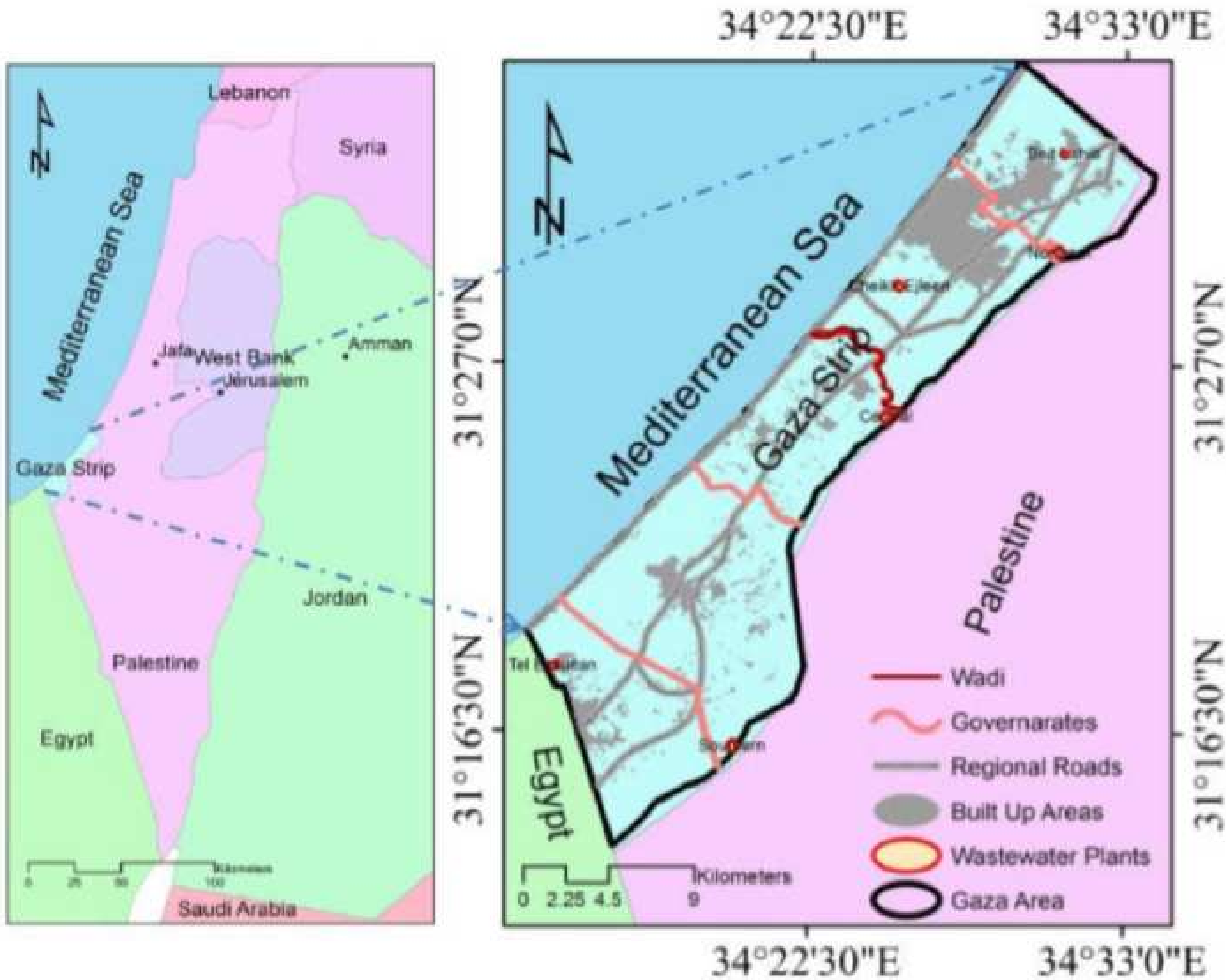

Figure 1

The Gaza strip Location map (S. S. Gharbia et al., 2015). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

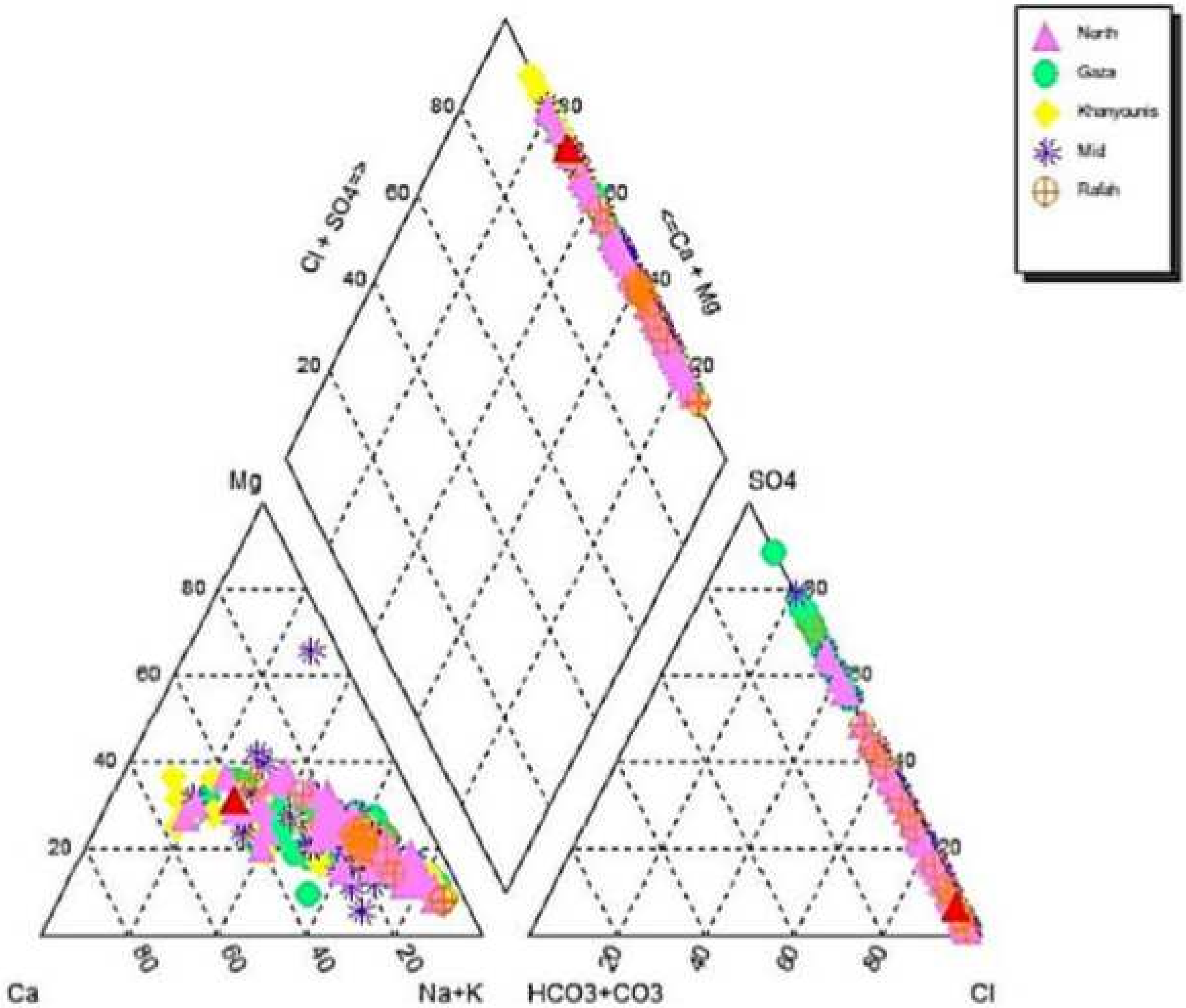

Figure 2

Gaza Strip Groundwater Quality Piper Diagram

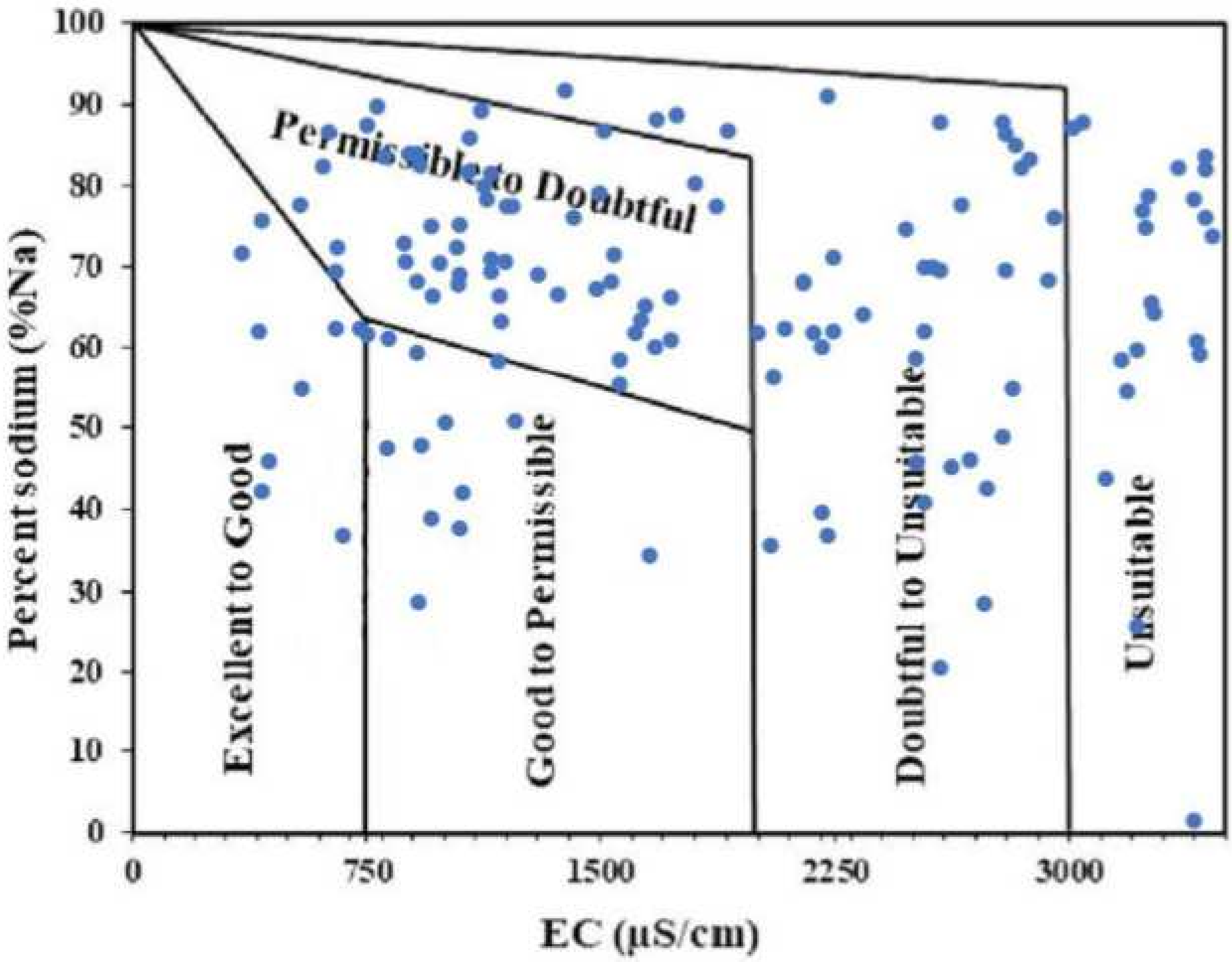

Figure 3

USSL Diagram Indicating the Suitability of Groundwater for Irrigation.

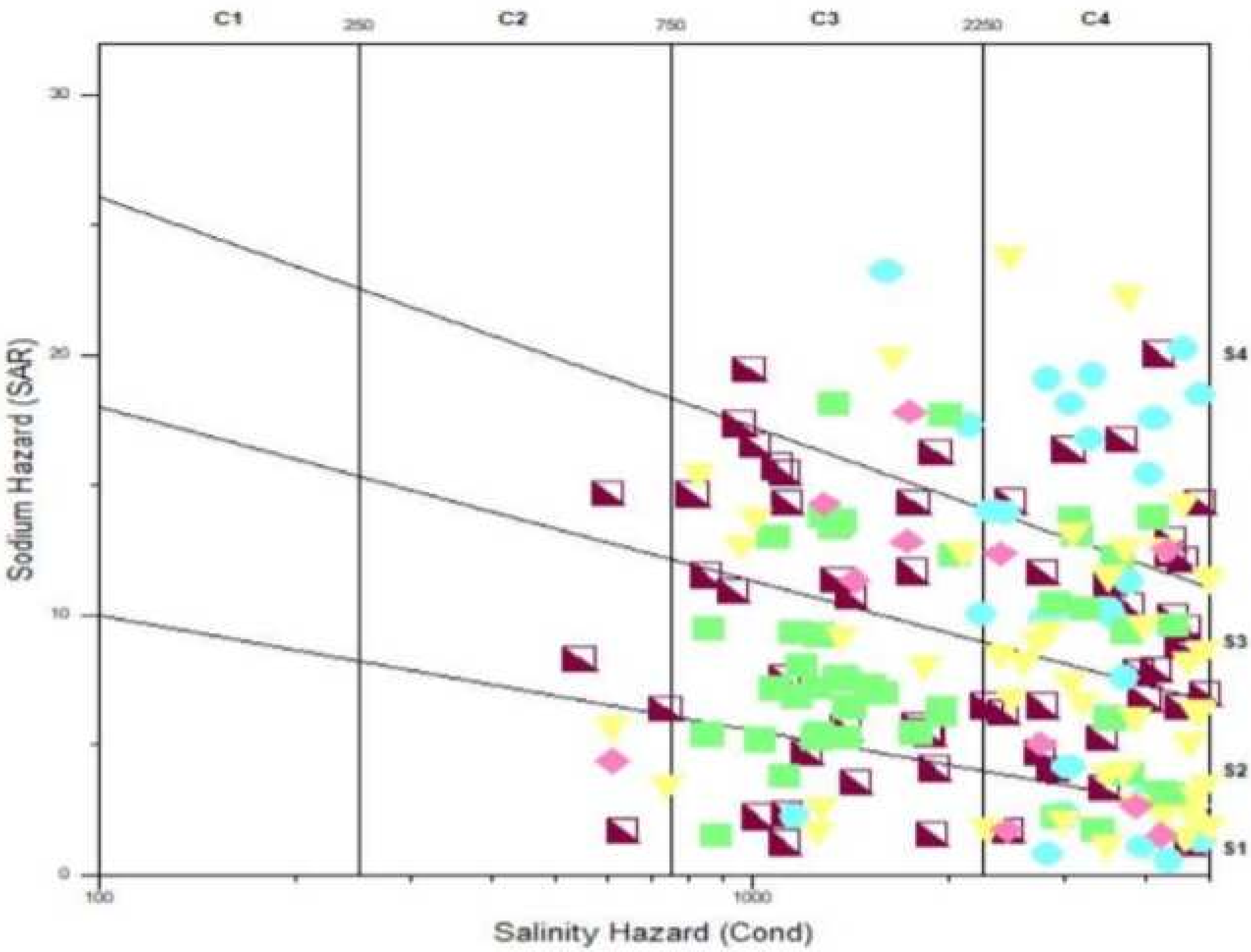

Figure 4

Wilcox Diagram Indicating the Suitability of Groundwater for Irrigation

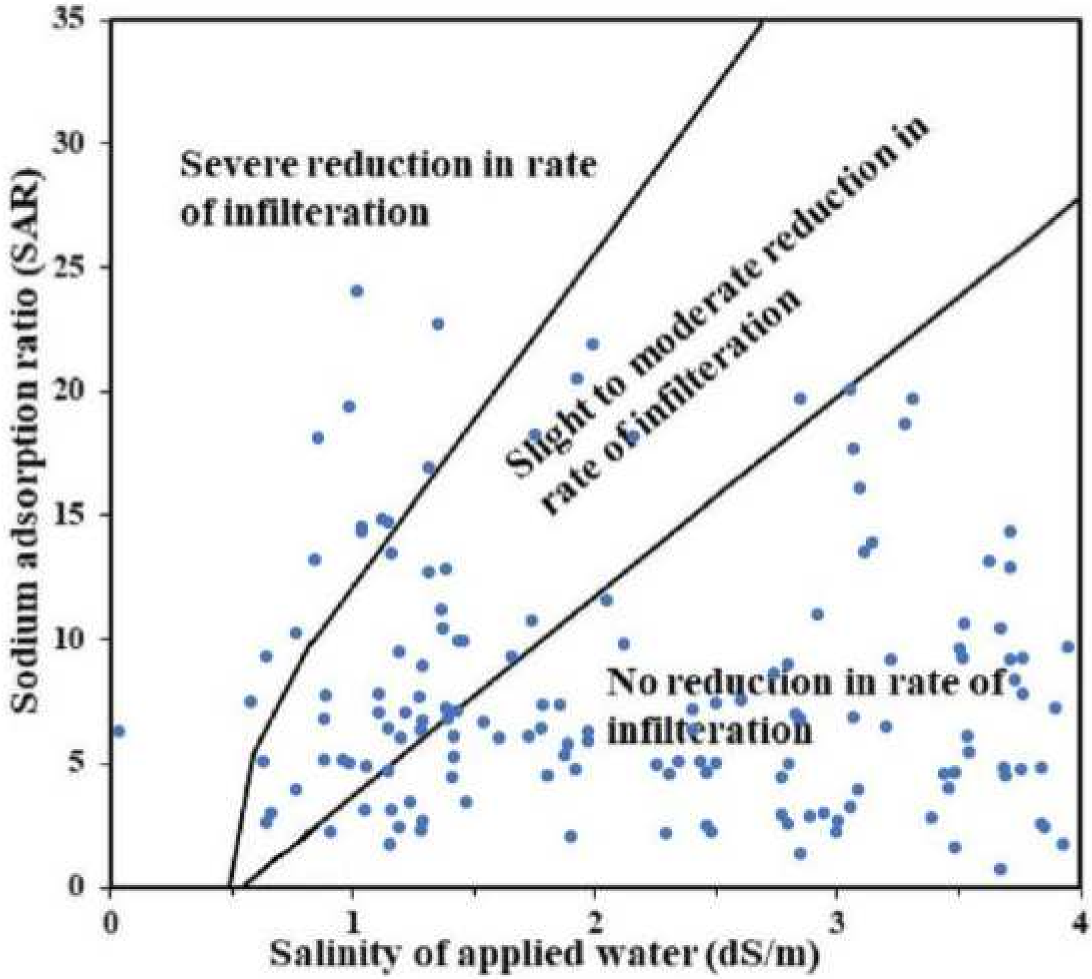

Figure 5

SAR versus Salinity Diagram Indicating the Suitability of Groundwater for Irrigation

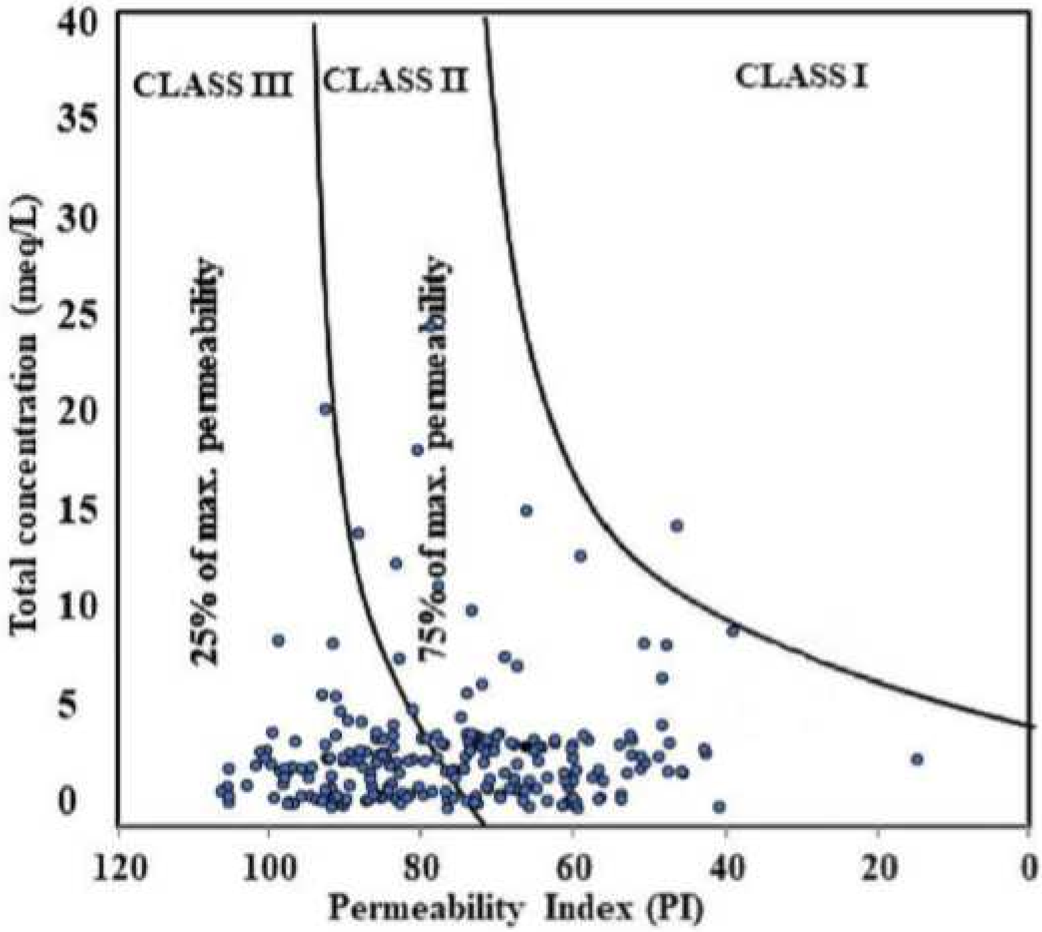

Figure 6

Doneen irrigation water classification diagram based on the permeability index

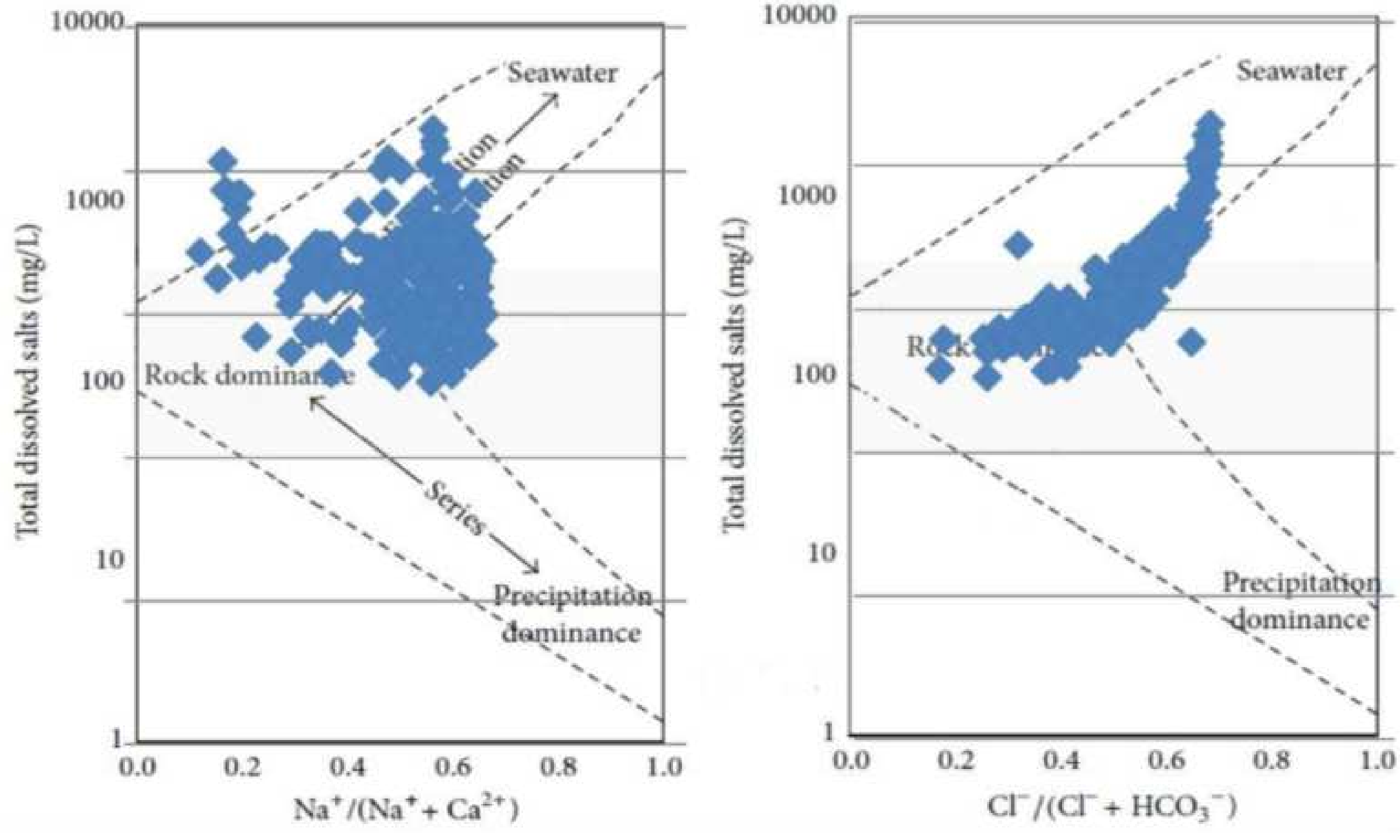

Figure 7

Gibbs Diagram Indicating the Suitability of Groundwater for Irrigation