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Long-term Evaluation of Temporal Variation in Groundwater Physicochemical Quality: A Case Study of Erbil City, Iraq (2003 – 2015)

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Abstract: Groundwater resources within Erbil City are facing a growing decline during the last decade as a result of increased water consumption, and climate change. Understanding the temporal variance of groundwater quality and showing an image of the historical physicochemical state of Erbil City groundwater are essential to identify potential pollution and to assist sustainable programs of groundwater management. In this study, a wide-ranging evaluation of groundwater physicochemical quality has been performed over a period of 2003-2015. It was found that sodium, calcium, magnesium, potassium, and nitrate are the most significant parameters contributing to groundwater quality variations. These variations are mainly resulted from natural geological sources and much less from anthropogenic activities. The results showed that the groundwater abstraction didn't cause a drastic alteration in groundwater quality. Significant recharging has relatively enhanced the groundwater quality in certain years at intermittent intervals. The study aids to establish a prediction tool for groundwater quality in the study area.

Keywords: Groundwater Quality, Groundwater Level Decline, Physicochemical Properties, Temporal Differences, Multivariate Analysis, Quality Index; Erbil City

1. Introduction

Groundwater is economically and environmentally an indispensable water resource, it is used for drinking, irrigation, agriculture, and other various human activities (Ackah et al., 2011; Magesh et al., 2013). In recent decades, climate change (temperature and rainfall variations) has undesirable impact on groundwater level, and quality (Brouyère et al., 2004). Consequently, studies showed that the drop of groundwater level due to climate change, and water consumption has not been substantially recuperated over the recharge (Owor et al., 2009; Panda et al., 2007). Water consumption have actively participated in the groundwater level decline, wherein at many regions, groundwater levels have dropped extremely, and hence causing groundwater quality deterioration (Rajmohan et al., 2007). At urban areas, and more especially, many big cities, studies have revealed that these cities are pressed by groundwater depleted and polluted groundwater resources (Choi et al., 2005). Excessive groundwater abstraction in big cities, that almost dependent on groundwater, causes aquifer level declining the way in which the hard slog recharge is exceeded as a result of climate change (Akther et al., 2009; Hoque et al., 2007). North of Iraq like other urban and rural areas in the Middle East and the world suffers from groundwater depletion (Voss et al., 2013). Erbil

City residents get all or a part of their drinking and domestic water from groundwater wells (Al-Jumur et al., 2016; Bapeer et al., 2006; Mawlood & Hussein 2016), in which 30% of the water supply is obtained from groundwater resources (Rajab and Esmail 2016). Rapid population growth and urban expansion in Erbil City after the year 2003 emerged clearly as an increasing demand of groundwater (Toma et al., 2013). Groundwater level decline in Erbil City started during the late nineties with a scarcity cycle of 1999–2001, where groundwater was noticeably affected, in which many shallow wells dried out, and the groundwater level in many parts was considerably dropped (Stevanovic & Iurkiewicz 2009). The groundwater level of Erbil City has declined substantially from 75m to 350m (from earth surface) in some parts in the city (Ahmed, 2016), while (Hameed et al., 2015) indicates that the groundwater level of the city, in general, has dropped about 54% from 2004 to 2014.

The previous method to define a water sample quality was to examine all the constituents concentrations in the sample, such description will be logic only to water chemistry and quality experts (Environmental Monitoring Support Laboratory 1982). There has been a growing concern about physicochemical properties of groundwater that might involve hazardous factors on human health and environment (Guo et al., 2007). The determining factors for the chemical quality of groundwater are the chemical structure of the underlying rocks, soil and the contact of time of groundwater with these rocks and soil (Abdulwahid, 2013). Therefore the chemical composition of a groundwater aquifer reflects the major soils and minerals that the water contacts (Edzwald, 2011). Few studies have been performed to assess the physicochemical values of Erbil City groundwater (Daham et al., 1998; Shareef & Muhamad, 2008; Toma, 2006), they found that the quality of groundwater in Erbil City is varying between low to moderately polluted water, but generally it meets the various recommended standards for drinking water purposes.

Many ways are used to demonstrate the groundwater quality, among them water quality index, which aims to translate a list of water composition parameters into a unique value (Abbasi & Abbasi, 2012). Water quality index is applied as communication mean by agencies and authorities to describe the health of a specific water (Sadiq et al., 2010). Whilst, multivariate statistical analysis like factor analysis are employed widely in water physicochemical data evaluation. These statistical analysis techniques proved to be efficient tools (Aris et al., 2015; Tahri et al., 2005; Tariq et al., 2006; Yidana, 2010). Multivariate analysis of variance MANOVA is used to compare different groups for significant divergence (Alkarkhi et al., 2008). No previous study was made about this subject, knowing that preliminary studies were conducted, but they were limited and didn’t cover long-term time period. The time period selected in this study is important as there is a significant and large growth in population and residential areas took place in the city, the period that corresponds to a noticeable decrease in the groundwater resources. The aim of this work is to assess the temporal changes in the groundwater quality in Erbil City during nearly one decade period from 2003 to 2015 by establishing a long-term temporal variation monitoring dataset for physicochemical groundwater quality, and then to be evaluated quantitatively and qualitatively. This paper highlights the variation in key physicochemical parameters of groundwater in order to evaluate the acceptability of the groundwater for human needs by different statistical analyses for the collected data to point out any interaction between temporal variance, groundwater depletion, and potential pollution could be determined. So this study may be considered as an important attempt to establish a reliable background for further programs aiming to develop and conserve of this precious water resource.

2. Materials and Methods

2.1 Study Area

Erbil City (E36.19º, N 44.0º), located at North Iraq, is the capital of Erbil governorate, has an area of 18,170 km^2 and has a population of two million people (Figure 1). Meteorological data of study area is a typical semi-arid continental climate that distinguished by a hot dry summer and a cold wet winter similar to other parts of Iraq (Aziz, 2011). The physiographic features of the study area, where Erbil city is located on a plain called Erbil plain, is alluvial plain with several small valleys. Erbil plain is bounded from north by Greater Zab River and from the south by Lesser Zab River, these rivers are tributaries of the Tigris River. These rivers with rainfall are the main source for groundwater for Erbil area (Aziz, 2008). The soils of the studied areas in Erbil City are of the Aridisol order - Orthid suborder, the soil of Erbil city is a part of alluvial Erbil plain soils sediments that carried by these rivers with floods (Mohammed et al., 2013). Over 80% of the study area of Erbil plain is overlaid by soils belong to Quaternary era underlain by a Pliocene period layer that mostly are gravels sands, silt, and clay (Al-Tamir, 2008). The reservoir that feeds Erbil City groundwater is recharged via rainfall and infiltration from surrounded rivers through the spaces within the underlain permeable rocks (Ghaib, 2009). The occurrence of this kind of movement of groundwater is governed by the intergranular pore spaces (Chidambaram et al., 2010). The aquifer under the study area is a Plio-Pleistocene type, where groundwater is branded into two groups: bicarbonate ($CaHCO_3$ and $Mg(HCO_3)_2$) and sulphate ($MgSO_4$ and Na_2SO_4) (AL-Kubaisi, 2008).

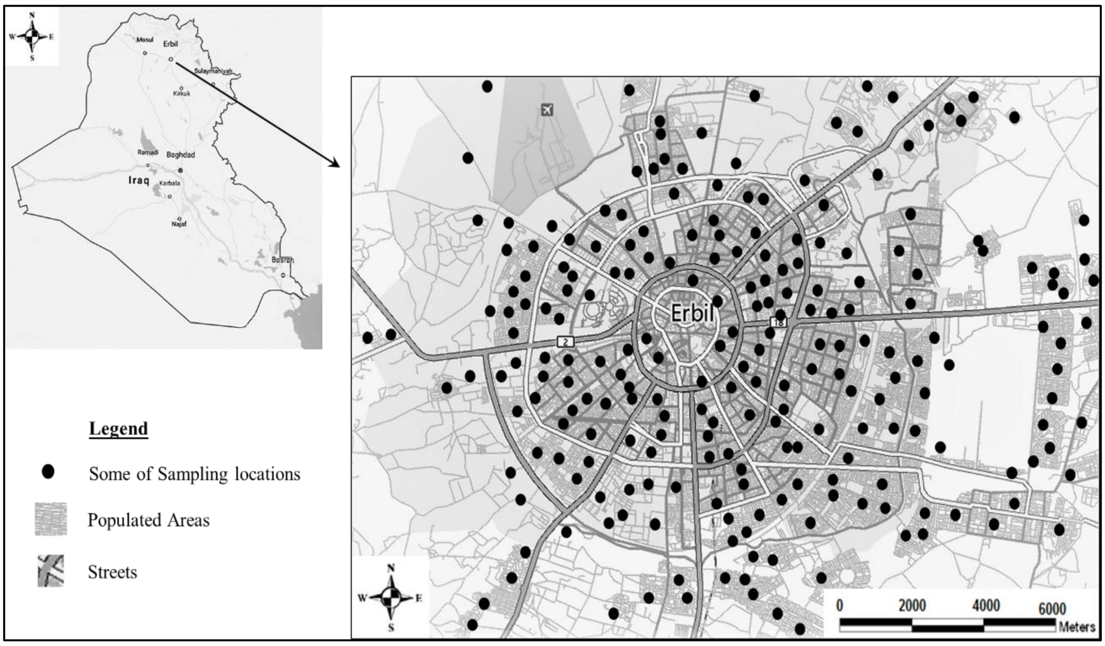


Figure 1: Map of study area, and some locations of water sampling

2.2 Water Sampling

In this study groundwater samples of Erbil City were collected in twelve months each of the years 2003 - 2015 to cover the seasonal variations. Groundwater samples have been analysed at laboratories of the Erbil City Municipality Directorate Centre. Procedures of analysis were in accordance to that proposed by (Apha et al., 1998). A dataset of a total of 9815 water samples was collected from 1704 wells, and analysed for 13 physicochemical parameters of pH, electrical conductivity, total dissolved solid, turbidity, total alkalinity, total hardness, sulphates, chlorides, nitrates, calcium, sodium, potassium, and magnesium over the study period of 2003-2015. These parameters were studied regarding their suitability for various domestic and drinking purposes. These parameters are highly relevant to the occurring groundwater quality variation and so they were chosen per Erbil City Municipality Directorate, where the evaluation of quality condition has become steadily required with the passing years.

2.3 Water Quality Index (WQI)

Generally, groundwater quality index is usually determined on a basis of various physicochemical parameters in water samples. The water quality is dependent upon the occurring activities during water sampling. Taking these activities into account is important for ensuring that environmental data are of the highest validity and quality (Tebbutt, 1997). For every tested parameter a relative weight was assigned ranged from 1 to 5, regarding the importance of the parameters in drinking and domestic use. WQI in this work was developed according to the index of US-NSFWQI developed by national sanitary foundation (Gharibi et al., 2012; Hoseinzadeh et al., 2015). This index can be used to assess the any water quality and is mathematically expressed as.

$$WQI = \sum_1^N W_i \,.\, Q_i \qquad (1)$$

W_i is the relative weight in terms of importance of the water quality ith parameter (Issa 2014). Other ways to calculate WQI exist for particular regions and conditions such as WQI for surface water resources, or for drinking water (Poonam et al., 2013). For calculating WQI, the relative weight W_i is usually inversely proportional to the recommended standard V_{standard} for the each parameter as the formula proposed by (Tiwari & Mishra, 1985).

$$w_i = K[1/V_{standard}]_i \qquad (2)$$

V_{standard} are prescribed by WHO (World Health Organization, 2011). The relative weight is determined as follows.

$$W_i = w_i \,/\, \sum w_i$$
(3)

The quality rating (Q_i) is calculated by the following equation

$$Q_i = 100 \,.\, [V_{actual} \,/\, V_{standard}]_i$$
(4)

While the quality rating for pH (Q_{pH}) was calculated on the basis of the following relation

$$Q_{pH} = 100 \,.\, [V_{actual} - V_{ideal}] \,/\, [V_{standard} - V_{ideal}] \qquad (5)$$

V_{ideal} is an ideal value that is applicable of pH which equals to 7.00, and V_{standard} is the value of recommended WHO standard of each parameter. Equation 2 makes sure the Q_i equals to 0 when a no pollution exist, and Q_i equals to 100 when water sample is polluted at maximum permissible limit. Thus the higher the value of Q_i is the more polluted (Alobaidy et al., 2010). Maximum permissible limits or standard values employed in this work are according to WHO (World Health Organization, 2011). Resulted groundwater quality WQI values are classified into five categories; excellent water (WQI < 50), good (WQI 50 - 100), poor (WQI 100 - 200), very poor (WQI 200 - 300), and unsuitable (WQI > 300) (Guo et al., 2007; Magesh et al., 2013; Monjerezi & Ngongondo, 2012). Assigned weights are shown in Table 1 (WQI calculated for the year 2011 as an example), where 13 parameters have assigned weights w_i ranging from 1 to 5 depending on the collective expert opinions, and from different previous studies on the perceived effect of each parameter on the primary health and various human uses (Srinivasamoorthy et al., 2008; Vasanthavigar et al., 2010). Assigned weights of each parameter abstracted from expert's opinion and the literature are shown in Table 1. An assigned weight of 1 is less important while, at value of 5 the assigned weight is highly important. The maximum weight of 5 was assigned to NO_3 for its major importance in groundwater quality assessment. This parameter is a key indicator for any contamination occurred due to infiltration or mixing of wastewater generated from anthropogenic activities. Nitrates as agricultural fertilizers is often percolating with the irrigation and rainwater to the groundwater sources in the study area (Al-Tamir, 2008). As there is no main wastewater treatment plants serves the city, and there are just two or three small wastewater plants for specific neighbourhoods. High assigned weights were also given to TDS and Cl, while Na and SO_4 have a moderate assigned weight each. Ca, Mg, and pH have assigned weights of low-moderate each.

Table 1: Calculation of overall WQI of Erbil City groundwater wells physicochemical properties during the years 2003-2015 based on the mean values of groundwater samples

Parameter	Mean observed value	Standard value	Assigned weight (Aw)	Quality rating (Qi)	$W_i.Q_i$
pH (pH unit)	7.38	8.0	3.0	37.74	2.46
Electrical conductivity (µS/cm)	569.83	250	4.0	227.93	19.82
Total dissolved solid (mg/l)	324.77	500	5.0	64.95	7.06
Chloride (mg/l)	22.28	250	5.0	8.91	0.97
Total alkalinity (mg/l)	213.18	100	3.0	213.18	13.90
Total hardness (mg/l)	255.31	100	2.0	255.31	11.10
Calcium (mg/l)	50.78	250	3.0	20.31	1.32
Sodium (mg/l)	19.66	50	4.0	39.32	3.42
Potassium (mg/l)	2.47	100	2.0	2.47	0.11
Magnesium (mg/l)	27.07	30	3.0	90.23	5.88
Nitrate (mg/l)	32.51	50	5.0	65.02	7.07
Sulphate (mg/l)	54.22	250	4.0	21.69	1.89
Turbidity (NTU)	1.39	5.0	3.0	27.71	1.81
				WQI=	76.81

2.4 Statistical Analysis

Datasets built on groundwater samples in Erbil City were subjected to different statistical analysis techniques; Pearson correlation coefficient matrix CM, multivariate analysis of variance MANOVA, agglomerative hierarchical clustering AHC analysis, and factor Analysis FA. The statistical computations were made using XLSTAT (version 2017 for Excel 2013 software). The merits of the applied statistical analysis techniques in this work provide useful manner to establish a comprehensive understanding for the temporal variance of physicochemical groundwater quality over the years 2003 - 2015. Pearson correlation matrix CM is used to explore the strength of relationships between each two or more physicochemical parameters during the time studied. MANOVA is applied to investigate the combined effect of groundwater level drop and the temporal change on the groundwater quality. FA is a suitable statistical multivariate technique for examining variable relationships for multifaceted conditions. It was used to investigate the impact of groundwater depletion with temporal variation on water quality by converting the physicochemical parameters into a few interpretable essential factors. The essential factors were developed on the basis that the multiple measured physicochemical parameters have similar patterns of responses during the investigated time because they are all associated with a not directly measured cause of water table decline. Agglomerative hierarchical clustering (AHC) was applied in this work to classify groundwater samples according to their temporal variation of physicochemical parameters in water samples. Ward-algorithmic linkage method and Euclidean distance are the basis to conduct statistical cluster analysis.

3. Results and Discussion

3.1 Descriptive Statistics

The descriptive statistics for the obtained dataset of groundwater quality is of 13 monitoring years and 13 quality parameters. The description as shown in Table 2 includes the mean, median, standard deviation, maximum, and minimum values for each monitoring period. The average physicochemical parameters in groundwater during the monitoring period (2003-2015) were arranged in an order according to their quality rating.

Table 2: Descriptive statistics of physicochemical parameters obtained from groundwater wells during the period 2003-2015

Parameter	Mean	Median	Maximum	Minimum	St. Deviation
pH (pH unit)	7.38	7.36	7.63	7.03	0.21
Electrical conductivity (μS/cm)	569.83	524.38	788.36	470.43	97.56
Total dissolved solid (mg/l)	324.77	301.08	504.55	235.44	86.00
Chloride (mg/l)	22.28	24.42	28.00	9.87	5.35
Total alkalinity (mg/l)	213.18	218.93	230.86	183.51	13.58
Total hardness (mg/l)	255.31	254.52	306.60	203.16	29.19
Calcium (mg/l)	50.78	55.41	65.10	31.28	12.75
Sodium (mg/l)	19.66	14.85	47.01	11.21	12.31
Potassium (mg/l)	2.47	1.34	12.96	0.79	3.26
Magnesium (mg/l)	27.07	28.47	38.39	0.97	10.70
Nitrate (mg/l)	32.51	29.92	60.01	22.71	10.25
Sulphate (mg/l)	54.22	31.02	112.64	19.21	37.05
Turbidity (NTU)	1.39	1.36	3.20	0.64	0.65

Characteristics of the physicochemical parameters in groundwater water samples for the dataset of 9815 water samples collected from 1704 wells are presented in Table 2. As illustrated in Table 2, the distribution of the measured parameters of groundwater samples over the period 2003 - 2015 shows that the mean and median values for the some parameters in groundwater samples are higher than maximum permissible limits MPL. EC has mean and median values of 569.83, and 524.38 µS/cm respectively, these values are higher than the double of MPL (250 µS/cm). The same status is exist for TA and TH. Their mean and median values are higher than the double of the MPL of 100 mg/L for each. This reveals the significance of these parameters on the chemistry of groundwater in the area. Mean and median values of Mg of groundwater samples are 27.07, and 28.47 mg/L respectively, these are near to the MPL for Mg of 30 mg/l, and hence this discloses the significant role of Mg in the drop of water quality of the area. Noticeable mean and median values of nitrates compared with MPL. The rest of the parameters showed lower concentrations in tested samples.

3.2 Annual WQI

The overall WQI for groundwater of wells at Erbil City during the period of 2003 – 2015 has a value of 76.81 (See Table 1). The annual WQI results are illustrated in Figure 2. However, the annual WQI didn't give a clear and particular vision for the physicochemical quality of groundwater in the study area during the observation time, as all the annual WQI fall in good quality (WQI< 100). However, from obtained results, it can be proposed that a considerable major nutrient like nitrate affects in many ways the groundwater quality (as highest assigned weight was attributed to nitrates of > 5). Most probably these nutrients come from anthropogenic activities.

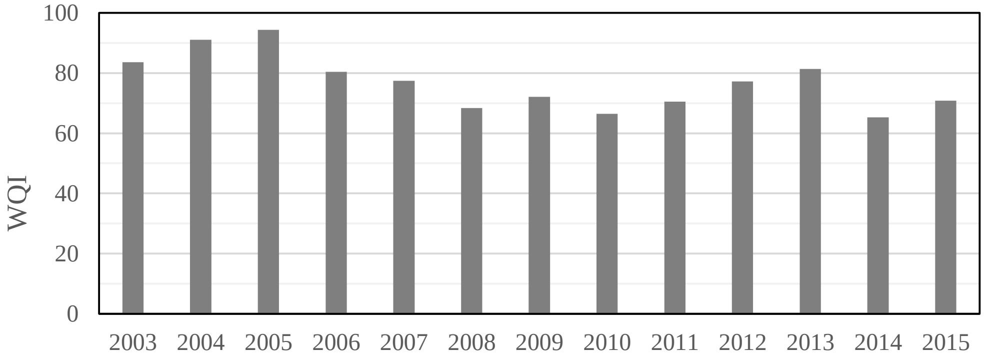


Figure 2: Groundwater WQI of Erbil City wells during the period 2003 - 2015

3.3 MANOVA Analysis

The results of multivariate analysis by MANOVA for groundwater samples in term of temporal differences for the monitoring period (2003 – 2015) are shown in Table 3. According to these results, the groundwater samples exhibit a significant variance in terms of selected physicochemical parameters. Since p-value < α = 0.0001 for all the tests, there is a significant difference between the time-based groups (years). The rejection of the null hypothesis H0 is true for p-values lower than 0.01% for all four MANOVA tests as shown in Table 3.

Table 3: Multivariate test (MANOVA) for the temporal variance of the period 2003 – 2015

Test	Value	F	P-value
Pillai's test	5.722	5.189	< 0.0001
Wilk's test	5.00E-07	21.246	< 0.0001
Hotelling-Lawley's test	493.395	193.457	< 0.0001
Roy's test	386.18	2198.253	< 0.0001

3.4 Correlation Coefficient Analysis

A correlation matrix CM of the physicochemical parameters established for the groundwater samples are displayed as Pearson correlation data presented in Table 4. Several strong positive and negative relationships can be seen in the CM. A significant positive relationship is exhibited between EC and TDS. Similarly, a strong positive relationship exists between Ca and Na; Cl and TA; Cl and K; Mg and SO_4 and between TH with all of K, SO_4, Mg, and Na. While TH, Ca and Na with Cl; all of TH, Mg, Ca and Na with K are significantly negatively correlated. Other parameters did not show the strong relationships between them. These results show that TDS has a strong association with EC. A insignificant relation was shown for NO_3 and pH. However, the direct relationship between Mg and TDS suggests that the TDS origin is mineral resulting from the natural weathering. The weak relationships of pH indicates that pH variation doesn't play a major role in dissolution of rocks underlie groundwater at the region (Shihab and Abdul Baqi 2010). The absence of more significant relationships between the remained parameters is apparently as a result of pollution occurrence. The high direct correlations for (TDS and EC), (TH and Ca), and (Cl and K) suggests that the dependence is caused by natural processes since they are all derived from natural compounds. Increasing in Ca, causes the quantity of inorganic matter to rise, in consequence, TH increases. The correlations between EC and TDS can be understood by the fact that high TDS caused by increased saline content which increases also the EC. The strong correlation between the dissolved minerals of Cl and K in groundwater aquifers come from soluble rocks like limestone and soils that underlie the aquifer in the study area.

Table 4: Pearson linear correlation coefficient matrix for the 13 physicochemical parameters in groundwater samples during 2003-2015

	pH	EC	TDS	CL^-	TA	TH	Ca^{++}	Na^+	K^+	Mg^{++}	NO_3^-	SO_4^{--}	Turb.
pH	1												
EC	0.31	1											
TDS	0.29	**0.94**	1										
CL^-	0.02	-0.16	-0.30	1									
TA	-0.08	0.02	0.05	**0.63**	1								
TH	-0.26	0.14	0.29	**-0.89**	-0.41	1							
Ca^{++}	-0.37	-0.23	-0.14	**-0.73**	**-0.51**	**0.73**	1						
Na^+	0.18	-0.05	-0.03	**-0.70**	**-0.60**	**0.51**	**0.56**	1					
K^+	0.06	-0.19	-0.34	**0.97**	**0.58**	**-0.91**	**-0.68**	**-0.64**	1				
Mg^{++}	-0.04	0.41	**0.54**	-0.44	0.02	**0.65**	-0.02	0.06	**-0.52**	1			
NO_3^-	-0.04	0.39	0.30	0.13	0.15	0.06	-0.12	-0.21	0.08	0.26	1		
SO_4^{--}	0.03	0.25	0.40	-0.37	-0.10	**0.58**	0.15	0.12	-0.44	**0.72**	0.10	1	
Turb.	0.20	0.23	0.27	-0.35	-0.21	0.23	0.18	0.34	-0.31	0.09	0.11	0.06	1

Values in bold are different from 0 with a significance level alpha=0.05

3.5 Hierarchical Cluster Analysis (HCA)

The HCA determines the similarity or dissimilarity among clustered generated by this technique, considerable internal clusters homogeneity and significant external cluster heterogeneity was identified regarding the temporal similarity between water samples in the study area. As shown in Figure 3, the dendrogram of HCA has generated three distinct clusters. Dissimilarity of water samples in term of sampling temporal variation are classified into three principal cluster groups. Main groups of sample locations are Cluster 1, contains sampling in the years 2003, 2004, 2005 and 2006. Cluster 2, includes sampling from the years 2007 and 2008. Cluster 3, combines samples of the rest of study period between the years 2009 and 2015. The cluster analysis results of the temporal division based principally on the physicochemical quality in groundwater samples. As shown in Figure 3, cluster 1 is different from other clusters and involves with low WQI recorded. Cluster 2 refers to groundwater samples of a quality that is relatively different. While cluster 3 represents a change in groundwater quality with time that could be more substantial. In comparison with annual rainfall rates on the Erbil area, clustering analysis seems to be very reasonable as the average rainfall for the last decades shows a significant declining (Al-Kubaisi & Gardi, 2012). Nonetheless, the annual rainfall was fluctuating during the study period 2003 – 2015, lowest rainfall rate was recorded of 125 mm at the years 2008, highest annual rainfall was observed in 2013 of 1552 mm (Nanekely et al., 2016).

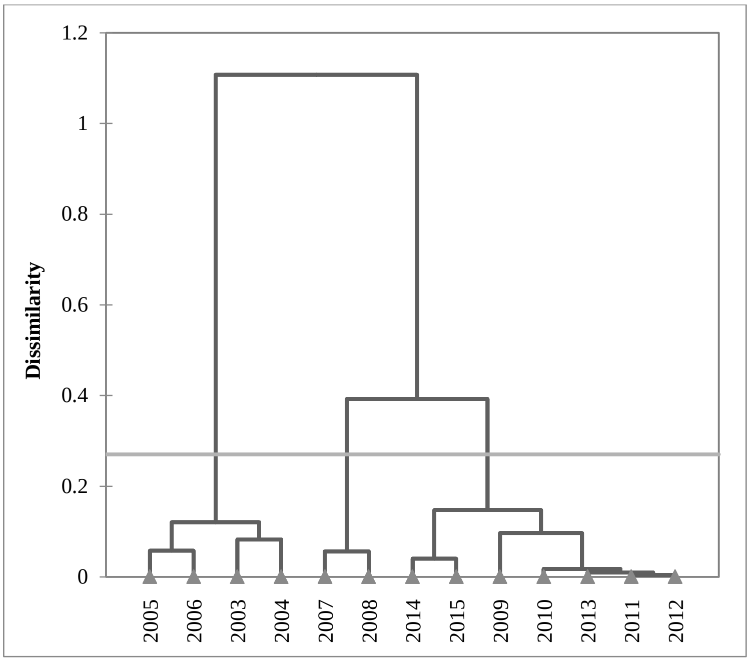


Figure 3: Hierarchical cluster analysis dendrogram of water samples temporal variation (2003-2015) of Erbil City groundwater

To investigate the relationship between physicochemical parameters, agglomerative hierarchical clustering AHC was run with respect to temporal variation of these parameters in water samples. The basis to conduct statistical cluster analysis, in this case, is Ward’s method as agglomeration method and Euclidean distance for measuring the similarity. Three major clusters or groups were generated as shown in the dendrogram of Figure 4. It can be seen that high correspondences exist between major ions of K, NO_3, and Na. This cluster suggests the interaction of groundwater with underlie rocks or recharge surface water interaction with soil. Another cluster relates Ca and Mg, in which the salinity parameters are related with each other and indicates the land nature of study area. While the third cluster exhibits the relationship between TH, EC, TDS, turbidity, etc. as one group, which most likely represents the joined effects of anthropogenic activities and the weathering of the groundwater on adjacent rocks and soil.

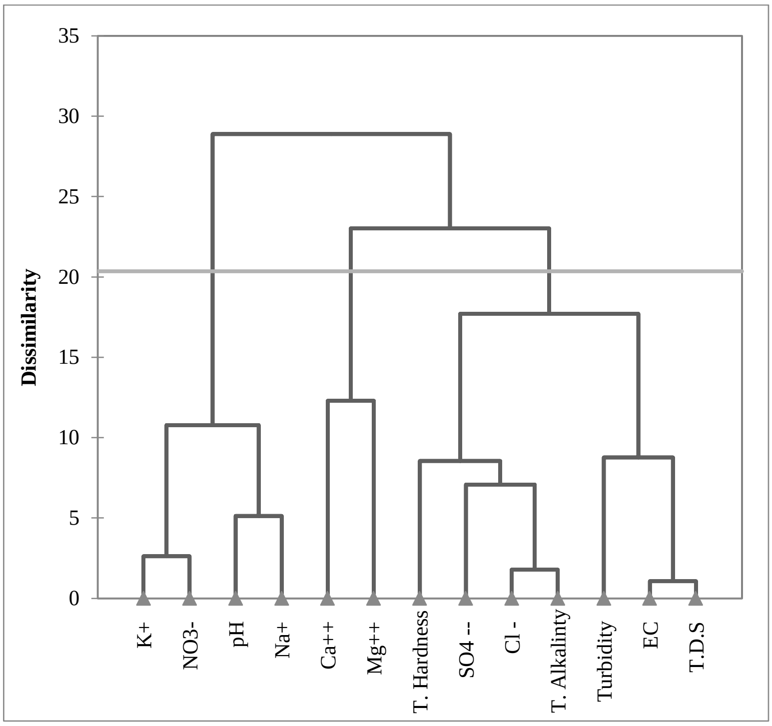


Figure 4: Dendrogram for 13 physicochemical investigated for Erbil City groundwater

3.6 Factor Analysis (FA)

Factor analysis was performed for the 13 parameters mean values to explore the temporal variance of physicochemical groundwater quality. The obtained eigenvalues indicate the significance of developed seven factors: high eigenvalues are related to the most significant factors. Classification of factor loading shows that F1 is the strongest, while F2 is a moderate factor, while F3 and F4 are relatively moderates. The rest are less important in terms of absolute loading values as shown in Figure 5 of scree-plot and Table 5 of factors pattern after Varimax rotation. The first two factors of factor analysis include totally more than 58.87 % of the total variance in each year respecting water quality dataset.

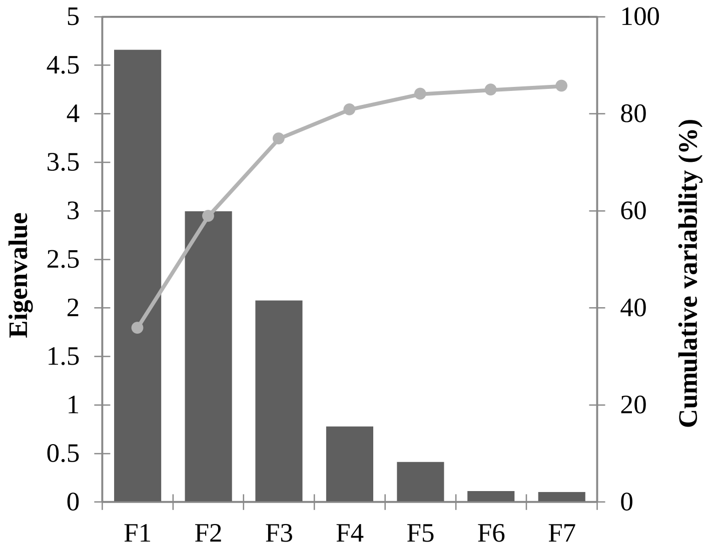
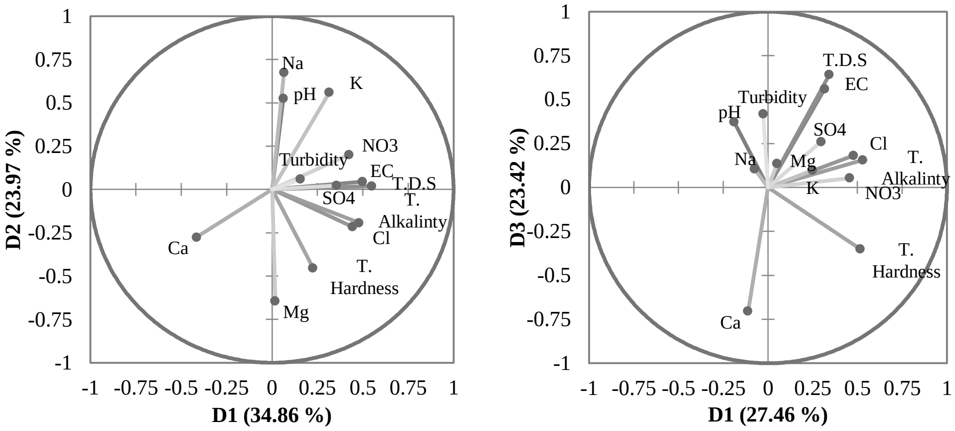


Figure 5: Scree plot and cumulative variability for the factor analysis for monitoring datasets during the period (2003 – 2015)

The scree-plot shows that up to 58.87% of the original data variability is on the first two factors and up to 80.86 % for the first four factors. The eigenvalues greater than one are considered important. A Varimax rotation of the principal factors of specific eigenvalues (Figure 6) was performed that explained more than 74.86 % of the total variance. Varimax rotation distributes the component loadings in a way that their distribution was maximized through reducing the number small coefficients, where dataset variabilities can be defined by a few factors without losing much information (Singh et al., 2004). Factor analysis based on eigenvalues and Varimax rotation for the most significant two factors explains most of the total variance of 74.86 % for the groundwater datasets after Varimax rotation of axes D1, D2 and D3 as shown in Figure 6. As illustrated in Figure 6, Na, Ca, Mg, K, TH, TDS, Cl, SO_4, NO_3 and EC are the most significant parameters contributing to groundwater quality variations for the monitoring period 2003 – 2015 from their positive and negative loading on D1, D2, and D3. Each groundwater quality parameter of a significant correlation coefficient value is regarded as a significant parameter contributing to annual variations of the groundwater quality of Erbil City.

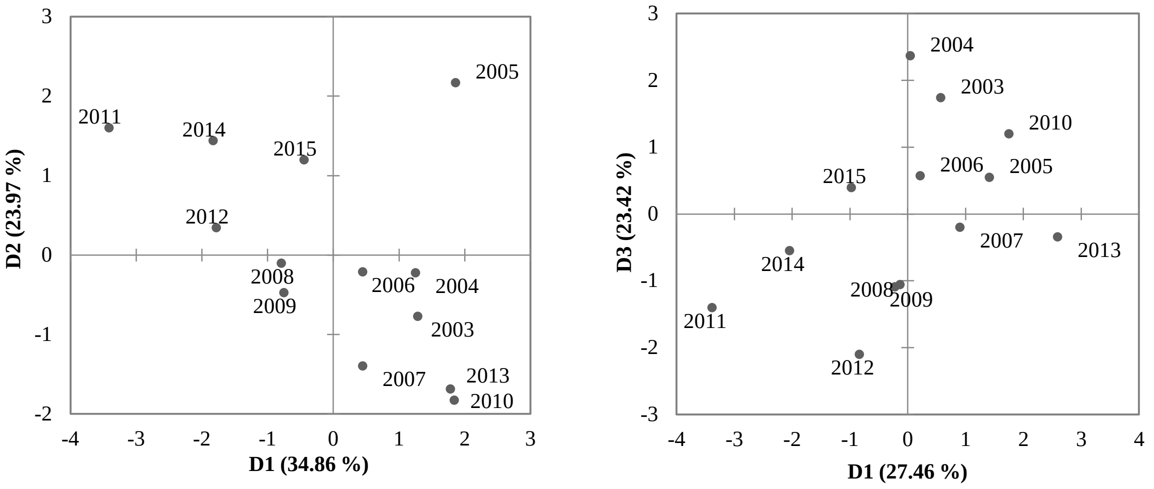
From Figure 6a, factor D1, which accounts 34.86 % of parameters variance, shows parameters of enriched relation in (EC, TDS, TA, and Cl with positive loading), and (Ca with negative loading). While (K, Na, and pH with positive loading) and (Mg with negative loading) values in D2, which accounts 23.97 % of parameters variance, regarded as significant parameters contributed to groundwater quality variations. In Figure 6b, D3, which accounts 23.42 % of parameters variance, shows strong positive loadings of TH, EC, and turbidity as significant parameters. So it can be observe that the generated three distinguishing factors are demonstrating groundwater quality; in which D1 is associated with high loading of the mineral Ca among the strong loadings, this usually comes from all the dissolved rocks and soil like limestone and also it may come from brines, and consequently EC, Turbidity, and TDS were increased (Ajdary & Kazemi, 2014). In this factor, it is also dominated by significant loading of SO_4, and Cl, that come from dissolved rocks and soil composed of these minerals such as $CaSO_4$ or $MgCl_2$ that deposited during the underlay formation in the study area. D2 is associated with NO_3, this mainly attributed to mixed origin from anthropogenic and geological sources. The contamination sources like different anthropogenic activities of local and agricultural (Menció et al., 2016). D2 is also associated with the effect of Na, Mg, and K that come from dissolved rocks and soil composed from these minerals. D3 is associated with the effect of Ca, TDS, EC and TH that may come from natural sources of rock dissolution.



(a) (b)

Figure 6: a and b. Two-dimensional plot of the 71.01.40% factor loading of D1, D2, and D3 after Varimax rotation, observations corresponding to the temporal period 2003 – 2015, collection differentiated from the central scatter plot

The distribution of temporal association of monitoring years in groundwater determined by factor analysis and based on eigenvalues and Varimax rotation is displayed in Figure 7. For factor analysis, the most significant three factors explain most of the total variance of 74.86 % of the groundwater dataset after Varimax rotation of axes D1, D2 and D3. In Figure 7, the temporal variation of physicochemical groundwater quality in Erbil City from 2003 to 2015. As it was previously factor categorized into D1 for the natural impact of dissolved rocks or soil of Ca, D2 represents mainly the contamination by anthropogenic activities, and D3 was attributed for the hardness impact. Figure 7 illustrates also that groundwater quality of Erbil City was strongly influenced by factor D1 of the natural source impact in the years 2005, 2010 and 2013. These ions had lowest influence in the years of 2010, 2012 and 2014. Weak impact was found in 2006 and 2015. Figure 7 displays that groundwater quality in Erbil City was strongly influenced by anthropogenic activities during the years 2011 and 2005, while it was less influenced in the remaining years. No considerable influences of anthropogenic activities on groundwater quality were found in 2010 and 2013. Figure 7, b shows that that effect of T. hardness on groundwater quality was the highest in 2004, and the lowest was in the year 2012. From these results, it is obviously clear that groundwater depletion has not greatly changed or altered the physicochemical properties of groundwater resource within Erbil City over the duration of 2003 – 2015.



(a)

(b)

Figure 7: a. and b. Observations (independent variables) years (2003 – 2015) of axes D1, D2 and D3 71.87% after Varimax rotation

4. Conclusion

Physicochemical properties of Erbil City groundwater were tested in this paper and the dataset have been assessed by diverse statistical methods of coefficient correlation, cluster analysis, factor analysis, and index analysis. The assessment was performed to understand the temporal variance of groundwater quality and impact of the latent groundwater depletion and any pollution during a period of 2003 – 2015. This period represents an important economic and urban growth and in Erbil City, that coincided with a growing decline in the groundwater level. Index analysis showed that water quality stayed always within a good level, despite the fact that index values were close to a moderate level at the start of the monitoring time and the values were then lowered in the last years of the monitoring time, this index was not able to show a clear view of the groundwater physicochemical property over testing period. Cluster analysis and factor analysis indicates more clearly the parameters that are responsible for water quality variations during the monitoring years 2003 - 2015. Three important cluster and factors were categorized for groundwater quality. In factor analysis, the first and second factors were taken into consideration as they have more than 59.87% of significance in contribution to groundwater physicochemical quality variations. Strong loading parameters Na, Ca, Mg, K, EC, NO_3, TH, and TDS are mostly the significant parameters in contributing to water quality variations for all study years. NO_3 was found in groundwater due to anthropogenic sources like agricultural and domestic discharges. For the rest, these parameters come mainly from natural geological sources. This environmental monitoring and assessment study leads to determine the temporal variation and indirect effect of groundwater decline on the Erbil City groundwater on water quality parameters during 2003 – 2015. Temporal variance didn’t show a significant influence on the tested physicochemical parameters in that period, so it is likely to say that groundwater depletion, and the climate changes didn’t result in a significant alteration in water physicochemical quality and a wide plan is needed for optimum groundwater management by avoiding unjust consumption to ensure conservation of the current quality.

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