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Multivariate statistical characterization of water quality analysis for Erbil wastewater channel

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Abstract: *Multivariate statistical analysis, such as principal component analysis (PCA), factor analysis (FA) and cluster analysis (CA), were applied for evaluate the water quality of Erbil wastewater channel. Seventeen variables have been monitored in three selected sites on monthly basis for one year (May 2010- April 2011). Results revealed that the most important variables are those related to salinity factors, temporal hardness and mineral salts according to PCA/FA techniques. In addition to, CA results showed that dissimilarity of site 3 from other two sites, and most similarity between ions related to processes of hydrogeochemical and mineralization.*

Generally, water quality for irrigation purposes comes under good water type (86% of total samples) to moderate type (16%) depending on EC- SAR values guidelines. Increases in ions concentrations for EC, TDS and hardness were observed from upstream toward downstream of Erbil wastewater channel.

Keywords: *Water quality, factor analysis, principal component analysis, cluster analysis, irrigation, wastewater.*

I. Introduction

The safety of human public health and the environment is very important issue related to monitoring of parameters used in assessing water and wastewater [1]. Physico- chemical properties and heavy metals determination for stream water monitoring is necessary to evaluate contamination level in wastewater, with increasing overpopulation, urbanization and different anthropogenic activities, there has been a rapid increase in domestic and industrial effluent discharge into streams and rivers, leading to increase pollution load [2].

Erbil wastewater channel is important stream that recipient of Erbil city untreated sewage, storm runoff rain water, in addition to industrial and agricultural runoff. In medial and downstream it being used for farm irrigation before discharged to Greater Zab River. According to Erbil city general directorate of water in 2012 they produced about 61000 $m^3.day^{-1}$ and every person in city will receive more than 400 $litter.day^{-1}$ for domestic consumption. Therefore, the quantity of sewage discharge differs from time to other, as a mean, it may reach 77760 $m^3.day^{-1}$ during dry season and 108000 $m^3.day^{-1}$ during rainfall season [3].

The application of different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied systems, allows the identification of possible factors sources that influences water systems and offers a valuable tool for reliable management of water resources, as well as rapid solution to pollution problems [4].

Many studies have been conducted on Erbil wastewater monitoring and its suitability for different purposes [5; 6; 7; 8; 9; 10; 11; 12].

The objects of present work are to assess levels of physico- chemical parameters in order to determine the source of pollutants and on quality of water in stream by using multivariate statistical methods, as well as, to evaluate their suitability for irrigation purposes.

II. Materials and methods

2.1 Study area

Erbil wastewater channel which extended from southwest of Erbil city with their elongation for more than 50 km passes through vast farmlands, orchards and several villages, after Gameshtapa village wastewater effluent discharges into Greater Zab River. Generally, Erbil sewer system is constructed for storm water and in most cases domestic sewers are connected illegally with storm sewer. The width of channel ranges from 2-4m with depth more than 1m at different locations [12].

2.2 Sample collection

In present investigation, water samples were collected regularly on monthly basis from 3 sites along Erbil wastewater channel during May 2010- April 2011 (Fig. 1). Standard techniques were used [13] to analyze the different physico- chemical parameters: pH, electrical conductivity in field by using (pH meter Philips 4014 and EC meter Philips 4025 respectively), total dissolved solids (TDS, evaporation at 180 ºC), total hardness, calcium and magnesium (EDTA titrimetric method), Cl (argentometric method), SO_4^{-2} (turbidimetric method), HCO_3 (titrimetric method), Na^+ and K^+ (flame photometric method), trace metals (Cd, Pb, Cu and Zn) by (Atomic absorption spectroscopy Philips Sp9) after concentrating 1L of samples (with addition of HNO_3). While, sodicity, including the Na% and SAR were calculated according to the formulas given by [14] as follow:

$$\text{Sodium percentage \% Na} = \frac{\text{Na x 100}}{\text{Na + K + Mg + Ca}}$$

$$\text{Sodium Adsorption Ratio (SAR)} = \qquad \text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

2.3 **Multivariate statistical methods**

Physico- chemical factors were compared statistically by using one way analysis of variance (ANOVA). Duncan test was used to examine multiple comparisons. Correlation was evaluated for significance using a Pearson product moment correlation test procedure. Principal component analysis/ factor analysis (PCA) was performed to relate different studied parameters and cluster analysis (CA) to evaluate similarities and dissimilarities between sampling sites and variables, all mathematical and statistical calculation were implemented using (SPSS version 20) program and Microsoft Office Excell 2007.

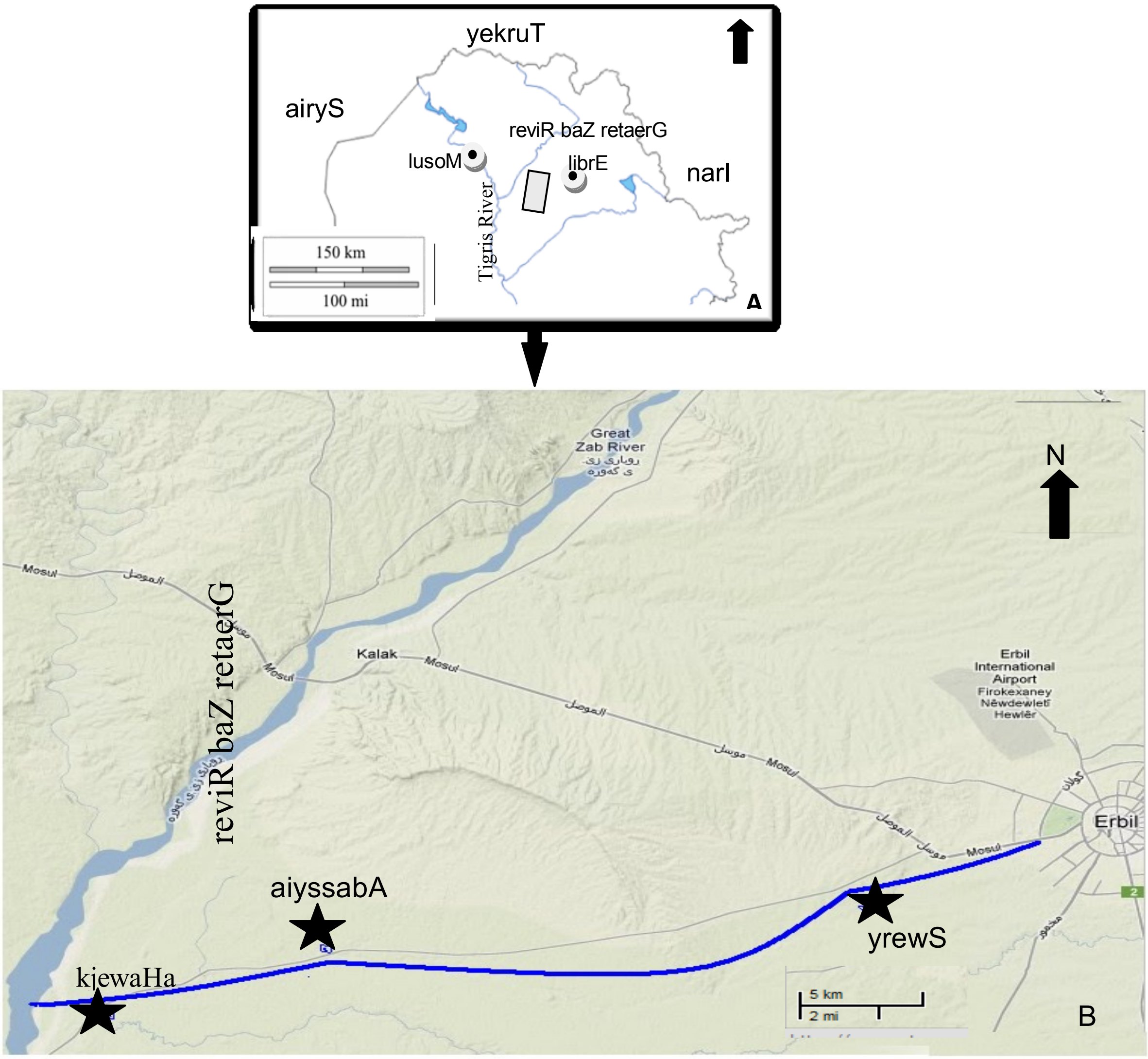

Figure 1: Map showing northern part of Iraq, and sampling sites along the Erbil wastewater channel.

Descriptive characteristics (minimum, maximum, mean and standard error) for chemical parameters are given in Table (1). The sewage water samples exhibited an alkaline pH in the range of 6.99 to 7.98. The minimum value observed at site 1 and maximum value at site 3 (Fig. 2). There is a significant difference ($P \leq 0.05$) between site 1 and sites 2 and 3. Generally, the obtained pH values fall within safe limit for crop production [15]. Previous studies [5; 9; 16] recorded similar results in the main sewage channel of Erbil city.

Conductivity is a measure of the ability of water to conduct an electrical current [17]. The electrical conductivity (EC) of water samples ranged from 486- 1032 µs. cm^{-1} throughout the studied period. Higher EC were observed in downstream channel (site 3) with trend to increase from site 1 to site 3, it may be related to effluent discharges into the stream [18]. Based on irrigation purposes in most cases EC classified as C2 medium type water and some cases as C3 saline type water.

Sodium Adsorption Ratio (SAR) is a relatively proportion of sodium ions to calcium and magnesium. Sodium effects soil structure through cation absorption, mainly on clay and fine silt fractions. As the percentage of sodium rises in relation to other cations, lead to reduced infiltration that cause a decrease in water supply to crop between irrigations and reduced soil aeration capacity [15]. SAR values ranged from (0.32- 1.84, 1.14- 2.16 and 1.14- 1.80 Meq.l^{-1}) for sites 1, 2 and 3 respectively. The water quality characterized by low SAR and lies in first class (S1) according to [19] classification, which can be considered as safe type for irrigation, since the maximum SAR value not exceed 3. These results are lower than obtained by [20]. Generally, about 84% of the total water samples fall in the C2- S1 zone of the salinity that regarded as medium salinity type. This comes under the good water quality zone for irrigation. While, 16% of water samples fall in the C3- S1 (high salinity type) that comes under moderate water quality zone for irrigation (Fig. 3) [19].

Total dissolved solids (TDS) showed same trend of fluctuation as noticed in EC values by increases from upstream to downstream of sewage channel (Fig. 4). TDS mean values were 345, 380 and 387 mg.l^{-1} respectively. The relative high ranges of EC and TDS values in the sewage water may be related to nature of municipality pollutants, industrial wastes and land use activities in the area [21]. High TDS concentrations automatically influenced the quality of the received water body. Elevated TDS can be toxic to freshwater animals by causing osmotic stress and affecting the osmoregulatory capability of the organisms [1]. Similar results were noticed by [11; 16], while, its lower than recorded by [8] at the same polluted channel. TDS values it considered as good type and entirely safe for irrigation as classified by [22]. Erbil wastewater can be regarded as a weak type according to [14]. There is high correlation coefficient observed between EC and TDS in this investigation. The TDS is related to conductivity in that if they are high, the EC also be high [23; 24].

Total hardness mean values varies from 277.9, 287 and 296.3 mg $CaCO_3$.l^{-1} from upstream to downstream respectively. There is no significant difference ($P \leq 0.05$) between studied sites. Water quality can be regarded as hard to very hard water [22].

Sodium and potassium are common felsic cation occurrences in nature, with high dissolvent (soluble) in water [25]. The mean values of Na^+ and K^+ from upstream to downstream were (1.73, 2.07 and 1.91 for Na and 0.21, 0.22 and 0.20 Meq.l^{-1} respectively). Highest Na^+ concentration than K in water samples may be due to domestic effluent characteristic that contain higher concentration of Na^+ [26] or to higher resistance of K minerals to weathering in relation to Na minerals [27]. There is a trend to increase concentration for both ions from site 1 to site 2 then reduction toward site 3. Same phenomenon was observed by [5] at same polluted channel. Higher values of Na^+ and K^+ was recorded by [8; 28]. While, similar ranges were observed by many researches [5; 9; 10] in the same polluted channel.

Calcium regarded as an important and dominant cation in water, magnesium comes after Ca, and both cations are necessary element for growth of plants and animals [25]. They react with carbonate to produce water hardness [29]. The Ca^{+2} and Mg^{+2} minimum and maximum concentration of wastewater was 1.44- 4.60 and 0.1- 0.42 mg.l^{-1} respectively. Site 2 characterized by highest Ca^{+2} value than other studied sites, while site 3 has more Mg^{+2} concentration than others sites, with no significant differences ($P \leq 0.05$) between studied sites. These results are lower than noted by [5; 10; 20].

The site with the highest chloride levels is site 1 with mean value 59.7 mg.l^{-1} followed by site 2 and 3 with 56.3 and 47.2 mg.l^{-1} respectively. [30; 31] commented that human excreta increase the amount of Cl^- in sewage. Decrease in chloride concentration was observed from upstream to downstream. There is a significant difference ($P \leq 0.05$) between site 1 and site 3. These results come in accordance with that observed by [16]. According to [14] guidelines the water is entirely safe for irrigation.

The results of sulphate (SO_4^{-2}) showed increases in their values from site 1 (922 mg.l^{-1}) to site 2 (1001.6 mg.l^{-1}) to site 3 (1309 mg.l^{-1}). The quality of stream water is affected by sulphates. The concentration of sulphate exceed [22] maximum permissible level for irrigation purposes. Moreover, SO_4^{-2} concentration was always higher than those of Ca^{+2}.

Alkalinity is a measure of the buffering capacity of water [32]. Most alkalinity value is due to bicarbonate ion. Generally, low concentration of HCO_3 was recorded in Erbil wastewater channel with mean values of 0.089, 0.096 and 0.087 Meq.l^{-1} respectively for studied sites. These values are lower than recorded by previous studies on the same channel [5; 8; 16]. The water quality is non-restricted to use for irrigation according to guideline of [14]. High sulphate values in water caused Ca^{+2} precipitation which lead to relatively increase in Na^{+} contain in soil that adsorbs to clay surfaces and effects on nutrients balanced in plants [33].

Table 1: Physical-chemical properties of Erbil wastewater channel, data represented as mean± S.E. with minimum and maximum values, during studied period.

Variables	Sites		
	1	2	3
pH	7.26± 0.065 6.99- 7.78	7.51± 0.056 7.15- 7.77	7.65± 0.072 7.24- 7.98
EC(µS.cm^{-1}) (at 25ºC)	602.0± 31.97 486.15- 838.8	636.8± 29.70 517.9- 869.6	680.4± 47.45 □529.1- 1032.6
TDS ($mg.l^{-1}$)	345.13± 21.88 □236.76- 491.2	380.14± 21.25 264.18- 529.9	661.46± 272.07 265.56- 648.9
Total hardness (mg $CaCO_3.l^{-1}$)	277.91± 11.22 □226.0- 346.0	287.08± 13.17 240.0- 380.0	296.33±8.78 242.0- 336.0
Na^{+} ($Meq.l^{-1}$)	1.73± 0.16 □0.38- 2.30	2.07± 0.098 1.56- 2.60	1.91± 0.077 1.42- 2.30
K^{+} ($Meq.l^{-1)}$	0.0053± 0.00044 □0.00- 0.01	0.0057± 0.00024 0.00- 0.01	0.0051± 0.00048 □0.00- 0.01
HCO_3^{-} ($Meq.l^{-1}$)	0.089± 0.0054 0.70-□ 0.13	0.096± 0.0064 0.60- 0.14	0.087± 0.0043 0.70- 0.11
Ca^{+2} ($Meq.l^{-1}$)	3.375± 0.199 1.80- 4.48	3.608± 0.170 2.68- 4.60	3.525 ± 0.233 1.44- 4.32
Mg^{+2} ($Meq.l^{-1}$)	0.182± 0.024 0.10- 0.42	0.178± 0.0154 0.10- 0.29	0.200± 0.0126 □0.12- 0.28
SO_4^{-2} ($Meq.l^{-1}$)	19.21± 2.233 4.17- 28.65	20.87± 1.875 6.67- 28.65	27.27± 3.598 6.67- 45.83
Cl^{-} ($Meq.l^{-1}$)	1.655± 0.129 0.86- 2.68	1.609± 0.073 1.26- 2.23	1.350± 0.079 0.88- 1.77
Na%	32.04± 2.405 11.63- 41.43	35.48± 1.583 28.29- 47.22	34.39± 1.373 27.59- 45.15
SAR	1.298± 0.120 0.32- 1.84	1.521± 0.085 1.14- 2.16	1.415± 0.050 1.14- 1.80
Cd (µg.l^{-1})	25.70± 2.475 0.00- 46.73	17.13± 1.529 0.00- 28.04	16.35± 1.071 0.00- 28.04
Pb (µg.l^{-1})	15.44± 2.06 0.00- 61.76	30.88± 4.31 0.00- 61.76	50.74± 6.26 0.00- 179.41
Cu (µg.l^{-1})	9.34± 1.81 □0.00- 18.69	0.00± 0.00 0.00- 0.00	14.02± 1.44 0.00- 18.69
Zn (µg.l^{-1})	12.82± 1.64 0.00- 76.92	32.05± 4.84 0.00- 153.85	25.64± 2.93 □0.00- 76.92

Sodium considered being the most important factor in determining the suitability of water for irrigation [34]. Maximum sodium percent (Na%) was 47.2% recorded in site 2. According to [35] the wastewater classified as good type of water for irrigation. These results come with results that obtained by [16], while, its lower than noted by [8] at the same polluted channel.

Generally, the mean concentrations of ions in wastewater were observed in the order: SO_4^{-2}> Cl> Na^{+}> HCO_3> Ca^{+2}> Mg^{+2}> K^{+}.

Water quality for Erbil wastewater channel characterized by dominance of the following heavy metals according to their content in sequences: Pb> Zn> Cd> Cu with highest mean values of 50.74, 32.05, 25.7 and 14.02 µg.l-1 respectively. [10] found heavy metal dominance in the same polluted channel in the following order: Zn> Pb> Cu> Cd. From previous results its can be concluded that the water channel is polluted by heavy metals that comes from human activities and industrial effluent [36].

3.2 Data structure determination and source identification

PCA is a powerful pattern recognition technique that attempts to explain the variance of a large dataset of intercorrelated variables with a smaller set independent variables (Principal component) [37].

Principal component analysis/ factor analysis was performed on the normalized dataset (17 variables) for three different sites in twelve months, in order to identified important water quality parameters. An eigenvalue gives a measure of the significance of the factor: the factors with the highest eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant [38] classification of factor loading in thus “strong”, “moderate” and “weak”, corresponding to absolute loading values of > 0.75, 0.75- 0.5 and 0.5- 0.3, respectively [39]. Corresponding, variables loading and explained variance with rotated factors are presented in (Table 2).

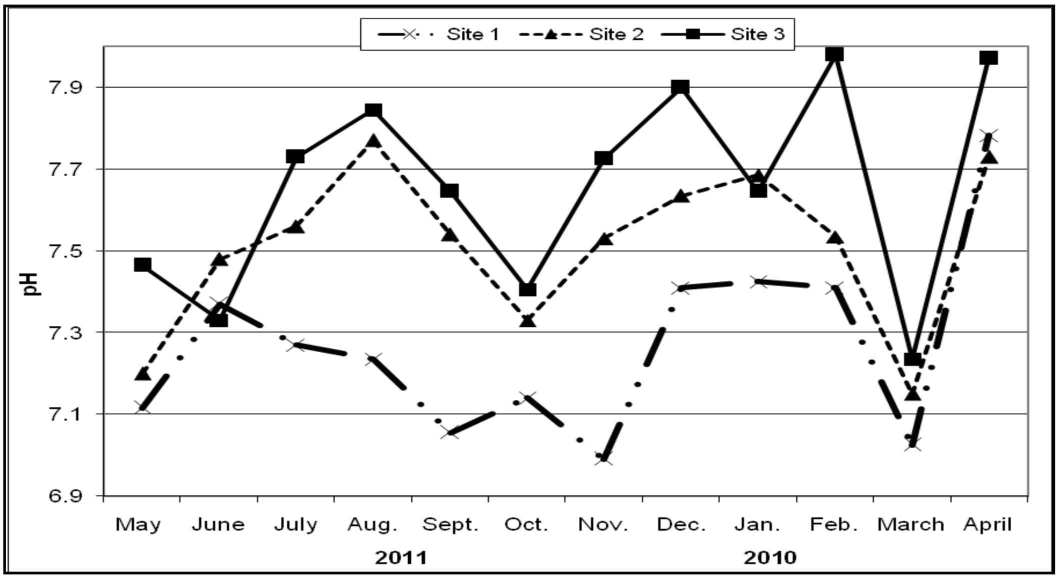

Figure 2: pH variation in Erbil wastewater channel during studied period.

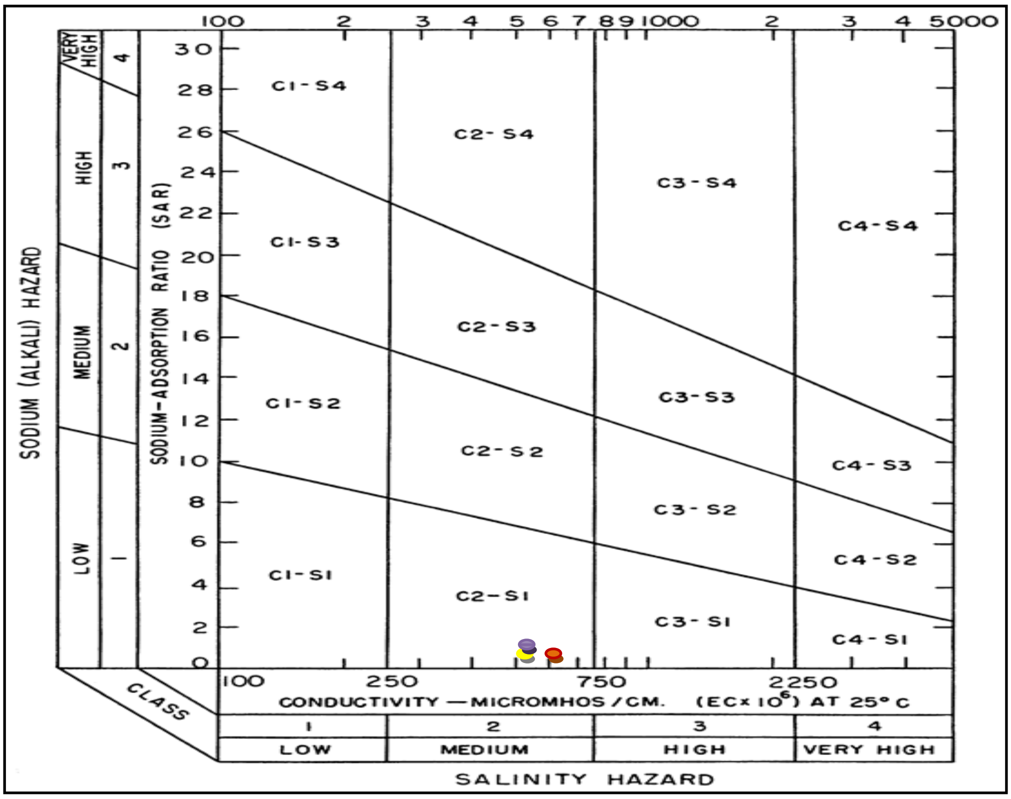

Figure 3: Classification of irrigation waters (19). Circles denoted the chemical data of the water sampling sites depending on mean value.

The results showed that first six components accounted for more than 80% of the total qualitative differences among the sites. The first component PC_1 accounted for 25.3% of the whole dataset, has strong positive loading on Na, Na% and SAR, which shows that the quality of water in these sites is affected by salinity factor, that may be comes from domestic uses and soap component [26]. For the second component PC_2 is associated with strong positive loading to total hardness and bicarbonate as the most significant parameters and moderate positive loading to Mg and Cl ions (Fig. 5 and 6). These variables are accounts for temporary hardness of water. While, third component PC_3 is strongly positive loading with SO_4^{-2} and moderately positive loading with pH, EC, Pb, and negatively with K^+ ions, it can be related to mineral salts and weathering [40].

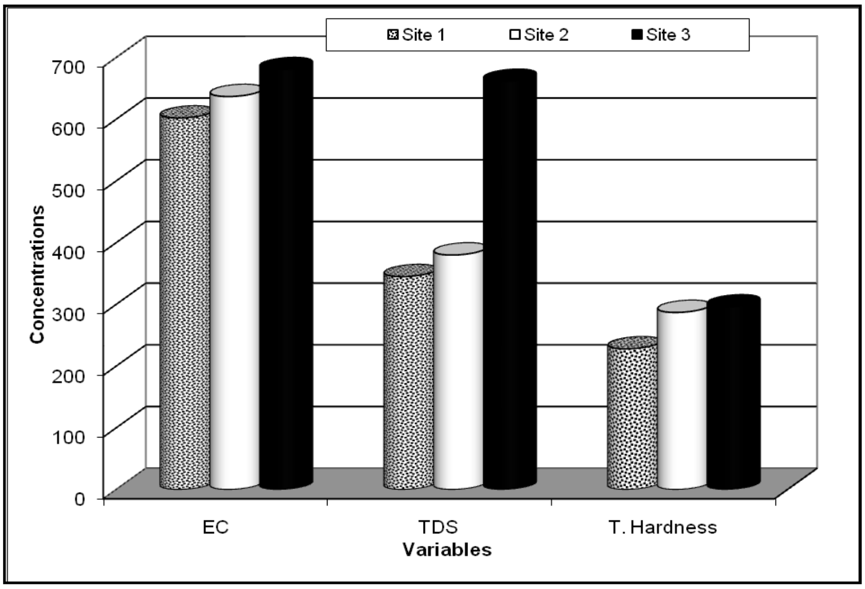

Figure 4 Shows increase in EC µS.cm^{-1}, TDS mg.l^{-1} and Harness $CaCO_3$.l^{-1} concentrations from upstream to downstream of Erbil wastewater channel.

3.3 Sites and variables similarity

The similarity between sites were obtained through cluster analysis using Wards method (linkage between groups) with Euclidian distance as a similarity measure and were amalgamated into dendogram plots (Fig. 7). As it shown there are similarity associations between site 1 and 2, both of them linked with site 3. Generally, in most studied variables site 2 considered as intermediate stage between sites 1 and 3 in both increasing value of variables or decreasing from upstream of channel toward the downstream.

Fig. (8) showed the similarity degree between studied variables in which two clusters of three groups were formed. First group linked TDS, EC and total hardness. The higher concentration of TDS related to EC and hardness ions is an indication of man- made pollution due to domestic waste [41]. Second group association between SO_4^{-2}, Na%, Cd and Pb were obtained. While, third group consists of association between three subgroups; in which association found between K^+, HCO_3, Mg^{+2} with Cl, SAR, Na^+, pH, Ca^{+2}, Cu all with Zn. These ions suggest the associated with a combination of various hydrogeochemical processes and augment more mineralized water [24].

IV. Conclusion

Hydrogeochemical, mineralization and sewage effluent discharges are the most important sources of ions in the polluted channel in which increases in ions concentrations from upstream polluted channel towards downwards according to EC, TDS and total hardness values were observed during period of investigation. Most of ions concentration comes under safeguard public health for irrigation purposes, but other human public health factors must be taking account such as pathogenic microrganisms.

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Table 2: Eigenvalue and percentage of variance explained by each of the seven principal components (PCs) for Erbil wastewater channel studied variables.

Principal component	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6
Eigenvalue	4.5590	2.9380	2.5070	1.8890	1.329	1.224
% total variance explained	25.326	16.320	13.930	10.496	7.381	6.798
% cumulative variance	25.326	41.646	55.576	66.072	73.453	80.251
Rotated factor correlation coefficients						
pH	-0.269	-0.071	0.591	0.056	-0.401	-0.172
EC	0.354	-0.247	0.600	0.496	-0.009	0.162
TDS	0.028	-0.124	-0.155	-0.465	0.418	0.045
Total hardness	0.010	0.899	0.302	0.113	-0.030	0.104
Na^+	0.897	0.208	0.025	0.359	0.025	0.006
K^+	0.447	0.452	-0.608	0.131	-0,218	-0.055
HCO_3^-	-0.040	0.825	-0.286	0.100	-0.034	-0.065
Ca^{+2}	-0.094	0.333	0.050	0.871	0.191	0.055
Mg^{+2}	0.078	0.609	0.214	-0.708	-0.162	0.063
SO_4^{-2}	0.063	0.087	0.790	-0.012	-0.101	-0.081
Cl^-	0.328	0.673	-0.336	0.008	0.278	-0.066
Na%	0.966	0.010	-0.049	-0.171	-0.084	-0.006
SAR	0.990	0.061	-0.001	0.038	-0.056	-0.024
Cd	-0.213	0.021	0.104	0.193	0.770	-0.093
Pb	0.002	-0.032	0.716	0.050	0.306	0.091
Cu	0.117	-0.135	-0.075	0.043	-0.369	0.785
Zn	0.230	-0.169	-0.055	0.022	-0.393	-0.710

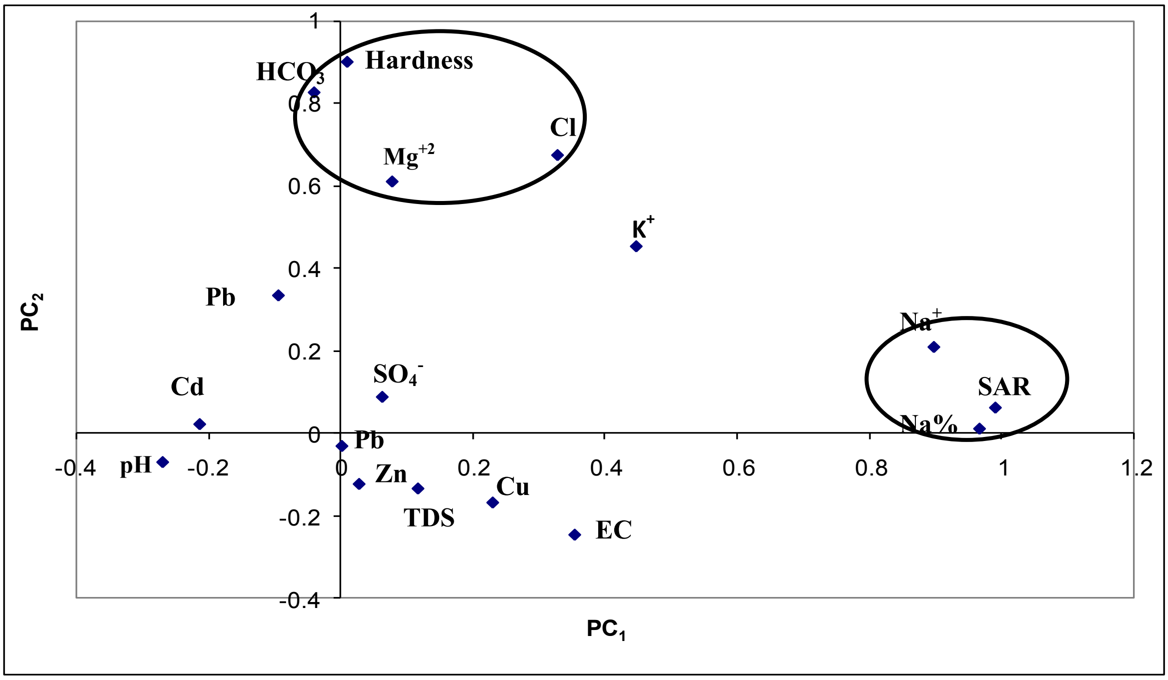

Figure 5: Principal component analysis (PCA) scatterplot for Erbil wastewater samples on the basis of studied water variable characteristics.

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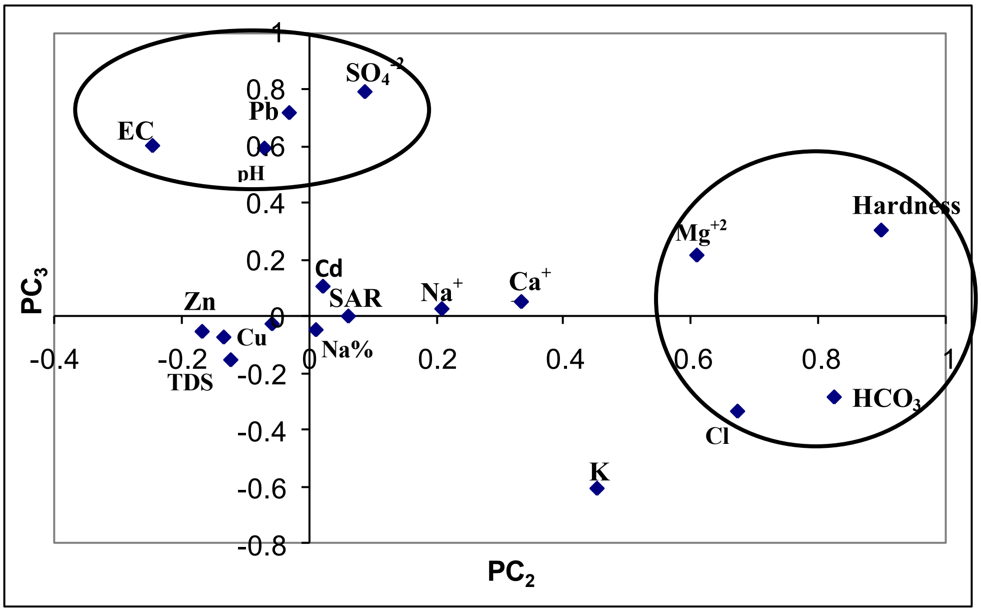

Figure 6: Principal component analysis (PCA) scatterplot for Erbil wastewater samples on the basis of studied water variable characteristics.

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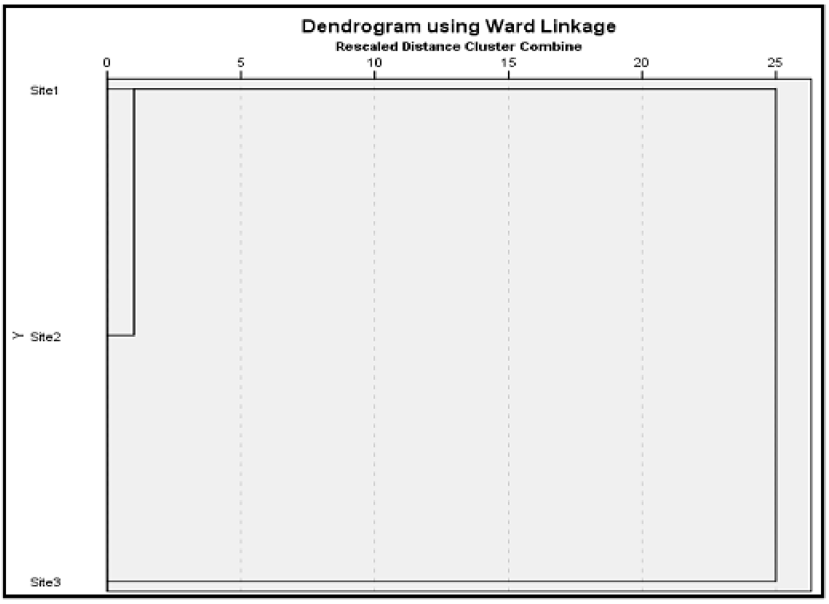

Figure 7: Similarity dendogram among sampling sites along Erbil wastewater channel from cluster analysis.

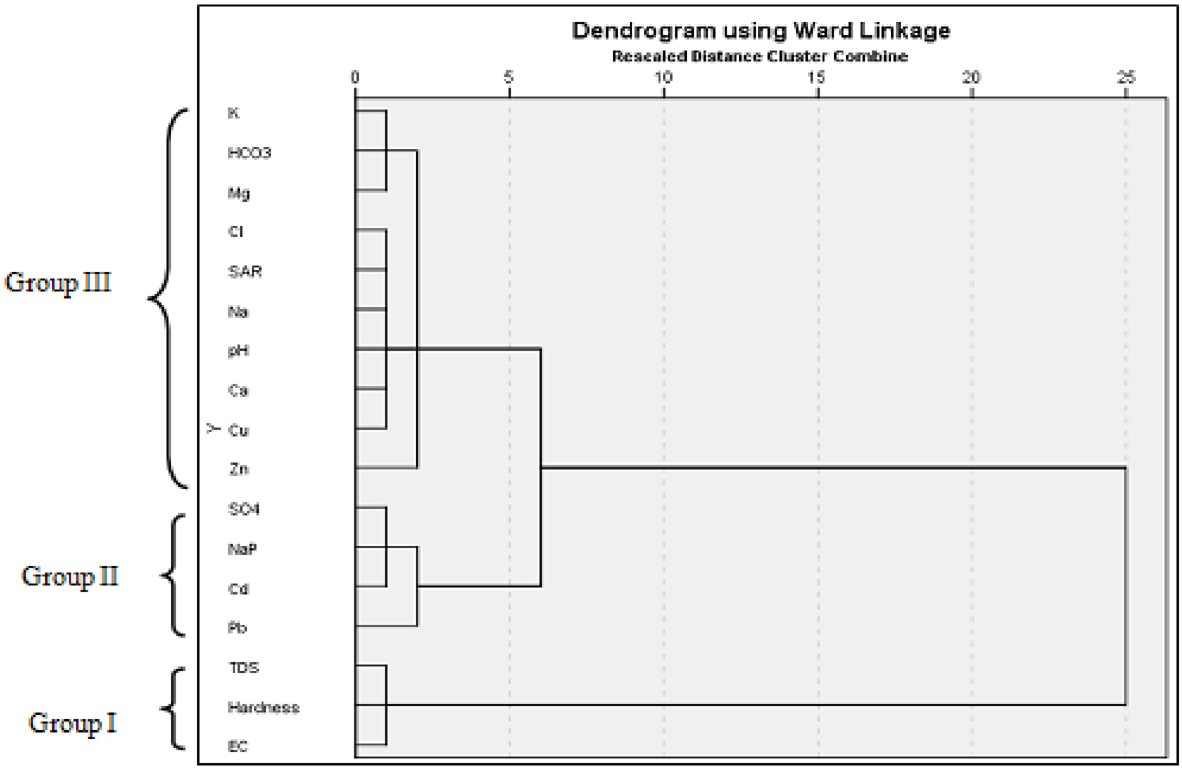

Figure 8 Similarity dendogram among variables concentrations of Erbil wastewater effluent from cluster analysis.