QUALITY EVALUATION OF WATER RESOURCES FOR IRRIGATION IN SULAIMANI GOVERNORATE, IRAQ

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(Received 16th Dec 2022; accepted 7th Apr 2023)

Abstract. Assessment of irrigation water quality is proposed using the irrigation water quality index (IWQI) according to Maia and Rodrigues (2012) and Ayers and Westcot (1985), principal component analysis and agglomerative hierarchical clustering of cations, anions and concentration of Co^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+}, and Zn^{2+}, water classification due to EC effect on broad bean yield in pot experiment were carried out and WQI was determined in Sulaimani Governorate Kurdistan region, Iraq. The pot experiment depended on 16 well waters, the experiment was done at Bakrajo technical institute field. Water samples were collected in November, 2021 then tested for physicochemical properties and some heavy metals concentration. In general, the studied water samples had similar classes approximately while they are differing in class numbers. The studied water was classified in to (4, 2, 4, 4, 4, 4, 4, and 3) classes according to Maia and Rodrigues (2012) and Ayers and Westcot (1985) PCA, cluster analysis of physiochemical water properties, PCA, cluster analysis for EC, PCA for yield and, cluster analysis for pot experiments yields, respectively. The broad bean yield decreased with increase in water EC, it means low irrigation water conductivity resulted high yield in both pot experiments and vice versa.

Keywords: *water classification, IWQi, broad bean, principal component analysis*

Introduction

The evaluation of water quality is an essential technique for environmental sustainability since it offers essential information for irrigation systems. Water supply for irrigation requires information of both quantity and quality; however, quality is frequently overlooked, particularly in underdeveloped nations. Water resources are renewable and important in the water supply of many nations' urban and sub-urban areas. The growth of understanding of hydrochemical processes is aided by hydrogeochemical analyses that alter the chemical characteristics of subsurface water. In turn, establishing correlations between different hydrogeological characteristics can aid in the effective use and long-term maintenance of water resources (Awad et al., 2022). Water quality is an important source of water in lakes and reservoirs that is used for a variety of reasons such as irrigation and fish culture. Another thing that made water quality a global issue is global population increase and contamination groundwater has lately become a critical issue (Sarhat, 2022).

Rajab (2022) studied the irrigation water quality index for 354 water samples, in Erbil governorate out of which 200 were taken from deep wells, their quality varied between poor, bad, medium, good and excellent classes depending on Erbil modified irrigation water quality index values (EM-IWQI**). Since water supply is critical for household and farming production in the Western desert of Iraq due to a shortage of surface and groundwater resources, the quality of groundwater and its suitability for agricultural use were assessed (Al-Mussawi, 2014). Also, many investigations on the quality of

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

groundwater in the Kurdistan area have been conducted (Ralph, 1955) The first efforts started in Erbil and Altun kupri plains in the 1950s. The majority of these studies exclude ionic content and movement; nonetheless, all chemical, physicochemical, and biological activities that occur inside the ecosystem, in addition to nutrient absorption by plants, are dependent on ionic activity rather than concentration (Esmail, 1992). The water quality index represents one of the most efficient values for communicating accurate information on water to concerned individuals and governments. The water quality index (WQI) is a rating that reflects the combined effect of many water quality factors. Horton (1965) pioneered the application of the WQI idea, which was subsequently expanded by Brown et al. (1970). The Water Quality Index (WQI) is a complex formula that is used to convert a vast variety of quality information into a single value that indicates the general quality of water at a particular location and time based on numerous water quality indicators. Ground water is a crucial valuable natural resource. It can be a sustainable or non - renewable resource depending on how it is used. It is believed that one-third of the world’s population drinks from groundwater. Groundwater is in severe condition due to the increased reliance of agricultural on groundwater resources. Agriculture has both direct and indirect effects on the chemistry of groundwater (Bohlke, 2002). Approximately 70 percent of total freshwater supplies were used for agriculture. The quality of groundwater in rural regions is vulnerable to contamination derived from agricultural chemicals (Chae et al., 2004). Water sources are widely exploited for agriculture, and water quality is deteriorating. To manage this rich resource effectively, it is vital to integrate all linked characteristics correctly rather than concentrating on a single isolated component (Kumari et al., 2020). The Faba bean or broad bean (*Vicia faba* L.) is a vital bean with high nutritive value since it is high in protein, fiber, vitamins, and minerals. This plant is sensitive to salt areas, and efforts are being done to boost its production and yields, mostly in marginal desert terrain (Souana et al., 2020), where salinity has been one of the most serious dangers to plant and agricultural yields for millennia, and its negative impacts are predicted to worsen as a result of climate change, particularly in countries with semiarid and arid regions. According to recent studies, and over 45 thousand hectares of irrigated area worldwide have been influenced by salt tension, and this number is constantly increasing (Isayenkov and Maathuis, 2019).

The aim of the research is to assess irrigation water quality index and classification according to Maia, and Rodrigues (2012) and Ayers and Westcot (1985), principal component analysis and agglomerative hierarchical clustering of cation anions and some heavy metals (Co^{+2}, Cu^{+2}, Fe^{+2}, Mn^{+2}, Ni^{+2} and Zn^{+2}) analysis, in addition to water classification based on electrical conductivity of irrigation water depending on the broad bean yield of pot experiments which principal component analysis and agglomerative hierarchical clustering compared with Maia and Rodrigues (2012) and Ayers and Westcot (1985) classifications.

Materials and methods

Study area

This study was carried out in Sulaimani governorate (province), which is one of the Kurdistan Region Iraq governorates with the GPS reading of latitude = 35.566864; longitude = 45.416107 and altitude of 882 m (*Fig. 1*). *Table 1* explains the information about the applied water resources in pot experiments. Current study used the water resource of 16 locations: L3 (TakTak), L4 (Gazalan), L6 (Ali Zangana), L7(Sofi

Hassan), L8 (Kani ShaitanVillage), L11 (Sharawany Allahi), L12 (Kazhzwa Village shar bazher), L14 (kani sard S1), L20 (Girdjan), L23 (Dolabafra), L33 (Swrdash), L37 (Gokhlan), L40 (Barrawa), L45 (TapiSafay khwarw/1), L52 (Tangisar Village S1), and L56 (Bakhtiary)).

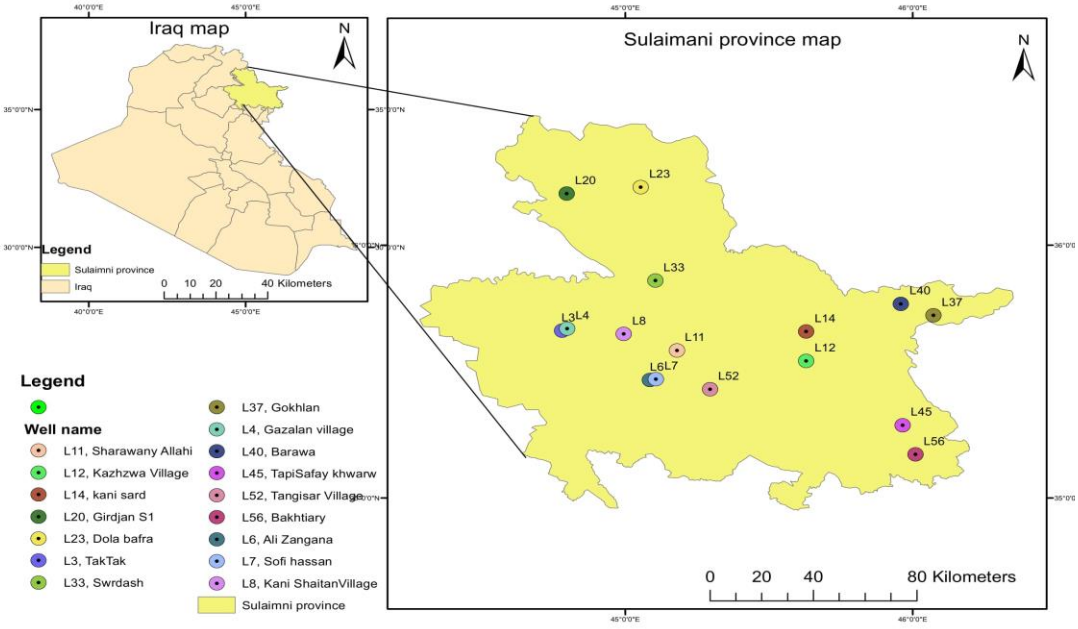

Figure 1. *Study area locations map*

Statistical analysis

XLSTAT 2019.59614 -statistical analysis software was used for statistical data set analysis. For direct comparison of treatments, principal component analysis with agglomerative hierarchical clustering and least square means test (LS means) among the treatment combination of the studied factor levels were used for testing the main effects of all the variables at statistical significance level of ($p \leq 0.05$).

Water sampling for the determination of water quality index

Water sampling for the evaluation of water quality index in this research included the following steps:

First: Water samples of 100 locations or wells (L1 to L100) were tested for surveying well waters in the study area, the samples were compared based on EC and pH values.

Second: Out of the 100 wells 57 differed, therefore, the number of the study samples was reduced to 57 samples for PhD dissertation.

Third step: The water of 57 selected wells were tested for physicochemical and some heavy metal, then 16 of them were selected for pot experiment using broad bean plant and for classification according to different methods (*Fig. 1; Tables 1* and *4*). Each sample of water was collected in a container of 1.5 L for physiochemical analysis, which Show from *(Appendix 1).*

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

Water analysis and calculating irrigation water quality index (IWQI)

Sixteen irrigation water quality parameters were analyzed according to APHA (1998) which included cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+), and anions (HCO_3^-, SO_4^{2-}, NO_3^-, and Cl^-). Heavy metal ions (Co^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+}, and Zn^{2+}) were analyzed using ICP-9820 plasma atomic emission spectrometer, Shimadzu, JAPAN. The pH and electrical conductivity (EC) were determined using portable pH-meter (Hanna pH h 98107) and EC-meter model (HI981311), respectively (*Fig. 2*). The sodium adsorption ratio (SAR) was calculated according to Ayers and Westcot (1985, 1999). *Table 2* shows pH, EC concentration of cations, anions some heavy metals and calculated IWQI.

Table 1. *Information on 16 wells and their locations, used in pot experiment*

Locations irrigation water sources	GPS UTM points	Elevation (m)	Drilling date	Depth (m)	Geological formation
L3 (TakTak)	519937 3946535	726	2010	40	Bai-Hassan and Muqdadeya
L4 (Gazalan)	518352 3947459	646	2014	54	Bai-Hassan and Muqdadeya
L6 (Ali Zangana)	3925659 3924852	680	2009	75	Injana & Fatha
L7 (Sofi Hassan)	490323 3925264	721	2016	100	Injana & Fatha
L8 (Kani ShaitanVillage)	500478 3945133	914	2001	60	Injana & Fatha
L11 (Sharawany Allahi)	483690 3937843	882	1998-2012	100	Kolosh-Khurmala-Sinjar-Gercus-Pilaspi
L12 (Kazhzwa Village Shar Bazher)	442901 3933460	1116	2008	54	Kometan-Qamchuqa-Aqra-Shiranish-Balambo
L14 (Kani Sard S1)	450996 3946263	896	2012	100	Bai-Hassan and Muqdadeya
L20 (Girdjan)	518366 4006752	542	2020	60	Metamorphic Rocks-Thrust Mountain
L23 (Dolabafra)	495160 4009491	559	2006	102	Alluvial and River Terrasses
L33 (Swrdash)	490620 3968490	1027	2012	100	Injana & Fatha
L37 (Gokhlan)	404897 3954728	1259	2020	71	Metamorphic Rocks-Thrust Mountain
L40 (Barrawa)	413262 3958718	1231	2015	90	MetamorphicRocks-Thrust Mountain
L45 (TapiSafay Khwarw/1)	412231 3905443	522	2009	153	Bai-Hassan and Muqdadeya
L52 (Tangisar Village S1)	473726 3920645	860	2015	60	Injana & Fatha
L56 (Bakhtiary)	591253 3873500	815	1985	141	Alluvial and River Terrasses

Table 2. *Concentration of cations, anions, some heavy metals and irrigation water quality index for irrigation waters used in pot experiments*

Study area	pH	EC	Ca^{+2}	M^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-}	NO_3^{-}	Cl^{-}	Co^{+2}	Cu^{+2}	Fe^{+2}	Mn^{+2}	Ni^{+2}	Zn^{+2}	SAR	IWQI
		($dS.m^{-1}$)	($Meq.L^{-1}$)								($Mg.\ g^{-1}$)						($Meq.L^{-1})^{1/2}$	
L3	7.7	0.943	5.384	3.60	0.371	0.021	5.67	1.96	0.57	2.00	0.0147	0.0296	0.0128	0.0395	0.0058	0.0141	0.175	3.07
L4	7.9	0.860	5.093	2.97	0.347	0.049	5.08	2.18	0.74	1.54	0.0156	0.0337	0.0156	0.0428	0.0050	0.0110	0.173	2.89
L6	7.5	0.798	4.423	2.11	1.014	0.052	3.98	2.79	0.46	0.69	0.0169	0.0380	0.0172	0.0418	0.0053	0.0063	0.561	2.50
L7	7.1	1.700	6.750	8.51	1.022	0.692	9.51	3.94	0.41	2.71	0.0093	0.1620	0.0689	0.3600	0.0015	0.0143	0.370	10.720
L8	7.8	0.702	4.795	1.96	0.100	0.013	3.21	0.74	0.23	2.83	0.0102	0.0291	0.0204	0.0404	0.0034	0.0071	0.054	2.746
L11	7.9	0.520	3.523	1.46	0.127	0.031	4.52	0.51	0.11	0.54	0.0001	0.0033	0.0017	0.0293	0.0002	0.0010	0.080	0.778
L12	6.6	1.125	8.477	0.78	0.633	1.044	7.41	1.57	0.85	1.63	0.0003	0.0217	0.0211	0.0551	0.0029	0.0091	0.294	10.716
L14	7.9	0.994	5.677	3.41	0.633	0.088	6.89	1.37	0.06	1.66	0.0002	0.0022	0.0012	0.0048	0.0067	0.0002	0.297	3.374
L20	7.6	0.820	6.314	1.56	0.208	0.034	7.08	0.78	0.52	0.63	0.0004	0.0096	0.0056	0.0335	0.0022	0.0043	0.105	1.382
L23	7.8	0.412	3.756	0.23	0.082	0.021	3.54	0.25	0.35	0.29	0.0009	0.0052	0.0075	0.0284	0.0011	0.0104	0.058	0.373
L33	7.8	0.743	4.744	2.02	0.184	0.161	5.62	0.95	0.35	0.71	0.0008	0.0078	0.0030	0.0307	0.0025	0.0076	0.100	2.054
L37	7.2	0.393	2.651	0.42	0.226	0.010	2.95	0.28	0.13	0.29	0.0006	0.0010	0.0387	0.0251	0.0016	0.0002	0.183	0.682
L40	7.6	0.570	3.209	2.14	0.254	0.017	4.49	0.55	0.34	0.34	0.0008	0.0018	0.0009	0.0241	0.0013	0.0003	0.155	0.484
L45	7.3	0.621	4.744	1.27	0.145	0.019	5.64	0.64	0.38	0.34	0.0014	0.0018	0.0010	0.0293	0.0014	0.0207	0.084	0.566
L52	7.2	1.290	6.895	4.74	1.064	0.067	7.95	2.05	0.16	2.80	0.0130	0.0620	0.0437	0.0538	0.0087	0.0209	0.441	5.198
L56	7.7	0.350	3.058	0.21	0.018	0.016	2.85	0.26	0.35	0.34	0.0201	0.0273	0.0146	0.0391	0.0039	0.0270	0.014	0.611

Figure 2. *Analysis of water cations and anions*

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

Soil preparation for pot experiments

For the pot experiments soil was gathered from Kany Panka Agricultural Research Station (GPS UTM (0565776, 3914591) with cooperation of Sulaimani Agricultural Research Directorate. The soil was taken from a depth of 0-30 cm, then air dried, lightly crushed, and sieved using a 4 mm stainless-steel sieve. A piece of the soil was sieved through 2 mm for physicochemical analysis.

Soil analyses were done as follows:

- Soil EC and pH, were determined in a 1:10 soil/distilled water solution using glass electrodes and conductance Resistance meter (YSI 34) (Thomas, 1996).
- Organic matter was determined using Walkley-Black technique (Walkley and Black, 1934).
- Total calcium carbonate concentration was assessed using the Scheibler calorimeter method (Loeppert and Suarez, 1996).
- Calcium and magnesium were determined by titration method using Na_2EDTA (Karita and Kaneta, 2016).
- Sodium and potassium were determined using flame photometer according to Havre (1961).
- HCO_3^- and CO_3^{2-} were determined according to Moss et al. (2016).
- Chloride was determined by titration with $AgNO_3$ (Nishanthiny et al., 2010).
- Phosphorus was determined using a spectrophotometer as mentioned by Olsen et al. (1954).
- Soil particle distribution (PSD) was determined according to Bouyoucos (1936) and Mwendwa (2022), *Table 3* explains the physicochemical properties of the studied soil.

Table 3. *Soil physiochemical analysis*

Soil properties		**Kanipanka location**
Soil texture type		Silty clay
Sand (g/kg)		3.23
Silt (g/kg)		53.91
Clay (g/kg)		42.86
pH		7.64
EC ($dS.m^{-1}$)		0.27
Organic matter		1.5
Available phosphate (ppm)		11.67
%$CaCO_3$		20
Calcium (Ca^{+2})	Soluble cations and anions (mmole/L)	1.42
Magnesium (Mg^{+2})		1.1
Potassium (K^+)		0.16
Sodium exchange (Na^+)		212.263
Carbonate ($CO_3^{=}$)		0.00
Bicarbonate ($HCO_3^{=}$)		2
Chloride (Cl^-)		0.3

Broad bean (Vicia faba L.) planting

The seeds of broad bean (Vicia faba L.) (Fito variety). The seeds were taken then soaked in water for about 24 h, then removed from the water and sown in pots of 25 L in size. The pot experiments were done to study the effect of 16 water qualities on broad bean yield using complete randomized design (CRD) with 3 replicates for each outdoor and indoor experiment. The number of experimental units or pots per experiment was 16 × 3 = 48 pots. After sieving the soil by 4 mm sieves, each pot was filled with 30 kilograms of soil. On November 14, 2021, broad bean seeds were planted with 3 seeds per pot.

Irrigation

The irrigation was done depending on weight method. The irrigation water was transferred from the selected 16 wells to the location of the pot experiment using 20-L containers for each well or water source locations. The amount of irrigation water added to each pot was 65 and 53 L for indoor and outdoor pot experiments, respectively. The reason of using two different climatic growing cultivation (indoor and outdoor) was to test the effects of rainfall on decreasing the risk of salinity on yield and growing of broad bean (*Vicia faba* L.) due to dilution effect to the depth of rainfall (precipitations amount) during the growing season of broad bean was 426.7 mm for outdoor experiment only which was equivalent to 26.80 L for the pot having radius of 20 cm. The rainfall caused the dilution of irrigation water by (26.80/53) = 0.50 or 505 dilutions of salinity of irrigation water for outdoor pot experiment. The average temperature of the experiment was ranged between -0.4-30°C and 4 to 35°C for outdoor and indoor experiments, respectively. The fertilizers were not applied due to using fertile soil in the pot experiments (*Table 2*). The infection of plants with disease were not noted and plants were healthy.

Harvesting

On April 26, 2022, the plants were harvested. After harvesting the yield and yield components were determined (Steadman et al., 2004). *Appendixes 2* and *3* show growing and planting of broad bean (*Vicia faba* L.).

IWQI calculation in 3 equations

The main steps for determining IWQI was summarized as follow:

(1) Calculating the deviation from the reference values for each variable, considering normal distribution of data, the Z-test was applied for data standardization as follow:

$$z_i = (x_i - \bar{x}) \,/\, SD \tag{Eq.1}$$

where: Zi = Standardized value of the studied parameter. Xi = Value of the property determined at the water source. X- = Mean value of the variable evaluated from the reference population. = Standard deviation of the parameter determined from the reference population.

(2) Calculating the IWQI for the studied parameters such as (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^{--}, SO_4^{2-}, and NO_3^-) by using the following equations:

$$WQI = \sqrt[3]{(z_i)^2}\,\cdot \tag{Eq.2}$$

WQIi = The Index value for the characteristic of the studied water quality. Zi = The standardized variable value.

(3) Calculating the IWQI as follow:

$$IWQI = \frac{1}{N}\sum_{i=1}^{n} WQIi \qquad \text{(Eq.3)}$$

where WQIi = The index Water Quality Index for the characteristic. IWQI = Irrigation Water Quality Index. Four irrigation water quality classes (1, 2, 3 and 4) were created (*Table 3*). The classification was determined based on the range of values from -1.96 to 1.96 for class I. This indicates a 95% probability that the WQIi value is statistically equal to the reference population; in other words, the values of the indices contained in the determined interval do not present any degree of restriction. The other classes were obtained according to *Table 4*. The main reason for choosing these parameters is that they are most relevant of relation of broad bean growth and yield to parameters. The method (Maia, and Rodrigues, 2012) arithmetic index was applied on the average values of each parameter in each suburb (Stations) to calculate IWQI. Also, irrigation water was classified according to this method (*Tables 2* and *4*).

Table 4. *Condition for classification of the water quality index for the characteristic evaluated (WQIi) and for the irrigation water quality index (IWQI)*

IWQi or WQIi	Restriction
WQIi or IWQI ≤ 1.96	1- (Excellent)
1.96 < WQIi or IWQI ≤ 5.88	2- (Good)
5.88 < Wii or IWQI ≤ 9.80	3- (Average)
WQIi or IWQI > 9.80	4- (Poor)

Results and discussion

Water classification depending on physiochemical properties using PCA and some global classifications

The selected water for pot experiments were classified depending on physiochemical analysis (*Table 2*) using different methods and tools, which were the followings: Maia and Rodrigues, 2012; Ayeres and Westcot, 1985; PCA, Cluster. PCA depending on EC only, Cluster analysis depending on EC. PCA depending on broad bean yield, Cluster analysis depending on broad bean yield. (*Table 5*). Depending on Maia and Rodrigues (2012) the irrigation water for (2, 1, 6 and 7) wells had poor. average, good and excellent classes respectively since the IWQI of the studied water samples ranged between less than 0.37 to 10.73 (*Table 2*). According to Ayers and Westcot (1985) referring to electrical conductivity the water of wells at locations (L8, L11, L23, L33, L37, L40, L45 and L56) had non-restriction of use class since their EC values ranged between (0.35 to 0.74) dSm^{-1}, while the water at locations (L3, L 4, L 6, L 7, L12, L14, L20, and 52) had severe to medium restriction of use since their EC values ranged from 0.80 to 7.90 $dS\ m^{-1}$, while comparison between each method of classification were done many of them were near in classification and some of them were different due to the chemical composition and geological formation.

***Table 5**. Water classification depending on PCA) and some global classifications*

Locations	**EC (dS m^{-1})**	**pH**	**Maia, and Rodrigues (2012)**	**Ayers and Westcot (1985)**	**Depending on water properties**		**Depending on EC (dSm^{-1})**		**Pot experiments classes**	
					PCA classes	**Cluster classes**	**PCA classes**	**Cluster classes**	**PCA classes**	**Cluster classes**
L3	0.94	7.7	Good	S-MR	1	1	1	1	1	1
L4	0.86	7.9	Good	S-MR	1	1	1	1	1	1
L6	0.80	7.5	Good	S-MR	1	1	2	1	4	1
L7	1.70	7.1	Poor	S-MR	4	2	3	2	2	2
L8	0.70	7.8	Good	NR	1	1	1	2	1	1
L11	0.52	7.9	Excellent	NR	2	3	1	1	1	3
L12	1.13	6.6	Poor	S-MR	3	2	4	2	2	4
L14	0.99	7.9	Good	S-MR	1	1	1	1	1	1
L20	0.82	7.6	Excellent	S-MR	2	4	1	1	1	1
L23	0.41	7.8	Excellent	NR	2	3	1	1	3	3
L33	0.74	7.8	Good	NR	2	4	1	1	1	1
L37	0.39	7.2	Excellent	NR	2	3	2	3	4	3
L40	0.57	7.6	Excellent	NR	2	3	1	1	3	3
L45	0.62	7.3	Excellent	NR	2	3	1	1	4	3
L52	1.29	7.2	Average	S-MR	3	5	3	2	2	4
L56	0.35	7.7	Excellent	NR	2	3	2	3	3	3

S-MR = Slight to moderate restriction, NR = no restriction

Classification of water depending on IWQI values and physicochemical properties using principal component analysis (PCA)

Figure 3 and *Table 5* illustrate the principal component analysis which used as a tool or method in the study for water classification depending on concentration of cations, anions and some heavy metals (*Table 2*) The studied water samples were categorized into 4 classes as follow:

- First class (C1) denoted by rectangular shape in *Figure 3* which included water samples from locations or wells (L8, L14, L 3, L4 and L6) and their EC values ranged between (0.70 and 0.99) dS m^{-1} (Ndoye et al., 2018).
- Second class (C2 or trapezoid shape) that consisted of (L20, L33, L40, L45, L23, L37, L11 and L56) with the electrical conductivity value of (0.39 to 0.74) dS m^{-1}.
- Third class 3 (C3 or circle shape) represented the water for locations (L12 and L52) with the EC value of (1.13 and 1.29) dS m^{-1}.
- Forth class (C4 or trigonal shape) in *Figure 3* only represented Location L7 with EC value of 1.70 dS m^{-1}. The factors which caused variation among water classes had an eigenvalue equal or greater than one (Hameed, 2013). When the loading factor values for the parameters ≥ than selection criterion (SC) value of factor means there is a significant effect on the current parameter. Similar results obtained by Sajadi (2020) and Arai et al. (2022). It is appeared from *Figures 3* and *4* that the (F1 and F2) caused 65.24% and 50.68% variation, respectively in the studied water parameters. These two factors may be geological formation of the studied location and the amount of rainfall or climatic factor (Rajab, 2021; Rashidi and Seilsepour, 2008).

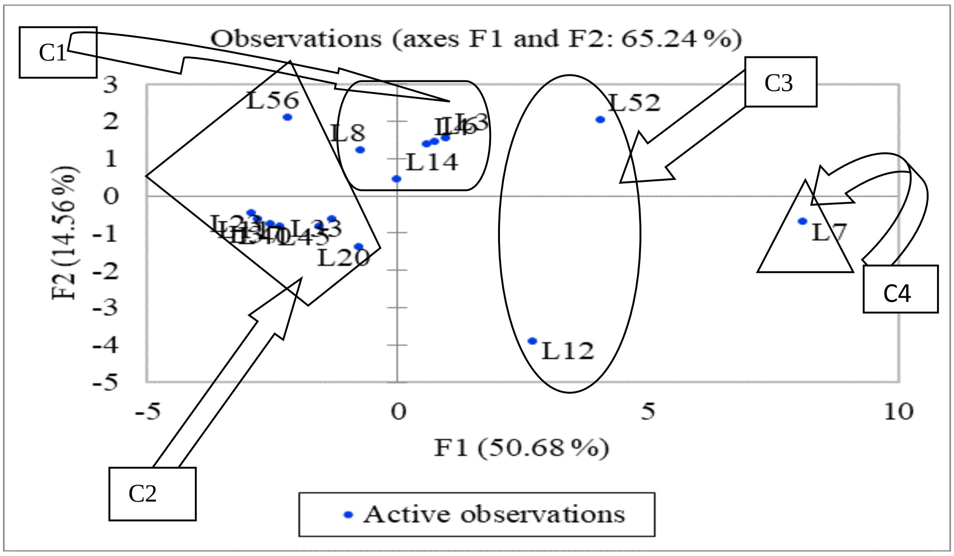

Figure 3. The biplot for the studied (cations, anions, EC, pH and heavy metals (Co^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+})) of active observation

Table 4 and *Figure 4* explain classification of water depending on IWQi values using the agglomerative hierarchical clustering tool or method for physiochemical properties of the studied water samples cations, anions, heavy metals, EC (dS m^{-1}) and pH. The results were as follow:

- First class included the water of five locations (L3, L4, L14, L20 and L52) with the EC and pH range of 0.82 to 1.29 dS.m^{-1} and 7.20 to 7.90? respectively.
- Second class represented the water for nine locations (L6, L8, L11, L23, L33, L37, L40, L45, and L56) having EC and pH range of 0.35 to 0.80 dS m^{-1} and 7.20 to 7.90, respectively.
- Third class included only the water for location 7(L7) with the EC and pH value of 1.70 dS m^{-1} and 7.10, respectively (Adimalla,2019).
- Forth class also included the water for location 12 (L12) only with the EC and pH values of 1.13 dS m^{-1} and 6.60, respectively (Ezea et al., 2022).

Depending on EC value class four must be a part of third class, but the chemical composition of the studied water samples also had great effect on water classification (Esmail, 1992; Kareem, 2022; El-Defan et al., 2016) classification explained from Table 4 and Figure 4.

Figure 5 and *Table 6* contain classification depended on EC value only using PCA method the results of classifications were summarized in *Table 7*.

Table 6. *Classification of the studied water depending on their EC (dS.m^{-1}) according to PCA*

Water class	**EC (dS.m^{-1})**	**Shape in Figure 4**	**No. of locations or wells**	**No. of wells**
Class$_1$ (C$_1$)	0.52-0.99	Circle	L3, L4, L8, L11, L14, L20 and L33	7
Class$_2$ (C$_2$)	1.13-1.70	Triangle	L7, l2 and L52	3
Class$_3$ (C$_3$)	0.35 -0.57	Diamond	L40, L23 and L56	3
Class$_4$ (C$_4$)	0.40-0.80	Rectangular	L6, L37 and L45	3

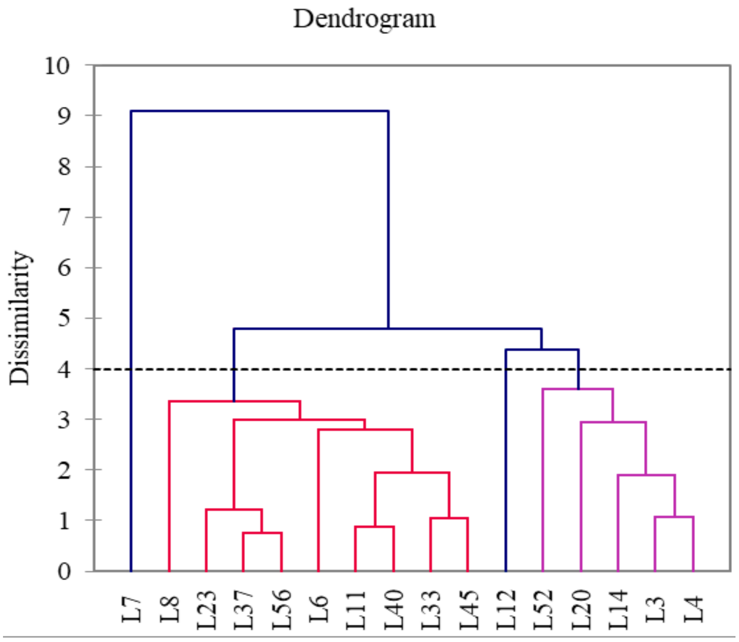

***Figure 4.** Dendrogram showing the clustering of (Cations, anions, EC, pH and Heavy metals (Co^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+}) collected from the different regions*

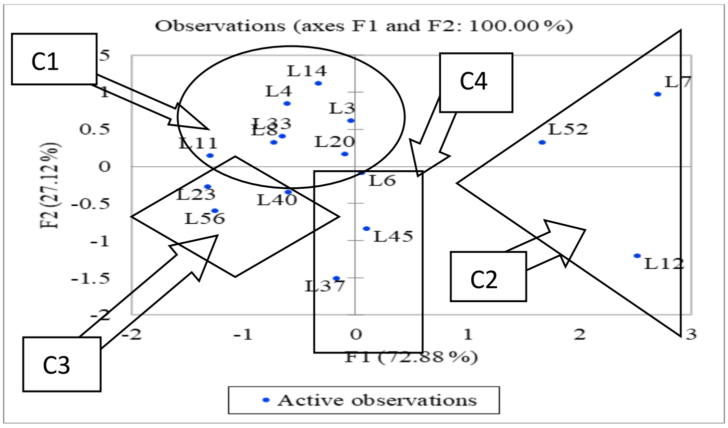

***Figure 5.** The biplot showing classification of IWQi according to EC (dSm^{-1}) and pH collected from the different regions*

The results of classification in *Table 6* were summarized in *Table 7*: The interference is existing among above water classes depending on PCA tool, for solving this problem the C1, C2 and C3 will combine together, and the final result of classification will be as shown in *Table 7*.

***Table 7.** Classification of the studied water depending on their EC using PCA method after solving the interferences in EC values*

Water class	EC (dS .m^{-1})	Shape in Figure 4	No. of locations or wells	No. of wells
Class$_1$ (C$_1$)	0.35-0.99	Circle	L3, L4, L8, L11, L14, L20, L33, L40, L23, L56 L6, L37 and L45	13
Class$_2$ (C$_2$)	1.13-1.70	Triangle	L7, L2 and L52	3

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

The results of water classification depending on cluster analysis using EC (dS m^{-1}) values

Table 8 explains classification of the studied water samples depending on electrical conductivity. The samples can be divided into four groups or clusters or classes as follow:

- First class (C1): The EC value ranged between 0.702 to 0.943 dS m^{-1} which covered L3, 4, 6, 8, 14, 20 and L33 locations (Safiur et al., 2017).
- Second class (C2): This class includes only L7 since its EC value was 1.7 (dS m^{-1}).
- Third cluster or class (C3): This class represents (L11, 23, 37, 40, 45, and L56), since their EC values ranged between (0.62 and 0.350) (dS m^{-1}).
- Fourth class (C4): This class covers (L12 and L52) with EC values of 1.290 and 1.125 dS m^{-1}, respectively (Akoachere et al., 2018; Dhaouadi et al., 2021; Zaman et al., 2018). The space is excessed between clusters, each cluster contains water samples having similarity or dissimilarity in the studied chemical properties of the water samples or the studied variables due to geological formation or agriculture processes. This result is in line with the findings of Alsubih et al. (2022) and Rawat et al. (2018).

Table 8. *Classification of irrigation water with agglomerative hierarchical clustering depending on EC (dS.m^{-1}) from the different locations*

Class $_1$	EC (dSm^{-1})	Class $_2$	EC (dSm^{-1})	Class $_3$	EC (dSm^{-1})	Class $_4$	EC (dSm^{-1})
L3	0.943	L7	1.7	L11	0.520	L12	1.125
L4	0.860			L23	0.412	L52	1.290
L6	0.798			L37	0.393		
L8	0.702			L40	0.570		
L14	0.994			L45	0.621		
L20	0.820			L56	0.350		
L33	0.743						

Irrigation water quality classification according to broad bean (Vicia faba L.) productivity (pot experiment classifications)

Figure 6 and both *Tables 5* and *9* explain broad bean productivity and irrigation water classification collected from the different regions which were divided into four classes depending on PCA as mentioned before.

Table 9. *Principal component analysis irrigation water quality classification according to broad bean (Vicia faba L.) productivity (pot experiment yield)*

Water classes	Locations	EC dSm^{-1}	Mean relative yield %	Relative ratio
Class 1	L3,4,8,11,14,20,23,33,40 and L45	0.994 to 0.412	47 to 82	1.23 to 1.67
Class2	L6,37 and L56	0.798 to 0.350	78 to 100	1 to 1.09
Class 3	L7 and L52	1.29 to 1.70	19 to 38	1.42 to 1.39
Class 4	L12	1.13	27	1.13

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

The results indicated that in general the increase in EC of water caused decrease in the mean relative broad bean yield for both outdoor and indoor experiment, it means the plant growth and yield are playing a great role in water classification and its suitability for irrigation data result shows in *Figure 6* and both *Tables 5* and *9* explain broad bean productivity and quality classification of irrigation water collected from the different regions using principal component analysis. Based on the results four classes were recorded as explained below:

- Class one (C1) circle shape in *Figure 6* that covers locations (L3,4,8,11,14,20,23,33,40, and L45) with EC values between (0.412 and 0.994 dS.m^{-1}) (El Sayed, 2014; Zaman et al., 2018).
- Second class (C2) or rectangular shape in *Figure 6* which consist of L6,37, and L56 their EC values ranged between 0.350 and 0.798 dSm^{-1}.
- Third class (C3) or triangle shape in *Figure 6* which includes L7 and L52 with EC between (1.290 to 1.7 dSm^{-1}).
- Fourth class (C4) or hexagon in *Figure 6* only covers (L12 with EC value 1.125 dS.m^{-1}). Effect of interaction between EC and productivity due to chemical composition of water for some locations similar in yield and high yield value with low conductivity and low yield with high conductivity (Akoachere et al., 2018; Dhaouadi et al., 2021).

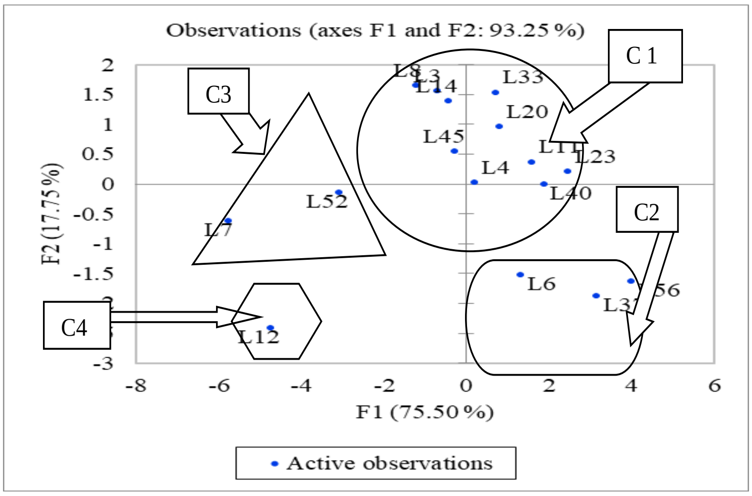

Figure 6. *The biplot for the studied broad bean productivity and irrigation water quality classification collected from the different regions*

Classification of irrigation water depending on EC and broad bean relative yield mean for both experiments (Figure 6 and Table 9)

Numerous plant parameters were studied in pot experiments as shown in *Table 10,* while the classification depended on the yield which is regarded as the most important parameter. *Figure 7* and *Tables 5* and *10* represent agglomerative hierarchical clustering analysis irrigation water quality classification according to broad bean (*Vicia faba* L.) yield. The water of the study area according to agglomerative hierarchical clustering was classified into three classes Class one (C1) covers locations (L3, 4, 6, 11, 14, 20, 23, 33, 40, and L45) with EC values between (0.412 and 0.994 dS.m^{-1}) and pH between (7.3 and 7.9) (El Sayed, 2014; Bahadori and Sepaskhah, 2022). The second class C2 consists of (L7, 8, 12, and L52) with EC between (0.702 and 1.7 dS.m^{-1}) and pH value between 6.6 to 7.8 (Meißner et al., 2021). The third class C3 covers L37 and L56 with EC between (0.350 to 0.393 dS.m^{-1}) and pH between (7.2 and 7.7) (Abahri, 2015; Ali et al., 2021). The chemical composition of water at the same EC values had great effect on yield**.**

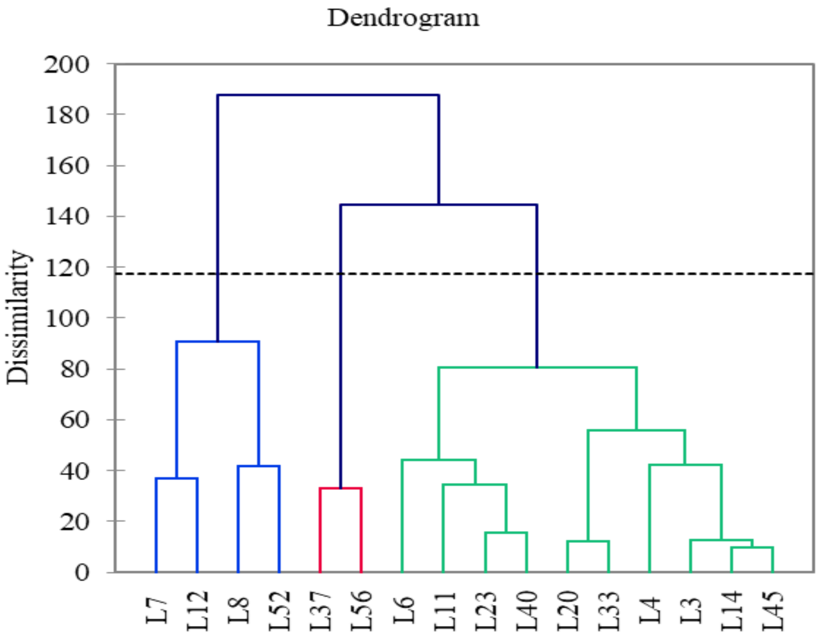

Figure 7. *Dendrogram showing the classification of irrigation water clustering of broad bean productivity of indoor and outdoor cultivation*

Table 10. *Agglomerative hierarchical clustering analysis irrigation water quality classification according to broad bean (Vicia faba L.) planting*

Water classes	**Locations**	**EC dSm^{-1}**	**Mean relative yield %**	**Relative ratio**
Class 1	L3,4,6,11,14,20,23,33,40 and L45	0.412 to 0.994	56.6 to 82.0	1.043 to 1.670
Class2	L7,8,12, and L52	0.702 to 1.7	19 to 47	1.13 to 1.63
Class 3	L37 and L56	0.350 to 0.393	94.4 to 100	1 to 1.09

Interaction influences of water quality and outdoor and indoor pot experiments on growth and yield of broad bean

Table 11 explains that the interaction between irrigation water quality and both pot experiments affected significantly at $p \leq 0.01$ growth traits and yield of broad bean. In general increase in EC of irrigation water in both pot experiments caused decrease in growth traits and yield of broad bean, with some exceptions due to differing water chemical composition. Since increase in water salinity or EC value of irrigation means decrease in their quality for irrigation (Labba et al., 2021; Richards, 1954; Ayers and Westcot, 1985; Rafdhi et al., 2021; El Mokh et al., 2022) broad bean parameters, especially yield can be regarded as an indicator to irrigation water quality. These results agree with those recorded by Nasrallah et al. (2022) and Bimurzayev et al. (2021).

Table 11. *Effect of the interaction of climate cultivation and irrigation water collected from different locations on the growth and yield traits of broad bean*

Locations	**EC (dS m^{-1})**	**Green pods**	**Dry pods**	**Green shoots**	**Dry shoots**	**No. of pods plant $^{-1}$**	**Length of pods (cm)**
		Weight (g plant^{-1})					
Indoor*L37	0.393	321.67 ^{b}	65.67 ^{a}	322.33 ^{a}	63.333 ^{a}	9.00 ^{bcd}	21.83 ^{a}
Indoor*L56	0.350	353.33 ^{a}	63.33 ^{ab}	281.67 ^{c}	59 ^{b}	9.50 ^{bc}	20.83 ^{ab}
Indoor*L11	0.520	228.00 ^{hi}	42.33 ^{gh}	288.67 ^{c}	57.400 ^{bc}	10.00 ^{b}	19.00 ^{cde}
Indoor*L23	0.412	255.67 ^{de}	46.67 ^{f}	261.33 ^{d}	52.67 ^{def}	11.50 ^{a}	19.17 ^{bcd}
Indoor*L40	0.570	244.00 ^{efg}	35.00 ^{jkl}	225.67 ^{g}	51.77 ^{efg}	9.00 ^{bcd}	20.00 ^{bc}
Outdoor*L37	0.393	257.33 ^{d}	57.00 ^{cd}	186.67 ^{h}	54.00 ^{cde}	633 ^{hij}	16.80 ^{fghij}
Outdoor*L23	0.412	247.33^{def}	55.00 ^{de}	184.33 ^{h}	56.67 ^{bc}	6.33 ^{hij}	16.10 ^{ghijk}
Outdoor*L56	0.350	260.00 ^{jk}	60.00 ^{bc}	186.33 ^{h}	54.33 ^{cde}	6.33 ^{hij}	17.33^{defgh}
Indoor*L33	0.743	191.33^{lm}	31.00 ^{m}	229.33 ^{fg}	56.33 ^{bc}	7.67 ^{fg}	17.80 ^{defg}
Indoor*L45	0.621	165.33 ^{op}	27·33 ^{n}	236.33 ^{f}	46.00 ^{ijk}	8.33 ^{def}	17.17^{efghi}
Indoor*L6	0.798	269.33 ^{c}	61.67 ^{b}	285.33 ^{c}	45.00 ^{jkl}	7.67 ^{efg}	17.47^{defgh}
Indoor*L8	0.702	130.00 ^{q}	31.33 ^{lm}	301.33 ^{b}	55.00 ^{cde}	7.33 ^{fgh}	18.50 ^{cdef}
Outdoor*L40	0.570	238.00^{fgh}	46.00 ^{fg}	173.33 ^{i}	46.33 ^{ij}	5.67 ^{jk}	16.50^{ghijk}
Outdoor*L11	0.520	218.33 ^{ij}	52.67 ^{e}	170.67 ^{ij}	41.67 ^{lmn}	6.00 ^{ij}	16.27^{ghijk}
Indoor*L20	0.720	202.67 ^{kl}	36.00 ^{jk}	191.67 ^{h}	36 ^{pq}	8.50 ^{cde}	17.17^{efghi}
Indoor*L4	0.860	203.00 ^{kl}	36.00 ^{jk}	254.33 ^{de}	56 ^{bcd}	6.67 ^{ghij}	13.67^{mnop}
Indoor*L14	0.994	167.67 ^{op}	34.00 ^{klm}	185.33 ^{h}	38.33 ^{nop}	6.33 ^{hij}	16.00 ^{ghijk}
Outdoor*L33	0.743	229.67 ^{hi}	44.67 ^{fgh}	154.33 ^{kl}	49.00 ^{ghi}	4.67 ^{kl}	15.23^{jklmn}
Outdoor*L45	0.621	184.33 ^{m}	41.00 ^{hi}	164.33 ^{ijk}	44.33^{jklm}	4.70 ^{kl}	15.20 ^{jklmn}
Indoor*L3	0.943	155.67 ^{p}	34.33 ^{klm}	232.67 ^{fg}	50 ^{fgh}	5.67 ^{jk}	14.83 ^{klmn}
Outdoor*L20	0.820	231.67 ^{gh}	42.67 ^{gh}	157.67 ^{k}	38.00 ^{op}	6.00 ^{ij}	15.67 ^{hijkl}
Outdoor*L14	0.994	192.67l^{m}	33.33^{klm}	142.67 ^{m}	41.33^{mno}	4.33 ^{lm}	13.93 ^{lmno}
Indoor*L12	1.125	91.00 ^{s}	27.33 ^{n}	171.00 ^{ij}	37.33 ^{p}	6.17 ^{hij}	11.83 ^{pqr}
Outdoor*L8	0.702	156.00 ^{p}	47.00 ^{f}	162.67 ^{jk}	42.67 ^{klm}	4.67 ^{kl}	13.47^{mnop}
Outdoor*L6	0.798	206.67 ^{jk}	47.33 ^{f}	154.33 ^{kl}	47.00 ^{hij}	4.67 ^{kl}	13.37 ^{nopq}
Outdoor*L4	0.860	183.33^{mn}	43.67 ^{fgh}	147.33 ^{lm}	41.00 ^{mno}	4.67 ^{kl}	12.70 ^{opq}
Indoor*L52	1.290	115.00 ^{r}	20.33 ^{o}	133 ^{n}	25.33 ^{s}	7.13 ^{ghi}	11.83 ^{pqr}
Outdoor*L3	0.943	191.33l^{m}	34.67 ^{klm}	131.67 ^{n}	37.00 ^{p}	4.33 ^{lm}	12.40^{opqr}
Outdoor*L12	1.125	75.67 ^{t}	16.40 ^{p}	103.67 ^{p}	32.00 ^{r}	2.67 ^{n}	10.57 ^{rs}
Indoor*L7	1.7	59.00 ^{u}	13.33 ^{pq}	82.33 ^{q}	15.33 ^{t}	3.33 ^{mn}	9.67 ^{s}
Outdoor*L52	1.290	64.33 ^{tu}	15.50 ^{pq}	102.33 ^{p}	32.67 ^{qr}	3.33 ^{mn}	10.73 ^{rs}
Outdoor*L7	1.7	60.33 ^{u}	12.17 ^{q}	105.33 ^{p}	36.000 ^{pq}	2.67 ^{n}	11.60 ^{qr}
Pr > F (climate cultivation*well name)		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Significant		Yes	Yes	Yes	Yes	Yes	Yes

Different letter or letters within each column mean significant differences and vice versa

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416

Conclusion

The application of (IWQI) water quality index (Maia, and Rodrigues, 2012; Ayers and Westcot, 1985) also, principal component software and agglomerative hierarchical clustering (AHC) used for irrigation water quality classifications approaches, also using broad bean (*Vicia faba* L.) plant to determine inclined yield and productivity could give highly valuable and efficient tools for decision makers to summarize and report on monitoring data.

The results of the irrigation water quality index (IWQI) were similar, according to the mentioned tools or systems of classification. The chemical composition of irrigation waters at the same EC value had great effect on yield.

Acknowledgments. The authors wish to acknowledge Prof. Dr. Akram Othman Esmail at Salahaddin University Department of Soil and Water – Erbil, and corresponding staffs of Soil and Water Science Department, College of Agricultural Engineering Science, Salahaddin University – Erbil and the staffs of College of Agriculture Engineering Science, Salahaddin University – Erbil. In addition, a very special thanks to Bakrajo Technical Institute (BTI), Sulaimani Polytechnic University staffs especially the Dean and Head and staffs of Garden Design department.

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APPENDIX

Appendix 1. *Water samples collection location (l)37*

Appendix 2. *Indoor planting of Vicia faba L.*

Appendix 3. *Indoor growing Vicia faba L.*

DOI: http://dx.doi.org/10.15666/aeer/2103_23972416