Agricultural Advances (2014) 3(6) 176-185
ISSN 2251-7820
doi: 10.14196/aa.v3i6.1425

Contents lists available at Sjournals

Agricultural Advances

Journal homepage: www.Sjournals.com

Original article

Determination of groundwater quality based on important irrigation indices using analytical hierarchy process method

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A R T I C L E I N F O

Article history,
Received 03 June 2014
Accepted 21 June 2014
Available online 27 June 2014

Keywords,
AHP
Eyvanakey plain
GIS
IDW
Water quality

A B S T R A C T

The purpose of this research is the zoning of groundwater quality for agriculture usages in the Eyvanakey plain, conjugating Interpolation methods by Geographic Information System (GIS) and selection of the best weights in Analytical Hierarchy Process (AHP). Achieving this aim, groundwater quality data from 19 wells in Eyvanakey plain were used. First, raster maps of the study area was prepared, using Inverse Distance Weighted (IDW) method, containing the Sodium Absorption Ratio (SAR), Permeability Index (PI), Kelley Ratio (KR), Magnesium Absorption Ratio (MAR), Residual Sodium Carbonate (RSC), Sodium solubility Percentage (SSP), Electrical Conductivity (EC) and Total Hardness (TH). Then, the final weights of parameters were determined by Hierarchical Analysis Process and pairwise matrix. Finally, the map of groundwater qualitative potential for agricultural purposes, prepared, using map overlaying and final weights of the parameters, applying in GIS. Results showed, the groundwater quality for agriculture uses in center and south is bad whereas at east is moderate and at west it was good.

1. Introduction

Chemical combination of soluble components in water is affected by different reactions and interactions between water and aquifer. Therefore, studying chemical combination is so important in order to identify water quality (Rezaei, 2010). Analytical Hierarchy Process Method is one of the most efficient techniques for decision making that was introduced by Saaty (1980) for the first time. This method, has been established on paired comparison and makes it possible for managers to evaluate different scenarios.

Appropriate Selection of indicators able us to make the best comparative decision between alternatives. If several criteria consider for evaluation, assessing process will absolutely be more difficult. Nowadays evaluation and comparison processes have changed from their simple analytical form that mind is capable of doing it and there will be a need for a practical analysis tool. Hierarchy Analysis Process is one of the widest multi-criteria decisions making methods (Omkarprasad and Sushi, 2006). From management point of view the biggest incentive for water quality studies is water quality needs and its effects on the various uses (Maroofi et al., 2009). Using this method has greatly contributed to the initialization of parameters and their integration in GIS.

Geographic Information System (GIS) is effective tool for water quality mapping and land cover mapping essential for monitoring, modeling and environmental change detection (Pius et al. 2011). This system is used in various fields such as groundwater quality zoning. Due to the increasing volumes of data, their digital nature, and development in applications and required analysis, traditional methods for geospatial data analysis, such as statistical methods, cannot solely be used with high reliability because these methods have basically been designed to be used with compact data and faced with the large volumes of data they will not have required speed and efficiency and also will not be able to be responsive against new requirements. Therefore, the use of GIS is applicable way for analyzing and extracting useful information from geospatial data (sadashivaiah, 2008; Ozcan et al., 2007).

Exploitation of groundwater resources requires knowledge of the quantity and particularly, quality of groundwater in the aquifer. Due to population growth and increasing demand for agricultural activities, studying proper locations for groundwater extraction has a superior importance. Quality potential map, specifies suitable and unsuitable places for agricultural usages and significantly helps the management of groundwater resources and offers a respectable wisdom about the quality process of studying and area planning in order to provide agricultural water resources in the future for decision makers.

Several studies have been done by different researchers in order to investigate the status of groundwater resources for the purpose of water quality parameters zonation using geostatistical methods. Christakos (2000) Theodossiou and Latinopoulos (2006) and Ahmadi and Sedghamiz (2007), exhibited that many of aquifer parameters have a spatial distribution. Sarath Prasanth et al. (2012) evaluate the groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha district in Kerala also Srinivas et al. (2013) studied the groundwater quality, their study was made to find the ground water quality for samples of the town located in the southern most end of India. The study was carried out to evaluate the major ion chemistry, the factors controlling water composition, and suitability of water for both drinking and irrigation purposes as well as Sajil Kumar and James (2013) carried some works in the groundwater quality studies.

Due to groundwater vital role in study area as a fundamental water demand responsible and its quality importance for irrigation purposes, this investigation was designed for determination the quality of Evanakey plain groundwater focusing on irrigation water quality, using APHA (American Public Health Association 1998) standard and general irrigation water quality evaluation graph (Wilcox) in order to specify proper areas for agricultural purposes using Analytical Hierarchy Process method(AHP), merging Geographical Information System (GIS).

2. Materials and method

2.1. Study area

Groundwater in arid and semi-arid regions such as Iran, that has mean precipitation about 1/3 less than the world average, is so important (Alizadeh, 2008). In the stable improvement process, qualitative and quantitative water resources protection, pollution decreasing or remediation and at last, optimum management don't apply properly without the deep recognition of these resources and their relationship to extraction, pollution and time-place changes.

Eyvanakey study area is located southern hillside of Alborz Mountain chain, Iran, in 35°,20′,15″ North and 52º,03′,59″ East with average 1000 m elevation above the sea level. There is temperate climate tending to arid with annual average precipitation about 180 mm. the most important river of study area is Namark that flows along the North to South. Deposits and formation of this area belong to Cenozoic and Quaternary chiefly (Figure 1 depicts the geology and geographical location of study area). Water table depth becomes gradually lower from center of plain to west whereas it becomes deeper towards east. General Groundwater flow direction in study area is from West and South-West towards East with average hydraulic gradient about 0.005. Study area water resources consist of deep wells and wells, springs and Qanat strings with 47436. , 1013.22, and 1241.38 TCM annual discharge respectively. The study area is densely populated, with extraordinary domestic, industrial and agricultural water demand from groundwater resources. In recent years, along of extraction well increment and also water table deep intensification, an enormous well loss has occurred. This act has caused aquifer quality diminution, reveals the necessity of serious studies about the Eyvanakey plain.

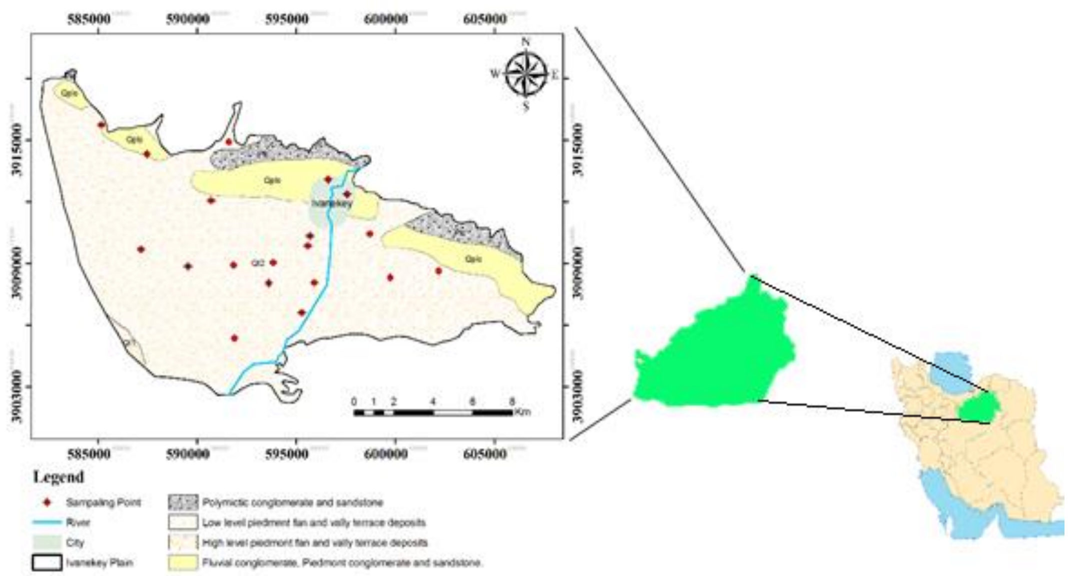

Fig. 1. Geological map and geographical location of the study area.

2.2. Water sampling and laboratory analysis

In order to evaluate the quality of groundwater for agricultural uses in Eyvanakey plain the mean values of quality parameters of 19 deep wells determined by the standard methods (APHA) that have been collected from 2012 to 2013 were utilized. Moreover, pH, electric conductivity (EC), and the total dissolved solid (TDS) were measured from the samples. Total hardness (TH), sodium absorption ration (SAR), and sodium solubility percentage (SSP) were calculated from the measured chemical parameters. The location of the sample sites is shown in Figure 1. Analysis accuracy was checked for charge balance for the water samples based on Hounslow (1995). The charge balance values for all the samples were less than 5 percent. Therefore, the analysis results were reliable. Table 3 presents the statistics of the chemical constituents in the water samples.

Table 3
Statistics for the groundwater samples.

Parameter	Unit	Minimum	Maximum	Mean	Median	STD	Skewness	Kurtosis
SO4-2	meq/L	6	38	14.13	11.7	7.96	1.86	3.72
Cl-	meq/L	8.6	105	29.41	20.4	23.88	1.94	4.67
HCO3-	meq/L	1.4	4.2	2.53	2.4	0.71	0.35	0.5
Na+	meq/L	80	109	26.06	20	23.51	2.65	8.67
Mg+2	meq/L	3.6	18	8.26	7.8	3.55	1.07	1.66
Ca+2	meq/L	4.2	24	11.28	9.2	6.19	1.18	0.14
TDS	mg/L	1290	9480	3100.8	2450	2007.08	1.92	4.77
TH	mg/L	480	1900	977.37	800	449.67	0.99	-0.22
EC	µmoh/cm	1875	14240	4542.2	3670	2969.66	2.09	5.66
PI	%	45	75	57.37	58.04	9.1	0.38	-0.78
SAR	-	2.73	20	6.27	5.55	4.19	2.14	5.72
KR	meq/L	0.62	2.87	1.23	1.05	0.6	1.39	1.83
MAR	%	29	65	43.43	44.44	8.94	0.77	0.87
RSC	meq/L	-35	-6.5	-17	-14.5	9.22	-1.01	-0.2
SSP	%	38	74	52.63	51.11	10.42	0.47	-0.71

Irrigation water are usually classified in terms of salinity hazard (conductivity or TDS) and sodium hazard (SAR). The salinity hazard dividing points are 250, 750 and 2250 µmohs resulting in four categories and sodium hazard is a function of both SAR and salinity that is exposed as logarithmic function of conductivity and SAR (Hounslow, 1995). The graph obtained from these calculations is called Wilcox diagram, shows the irrigation water category in 16 portion from C_1S_1 to C_4S_4 that have the best and the worse irrigation water quality respectively. Figure 2 shows the collected samples category of the study area.

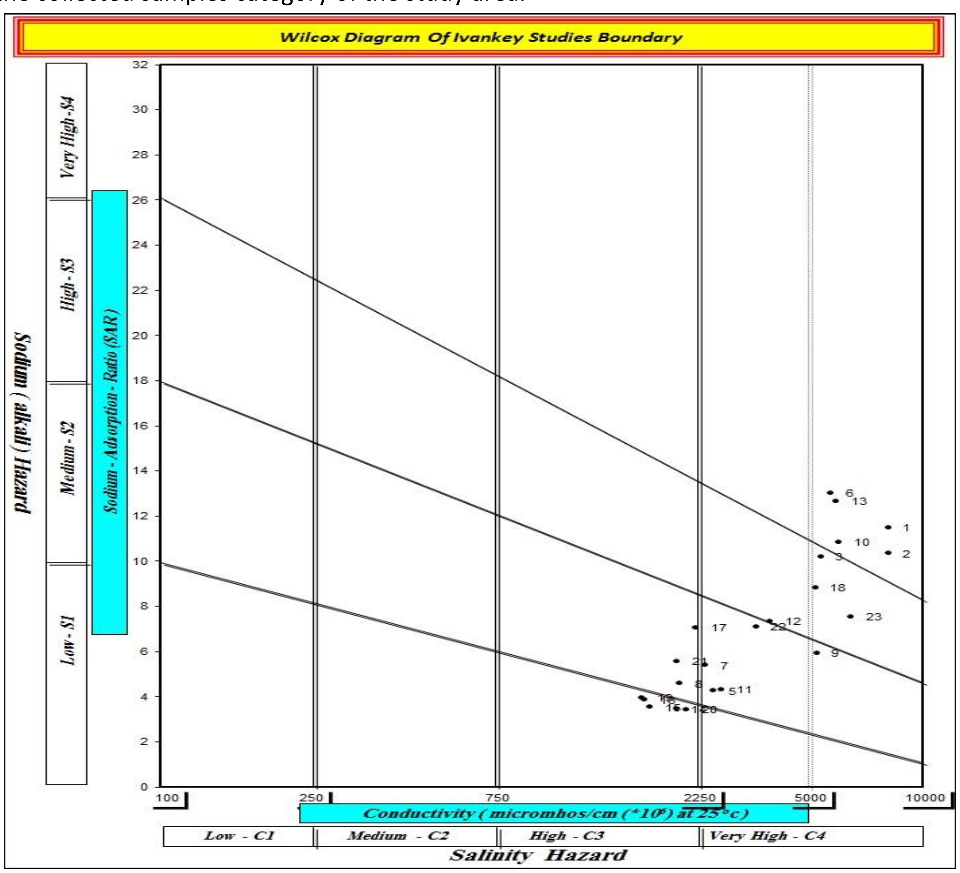

Fig. 2. Wilcox Diagram of Eyvanakey Study Area.

2.3. Parameters Calculation

Considering that absolute values of the concentrations of different cations of water in themselves cannot be of use for the purpose of estimating water quality or the harmfulness rate of water for the plant, Inverse Distance Weighted method were applied ,to Sodium Absorption Ratio(SAR), Permeability Index(PI), Kelley Ratio(KR), Magnesium Absorption Ratio (MAR), Residual Sodium Carbonate(RSC), Sodium Solubility Percentage(SSP), Total Hardness(TH) and Electrical Conductivity(EC) maps extract in raster form.

The amount of sodium or alkalinity hazard is expressed in terms of Sodium Absorption Ratio (Gholami and Srikantaswamy, 2009). SAR values less than 10 are excellent for irrigation. Values from 10 to 28 are average and more than 28 are dangerous. Sodium Absorption Ratio has been calculated according to equation 1.

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad (1)$$

Percentage of sodium solubility has been calculated as below (equation 2). Percentage of sodium solubility is the ratio of sodium soluble in groundwater to the total cations. Higher than 60% soluble sodium may be due to accumulation of Na and probably due to the soil structure, penetration and weathering (Hakim et al., 2009). Sodium concentration in quality evaluation of groundwater is important for irrigation because higher amounts of sodium cause reduction in permeability of the soil (Todd and Mays, 2005). Sodium Solubility Percentage and Electrical Conductivity are of great importance in quality classification of groundwater for agricultural purposes (Khodapanah et al., 2009).

$$SSP = \frac{(Na + K)100}{Ca + Mg + Na + K} \quad (2)$$

The Residual Sodium Carbonate is a valuable parameter that is of great importance in determining the acceptability of water for agricultural purposes (Bokhari and Khan, 1992). If we assume all the deposits of calcium and magnesium are in the form of carbonate sediment, then according to the index offered by Eaton (1950) the amount of residual sodium carbonate is obtained from the following relation.

$$RSC = (CO_3 - + HCO_3) - (Ca + Mg) \quad (3)$$

If the amount of RSC in water is more than 2.5, the water is unsuitable for irrigation. The amount of RSC is between 1.25 to 2.5 is moderate quality for irrigation and if this amount is less than 1.25, then groundwater quality will be suitable for irrigation.

Doneen (1962) began to evaluate the quality of groundwater for irrigation based on permeability index. Permeability index has been calculated according to equation 4.

$$PI = \frac{(Na + \sqrt{HCO_3}) \times 100}{Ca + Na + Mg} \quad (4)$$

Values exceeding 50 are considered dangerous and inappropriate for irrigation. The MAR has been calculated according to equation 5 (Raghunath, 1987).

$$MAR = \frac{Mg \times 100}{Ca + Mg} \quad (5)$$

Kelley (1940) introduced a parameter that evaluated irrigation water quality on the basis of measured sodium compared to calcium and magnesium. Waters with less than 1 KR are suitable for irrigation. The KR has been calculated according to Kelley (1963) equation.

$$KR = \frac{Na}{Ca + Mg} \quad (6)$$

And also Total Hardness is calculated in terms of calcium carbonate and upon of the calcium and magnesium ions amounts (Raghunath, 1987).

$$TH = (2.5 * Ca) + (4.1 * Mg) \quad (7)$$

Water with TH of less than 75 mg/L, between 75 to 150 mg/L, between 150 to 300 mg/L, and above 300 mg/L are classified as soft, semi-hard, hard and very hard waters, respectively.

The aforementioned Indices (SAR, SSP, MAR, PI, KR, TH, EC and RSC) were compared in pairs in order for determining the weight of each index. Using IDW approach, raster maps related to each index in GIS were extracted and applicable rank were given to them; the highest and lowest ranking are related to the poorest and the best quality of each index, respectively. After that, the weights of indices are determined by AHP method (Analytic Hierarchy Process).

AHP is a comprehensive approach to multi-criteria decision-making problems. Saaty and Vargas (2001) designed AHP to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria; AHP involves the principles of decomposition, pairwise comparisons, and priority vector generation and synthesis (Tolga et al, 2004).

Weight giving operations were performed and final weights of each hydrochemical index for each layer were applied in GIS. Table 1 shows rates and weights for the used layers.

Table 1
Rates and weights for the used layers

Index	Unit	Weight	Range	Rate	Final Weight
EC	µmohs	2.3	450-700	5	11.5
			700-3000	7	16.1
			>3000	9	20.7
SAR	-	3.2	0-3	5	16
			3-6	7	22.4
			6-8.13	9	28.7
SSP	%	1.1	35-40	4	4.4
			40-60	5	5.5
			60-80	7	7.7
			80-85.4	9	9.9
RSC	Meq/L	1	(-10.6)-(-4.2)	4	4
			(-4.2)-(-1.9)	5	5
			(-1.9)-(-0.35)	7	7
			(-0.35)-(2.7)	9	9
PI	%	0.45	29-40	5	2.25
			40-60	7	3.15
			60-80	9	4.05
MAR	%	0.6	18-20	4	2.4
			20-40	5	3
			40-60	7	4.2
			60-72	9	5.4
KR	Meq/L	1.15	0.21-0.44	4	4.6
			0.44-0.6	5	5.75
			0.6-0.84	7	8.05
			0.84-1.58	9	10.35
TH	Mg/L	0.2	150-430	4	0.8
			430-703	5	1
			703-1027	7	1.4
			1027-1743	9	1.8

As it can be clearly seen, From among the eight under consideration indices in AHP method, Sodium Absorption Rate and Total Hardness parameter were allocated the maximum and minimum weight, respectively.

3. Results and discussion

For groundwater quality determination of the study area, the index layers were built. In figures 3, 4, 5 and 6 the layers for of Permeability Index (PI) and Sodium Absorption Ratio (SAR) Kelley Ratio (KR) and Magnesium

Absorption Ratio (MAR), Sodium Soluble Percent (SSP) , Residual Sodium Carbonate (RSC), Electrical Conductivity (EC) and Total Hardness (TH) have been shown respectively . After that these indices are multiplied by resulted weight from Analytical Hierarchy Process method and their sum is divided by the sum of the main weights. Relation 8 shows the combination way of these layers and extraction of the final map.

$$\frac{[(SAR\times 2.3)+(RSC\times 1)+(TH\times 0.2)+(EC\times 2.3)+(KR\times 1.15)+(MAR\times 0.6)+(PI\times 0.45)+(SSP\times 1.1)]}{10} \quad (8)$$

Applying the weights and overlaying of the indices layer, final map derived which have been shown in Figure 7. In general, in center and south of the study area the groundwater quality is bad whereas at east is moderate and at west it was good.

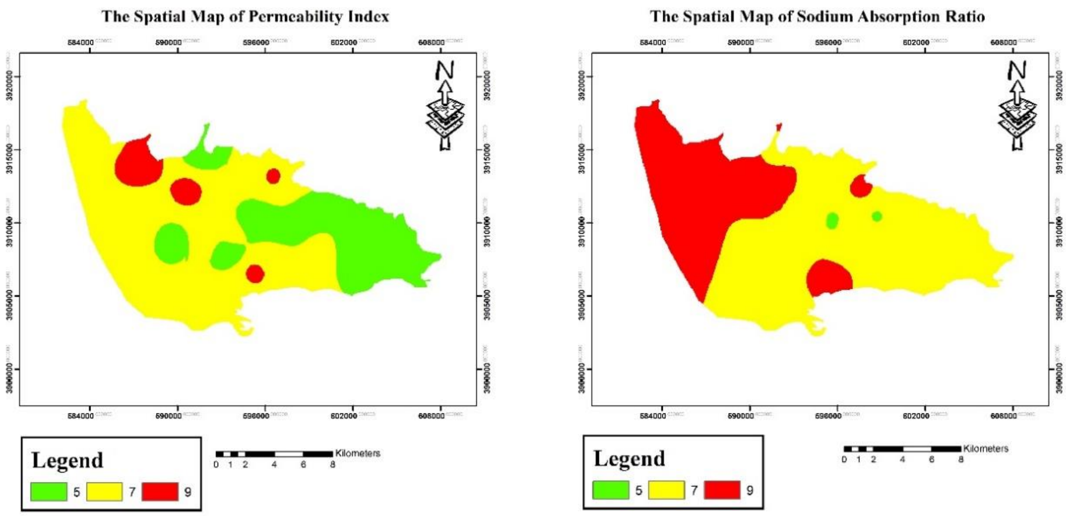

Fig. 3. Raster layers for Permeability Index and Sodium Absorption Ratio.

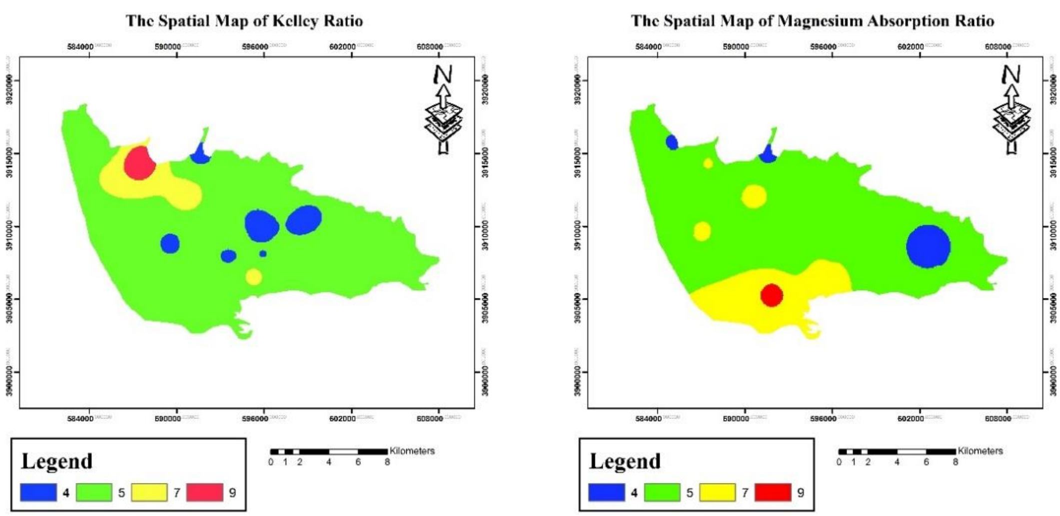

Fig. 4. Raster layers for Kelley Ratio and Magnesium Absorption Ratio.

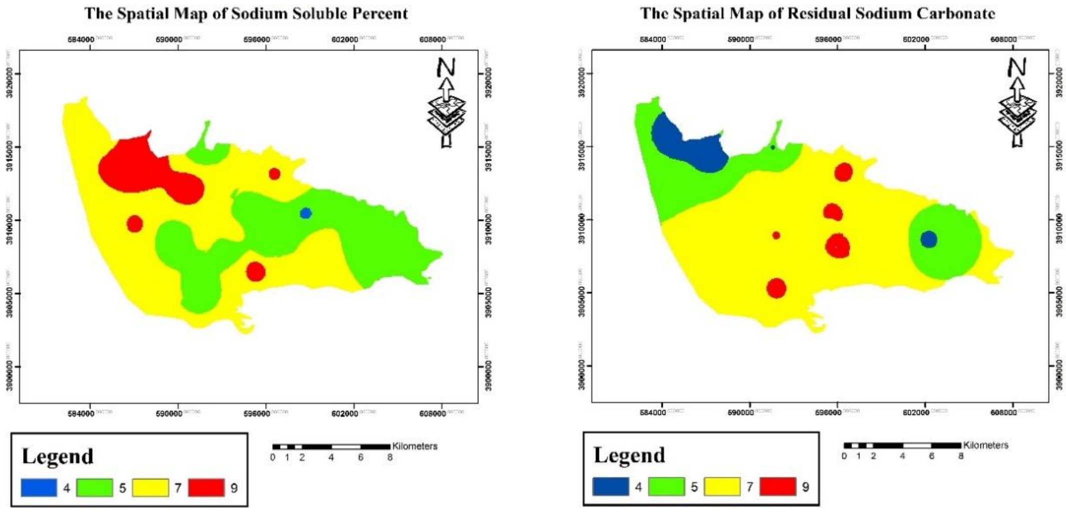

Fig. 5. Raster layers for Sodium Soluble Percent and Magnesium Absorption Ratio.

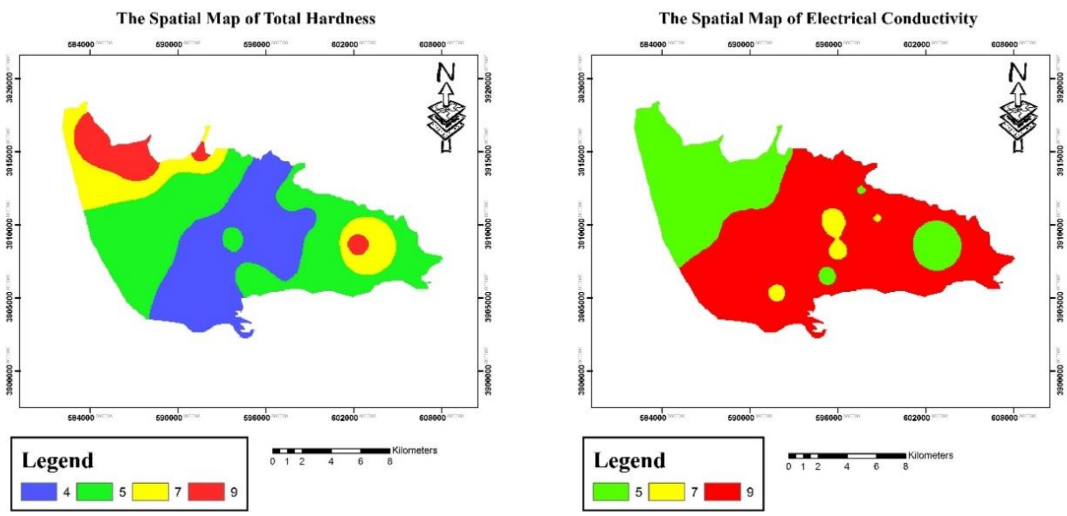

Fig. 6. Raster layers for Electrical Conductivity and Total Hardness

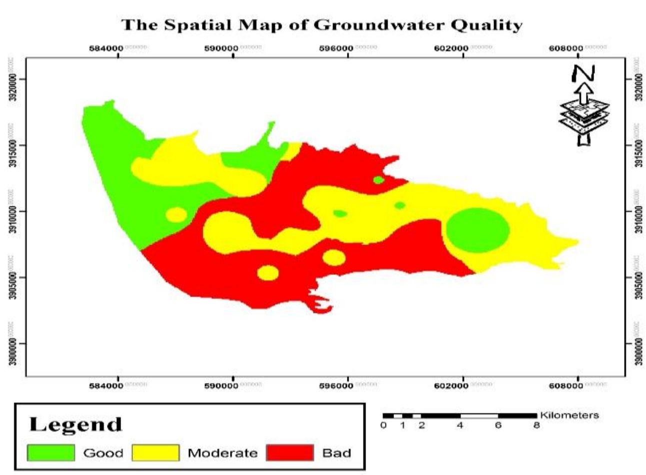

Fig. 7. Final map obtained from integration of the layers.

4. Conclusion

Results showed, about 48, 86 and 76 square kilometers out of 211 square kilometers of the study area have been located in good, moderate and bad ranges, respectively. The groundwater quality for irrigation consumption in the North and South locations of the study area, is considered bad and the Moderate part occupied the East part through the center and a region of North West. Some part of the study area is given to the Good quality and is appropriate for agricultural purposes. Also, it has been clearly seen that about 36 percent are classified as bad and 41 and 23 percent of the study area, has a Moderate and Good quality for agricultural purposes respectively. Finally, it is revealed that integrated study of water quality parameters is more appropriate than their study separately.

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