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EVALUATION AND MAPPING GROUNDWATER SUITABILITY
FOR IRRIGATION USING GIS IN NAJAF GOVERNORATE, IRAQ

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Irrigation Water Quality Index (IWQI) for groundwater within the Geographic Information System (GIS) environment is proposed so that it can be used in assessing the groundwater vulnerability. The model was applied to the Damman aquifer in the western part of Iraq. Thirty nine sites were chosen for the investigation of the Damman aquifer. Triplicate ground water samples were collected from each site (during wet and dry seasons of 2013). Variables tested in each sample include: pH, EC, total hardness Ca^{+2}, Mg^{+2}, Cl-, Na^{+} and SAR. The final water quality map constructed for the aquifer showed that there are three major regions. The first is in the northeastern part of the area while the second region is confined to the southeastern part. Finally, the third region extended along the western part of the study area. When this map was converted according to the suggested model, it showed that the water quality of the Damman aquifer is marginal for use for agriculture purposes.

INTRODUCTION

Groundwater is the main source of water in most of the countries in the Middle East and North Africa (MENA) apart from Sudan, Egypt and Iraq. This region is also known by its shortages of water resources in the Middle East (Rogers and Lydon, 1994; Biswas, 1994; Al-Ansari, 1998 and 2013). At least 12 countries have acute water scarcity problems with less than 500 m^3 of renewable water resources per capita available (Cherfane and Kim, 2012 and Barr et al., 2012). The supply of fresh potable water is essential to life, socioeconomic development, and political stability in the region. It was reported that one cubic meter of water can provide drinking water for one person for one year or the same quantity can produce only one kg of food grain when used for irrigation in a dry climate (Perry and Bucknall, 2009). The need for a rationalized holistic management of this most vital natural resource is paramount in order to attain a sustainable society.

The largest consumer of water across the region is agriculture which accounts for 66% of demand, (Hiniker, 1999) and therefore the water shortage problem cannot be objectively analyzed nor adequately addressed without a thorough consideration of agriculture in the region (Sadik and Barghouti, 1994). For example an approximate 10 percent transfer of water away from agriculture would produce a 40 percent increase in domestic water supply for Jordan (Sadik and Barghouti, 1994). Postel (1992) argues that rather than diverting precious water to agriculture this water could be saved by importing the food/grain. However, this is not the case in many MENA countries which have unrealistic aspirations of food self-sufficiency and in it would require a most fundamental change in national outlook (Charrier and Curtin, 2000).

In addition to the above, the effect of climate change is expected to intensify the water shortage problem in MENA countries. The MENA region contains hyper-arid, arid and semi-arid zones (WRI, 2002). Several research projects concluded that arid and semi-arid regions are highly vulnerable to climate change (e.g. IPCC, 2007). It is expected that the region will suffer from higher temperatures and intense heat waves affecting inhabitants and crop yields, and will also affect marine ecosystems and fisheries. Less but more intense rainfall, coupled with higher temperatures, will likely cause more droughts and greater flooding, sea level rise, more intense cyclones and new areas exposed to dengue, malaria, and other vector and waterborne diseases. Al-Ansari and Baban (2005) and Al-Ansari et.al. (1999 and 2006), indicated that future rainfall forecast is decreasing with time in Jordan. The drought will affect the agricultural life and water supply (Medany, 2008). This is due to the fact that most of the agricultural areas of the MENA region are rain-fed (Oweis and Hachum, 2004) and decreases groundwater recharge which is already depleting (Voss et.al., 2013).

Iraq was considered to be rich in its water resources compared with other countries where the annual allocation per capita reached 6029 m^3 in 1995 and expected to be 2100 m^{3}in 2015 (Postel, 1992). Now, Iraq is suffering from water shortage problems. This is due to the construction of dams on the Tigris and Euphrates and their tributaries outside the border of Iraq, the effect of global climate change and mismanagement of water resources are the main factors in the water shortage problems in Iraq (Al-Ansari, 2013). Restoring the marshes (UN, 2010, Al-Ansari et al., 2012) and the growing demand for water in Turkey and Syria will lead to dry the Tigris and Euphrates Rivers in 2040 (UN ,2010)). Furthermore, the supply will be 43 and 17.61 BCM in 2015 and 2025 respectively while current demand is estimated between 66.8 to 77 BCM. The World Bank (Postel, 1992) stated that 100% of the Euphrates water comes from outside the borders of Iraq while 67% of the Tigris water also comes from

outside sources. It was also stated that groundwater resources are about 1.2 BCM and form about 2% of the total water resources of Iraq. Therefore, it will be very logical to use groundwater more as one of the measures to be taken to overcome this problem (Postel, 1992).

Groundwater resources are dynamic in nature and are affected by factors such as the expansion of irrigation activities, industrialization and urbanization; hence monitoring and conserving this important resource is essential. The quality of water is defined in terms of its physical, chemical and biological parameters. Ascertaining the quality is crucial before its use for various purposes such as drinking; agricultural recreational and industrial uses (Sargonkar and Deshpande, 2003; and Khan et al., 2003).

In Najaf, the quality of groundwater has particularly received immense attention since water of high quality is required for domestic and irrigation needs. Till recently, groundwater assessment has been based on laboratory investigation, but the advent of Satellite Technology and Geographical Information System (GIS) has made it very easy to integrate various databases. GIS can be a powerful tool for developing solutions for water resources problems, assessing water quality, determining water availability, preventing flooding, understanding the natural environment and for managing water resources on a local or regional scale (Ferry, et. al., 2003)

Water quality index provides a single number that expresses overall water quality assessment at certain location and time based on several water quality parameters. The objective of an index is to turn complex water quality data into information that is understandable and useable by the public, a single number cannot tell the whole story of water quality; there are many other water quality parameters that are not included in the index. However, a water quality index based on some very important parameters can provide a simple indicator of water quality (Yogendra and Puttaiah, 2008).

Although Water Quality Index (WQI) is usually orientated to qualify urban water supply, it had been widely used by environmental planning decision makers. The quality of the irrigation water has to be evaluated to avoid or at least, to minimize negative impacts on agriculture (Mohammed, 2011).There are number of classifications to evaluate the suitability of water for irrigation. Among these is Richard classification which depended on Sodium Absorption Ratio (SAR) and electrical conductivity (EC) (Richards, 1954). Wilcox in (1955) proposed another classification which is based on sodium percentage concentration (Na %) instead of SAR in its relationship with EC. Later, in 1985, Ayers and Westcot proposed a classification taking into consideration five groups for the evaluation based on the hydrochemical changes. They are: salinity, cations and anions concentration (epm), nutrients concentration (ppm), and miscellaneous influences. In 1995, Don suggested a classification which depends on EC, TDS, SAR, and %Na.

The requirements for irrigation water quality could differ from one field to the other depending on the cultivated crop pattern as well as the regional soil and climatologic conditions (Babiker et al. 2007). In this context, irrigation water quality mapping is considered to be a valuable instrument for the spatially distributed assessments of individual quality parameters. Accordingly, GIS provides an important platform for visualizing such maps and making comparative evaluations. However, in addition to individual assessments, a critical phase of the quality management procedure is to collectively evaluate all parameters mentioned in the previous section. The Water Quality Index (WQI) has been widely used to determine the suitability of groundwater for drinking and irrigation purposes and as a management tool for groundwater quality (Khalaf and Hassan, 2013, Hussain, et al., 2012a,b, Kalra, et al., 2012, Rokbani et al., 2011, Al-Haidarey, 2010, Jerome and Pius, 2010). Khalaf and Hassan (2013) and Simsek and Gunduz (2007) used irrigation water quality index (IWQI).

The purpose of this study is to find the Irrigation Water Quality Index (IWQI) for Dammam Aquifer at Najaf, Iraq. The main variables considered in the |IWQI were EC, Na^+, Cl^-, HCO_3^- and SAR, within the Geographical Information System (GIS).

STUDY AREA

The study area represents a part from Najaf area which lies between latitudes 29° 48' 20" to 32° 23' 15" N and longitudes 42° 48' 51" to 44° 45' 10" E with total area of approximately 28824 km^2 (Figure 1). The studied aquifer is Dammam Formation (Middle-Late Eocene). This formation is exposed at the eastern part of the western desert (Sissakian and Mohammed, 2007). The Dammam Formation was deposited mostly in shallow neritic environment (Buday, 1980) The type locality of the formation is located in Saudi Arabia on Dammam dome (Bellen et al., 1959). At its type locality it is composed of whitish grey, porous, dolomitized limestone. The thickness of the formation in the western desert according to Al-Mubarak and Amin (1983) is 32 to 99 meters.

This region is characterized by its low annual rainfall which does not exceed 100mm per year. For this reason, small dams had been constructed on the valleys of the Western Desert for harvesting water during rain seasons to be used in summer (Al-Ansari, 2013). The population density is about 5 inhabitants/km^2 (Al-Ansari, 2013). Maximum daily temperature might exceed 55°C during summer while the minimum drops below 0°C during winter (Al-Ansari, 2013, Al-Ansari et al, 2014a,b). Groundwater is the only water resource in the area due to the lack of any surface water. There are many springs in the north-eastern part of the study area (Najaf depression). These springs extend along the line of the Abu-Jir fault. In addition, there are many artesian wells distributed within the study area. These wells had been drilled during the period 1960-1994. In addition, many non-artesian wells are distributed within the study area. These wells drilled after 1994 to reduce ground water utilization from artesian wells. Most of the study area is desertic with some sand dunes in Al-Ramla area in the Najaf depression. Also, some mesa features occur in the study area.

The Dammam Formation in the study area is composed of limestone (chalky, organo-detrital or dolomitic), dolomites, marls, and shales. The thickness of the formation, in the Iraqi supplementary type area reaches 250 m. The maximum known thickness is 298 m in water well K7-17 south west of Anah. In the study area Dammam aquifer is of a confined type. It is one of the most important aquifers in southwest Iraq. It consists of three beds; upper, middle (which represents the main source of Dammam water) and impermeable lower Jil bed which separate the formation from Umm Erdhama Formation. Limestone is the main rock constituent of Dammam aquifer which is heterogeneous rock. Diagenetic processes (dolomitization and silicification) had great influence on the permeability of the aquifer. The porosity of the rocks in the aquifer is mainly due to karstification cavities associated with fissures which controls the aquifer storage properties. Karstification and high permeability near the water table is controlled by ground water level fluctuations. Permeability of the aquifer decreases with depth. Highest permeability occurs in depressions where strong water circulation exists. Infiltration through the karst system is fast and facilitates ground water recharge.

Significant recharge occurs through sinkholes, depressions and highly permeable beds in the valleys (Alsam et al., 1990). The direction of ground water flow is generally from south west to north east of the study area. Despite the fact that rainfall is so low in the study area, the Dammam confined aquifer is recharged from rainfall through faults and fractures at the western area toward Iraqi-Saudi border. Many studies concluded that the main source of most of Dammam water comes of ancient origin probably associated during the deposition of Dammam aquifer or shortly after that (Waierdy, 1994).
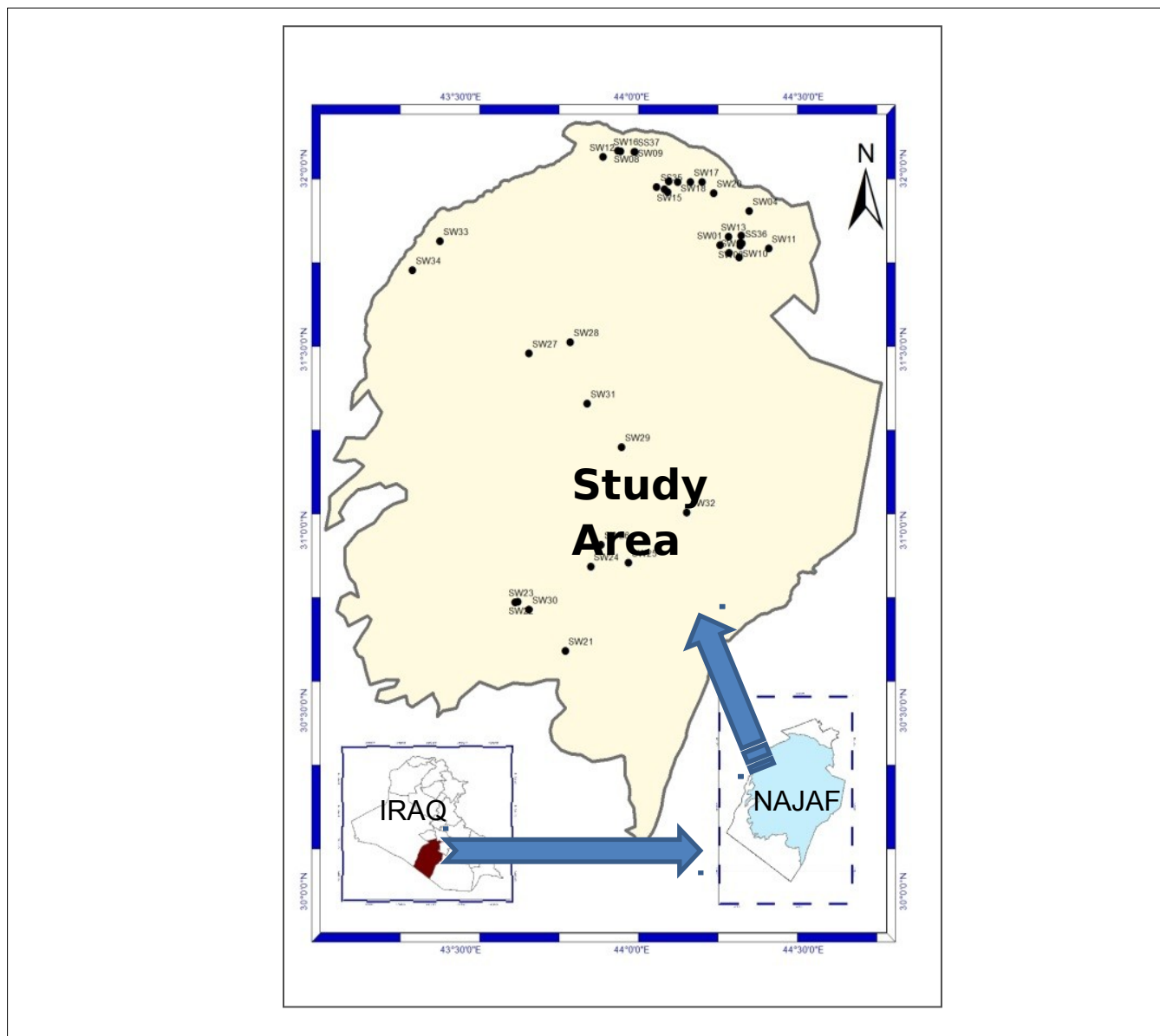
Figure 1: Location of the Study Area in Iraq and Sampling Locations

MATERIAL AND METHODS

Thirty six sites were chosen for the investigation of Dammam aquifer. Triplicate ground water samples were collected from each site during dry Season (August) and wet season (March) of 2009. The water samples were collected in clear pre-sterilized polythene bottles. Physic-chemical characteristics were determined as per the standard methods (APHA, 1989) Figure (1).

Calculation of Irrigation Water Quality Index (IWQI)

The Irrigation water quality index (IWQI) model was applied in this study. The model was developed by Meireles et al. (2010) in two steps. In the first step, parameters that contribute to most

variability in irrigation water quality were identified using principal components and factor analysis (PC/FA) as described in SPSS Software. In the second step a definition of quality measurement values (qi) and aggregation weights (wi) was established. Values of (qi) were estimated based on each parameter value, according to irrigation water quality parameters proposed by the University of California committee of Consultants- UCCC and the criteria established by Ayers and Westcot (1999), shown in Table (1). Water quality parameters were represented by a non-dimensional number: the higher the value, the better the quality water.

Values of qi were calculated using the Equation 1, based on the tolerance limits shown in Table (1) and water quality results determined in laboratory:

$$q_i = q_{i\max} - \left[\frac{(X_{ij} - X_{\inf})}{X_{amp}} q_{iamp} \right] \qquad (1)$$

where q_{imax} is the maximum value of qi for the class; X_{ij} is the observed value for the parameter ; X_{inf} is the corresponding value to the lower limit of the class to which the parameter belongs; q_{iamp} is class amplitude; X_{amp} is class amplitude to which the parameter belongs.

In order to evaluate X_{amp} , of the last class of each parameter, the upper limit was considered to be the highest value determined in the physical-chemical and chemical analysis of the water samples.

Each parameter weight used in the IWQI was obtained by Meireles et al. (2010) as shown in Table (2). The wi values were normalized such that their sum equals one.

The irrigation water quality index (IWQI) was calculated as

$$IWQI = \sum_{i=1}^{n} q_i * w_i \qquad (2)$$

IWQI is dimensional parameter ranging from 0 to 100; *qi* is the quality of the ith parameter, a number from 0 to 100, function of its concentration or measurement; *wi* is the normalized weight of the ith parameter, function of importance in explaining the global variability in water quality. Division in classes based on the proposed water quality index was based on existing water quality indexes, and classes were defined considering the risk of salinity problems, soil water infiltration reduction, as well as toxicity to plants as observed in the classification presented by Bernardo (1995) and Holanda and Amorim (1997). Restriction to water use classes were characterized as shown in Table (3).

RESULTS AND DISCUSSION

Salinity problem

Electrical conductivity is commonly used for indicating the total concentration of the ionized constituents of natural water. It is closely related to sum of the cations (or anions) determined by chemical analysis and it correlates well with the values for dissolved solids. Under average conditions, there is a closed relationship between these soils. The range of EC values are (1531 μscm[-1]), (3460 μscm[-1]) with mean (2727 μscm[-1]) of the dry season and (1382 μscm[-1]), (3070 μscm[-1]) and with mean (2446 μscm-1) of the wet season respectively Table (4). The spatial distribution of EC values in the

study area is shown in Figure (2) (A1) and Figure (3) (A2).

Table 1: Parameter limiting values for quality measurement (qi) calculation (Meireles et al., 2010)

qi	EC (μs/cm)	SAR (mmol/L)$^{1/2}$	Na$^+$	Cl$^-$	HCO$_3^-$
				(mmol/L)	
85 – 100	200≤EC<750	2 ≤SAR< 3	2 ≤ Na < 3	1 ≤ Cl < 4	1≤ HCO$_3$<1.5
60 – 85	750≤EC<1500	3 ≤SAR< 6	3 ≤ Na < 6	4 ≤ Cl < 7	1.5≤ HCO$_3$<4.5
35 – 60	1500≤EC<3000	6≤SAR<12	6 ≤ Na < 9	7 ≤ Cl < 10	4.5≤ HCO$_3$<8.5
0 - 35	EC<200 or EC≥3000	SAR<2 or SAR≥12	Na < 2 or Na ≥ 9	Cl< 1 or Cl≥ 10	HCO$_3$<1 or HCO$_3$≥ 8.5

Table 2: weights for the IWQI parameters (Meireles et al., 2010)

Parameters	wi
Electrical Conductivity (EC)	0.211
Sodium (Na$^+$)	0.204
Chloride (Cl$^-$)	0.194
Bicarbonate (HCO3$^-$)	0.202
Sodium Adsorption Ratio (SAR)	0.189
Total	1.00

Table 3: Irrigation Water Quality Index Characteristics (Meireles et al., 2010)

IWQI	Water Use Restriction	Recommendation	
		Soil	Plant
85 ≤ 100	No restriction (NR)	May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability	No toxicity risk for most plants
70 ≤ 85	Low restriction (NR	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay levels 2:1.	Avoid salt sensitive plants
55 ≤ 70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts.	Plants with moderate tolerance to salts may be grown
40 ≤ 55	High restriction (HR)	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2.000 dS m^{-1} and SAR above 7.0.	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO3 values
0 ≤ 40	Severe restriction (SR)	Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and HCO3.

Specific Ion Toxicity

The sodium ion (Na+) concentration of water samples ranged between (222 ppm) to (434 ppm) with mean (281ppm) in dry season and between (159 ppm) to (374 ppm) with mean (222 ppm) in wet season Table (4). The spatial distribution of sodium ion concentration in the study area is shown in Figure (2) (B1) and Figure (3) (B2).

Table 4: Descriptive statistics of parameters used in groundwater analysis for irrigation purpose

	August of 2009					March of 2009				
	EC	Na^+	Cl^-	HCO_3^-	SAR	Ec	Na^+	Cl^-	HCO_3^-	SAR
Minimum	1531	222	275	119	3.10	1382	159	238	110	2.49
Maximum	3460	434	585	399	6.43	3070	374	497	275	6.20
Average	2727	281	428	210	4.51	2446	222	386	180	3.80
SD	357	58	63	50	0.95	309	50	65	42	0.84

Chloride concentrations are presented as the other parameter defining the specific ion toxicity. The chemical analysis of groundwater showed that the maximum, minimum and mean values are (275 ppm), (585 ppm) and (428 ppm) of dry season and (438 ppm), (497 ppm) and (386 ppm) of wet season respectively Table (4). Spatial distribution of chloride ion concentrations are shown in Figure (2) (C1) and Figure (3) (C2). The figures show that the ion concentrations are relatively very high in all water sampling.

Miscellaneous Effects

The bicarbonates ion (HCO3-) concentration of water samples ranged between (119 ppm) to (399 ppm) with mean (210 ppm) of dry season and ranged between (110 ppm) to (275 ppm) with mean (180 ppm) of wet season Table (4). Spatial distribution of bicarbonates ion concentrations are shown in Figure (2) (D1) and Figure (3) (D2).

Infiltration Hazard

The most common water quality factor that influences the normal rate of infiltration of water is the relative concentrations of sodium, magnesium and calcium ions in water that is also known adsorption ratio (SAR) and it is computed as:

$$SAR = \frac{Na^+}{\sqrt{\frac{[(Mg^{+2})+(Ca^{+2})]}{2}}} \quad (3)$$

in which the concentrations are expressed in expressed in (meq/L).

The minimum, maximum and mean values of SAR are (3.10), (6.43) and 4.51) of dry season and (2.49), 6.2) and (3.8) of wet season respectively Table (4). The spatial distribution of SAR concentration in the study area is shown in Figure (2) (E1) and Figure (3) (E2).
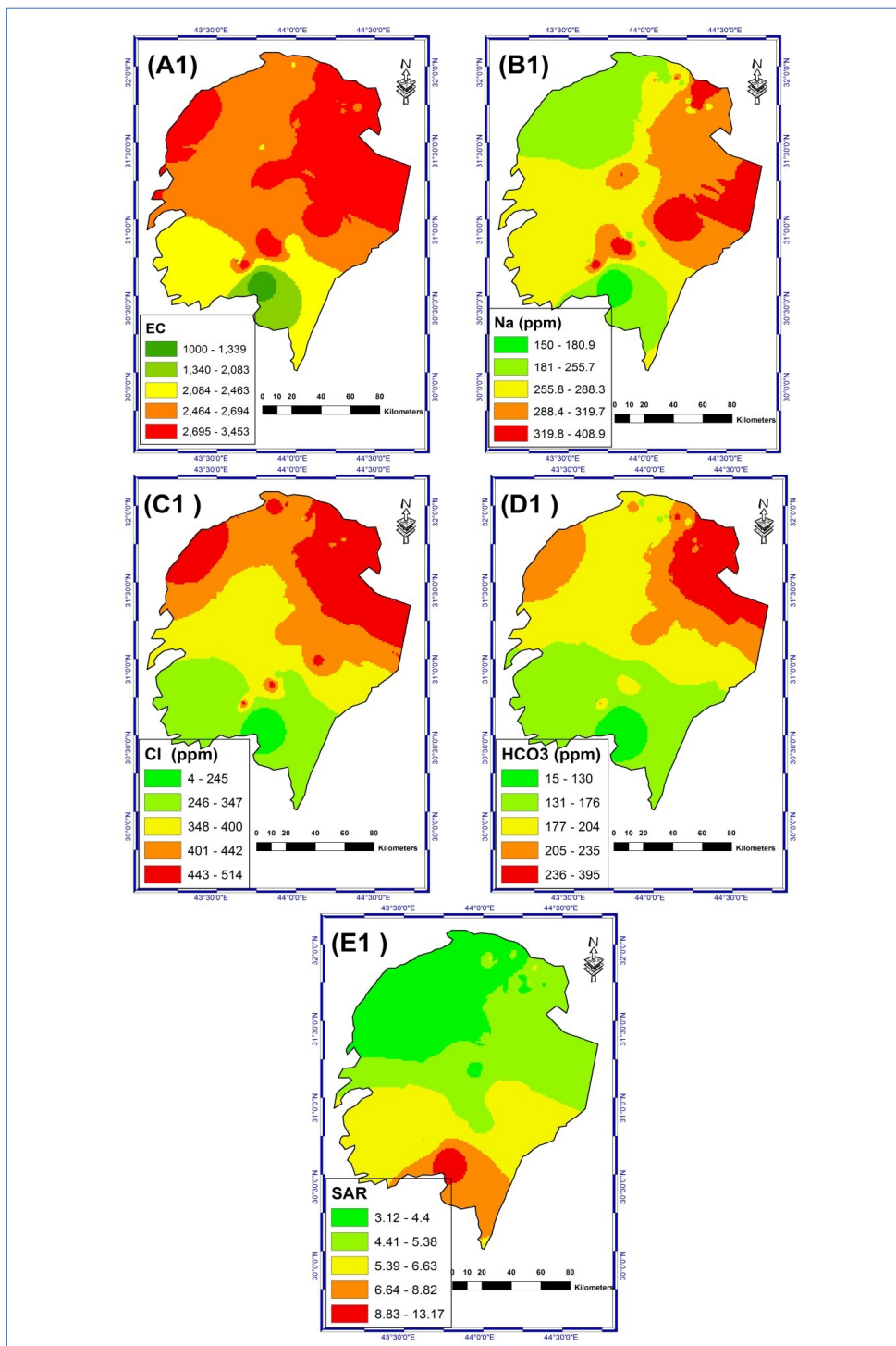
Figure (2) Spatial Distribution for the concentration of (A1) EC, (B1) Na, (C1) Cl, (D1) HCO_3 and (E1) SAR for the study area in dry season
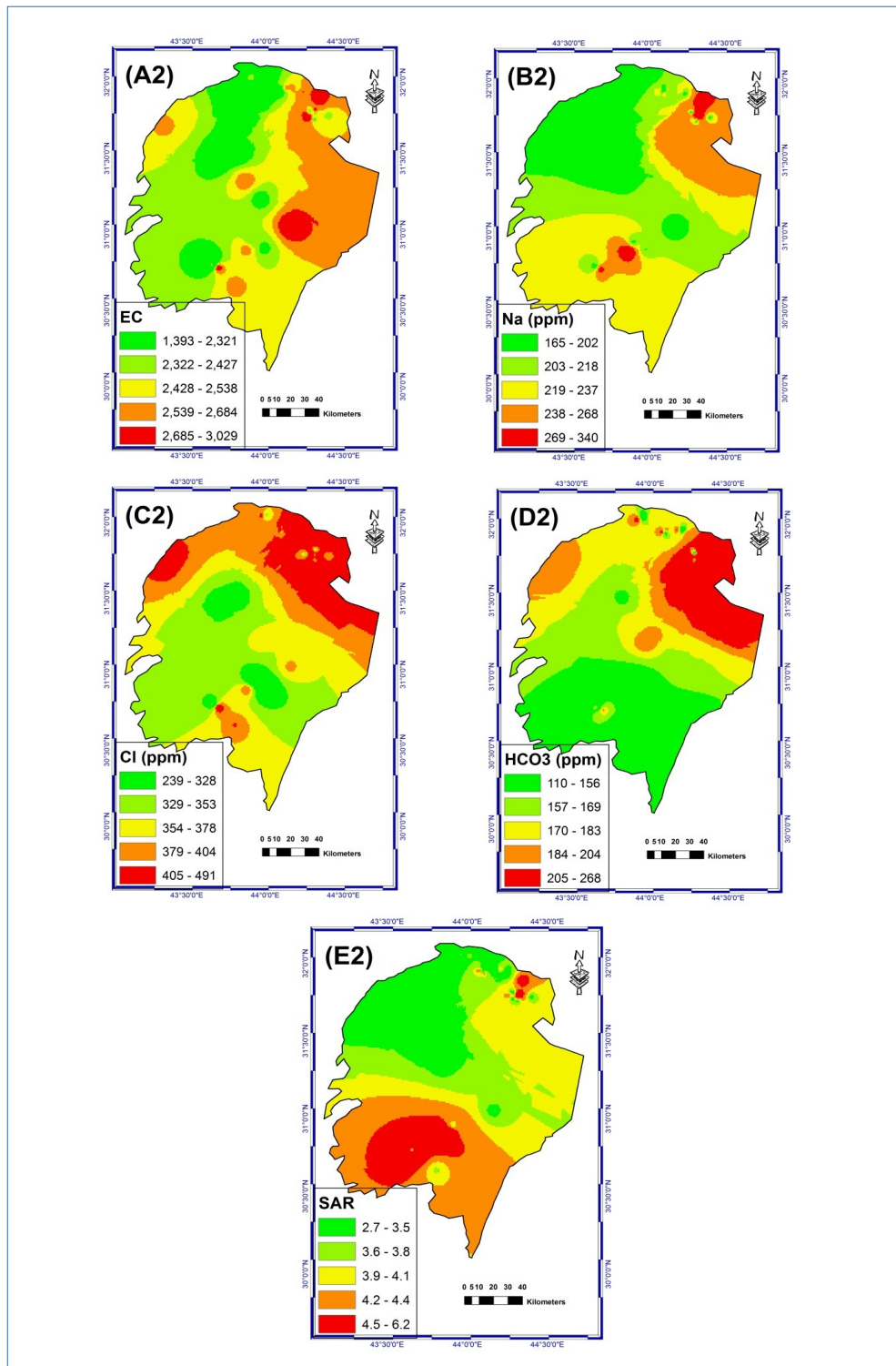
Figure (3) Spatial Distribution for the concentration of (A2) EC, (B2) Na, (C2) Cl, (D2) HCO3 and (E2) SAR for the study area in wet Season
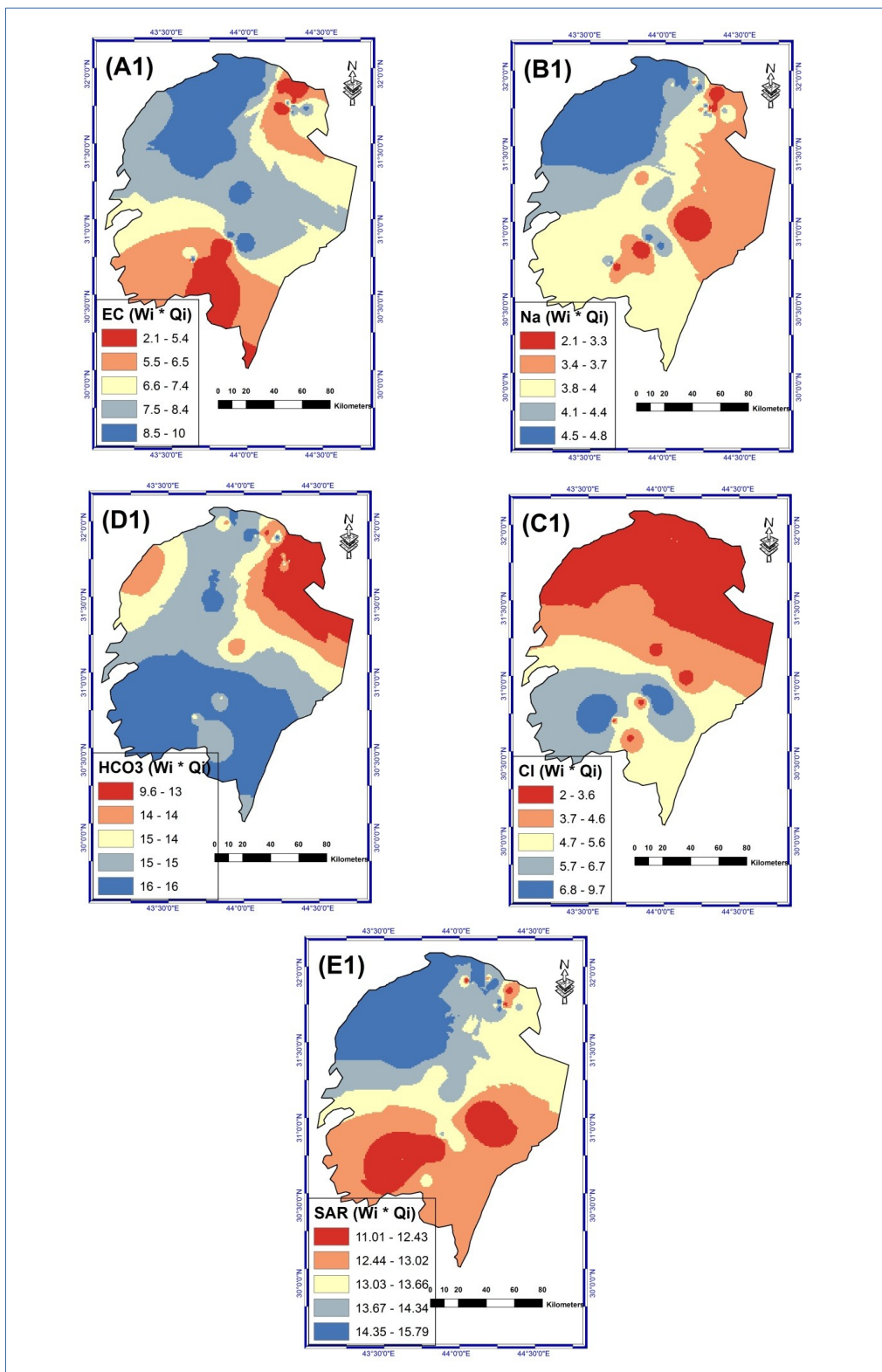
Figure (4) Spatial Distribution of the (Qi * Wi) for parameters (A1) EC, (B1) Na, (C1) Cl, (D1) HCO$_3$ and (E1) SAR for the study area in dry season
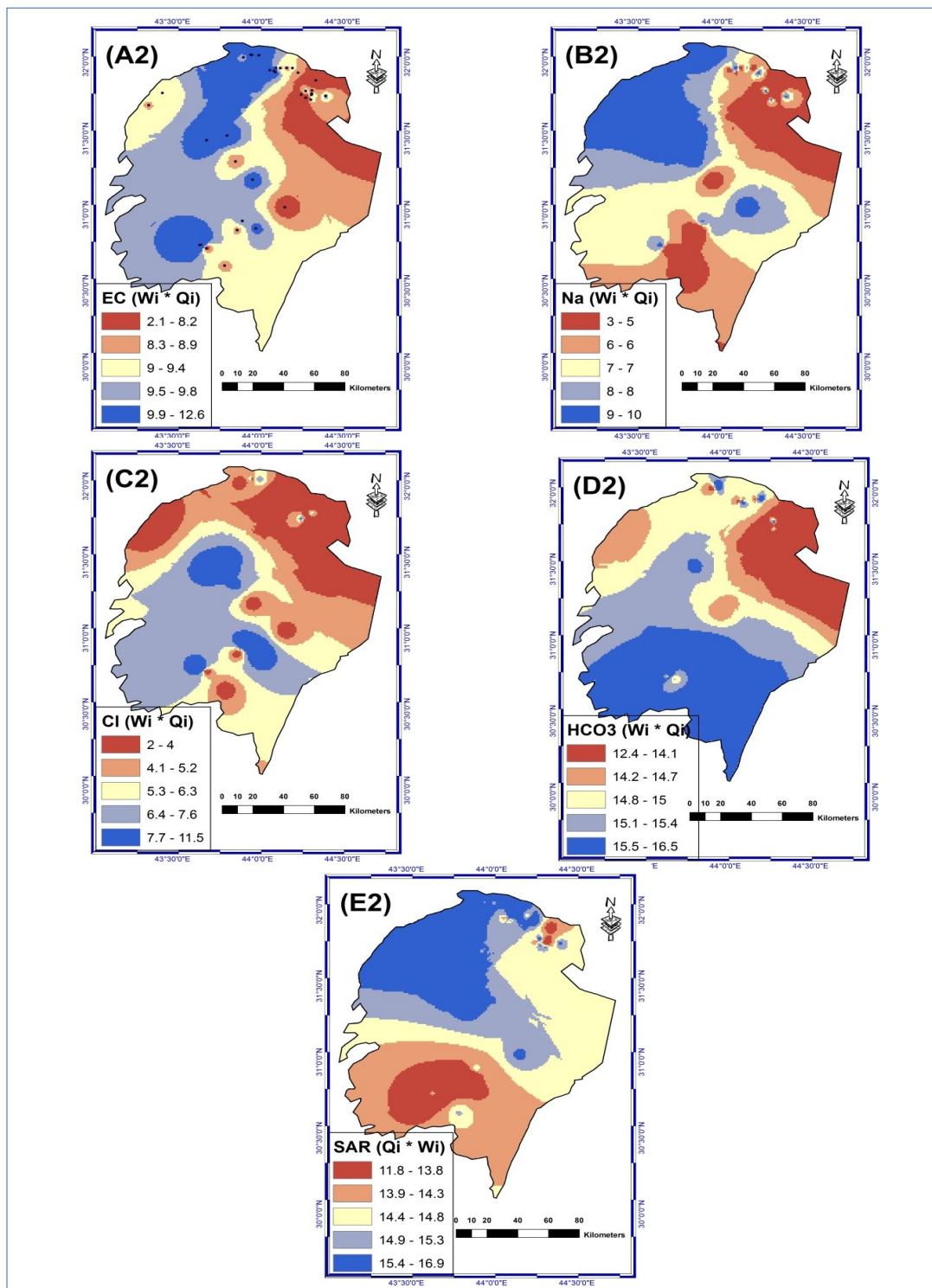
Figure (5) Spatial Distribution of the (Qi * Wi) for parameters (A2) EC, (B2) Na, (C2) Cl, (D2) HCO$_3$ and (E2) SAR for the study area in wet season
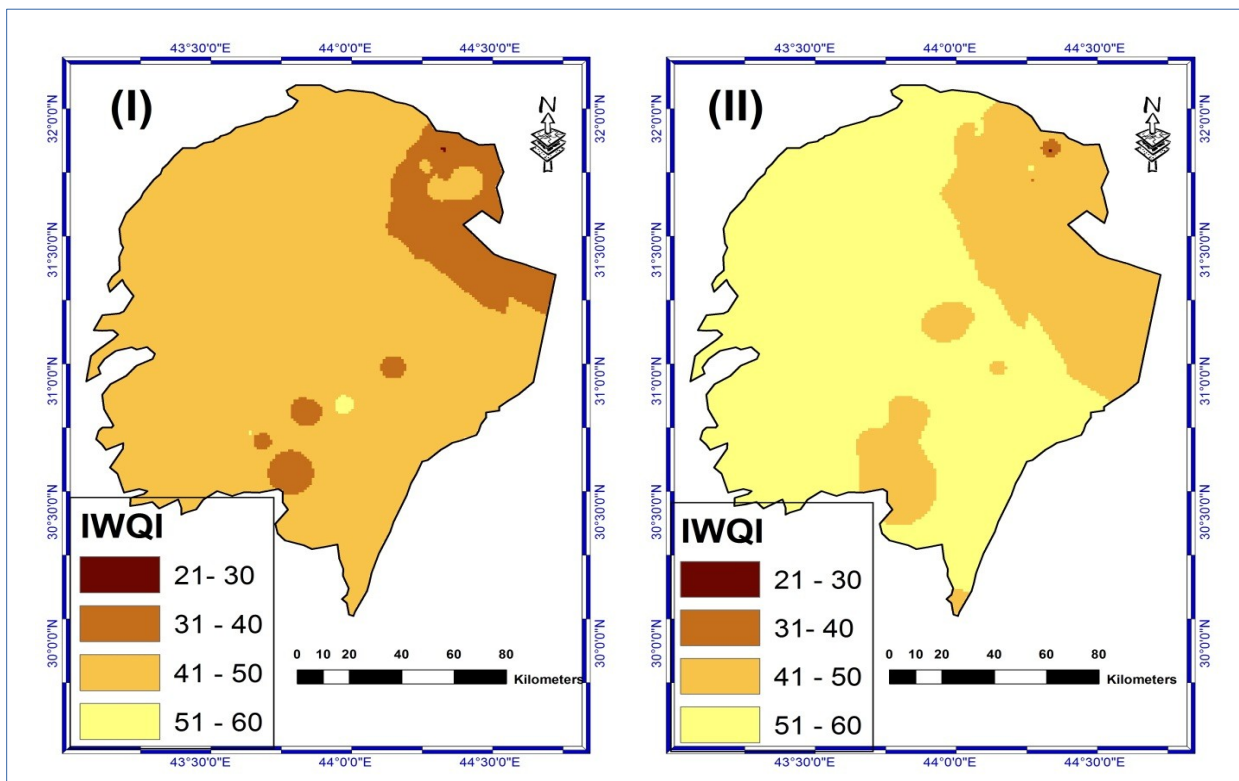
Figure (6) Spatial Distribution of IWQI map for the study area in (I) dry season and (II) wet Season

Calculation of the Irrigation Water Quality Index (IWQI)

ArcGIS Spatial Analyst extension was using to carry out the spatial integration for groundwater quality mapping. According to the Equation (2) the Irrigation water quality index (IWQI) was produced by overlapping of the thematic maps for the parameters (EC, Na, Cl, HCO3 and. SAR) Figure (4) and Figure (5) respectively.

Finally the result of these integration was the IWQI maps for dry season (August) and wet season (March) Figure (6) (I) and (II) respectively.

CONCLUSIONS

The present paper proposed a simple model to assess and map groundwater suitability for irrigation purposes in Najaf Governorate. Ordinary kriging method was used for preparation of thematic maps of groundwater quality parameters such as EC, Na, Cl, HCO3 and SAR. The groundwater quality index was devised to analyze the combined impact of different quality parameters on irrigation purposes.

Figure 7 (I) shows spatial distribution of IWQI in the dry season for study area and it varys from severe restriction (SR) to high restriction (HR) according to Table (3). The areas for high restriction water quality cover 88 % of total study area. The rest of the study area, which is about 12%, has water classified as severe restriction quality levels.

The spatial distribution map of the IWQI in the wet season is shown in Figure 7 (II) and it varys from severe restriction (SR) to moderate restriction (MR) according to Table (3). The areas for severe

restriction water quality cover 0.19 % of total study area. And the areas for high restriction cover 92% of total area. The rest of the study area, which is about 7.81%, has water classified as moderate restriction quality levels.

As shown from Figure 7 (I) and (II), the values of IWQI decrease through the wet season, because of dilution of water from rainfall and decreasing the discharge which are using for irrigation.
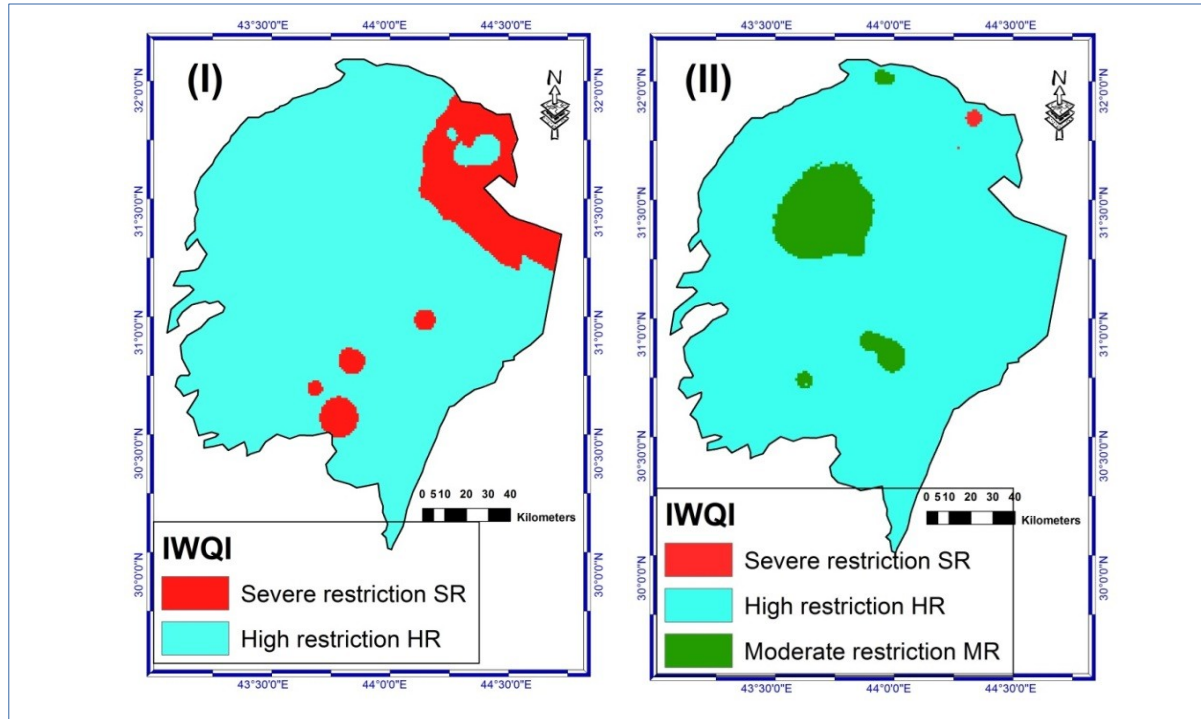

Figure (7) IWQI Classes map for the study area in (I) dry season and (II) wet season

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