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Analysis of spatiotemporal relationships between irrigation water quality and geo-environmental variables in the Khanmirza Agricultural Plain, Iran

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Abstract

The goal of this work was to explore spatiotemporal relationships between irrigation water quality index (IWQI) and geo-environmental variables in the Khanmirza agricultural plain, Iran. Data from 1987 to 2013 was applied to analyses of local statistics by geographically weighted regression (GWR). For this purpose, a statistics index was used to generate IWQI maps applying ionic composition of the water used for agriculture. Geo-environmental variables such as, electrical conductivity soil (EC), changes in water table, aquifer thickness and changes of land cover were applied in the current research. Data for all variables were acquired from field observations, lab analysis, and from several local projects in the region. According to IWQI outputs, throughout the study area, and particularly in the central parts of the plain, groundwater quality had gradually declined over the past 26 years. All results for spatial distribution of local R^2 determined by the GWR approach showed that relationships between IWQI and the four geo-environmental variables were consistent over space; this result was attributed to natural characteristics and from groundwater management in the region. Likewise, results of t values for local parameter estimates revealed both positive and negative relationships with higher significance ($p \leq 0.01$ and $p \leq 0.05$) between IWQI and geo-environment variables, which were mainly centralized in central parts of the study area. The current study provides essential information for groundwater resources planning in regions with a severe decrease of water quality and in regions where agricultural land is mainly irrigated by groundwater.

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Introduction

The supply of good quality groundwater is essential for human existence, but increasing demand in areas with insufficient or limited supply of surface water and increasing demand has put tremendous pressure on these valuable water resources (Chen *et al.,* 2010b; Rashid *et al.,* 2012). The supply of appropriate water quality for agriculture puts pressure on an environment and is by far the most dominant use of groundwater globally (Zahed sharifi and Safari sinegani 2012). There are problems with the quality of irrigation water in many parts of the world and these have been addressed in much research (Mandal *et al.*, 2008; Chen *et al.*, 2010a; Sharifi & Safari Sinegani 2012). In past decades, increasing demand for water has imposed constraints on quality and quantity of groundwater resources and groundwater degradation as a result human activities and natural conditions, which make it a matter of urgency to intensify efforts to preserve the quality of groundwater resources (Fianko *et al.*, 2009). Scientific interpretation of the relationships between irrigation water quality, as an important indicator for water quality assessment of agriculture and geo-environment variables, provides important information that can be applied to groundwater resources planning and management in agricultural regions.

Spatial variation of relationships between natural factors is common, and caused by complex processes (Timez *et al.*, 2012). It is clear that better knowledge of spatiotemporal relationships between irrigation water quality and geo-environmental variables can have an important role in effective and efficient water resources planning. Water quality for agricultural usages is affected by many human and natural characteristics such as changes in vegetation cover, geology and climate (Scanlon *et al.*, 2007; Tu 2013). Irrigation water quality index (IWQI) is one of the most important indicators for water quality assessment, applicable to agriculture (Maia 2012; Bakr *et al.*, 2012). The relationship between IWQI and proximate causes introduces complexity and interconnections between water quality and associated factors. According to studies carried out by various researchers, quality of irrigation water in a region is closely related to various geo-environmental variables such as change in land use/cover (Weatherhead & Howden 2009; Fianko *et al.*, 2009; Singh *et al.*, 2011; Tu 2013), geological properties (Rashid *et al.*, 2012), water table depletion (Scanlon *et al.*, 2005), and soil salinity (Mandal *et al.*, 2008; Sahrawat *et al.*, 2010; Sharifi and Safari Sinegani 2012).

Analysis of relationships between IWQI and geo-environmental variables needs to allow parameters in a model to be applicable across various regions. There are many approaches among statistical modeling to determine these spatial relationships (Timez *et al.*, 2012). Geographically weighted regression (GWR) is a tool that deals with spatial non-stationary in spatial data and estimates regression coefficients locally, using spatially dependent weights (Fotheringham *et al.*, 2002; Gao & Li 2011). Therefore, GWR can be applied for analysis of spatial relations as a local statistical approach by exploring relationships between variables over space.

Groundwater resources in the Khanmirza agricultural plain in the southwest of Iran have faced an ongoing threat of declining water quality in recent years (Rahimi and Pourkhosravani 2012; Taghipour Javi *et al.*, 2014). In this region, the use of groundwater resources for agriculture has increased dramatically in recent decades. Extreme groundwater overdraft in the region has contributed to excessive pressure on aquifers, which has led to a reduction in water quality. This reduced quality of groundwater resources has had an adverse affect on the environment in that groundwater and agricultural land have become salinized. The analysis of groundwater quality monitoring in relation to the geo-environment variables is required for water resources planning the future of this plain.

The goals of the present study were twofold. The first objective of this research was to apply a statistically based index to irrigation groundwater suitability in Khanmirza agricultural plain by IWQI using various ionic compositions of water for irrigation. The main aim of the current study was to apply GWR as a local statistical approach and spatial technique to determine relationships between IWQI and some geo-environmental variables, in order to further develop an understanding of such relationships at a local scale for groundwater resources management in the Khanmirza agricultural plain.

Materials and methods

Study area

Khanmirza agricultural Plain covers approximately 257 km^2 and is located between 31°24′08″ and 31°38′18″ north Latitude and 50°58′51″ and 51°11′16″ east Longitude (Fig. 1). The economy of this region depends mainly on agriculture activates and farmland represents about 70% of the total area. In the three past decades, farmers have focused thoroughly on groundwater resources as the most important water resources in this district (Taghipour Javi *et al.*, 2014). Based on the synoptic weather station records, the annual average precipitation for this plain is 587 mm, 90% of which occurs between December and April. This annually rainfall is not sufficient to meet out the crop-water requirement; therefore groundwater exploitation for irrigation has increased sharply. The number of agricultural wells and the groundwater overdraft in the Khanmirza plain has added to the excessive pressure on confined aquifers, which has adversely affected the environment in such ways as salt in groundwater resources and agricultural lands.

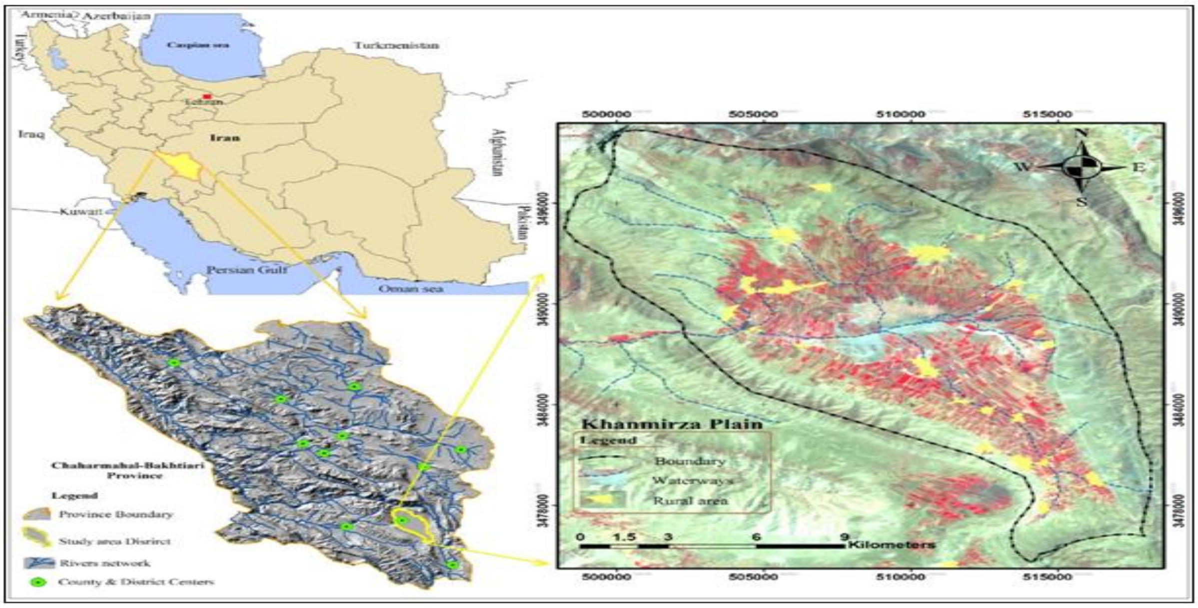

Fig. 1. Location of the Khanmirza agricultural Plain in the Chaharmahal-Bakhtiari Province-Iran.

Irrigation water quality data

Data for chemical parameters of water quality were supplied by the databank and local and regional projects by the regional water company of Chaharmaha-Bakhtiari province (2014) and Yekom consulting Company (2002), respectively. IWQI evaluations were determined from 102 samples taken from piezomeric and agricultural wells; accordingly, 28 samples were taken from 1987, 33 from 2000 and 41 samples were from 2013; these were applied as dependent variables. Evaluations for mean value, standard deviation and coefficient of variation (CV) for characteristics and for each period included in the study are shown in Table 1. For all chemical parameters, data normality was confirmed by the Lilliefors test. These values were applied to obtain a classification index of ionic composition, as well for determinations of irrigation water quality.

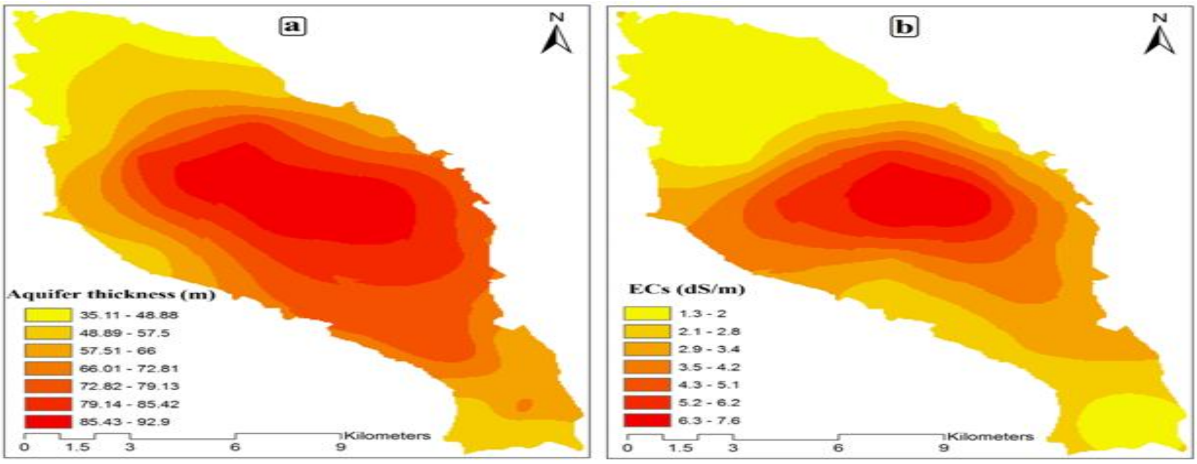

Fig. 2. Spatial pattern maps in; a) aquifer thickness and b) electrically conductivity evolutions of soil samples.

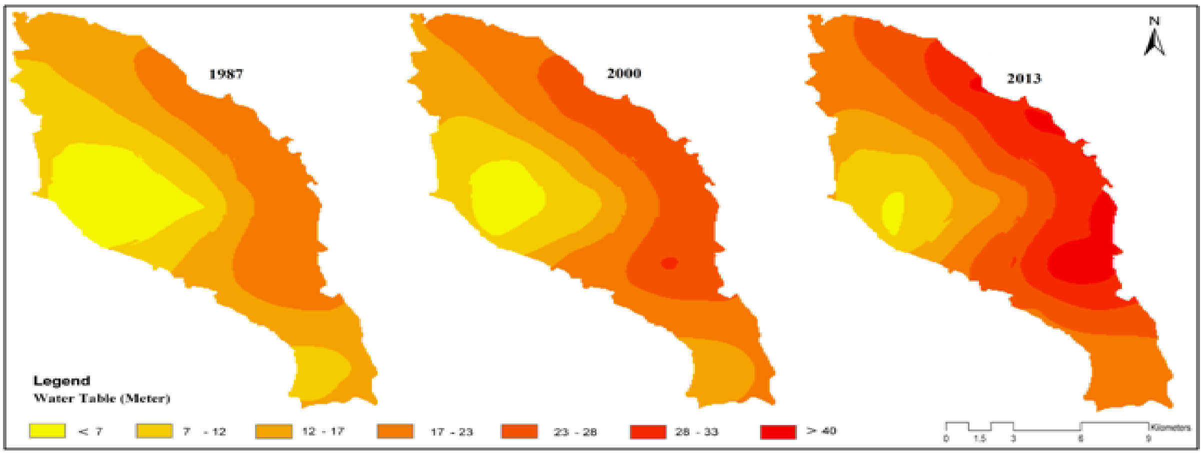

Fig. 3. Water table changes in the Khanmirza agricultural plain in the years a) 1987, b) 2000, and c) 2013.

Explanatory variables: geo-environmental factors

Aquifer thickness

Karstic aquifers are relatively well known as they have been exploited as a water resource and constitute one of the most important geological events of this alluvial region. Data on aquifer thickness were delineated by Yekom consulting Company (2002) using vertical electrical sounding (VES). All VES sample data were interpreted using the Kriging method to obtain local distribution and spatial coverage. However, the study area was that of a descended plain with a confined aquifer of quartz sediment. According to Fig 2a, there were considerable local deposits of sediment up to 93m thick in the region, but these were mostly centralized in the central part that contains alluvium deposits, flood plains and karst features and these types of geographical feature in the study area facilitate good water-holding capacity.

Electrical Conductivity of soil samples

Electrically conductivity of soil (EC) has an important effect on water quality and is considered as an important parameter in assessing water quality in irrigation water; Therefore, EC is commonly used as an indicator for salinity. 36 samples from several local projects were used to evaluate EC for the year 2000; this was done by the Yekom Consulting Company (2002) for land use management in the Khanmirza plain. Laboratory analysis was also carried out on 33 soil samples to determine soil salinity in the region for 2013. All data for EC were interpolated using Kriging method in order to obtain spatial distribution and coverage. According to Fig. 2b, approximately 50% of the area had low-level salinity of less than 3.5 dS m^{-1} in 2013. In contrast, the area covered by fairly high-level salinity ranged from 6.3 to 7.6 dS m^{-1} that was approximately 12% of the total study area, which was mainly concentrated in the central part. In fact, the cause of accumulations of salinity on the ground in those areas was mainly due to either natural characteristics of the region (saline groundwater resources) or inappropriate use of land and water resources for agricultural activities.

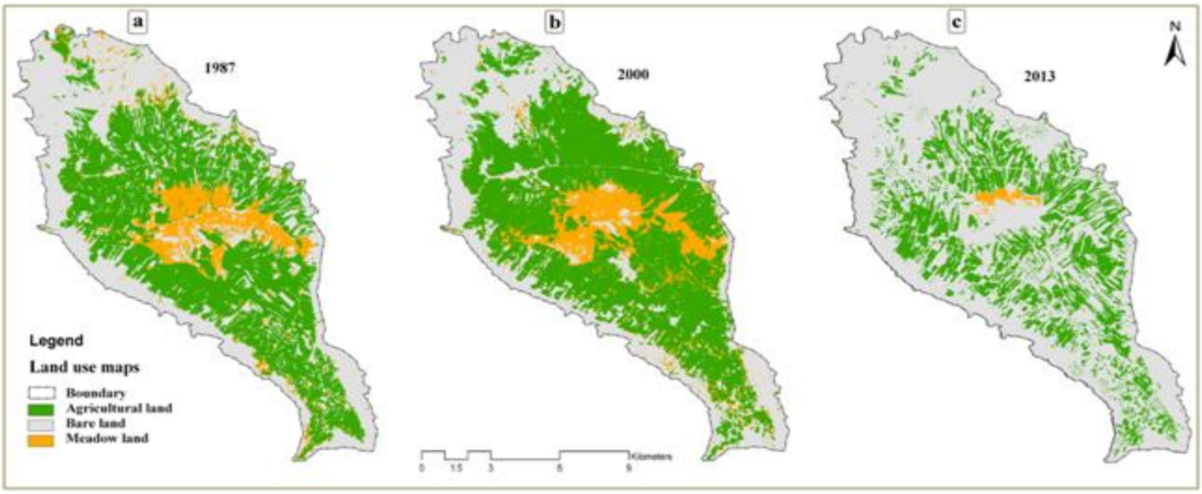

Fig. 4. Land cover classification maps using DTc for Khanmirza plain in a 1987, b 2000, and c 2013.

Water table

Intensive groundwater withdrawal from areas of limited saturation thickness has contributed to a severe decrease of groundwater resources in the study area. In this research, data on the water table were obtained from 17 piezometric well tubes that regularly documented monthly changes of the water table. These data were supplied by the regional water company of Chaharmahal-Bakhtiari province (2014). Approximately 70% of the entire region faced a dramatic decrease owing to over-exploitation of the confined aquifer; many agricultural wells had dried up, inasmuch as the water level had reduced in most places, evaluations showed a range of more than 28 meters (Fig. 3). For 2013, groundwater availability was determined as unsustainable for crop irrigation because of economic and physical constraints to water availability, so that farmland was no longer profitable compared to past years (Fig. 3c). A result of this sharp decline in water level led to deterioration of groundwater quality and encroachment of saline water to the fresh water of the region's aquifers.

Changes to Land Cover

It is well known that land use/land cover is important for quality characteristics of groundwater. Land cover maps for 1987 and 2000 were acquired from previous research project by Taghipour Javi *et al.* (2014). TM satellite image of 2013 was classified based on three different land use types, including agriculture land, bare land and meadow land using decision tree classification along with ancillary data and post classification comparison processing in ENVI 4.5. Classification maps of TM satellite images in 1987, 2000, and 2013 depicted several fluctuations in severity in the intervening 26 years. According to Fig. 4 all vegetation cover severity decreased and the agricultural landscape trended toward fragmentation from 2000 to 2013.

Fig. 5 shows that agricultural land increased by 8,205 ha from 1987 to 2000, but then rapidly decreased by 4,302 ha in 2013. The cause of this reduction can partly be attributed to water quantity and mostly to loss of water quality for agriculture purposes. Moreover, two noteworthy changes are understandable; Fig 5 demonstrates that firstly, an intensive increase occurred in bare land from 1,679 to 11,215 ha in the second period (2000–2013); and secondly, that there was a considerable decrease in meadowland from 6,791 to 125 ha over the same period. Hence, maps revealed that the three main types of land cover; agricultural land, meadowland and bare land were considerable and faced dramatic changes in terms of conversion to other types of land cover in the study area. However, large areas of agricultural land and meadowland were had been converted to bare land mainly due to a severe reduction of groundwater resources and high saline concentration of groundwater over the period.

IWQI and GWR approaches

IWQI involving chemical parameters was introduced by Sepehr *et al.*, (2007); it was also applied by Bakr *et al.*, (2012) for assessment of land sensitivity to desertification. Maia *et al.*, (2012) developed a statistical method to classify water according to IWQI to evaluate ionic composition of water for use in irrigation. This index can be defined as a parameter which reflects the overall water quality for irrigation water quality status (Singh *et al.*, 2011). In the current study, a statistics method (proposed by Maia *et al.*, (2012)) was used to classify agricultural water quality and generate IWQI maps applying ionic composition of the water used for irrigation. The acquired data were chemically analyzed for parameters such as Na, Ca, Mg, K, Cl, HCO_3, SO_4, CO_3, pH, EC, and SAR. The SAR also was calculated via SAR = Na/ $((Ca+Mg)/2)^{0.5}$. To calculate the deviation from the reference values for each characteristic the data were standardized using following equation.

$$\boxed{Z_i = \frac{x - \bar{x}}{\sigma}} \qquad (1)$$

where Z_i is standardized value of the characteristic analyzed; x = value of the characteristic evaluated at the water in each period; $\bar{x}$ = mean value of the characteristic evaluated; s = standard deviation of the characteristic evaluated.

The quality index was calculated for each characteristic (WQIi) in the sample, for which WQIi was determined for each ions and chemical compositions (equation 2) and the IWQI by equation 3.

$$\boxed{WQI_i = \sqrt{Z_i^2}}$$

(2)

$$\boxed{IWQI = \frac{1}{N}\sum_{i=1}^{N} WQI_i} \qquad (3)$$

where WQIi is water quality index for the characteristic; Zi = standardized value of the variable; N =number of characteristics evaluated. Based on recent research findings (Maia *et al.*, 2012, Barkr *et al.*, 2012) and considering local conditions of the region, IWQI made classifications according to four classes; I (< 1.96), II (1.96–5.88), III (5.88–9.80), and IV (>9.80) to determine quality characteristics of irrigation water.

For the spatial relations analysis in this region, the geographically weighted regression (GWR) approach applied to explore the relationship between variables over space. The GWR technique extends the conventional global regression by generating a local regression equation for each observation, and the model can be stated as Equation 4 (Fotheringham *et al.*, 2002).

$$\boxed{y_j = \beta_0(u_j, v_j) + \sum_{i=1}^{P} \beta_i(u_j, v_j)x_{ij} + \varepsilon_j} \qquad (4)$$

where u_j and v_j denotes the coordinate location of the j^{th} point, $\beta_0(u_j, v_j)$ is the intercept for location j, $\beta_i(u_j, v_j)$ represents the local parameter estimate for independent variable x_i at location (the subscripts j and i stand for the spatial locations and the independent variable number, respectively). More detailed about GWR can be found in Fotheringham *et al.*, (2002) and other papers in different environmental researches (e.g. Tu & Xia 2008; Terron *et al.*, 2011; Sholf *et al.*, 2011; Brown *et al.*, 2012).

Results and discussion

Analysis of IWQI status

Groundwater quality for agricultural purposes in the region was associated with various parameters that influence chemical properties of the water. Table 1 shows that although ions with low variability such as Ca, were determined in all three of the time periods, mean values and CV of ions with higher amounts were found for Cl, Na, and SO_4. This variability of determinations of ions concentrations partially occurred for all ions over space each year. Whereby, value distributions of groundwater chemical parameters were strongly heterogeneous and centralized in specific areas of the study region. Relatively low concentrations of chemical compositions, ECw and SAR were found in samples in the north and the northwest of the study area in 2013. Moreover, higher concentrations of ECw and ions were found in wells in the surrounding marginal farmland at junctions of land use type such as meadowland and agricultural areas in central places in all three years included in the study; 1987, 2000, and 2013.

Table 1. Mean value, standard deviation (SD) and coefficient of variation (CV) for the chemical characteristics of water quality in the three years of 1987, 2000, and 2013.

Year	Index	N.S	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	SAR
			dS m^{-1}	mmol L^{-1}							$(mmol\ L^{-1})^{0.5}$
1987	Mean	28	842.26	3.20	2.55	2.47	0.02	3.13	4.17	0.63	1.27
	Max		3203.43	4.13	5.43	22.11	0.03	30.12	4.78	1.93	7.23
	Min		241.17	0.63	0.01	0.06	0.008	0.03	2.23	0.05	0.01
	SD		918.54	1.34	2.03	5.81	0.01	7.08	1.19	0.64	2.13
	C.V%		101.73	47.00	66.26	171.32	49.00	179.41	18.01	91.19	147.10
2000	Mean	33	930.04	3.26	2.26	3.83	0.02	4.47	4.63	0.74	2.10
	Max		3840.27	7.00	8.50	25.01	0.04	32.88	5.51	2.10	8.22
	Min		287.24	1.70	0.71	0.11	0.01	0.11	2.91	0.10	0.07
	SD		947.01	1.56	1.50	6.57	0.01	8.02	0.75	0.52	3.09
	C.V%		109.00	47.81	79.50	212.00	50.02	226.00	25.72	100.50	167.00
2013	Mean	41	1027.21	3.41	2.73	4.02	0.05	4.93	4.97	0.71	2.02
	Max		4819.68	9.84	11.76	26.80	0.05	33.41	9.24	3.32	10.58
	Min		349.80	2.16	1.19	0.40	0.01	0.19	3.20	0.18	0.11
	SD		1103.56	1.72	2.22	8.65	0.08	9.07	2.09	0.78	3.31
	C.V%		104.41	50.43	81.31	215.17	160.00	183.97	42.05	109.85	163.80

According to generated IWQI map in Fig. 6a, continuous values of water quality index for irrigated farmland ranging from 0.07 to 3.50 in 1987. Hence, for 1987, approximately 78% and 22% of the whole area determined IWQI value of less than 1.96 and higher than 1.96, results which were classified as I (excellent) and II (good), respectively (Fig. 7a). Similarly, water quality statues identified majority favorable and partly classified by approximately 165 ha (about 1%) in IWQI III (average quality) for 2000 (Fig. 7b & Fig. 6b). For 2013, the region faced a considerable loss of water quality by 7% (1154 ha) IWQI III (Fig. 6c). Therefore, in comparison with the two past periods, excellent and good water quality was gradually lost over space (Fig. 6c). As a result, the main areas with lower groundwater quality were located in the central part of the region over the 26 past years.

In continuation, the current study intended to indicate spatially varying relationships between IWQI and geo-environmental variables in the study area using GWR. The region was relatively heterogeneous in terms of natural characteristics (Taghipour Javi *et al.*, 2014), so in order to perform local statistical analyses, a basic study map was created with homogenous units based on soil and geological properties (for use in spatial analysis in Figs 8&9). In this way the GWR approach was applied to variables that focused on spatially varying associations of IWQI and explanatory variables over space in the study area.

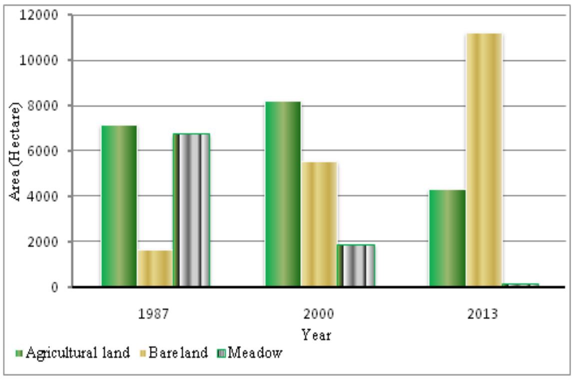

Fig. 5. Area changes for different land use/cover types.

Spatial varying relationships explored by GWR

Local regression results of the GWR approach, including local R^2 values and results of the t test on local parameter estimates were interpreted to understand spatial variations in relationships between IWQI and four geo-environmental variables in the study area. Results of the local R^2 for estimated parameters are presented for all variables in the two periods of 1987–2000 and 2000–2013 in Fig. 8. Fig. 8a shows that change in water level was variable and explained approximately 50% of spatial variation in IWQI in the northern areas in the first period. It also explained more than 75% of IWQI in those areas in the second period (Fig. 8b). However, higher R^2 values confirmed the model's ability to explain more variance in the dependent variable as a function of the explanatory variables (Brown *et al.*, 2012). According to Figs. 8c & d, the best fitted model with observational data for ECs parameter, was located in southern areas of the region, and the highest local R^2 was calculated at about 0.7 in the south and southeast of the study area in 2000-2013.Similarly, the highest local R^2 values for both the above-mentioned variables were found in the northeast and southeastern parts of the study area in both periods. In contrast, lower local R^2 values were determined mainly in the west, the northern areas and partially in the southeastern parts of the region. In total, local R^2 results in 2000–2013 determined a better fit than results for the first period.

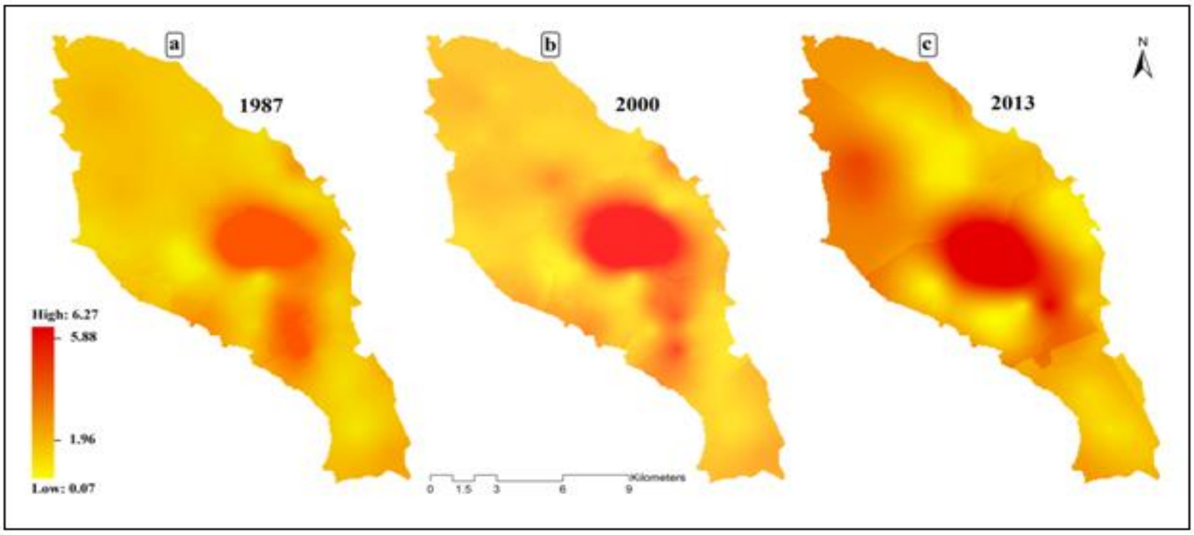

Fig. 6. IWQI mapping in the Khanmirza plain for different years; a) 1987, b) 2000, and c) 2013.

Although different amounts were not identified for the local R^2 in terms of the aquifer thickness variable in the two studied periods, there was non-stationary spatial distribution between IWQI and aquifer thickness in the region (Figs. 8e, &f). Local R^2 values for land cover change in relation to irrigation water quality are shown in Figs. 8g & h. Higher local R^2 values were found in vast areas of central parts of the region in the first period (Fig. 8g). In contrast, the best fit of the model was located just in the northwestern part of the plain in 2000–2013 (Fig. 8h). These results show that local R^2 values for all variables were not consistent in the research performed in different places over periods owing to inconsistent geo-environmental characteristics of the study area over space.

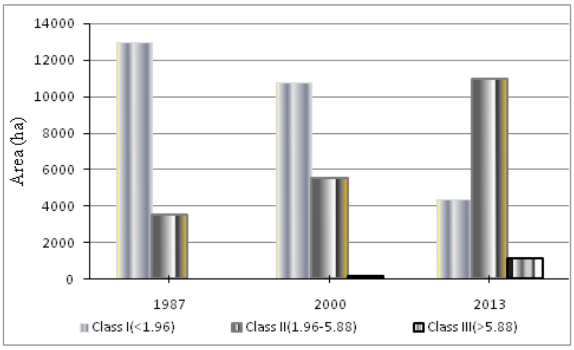

Fig. 7. Classes of irrigation groundwater quality for the Khanmirza agricultural plain in the three periods.

All three types of significance negative, positive, and non-significant in the relationships between IWQI amounts and water table changes variables were observed in the study area using the *t* test in the two periods (Figs. 9). As shown by the *t* value map in Fig. 9a, the most significant relationship for the water table variable was located in central parts of the plain in 1987–2000. In addition, there was a positive significant relationship among them in most of the central places during the period 2000 to 2013 (Fig. 9b). This result determines a positive spatial variation of the IWQI with high values associated with a considerable change of water level. Hence, spatial patterns of relationships in groundwater depletion can be explained by natural recharge of saline water that penetrates to fresh groundwater and passes from east to west of the region. Although this study only applied data from 1987 to 2013, it can be assumed that significant IWQI and water depletion had not occurred before 1987 owing to a considerable decline level of the water table.

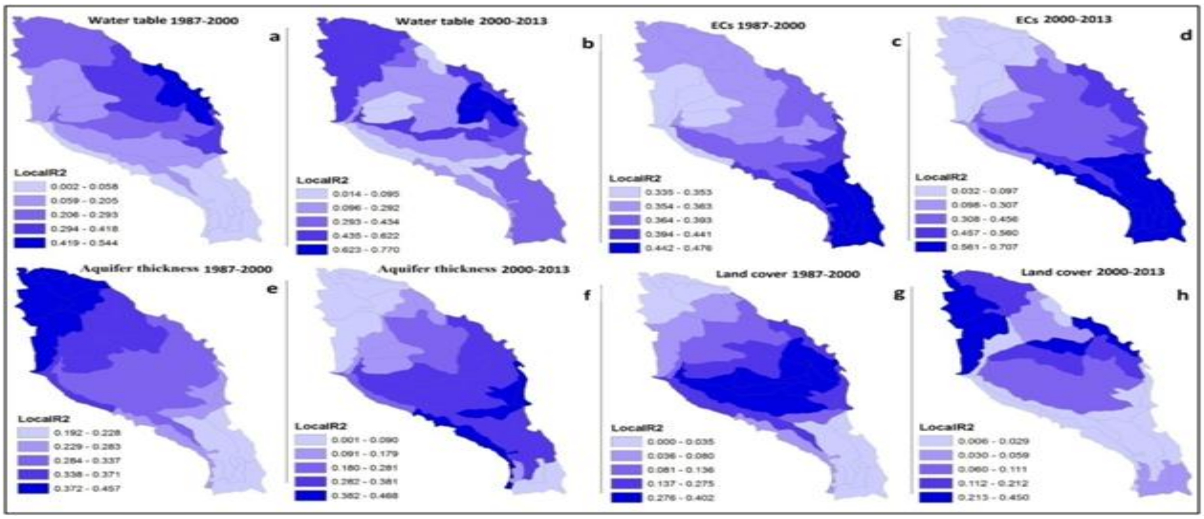

Fig. 8. Local R^2 values of geo-environmental variables from the GWR model.

It is well known that groundwater quality is closely connected to thickness and properties of an aquifer (Ghayoumian *et al.*, 2007; Lerner *et al.*, 2009). Also, in this region, groundwater quality is a naturally highly variable and mostly dependent on the properties of an aquifer. Results of the *t* test, shown in Figs. 9e determine a positive, significant relationship ($p \leq 0.05$) for the variable of aquifer thickness, mainly found in the central district of the region. Similarly, strong correlations with levels of significance 95% and 99%were determined for the second period (Fig. 9f). These results indicate that aquifer thickness as an important geological factor that had a considerable effect on groundwater quality in the Khanmirza agricultural plain.

In the first study period, positive significant relationships are found between IWQI and ECs in the eastern part toward the western part of the region

(Fig. 9c). In contrast, similar relationships (mainly significance at $p \leq 0.05$ and $p \leq 0.01$) were determined in the aforementioned variable in the second period (Fig. 9d). Hence, EC evaluations serve as an indication of the source of salinity especially in areas with high concentrations of salinity, the salt particulates determined for the soil surface had penetrated the underground water resource by rain and irrigation of agricultural land.

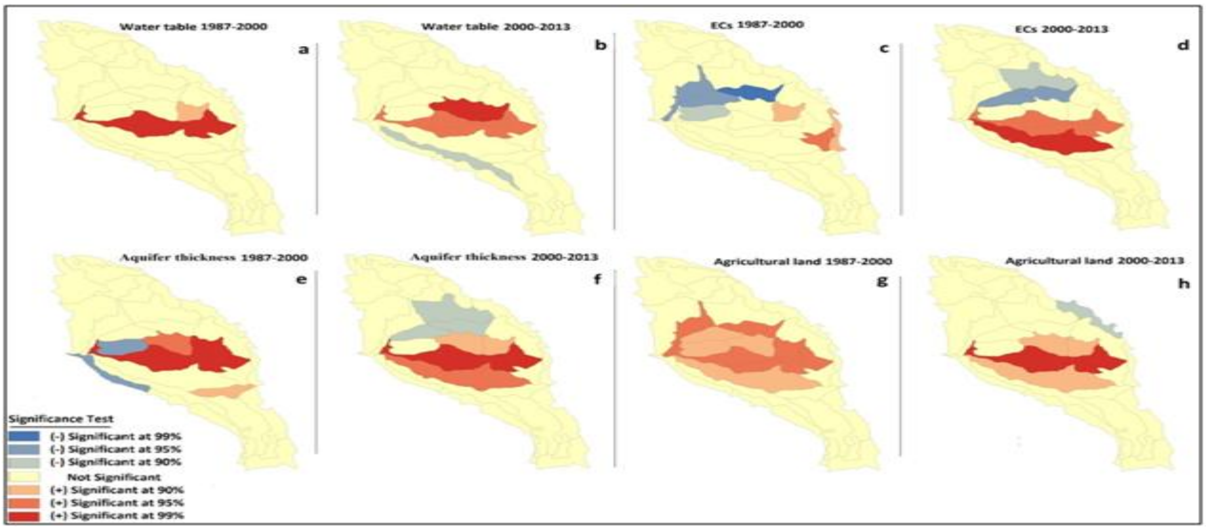

Fig. 9. Results of *t* test on the parameter estimates for geo-environmental variables from the GWR approach.

Groundwater quality is also closely related to type of land cover and infiltration rate that is directly proportional to land cover density (Scanlon *et al.*, 2005; Lerner *et al.*, 2009). According to Fig. 9g results showed positive significance at the range of 90% to 95% for the vast parts of the plain in 1987–2000. However, high demand in water use for irrigation caused a drop in the water table and reduced groundwater quality. Accordingly, results for the second period under evaluation were similar to those of the first period (Fig. 9h). As a result, spatiotemporal relationships between IWQI in relation to change in land cover revealed by GWR in the study area.

Results of the *t* test showed that relationships between IWQI and the four geo-environmental variables were not consistent throughout the different areas. The natural and anthropogenic characteristics of the region determined that agricultural activities and water and land resources management are not always constant over space in the Khanmirza agricultural plain. Moreover, *t* values determined for local parameter estimates for the entire geo-environment layers showed that not all relationships in the study area were significant. However, both positive and negative relationships were determined between quality of irrigation groundwater and all studied geo-environmental variables that were mainly centralized in the central part of the study area.

Conclusions

Spatial and temporal relationships affecting quality of irrigation water quality for agricultural water resources monitoring demands consideration of complex geo-environmental layers. In the current study, statistical and spatial analyses were employed to examine spatially varying relationships between irrigation water quality index (IWQI) and geo-environmental layers to determine information on a local scale in the Khanmirza agricultural plain for 1987–2013. Application of chemical parameters such as Na, Ca, Mg, K, Cl, HCO_3, SO_4, CO_3, pH, EC, and SAR were applied to calculate IWQI as a dependent variable. In this region, IWQI evaluations were significantly associated with the following four variables; geo-environment, including land cover change; change in water level, aquifer thickness and evaluations of soil electrical conductivity (EC). The maps generated to show local parameter estimates, demonstrated that local R^2determined by the GWR approach, allowed visualization of spatial varying relationships between IWQI and geo-environmental layers.

Results of this study reveal that local R^2 values for both water table and ECs variables had higher spatial variability among variables for the period of 2000–2013 than for the period 1987–2000. Also, all relationships were determined as positively significant, whereby a high value of IWQI was closely related to a high value for each geo-environmental layer in the two periods; likewise, higher significance was determined in central parts of the region for evaluations of reduced groundwater level, considerable change in land cover, high concentration of EC, and high depth in aquifer thickness. Nevertheless, significance level and areas with high relationships were more apparent in the second period. In those parts that relationships were determined as non-significant, there was no considerable fluctuation in terms of amounts of variables. Therefore, all results for distribution of R^2 values confirmed the assertion that there is a spatially varying relationship between IWQI and geo-environmental variables within the region.

Finally, the GWR approach determined that various spatial patterns and spatial non-stationary relationships between IWQI and different geo-environmental data in the Khanmirza agricultural plain over the past 26 years. Maps generated for the study identified local variation, which can be applied to inform managers of the key role of irrigation water quality related to different geo-environment variables in many parts of the study area. Also, these results obtained by the present study can be applied to groundwater management scenarios for planning possible future changes at a local scale, essential for appropriate action toward development of sustainable water resources.

Acknowledgments

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