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Modifying the analysis made by water quality index using multi-criteria decision making methods

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A B S T R A C T

Groundwater should be considered as the most important drinking water resource in arid/semi-arid regions such as Karaj, Iran. Provision of drinking water with a preeminent quality is, accordingly, a real matter of concern in these regions. Despite being an essential factor for rating of under exploitation water wells, Water Quality Index (WQI) entails conflicting issues. As a result, Multiple-criteria decision making (MCDM) models, such as Technique for order preference by similarity to ideal solution (TOPSIS), Compromise Programing (CP) and Ordered Weighted Averaging (OWA) operators were adopted to alleviate contradictions involving WQI index. In the current paper, compromise programming was utilized assuming $p = 1\&2$ and the average value of ranks attained from all the above MCDMs (Averaged value rating) was correspondingly cited as a rating reference. Putting the above MCDM models into practice, ultimately, led to striking variations not only in the rankings but in category of water wells. It was clarified that compromise programming when p values are assumed to be 1 and 2 (CP ($p = 1$) & CP ($p = 2$)), TOPSIS and OWA could be recognized as proper techniques to eliminate contradictions involving ranking by WQI index.

1. Introduction

Groundwater is among the vital water resources on the earth planet, being exploited for fundamental uses such as drinking, agriculture and industry (Wu and Sun, 2016; Li et al., 2016; Chitsaz and Azarnivand, 2016; Jamshidzadeh and Mirbagheri, 2011). Rainfall penetration through the soil and stones on the ground surface is the most important source of groundwater provision. This water resource accompanied by water penetration of rivers/lakes as well as artificial recharge of groundwater and reused waste waters are the major sources for augmentation of groundwater resources (Adetunde et al., 2011). In general, population growth and the expansion of urbanization as the chief cause of agriculture and industry evolution gave rise to instability of aquifers (Krishan et al., 2016).

Moreover, the exponential rise of population and over exploitation of groundwater resources has ended in quality degradation of groundwater (Pophare et al., 2014). In particular, just like the quantity, quality of groundwater should be taken into a serious consideration (Aghazadeh and Asghari-Moghadam, 2010). Considering this fact that, artificial recharge, environmental rainfall, ground water penetration and groundwater geo-chemical reactions might influence the quality of groundwater (Vasanthavigar et al., 2010), its pollution would threaten human's health, economic development and social welfare (Milovanovic, 2007). Several factors and methods have so far, been innovated to present water quality parameters. Among all, Water Quality Index (WQI) is appreciated as a prominent factor for classification and quality management of groundwater (Hosseini-Moghari et al., 2015).

In order to evaluate the quality of drinking water in Sabalan aquifer —as a volcanic region- Mosaferi and his colleagues (Mosaferi et al., 2015) put WQI into practice using 7 qualitative parameters. In addition, Sadat-Noori et al. (2013) performed zoning of adequate regions for drinking exploitations in Saveh-Arak plane. While having a positive effect on the qualitative assessment of groundwater resources, WQI is expected to entail drawbacks. Lermontov et al. (2009) stated that classifications which are adopted from this index would generate inflexible and definite

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results. Moreover, Dahiya et al. (2007) explained that this analysis, in some cases, presents unreliable consequences. For instance, based on the analysis made by WQI, the quality of water has been reported to be adequate for drinking purposes, while assessed to be inadequate for agriculture using Wilcox diagram. Such an assumption should be considered a genuine contradiction as sensitivities to drinking water is remarkably higher compared to the water used in agriculture. In line with the above elucidation, Multi-criteria decision making methods were recommended in order to avoid conflicts in the qualitative classification of samples. In particular, when the value of the qualitative parameter (Mg/L) is higher than the standard limit and besides that other factors are located in an appropriate range (Mg/L), the effect of a factor with a higher value than the standard limit (Mg/L) on the water quality index is decreased in case that parameters are assigned with weight factors. On the account of using these methods, the effects given rise by all the parameters related to each well as well as the effect of WQI index on the drinking water quality can be assessed through normalization.

MCDMs are extremely under the focus of researchers working on classification of surface/Subsurface water and groundwater resources as well as water quality assessment (Azarnivand et al., 2017; Li et al., 2012). The basis of MCDMs such as TOPSIS entails three fundamental principles: 1- variables 2- alternatives and 3- the effect of each alternative on each variable (Madani and Lund, 2011). In the current investigation, discussion on efficiency of the WQI index was conducted using Multi-criteria decision making with three different approaches, namely, TOPSIS, Compromise programing and OWA. These methods have been reported to present relatively precise analysis on solving conflicts of agricultural lands (Shiau and Chou. 2016), (Chitsaz and Banihabib, 2015), scheduling of watershed areas (Azarnivand and Banihabib, 2016), preservation of coastal areas (Pourebrahim and Mokhtar, 2016), water reservoir exploitation (Bozorg-Haddad et al., 2016), flood risk decrement, water resources reservation (Shiau and Lee, 2005), water allocation (Dogra et al., 2014), and groundwater quality classification (Zahedi et al., 2017). Zahedi (2017), on the other hand, asserted that CP and OWA would be effective in water quality ranking of shared extraction wells and could be applied to decrease contradictions between domestic and agriculture sectors. Flexibility of this technique in water quality monitoring was confirmed by a combined application of TOPSIS method and entropy weight along with utilizing rough set theory (Li et al., 2011; 2013b). Moreover, another research by Li et al. (2013a, 2013c) revealed that using TOPSIS could result in a reliable analysis for sensitivity of different physiochemical parameters' weights.

In summary, one may mention that the aim of the present research is firstly to present a realistic overview on degree of reliability of the analysis made by WQI method and is secondly to eliminate probable contractions involved in calculations of WQI using MCDM models.

2. Materials and methods

2.1. Study area

Karaj Plain is a part of former/present Tehran and Alborz provinces. This territory is extended on an area of 507.94 square meters, nestled between longitudes of 50° 45‘ to 51° 70‘ east and latitude of 35° 39‘ to 35° 55‘ north. This territory is confined by the following regions: from north and east by the Karaj regional aquifer and southern formation of Alborz mountains, from west by Hashtgerd and Eshtehard plains and formative portion of west of the study area which is a part of Alborz mountains, from south by Shahryar, Robat-Karim and Tehran plains and North Saveh heights (Fig. 1). The mean altitude of the study area is about 1015–1385 m above mean sea level (AMSL). The total amount of annual precipitation is equal to 205 mm.

Alborz Regional Water Authority (ARWA) is the responsible organization to monitor wells which are specified for water quality assessment. For this purpose, 29 monitoring wells were periodically put into quality assessment tests -as the reference sample- and the evaluations were implemented every six months from 1998 to 2014. Moreover, the quality of water in observation wells were monthly monitored for evaluation of groundwater table and aquifer loss. In order to analyze groundwater quality of the aquifer, the samples were transferred to central laboratory of ARWA. The available parameters included T.H, S.A.R, K, Na, Mg, Ca, HCO_3, Cl, SO_4, pH, T.D.S, E.C, and NO_3 (Table 1). Locations and layout of the above-mentioned 29 quality monitoring wells as well as 190 Drinking water wells can be found in Fig. 1. In addition, soil classification and land-use maps of the case study are depicted in Fig. 2.

2.2. Water quality index

WQI was initially innovated by Brown et al. (1970). It was subsequently modified by Beckman et al. (1998). This index should be considered as an impressive parameter for evaluating drinking water quality. This index can also make major contributions to ground water quality assessment. Referring to the scientific reports released by the “World Health Organization (WHO)" in 2004, WQI is a rating method, by using which composite effect of each parameter as well as that of all qualitative parameters on drinking water can be clarified (See Table 2). Each qualitative parameter's weight, in this method, is determined based on the recommended standards and is correlated to other parameters. In particular, calculations of WQI entail three following steps:

1. Considering the effect of a parameter, relative weight of each (out of 10) qualitative parameters -present in the qualitative analysis-should be determined.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

2. The quality rating of each parameter, as shown in Eq. (2), can be obtained through dividing the concentration of each parameter (C_i) by their standard WHO values (S_i).

Each parameter has been weighed based on its effects on human health. This information has been primarily published by WHO (2004) and was later applied by Goher et al. (2014).

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

where C_i is the concentration of each parameter ($^{mg}/_{L}$) and S_i is their standard WHO values.

3. Sub-quality index of each parameter should be calculated by multiplication of their specific relative weights to their quality rating scale, as referred in Eq. (3).

$$SI_i = q_i \times W_i \tag{3}$$

where W_i is the relative weight of a parameter, q_i is the quality rating obtained from equation (1), and SI_i is the value of sub-quality index related to each parameter.

Finally, the water quality index of each sample can be computed

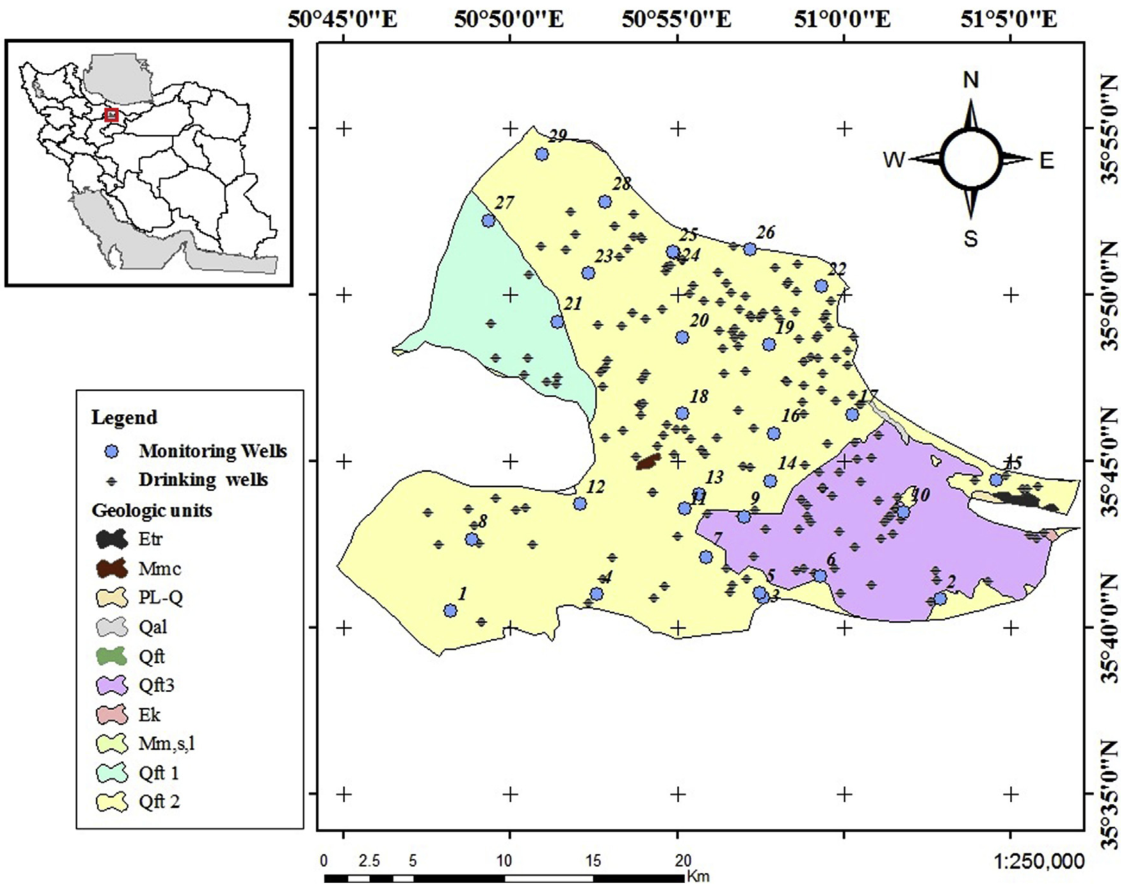

Fig. 1. Position of Karaj Plain, Geological map of the case study and Layout of water quality monitoring wells and drinking water wells in Karaj study area.

Table 1
The location and the averaged amount of each chemical parameter among years 1998–2014.

Wells' codes	UTM (X)	UTM (Y)	$[K^+]$[a]	$[Na^+]$[a]	$[Mg^+]$[a]	$[Ca^+]$[a]	$[HCO_3^-]$[a]	$[Cl^-]$[a]	$[SO_4^-]$[a]	[pH]	[T.D.S][a]	$[NO_3^-]$[a]	[S.A.R][b]	[E.C][c] (µs/m)	Cations (meq/L)	Anions (meq/L)	[T.H][a,d]
num 1	482205	3947933	4.6	291.7	188.6	395.7	400.1	486.6	962.1	7.6	1822.9	66.7	4.3	2969.2	30.4	30.9	881.6
num 2	504396	3948564	1.3	16.8	25.5	101.8	113	21.1	185.4	8	272.4	9.3	0.5	441.8	4.4	4.5	179.4
num 3	496383	3948657	2.2	74.3	20.4	98.2	128.4	59.4	223.8	7.7	373.5	49.6	2.5	645	6.6	6.9	164.5
num 4	488800	3948813	2	61.9	50.9	159.3	254.8	54.4	291.4	7.9	518.4	39.3	1.5	865.5	8.8	9.1	303.4
num 5	496200	3948900	1.3	49.8	19.5	85.6	127.8	51.8	124.2	7.9	322.6	38.8	1.8	530.1	5.1	5.2	146.8
num 6	498935	3949820	1.9	26.8	50.6	187.3	129.9	108.9	205.8	7.9	497.3	64.8	0.6	808.7	8	8	337.8
num 7	493760	3950900	1.2	22.6	27.6	102.4	182.5	21.5	100.6	7.9	259	13	0.7	454.7	4.7	4.9	184.5
num 8	483162	3951911	3	146.5	43.8	119.7	184.7	187.3	302.2	8	692.4	6.8	4.2	1163.9	11.2	11.6	239.3
num 9	495493	3953142	0.5	12.8	31.7	159.7	111.4	68.6	178.4	7.9	382.6	59.9	0.3	605.1	5.9	6	264.4
num 10	502739	3953390	1	15	26	96.4	124.4	30.2	117.3	8	244.1	9.5	0.5	413.3	4.2	4.2	173.7
num 11	492800	3953600	0.6	19.8	24.6	96	165.3	16	107.5	7.9	248.8	18.6	0.7	417.6	4.3	4.4	170.2
num 12	488050	3953850	2.2	116.4	70.7	215.7	212.6	158.1	510.3	7.9	850.3	53.2	2.5	1338.7	13.4	13.7	414.6
num 13	493431	3954370	0.9	18.8	23.9	95.6	146	21.1	107.4	8.1	248.2	15.9	0.6	411.1	4.2	4.3	168.5
num 14	496700	3955125	0.9	11.9	18.8	91.7	131.5	17	90.5	8	193.3	7.4	0.4	343.2	3.6	3.7	153
num 15	506939	3955147	1.2	22.5	40.7	171.8	166.6	71.6	191.6	7.7	414.1	24.8	0.6	684.3	7	7	298.1
num 16	496860	3957780	0.5	10.5	17	103.2	121.5	26.6	91.3	7.9	223.1	12.4	0.4	369.4	3.7	3.7	163.7
num 17	500385	3958840	0.7	13.9	33.8	163.5	189.1	36.1	178	8	352.3	24.8	0.4	594.8	6.1	6	273.4
num 18	492721	3958867	1.5	34.2	45.8	107.5	177.7	34	206.9	8	352.9	31.8	1	599	6.1	6.3	228.4
num 19	496630	3962680	1.4	43.7	49.4	120.7	192.5	60.6	157	7.9	405.8	47	1.2	688.9	7	6.9	252.1
num 20	492730	3963100	0.8	49.8	61.3	106.9	226.5	49.4	218.1	7.9	455	35.4	1.4	767.5	7.4	7.7	259.4
num 21	487058	3963996	0.4	51.4	43.8	79.4	186.2	26.7	192	8.2	363.5	26.4	1.6	597.9	6	6.1	189
num 22	499004	3965909	0.4	170.3	25.1	51.8	292.6	94.7	201.8	8.2	576.6	37.2	7	972.9	9.7	10.1	116.2
num 23	488459	3966665	0.4	73.8	43.4	90.3	171.4	49	287.2	8	467.5	18.6	2.3	748.5	7.3	7.3	201.9
num 24	492350	3967770	0.8	348.9	16.4	26.1	533.5	122.7	411.2	8.3	995.5	25.6	19.7	1643	16.5	17.1	66.4
num 25	492290	3967860	1	239	29	87.3	201.5	142.4	622.3	8.1	892.3	25.6	8.1	1418	13.8	14.1	168.6
num 26	495777	3967965	0.7	128.3	33.1	109.7	215.3	89.3	354.3	8	611.2	35.1	4	992.9	9.7	10	204.8
num 27	483947	3969615	0.8	23.3	32.6	82.9	183.7	13.6	92.2	8.1	251.1	10.9	0.8	421.7	4.4	4.5	170.4
num 28	489237	3970666	0.9	177.2	32.6	79.1	261.5	76.7	427.7	8.2	694.3	44.9	6	1153.4	11	11.1	165.6
num 29	486380	3973305	2.1	240.9	82.1	219.9	265.5	172.8	953.6	7.8	1283.4	18.6	5	1987.4	19.4	19.2	443.2

[a] Unit of the chemical parameter is (mg/L).
[b] Sodium Adsorption Ratio.
[c] Electrical Conductivity.
[d] Total Hardness.

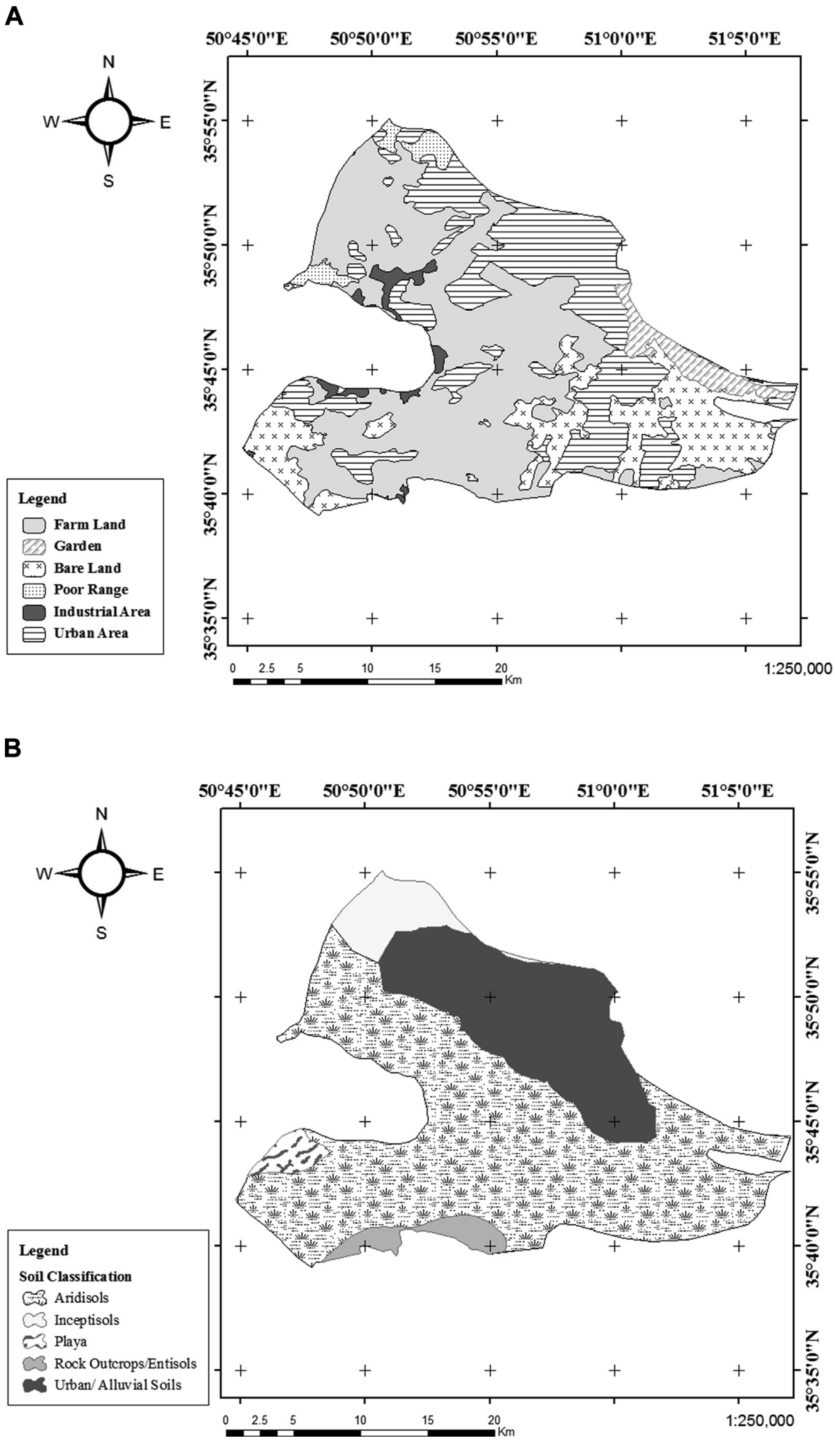

Fig. 2. Soil classification map (a) and Land-use map of the study-area (b).

Table 2
The weight (w_i) and relative weight (W_i) of each chemical parameter reported by the World Health Organization (WHO), (WHO, 2004).

Parameter	WHO Standards (mg/L)	Weights (w_i)	Relative weights (W_i)
$[K^+]$[a]	12	2	0.056
$[Na^+]$[b]	200	4	0.111
$[Mg^+]$[c]	50	3	0.083
$[Ca^+]$[d]	75	3	0.083
$[HCO_3^-]$[e]	120	1	0.028
$[Cl^-]$[f]	250	5	0.139
$[SO_4^-]$[g]	250	5	0.139
[pH][h]	8.5	3	0.083
[T.D.S][i]	500	5	0.139
$[NO_3^-]$[j]	11	5	0.139
		$\sum w_i = 36$	$\sum W_i = 1$

[a] Potassium.
[b] Sodium.
[c] Magnesium.
[d] Calcium.
[e] Bicarbonate.
[f] Chlorine.
[g] Sulfate.
[h] Potential of Hydrogen.
[i] Total Dissolved Solids.
[j] Nitrate.

by summing all sub-indices, as defined in Eq. (4).

$$WQI = \sum SI_i \tag{4}$$

Regarding the value of WQI, the groundwater can be classified into the five categories of excellent, good, poor, very poor, and unsuitable for human consumption (See Table 3).

2.3. Multi criteria decision making method

Multi-criteria decision making methods generally constitute of two branches: 1- Multi-criteria optimization and 2- analysis of Multi-criteria decision. While a multi-criteria decision concentrates on multi-criteria tasks with a few numbers of options and it is mainly made under unreliable situations, the so-called optimization covers the problems that can be solvable through a mathematical soft-ware structure, entailing more than one objective (Odu and Charles-Owaba, 2013). As a matter of the fact, the focus on the current scientific topic has commenced at 1960s and it is still contributing to generating relative knowledge. In particular, several theories and algorithms reported in research papers as well as handbooks have been presented based on these criteria. What should be taken into account in this concern is that the comparison between potential actions must be general and pervasive such that considers all criteria. As a result, several methods have been proposed to realize the above purpose.

Three basic elements involving criteria, alternatives and performances of each alternative under each criterion constitute the structure of a MCDM problem (Madani and Lund, 2011). Three techniques of TOPSIS, CP and OWA were used in this study considering the following assumptions:

TOPSIS: Assuming a decision matrix involving m wells and n chemical parameters with the intersection of each well and chemical given as V_{ij}, one can evaluate the rank of each well via TOPSIS through the following formula in maximizing the C_j^* (Hwang and Yoon, 1981):

$$C_j^* = \frac{\sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2}}{\sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^*\right)^2} + \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2}} \tag{5}$$

where V_j^*, V_j^-, and C_j^* are weighted ideal and negative-ideal solution, and similarity ratio, respectively.

CP: Second prioritization method in this paper is CP which evaluates the wells' ranks using formula (6). Among the wells, the best one has the least distance from the ideal point (Zeleny, 1973).

$$L_p(Well_i) = \left[\sum_{j=1}^{n}\left(\frac{W_j}{\sum_{j=1}^{n} W_j} \times \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right)^p\right]^{1/p} \tag{6}$$

where $L_p(Well_i)$ represents the distance of the well to the ideal solution. f_j^* and f_j^- are ideal and negative-ideal solutions, respectively. The measurement of the distance is based upon the p parameter, where Zeleny (1973) suggested 1, 2 for p. For an easier citation in the text, compromise programming methods with different p values of 1 and 2 are coded by CP (p = 1) and CP (p = 2), respectively.

OWA: The final prioritization method used in the current paper is OWA which evaluates the wells' ranks using Eq (7) to Eq (9). Among the wells, the best one has the least distance from the ideal point (Yager, 1988; Yari and Chaji, 2012).

$$Max\ H(w) = -\sum_{j=1}^{n} w_j \ln(w_j) \tag{7}$$

$$\alpha = -\sum_{j=1}^{n} \frac{n-i}{n-1} w_j \qquad 0 \le \alpha \le 1 \tag{8}$$

$$F(well_j) = \sum_{j=1}^{n} w_j\, b_j \quad j \in \{1, 2, 3, \ldots, n\} \tag{9}$$

where w_j represents associated weights according to which $\sum_{j=1}^{n} w_j = 1$ & $w_j \in [0, 1]$, α is the optimism degree which is equal to 0.614 in this research and bj is the ith largest normalized weight of each chemical parameter.

Zahedi (2017) put MCDM techniques for WQI ranking into practice for analyzing Varamin Plain and developed a new method in water quality ranking based on WQI and MCDM techniques. The major difference in the current study on Karaj plain is that contribution of WQI classes has been omitted in calculation of MCDMs. The underlying reason behind this action was related to the low number of monitoring wells and absence of appropriate number of monitoring wells for each WQI class in Karaj Plain compared to Varamin Plain. Another prominent reason was analysis of changes in ranks without considering class boundaries. Details of Modified version of WQI Classification by Zahedi et al. (2017) can be found in the supplementary material. Moreover, use of OWA method instead of CP (p = ∞), in the current study, is another factor having distinguished this work from the previous one (Zahedi et al., 2017). Results of this study, on the other hand, validated effectiveness of the method developed by Zahedi et al. (2017) in water quality ranking of drinking water wells. A precise analysis can be presented

Table 3
WQI classification.

Range	Type of Groundwater
<50	Excellent water
50–99.99	Good water
100–199.99	Poor Water
200–299.99	Very poor water
≥300	Unsuitable for drinking/Irrigation purpose

by this method when the case studies possess a low number of monitoring items for prioritizing of drinking water exploitation.

3. Results and discussion

3.1. -Results of qualitative analysis conducted on wells in Karaj study area

These results have been attained based on the averaged value of the whole data related to each well, presented through an identity matrix.

Table 4 presents an initial perspective from water quality of the case study using Pearson coefficient of correlation (r). The purpose is to achieve accurate information about ground water quality of the region by determining few experimental parameters. As can be observed, the correlation factor between anions and cations exceeds 0.99, according to which validation of the qualitative analysis can be confirmed.

3.2. -Results obtained by a combined use of WQI and multi-criteria decision making methods

In the current research, qualitative situation of drinking water in the Karaj study area was evaluated using water quality index (WQI).

Table 4
Correlation of qualitative parameters in Karaj Plain.

Materials	[T.H]	[pH]	[T.D.S]	[S.A.R]	[E.C]	Cations	[K^+]	[Na^+]	[Mg^+]	[Ca^+]	Anions	[$HCO3^-$]	[Cl^-]	[$SO4^-$]	[$NO3^-$]
[T.H]	1														
[pH]	−0.664	1													
[T.D.S]	0.729	−0.222	1												
[S.A.R]	−0.117	0.476	0.552	1											
[E.C]	0.727	−0.218	0.999	0.561	1										
Cations	0.741	−0.231	0.997	0.552	0.999	1									
[K^+]	0.793	−0.609	0.679	0.047	0.688	0.699	1								
[Na^+]	0.315	0.161	0.875	0.866	0.879	0.871	0.404	1							
[Mg^+]	0.965	−0.542	0.786	0.001	0.788	0.801	0.775	0.425	1						
[Ca^+]	0.979	−0.727	0.65	−0.204	0.645	0.658	0.769	0.213	0.892	1					
Anions	0.733	−0.226	0.996	0.562	0.999	0.999	0.698	0.876	0.796	0.649	1				
[$HCO3^-$]	0.285	0.215	0.727	0.833	0.742	0.747	0.282	0.848	0.416	0.169	0.754	1			
[Cl^-]	0.833	−0.389	0.925	0.349	0.931	0.937	0.817	0.714	0.863	0.77	0.938	0.565	1		
[$SO4^-$]	0.695	−0.247	0.953	0.45	0.942	0.934	0.616	0.812	0.732	0.633	0.93	0.583	0.826	1	
[$NO3^-$]	0.532	−0.487	0.354	−0.013	0.356	0.367	0.411	0.129	0.484	0.544	0.371	0.145	0.456	0.257	1

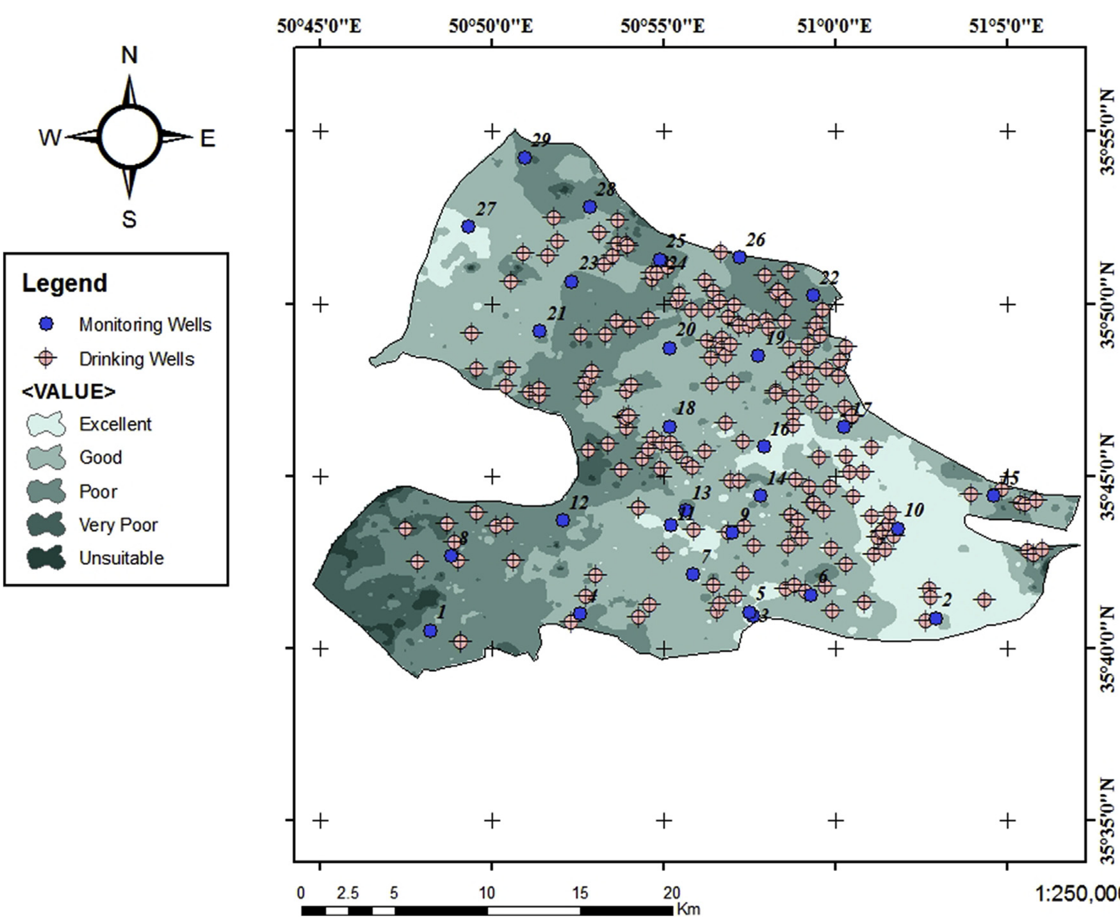

Fig. 3. Evaluating situation of drinking water wells (in Karaj plain) using WQI kriging interpolation.

In addition, three MCDM methods of TOPSIS, compromise programming and ordered weighted averaging operators were employed to eliminate the existing conflicts within the general WQI method. The process of obtaining WQI index besides categorizing it along with utilizing TOPSIS, compromise programming and ordered weighted averaging methods have been described in details through the “Introduction” of the current paper.

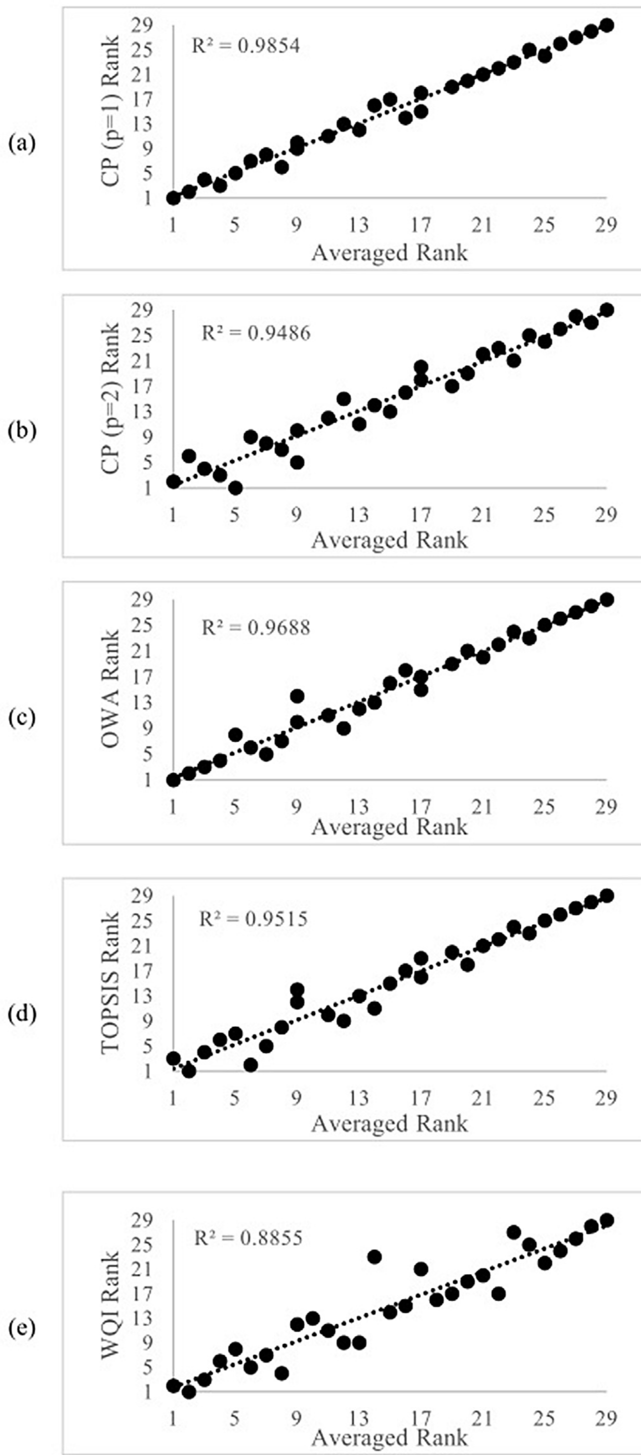

Fig. 4. Coefficient of determination for CP (p = 1) (a), CP (p = 2) (b), OWA (c), TOPSIS (d) and WQI (e) compared to averaged rank.

According to Fig. 3, one can realize that above 70% of area of the Karaj case study would be categorized in the classes of either excellent or good, considering WQI analysis.

Considering the above figure, one can specify that 5 wells from 190 drinking water wells are located at the excellent class concerning the water quality, 78 are settled in good class, 105 wells in poor and 2 well can be categorized in very poor class of WQI analysis. Moreover, it can be clarified that southeastern and northwestern regions of the study area enjoy drinking water resources with higher quality compared to those of central and southwestern regions. That can be attributed to the presence urban districts and existence of absorption wells in this part of the study area. Positions of the reference wells utilized for qualitative assessment in the study area are marked with black while one can find out that rating of the wells have only been conducted for these wells due to lack of quality assessment information. Details of GIS application and Kriging method have been presented in the “Supplementary” material. That can also be found in Goovaerts (1997), ESRI (1999).

As formerly discussed, using WQI method involve contradictions as a result of which the weight exponent assigned to each qualitative parameter decreases the effect of a parameter higher than the standard value on drinking water quality and manipulates the qualitative rating of wells. Consequently, three methods of decision making namely, TOPSIS, OWA and Compromise programming are proposed to make a comparison between their rating procedures and averaged rating using the following figures. What should be noted is that, averaged rating is the averaged value of each wells' rank conceived by averaging the values obtained from MCDMs (CP (p = 1), CP (p = 2), OWA and TOPSIS).

Considering Fig. 4, one can find that all the above-mentioned assumptions are in a good accordance with each other. It should be noted that use of the methods of CP (p = 1&2), OWA and TOSIS could end in reliable results for rating of wells after normalization of the achieved data. The positive attribute raised by normalizing each qualitative parameter in these three methods is to observe the effect of each single parameter besides their overall influence in rating of wells. Moreover, the above four methods (CP (p = 1), CP (p = 2), OWA and TOPSIS) are facilitated with a higher Coefficient of determination (R^2) compared to WQI, substantiating their high precision. The results relating the rating of the 29 qualitative wells using the four methods of CP (p = 1), CP (p = 2), OWA, TOPSIS and WQI are presented in Table 5.

Considering Table 5, one can find that results of WQI based rating of wells can be highly altered after employing MCDM models of OWA, TOPSIS and compromise programming (CP). Such transformations can be normally observed in the range of wells with closed WQI values. The influences such as the above are more highlighted when a sample with a lower value of WQI has a chemical parameter with extremely higher value compared to other specimens with near WQI ranks. Regarding the calculations of general WQI, despite applying sub-quality index of each parameter accompanied by its relative weight, the impact of each parameter in WQI ranking is not perceptible. However, using normalized value of each parameter in MCDM calculations could give rise to increase its impact in WQI ranking. For instance, the well number 6 in the table is placed in the category of poor based on WQI analysis with the rank of 22. It is confusing when we find out that well number 8 which is placed in the category of good by WQI and rank 23 has an inferior rank compared to the well number 6, considering the averaged rank obtained from MCDM methods. The major reason for such an observation may lie in the rank of this well when OWA and TOPSIS methods were applied. These methods, in particular, calculate the wells' rank based on the influence of each parameter in contamination of water. It can be observed that

Table 5
Rating of all quality monitoring wells based on the 5 methods of Compromise programming (p = 1, p = 2), OWA, TOPSIS and WQI.

Wells' codes	WQI		CP(p = 1)		CP(p = 2)		OWA		TOPSIS		Averaged rank
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	
num 14	43.967	1	0.976	2	0.406	6	0.020	2	0.998	1	2
num 16	51.560	2	0.847	1	0.255	2	0.020	1	0.997	3	1
num 10	51.882	3	1.130	7	0.378	9	0.022	3	0.997	4	3
num 27	53.004	4	1.278	4	0.468	4	0.023	6	0.997	2	6
num 2	56.127	5	1.260	8	0.415	8	0.024	7	0.995	8	8
num 7	57.150	6	1.163	3	0.233	3	0.024	8	0.996	7	5
num 13	59.469	7	1.288	5	0.463	1	0.022	5	0.996	5	7
num 11	62.323	8	1.106	6	0.272	7	0.022	4	0.996	6	4
num 21	85.405	9	1.938	10	0.804	10	0.028	9	0.984	9	12
num 23	86.489	10	1.929	13	0.598	15	0.030	12	0.972	13	13
num 17	87.890	11	1.841	11	0.601	12	0.029	11	0.983	10	11
num 5	91.972	12	1.725	16	0.582	14	0.029	10	0.974	12	9
num 15	93.103	13	1.717	12	0.390	11	0.032	14	0.969	14	9
num 8	94.906	14	3.036	14	1.216	16	0.052	24	0.813	24	23
num 18	95.361	15	2.158	9	0.721	5	0.032	13	0.976	11	14
num 20	107.651	16	2.196	18	0.631	18	0.035	16	0.962	15	15
num 22	112.282	17	2.844	17	1.363	13	0.040	20	0.910	21	21
num 3	115.264	18	2.087	15	0.827	20	0.037	18	0.943	17	16
num 19	117.043	19	2.396	21	0.888	22	0.036	17	0.952	16	17
num 26	121.437	20	2.655	20	0.871	19	0.039	19	0.910	20	19
num 4	124.362	21	2.798	19	0.941	17	0.041	21	0.939	18	20
num 9	131.815	22	2.153	23	1.166	21	0.035	15	0.933	19	17
num 24	134.697	23	4.511	22	3.541	23	0.064	27	0.711	27	27
num 25	138.450	24	3.531	25	1.687	25	0.055	25	0.726	25	25
num 6	152.653	25	2.946	27	1.532	28	0.045	22	0.882	22	22
num 28	155.000	26	3.538	24	1.836	24	0.046	23	0.864	23	24
num 12	180.881	27	4.118	26	1.906	26	0.057	26	0.722	26	26
num 29	185.025	28	4.852	28	2.854	27	0.076	28	0.486	28	28
num 1	321.845	29	8.515	29	8.158	29	0.128	29	0.004	29	29

the well number 8 holds a qualitative parameter with an extremely high value. This led to the rank of 24 for this well using OWA, while the well number 6 has gained the rank of 22 considering this method of assessment. Moreover, Well number 14 could keep the rank 1st only when the applied rating methods were TOPSIS and WQI. By using CP (p = 1&2) and OWA, however, rank of this well was obtained to be 2, 6 and 2 when the utilized rating methods were CP (p = 1), CP (p = 2) and OWA, respectively. The averaged value of MCDM ranks for well number 14 was attained to be 2.

Some critical examples of changes in ranks of wells considering their classes are also presented in Table 6. These rank variations are shown two by two to highlight the impacts of normalized values of each parameter in all samples. Thereby, employing MCDMs such as CP, OWA and TOPSIS concluded correct ranks with high accuracy in the calculation process of samples with closed WQI values.

4. Conclusion

Water Quality Index (WQI) is considered as one of the major factors for evaluating drinking water quality. In the Karaj study area, 29 monitoring wells were adopted as the reference samples and the assessment was performed using Kriging interpolation. Results of the studies revealed that among 190 drinking water wells, 5 of them were placed in the category of excellent considering WQI analysis. Following the exploration, 78 wells were placed in the category good, 105 in the category poor and 2 wells were found to be in the category very poor. However, due to the conflicts involving the results realized by the general WQI index, Multi-Criteria Decision Making Models (MCDM) were adopted as novel methods of rating wells. In particular, the main objective of the current study was to explore a solution to mitigate probable errors aroused by use of WQI method in classification of water quality classes. As a result Technique for order preference by similarity to

Table 6
Some examples of changes in ranks of the wells according to the classes.

Code of Well	WQI		CP (p = 1)		CP (p = 2)		OWA		TOPSIS		Averaged Rating
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	
num 2	56.127	5	1.260	8	0.415	8	0.024	7	0.995	8	8
num 11	62.323	8	1.106	6	0.272	7	0.022	4	0.996	6	4
num 17	87.890	11	1.841	11	0.601	12	0.029	11	0.983	10	11
num 5	91.972	12	1.725	16	0.582	14	0.029	10	0.974	12	9
num 23	86.489	10	1.929	13	0.598	15	0.030	12	0.972	13	13
num 17	87.890	11	1.841	11	0.601	12	0.029	11	0.983	10	11
num 25	138.450	24	3.531	25	1.687	25	0.055	25	0.726	25	25
num 6	152.653	25	2.946	27	1.532	28	0.045	22	0.882	22	22
num 8	94.906	14	3.036	14	1.216	16	0.052	24	0.813	24	23
num 9	131.815	22	2.153	23	1.166	21	0.035	15	0.933	19	17
num 26	121.437	20	2.655	20	0.871	19	0.039	19	0.910	20	19
num 22	112.282	17	2.844	17	1.363	13	0.040	20	0.910	21	21

ideal solution (TOPSIS), Ordered Weighted Averaging (OWA) operators and Compromise Programing (CP) were the basic MCDM methods used for evaluation. The most striking features to emerge from this study are as follows:

1 Using WQI method may lead to conflicting results such as a decrease in WQI value. That can stem from the influence of a low quantity parameter with high relative weight or less computational effectiveness of a parameter with low relative weight but high quantity. Furthermore, small variations in a parameter may end in an overwhelming shift in WQI results.
2 One could find that CP methods when p value is assumed to be 1 and 2 (CP ($p = 1$) and CP ($p = 2$)) as well as TOPSIS and OWA were adequately successful to eliminate the conflicts within WQI results. Calculating an averaged value (Average value rating) of the ranks obtained from MCDM methods was also found reliable for removing the above probable contradictions.
3 These results indicated that by employing MCDM methods such as TOPSIS, OWA, CP ($p = 1$) and CP ($p = 2$), some of the wells could gain higher scores despite existing in the lower quality class of general WQI range.
4 In case of a proper application of MCDMs, development of novel MCDM-based water quality assessment models is highly recommended for future researches. It should also be determined, if high or low quantity of monitoring items such as monitoring wells could increase the efficiency of rating results using MCDM models.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jafrearsci.2017.11.019.

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