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

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ABSTRACT

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