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Application of Entropy Weighted Water Quality Index and Physicochemical Indices to Evaluate Groundwater Quality in Damghan Plain

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| Article Info. | ABSTRACT |
|--|--|
| | In this study, the Enterney Weighted Weter Oveliter Index (EWOI) even used to |
| Article type: Desearch Article | In this study, the Entropy weighted water Quanty Index (EwQI) was used to assess the groundwater suitability for drinking purposes in Damghan Plain Iran |
| Research Article | This index has been known as the most unbiased model for assessing drinking |
| | water quality Additionally physicochemical indices including Sodium |
| | Adsorption Ratio (SAR) Magnesium Hazard (MH) Kellev's Ratio (KR) |
| | Salinity Hazard (SH) Synthetic Harmful Coefficient (K) Potential Salinity (PS) |
| Article history: | Total Dissolved Solids (TDS), Chloride (CL), Permeability Index (PI) and |
| Received: 05 Jun. 2023 | Soluble Sodium Percentage (SSP) were used to evaluate the suitability of |
| Received in revised from: 11 Aug. 2023 | groundwater for irrigation purposes at August 2018 (dry season) and February |
| Accepted: 27 Sep. 2023 | 2019 (wet season). The results indicated that sodium (Na ⁺) and chloride (Cl ⁻) are |
| Published online: 27 Dec. 2023 | exceeding the permissible limits based on WHO standards and Cl has the highest |
| | entropy weight. EWQI maps illustrated that the groundwater has moderate quality |
| | in the western parts and poor quality in the eastern parts of the study area. The |
| | mean value of this index has decreased from 149.47 in August 2018, to 147.26 in |
| | February 2019, which reflects that the groundwater quality has been improved |
| Keywords: | for drinking purposes. The values of SAR, KR, PI and SSP indices slightly |
| Drinking, | increased, which indicated that the quality of groundwater has more deteriorated |
| Irrigation, | in terms of these indices. The mean value of MH, SH, K, PS, TDS and Cl-indices |
| Water Resources, | have slightly decreased during the study period. Finally, Land Use-Land Cover |
| Damghan. | (LULC) map was used to show which groundwater consumption is appropriate |
| | with its quality. Groundwater in the urban areas has moderate and poor quality |
| | for drinking purpose and suitable quality in terms of SAR, K and PI and |
| | unsuitable in terms of MH, KR, SH, PS, TDS, CI and SPP in agricultural lands. |
| | The suitable condition in terms of SAR, K and PI is because of the high $(M_{2+})^{2+} = 10^{-2+}$ The suitable condition in terms of SAR, K and PI is because of the high |
| | concentration of Mg ²⁺ and Ca ²⁺ . Thus, groundwater is not suitable for irrigation |
| | in the agriculture sector. |

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182

1. Introduction

Today, water resources play a vital role in economic, social developments and quality of life across the world. Human activities such as urbanization, and agricultural and industrial development are deteriorating the quality of these resources (Oki and Akana, 2016). However, decreasing water quality is one of the most important problems in recent century (Nair *et al.*, 2015; Li *et al.*, 2017).

In arid and semi-arid regions, groundwater resource is the most important source of fresh water for various requirements such as human consumption, agricultural and industrial purposes, due to lacking rainfall and surface water. Population growth and increasing use of these resources have caused depletion in groundwater levels and decreased its quality for various agricultural purposes (Asghari Moghaddam and Vadiati, 2016). Additionally, groundwater and its effects on humans' health and development are closely related in these regions. Therefore, if its quality is poor, caused by excessive application of fertilizers for instance, humans' health will be in danger (Pei-Yue *et al.*, 2010) and this dependency has increased in the recent decades (Adimalla, 2020). Thus, this is the reason for a comprehensive assessment of the quality of groundwater for proper management of this important resource.

The groundwater quality is determined by some parameters from physical, chemical and biological aspects (Schriks *et al.*, 2010). The concentration of some physicochemical parameters can affect its suitability for drinking, irrigation and industrial purposes. Therefore, it is necessary to be aware of the physical and chemical composition of groundwater to evaluate its usefulness for various purposes (Venkateswaran *et al.*, 2011). Analyzing groundwater is important to employ a groundwater resource management strategy. Mapping spatial variation of various physicochemical compositions is essential to correctly develop the groundwater schemes and management, consequently (Manoj *et al.*, 2017).

Various methods have been used to evaluate the quality of water over time. Traditional methods are often qualitative and cannot accurately describe its quality (Asghari Moghaddam and Vadiati, 2016). However, new water quality assessment methods have been increased, recently. One of the common methods for drinking purposes is Water Quality Index (WQI). This index is a numerical way to determine the suitability of water (Amiri et al., 2014) and considered in many parts of the world, due to its high capability in expressing water quality information and application of important and effective parameters in the evaluation of water quality (dos Santos Simões et al., 2008). A necessary step in this method is to assign a weight of each parameter which is determined by experts based on their experience, knowledge and discretion (Amiri et al., 2013). Therefore, assigning a correct weight for each parameter is required to take the maximum advantage of this index. There are various ways to determine the weight of the parameters, such as the entropy method. In this method, the weight of parameters determine based on their concentration and shows the relative importance of parameters in groundwater quality. This method provides the most unbiased, justifiable, accurate, and reliable analysis of groundwater quality. Combining WQI with the entropy method is a way to reduce the subjectivity errors while assigning the weight of water quality parameters (Peiyue et al., 2010). Entropy Water Quality Index (EWQI) is a model which provides unbiased, accurate and reliable analysis of groundwater quality by determining a suitable weight for each water quality parameter (Feng et al., 2019; Singh et al., 2019; Wang et al., 2019; Maskooni et al., 2020; Ukah et al., 2020;).

In terms of irrigation purposes, the water quality is supposing a significant necessity with the rising pressure on agriculture (Wijnen *et al.*, 2012). For adopting a suitable plan for agricultural lands, an adequately understand the properties of water is needed and measurement of physicochemical parameters in water reservoir is necessary to achieve this aim. There are various indices to evaluate the quality of water, such as Sodium Adsorption Ratio (SAR),

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

183

Magnesium Hazard (MH), Kelley's Ratio (KR), Salinity Hazard (SH), Potential Salinity (PS), Sodium Percentage (Na%) and Permeability Index (PI) which are widely used over the world (Sharma *et al.*, 2017; Ememu and Nwankwoala, 2018; Jain and Vaid, 2018; Ghazaryan *et al.*, 2019; He *et al.*, 2019; Kahsay *et al.*, 2019; Kumari and Rai, 2020; Singh *et al.*, 2020).

Damghan Plain, Iran, is located in an arid region and surface water is limited, so the major source of fresh water is groundwater. Therefore, groundwater, as the only source of clean water, needs to be well-used. Thus, in the present study, the suitability of groundwater quality in Damghan Plain for drinking uses has been assessed by EWQI, as well as for the agricultural purposes using physicochemical characteristics and indices through GIS. Combining the groundwater data with GIS can provide suitable and effective results of groundwater conditions. As Damghan Plain has limited surface water resources, groundwater is the main freshwater resource, and it is essential to investigate the groundwater quality for proper management, thus in the present study the groundwater in this plain has been evaluated.

2. Materials and methods

2.1. Case Study

Damghan Plain is located in Semnan province between $35^{\circ} 51'$ and $36^{\circ} 09'$ latitude and $54^{\circ} 04'$ and $54^{\circ} 26'$ longitude, with an area of 732.51 km². It is located in the south of the Alborz mountain range and north of the Kavir desert with an arid and semi-arid climate (Arabameri *et al.*, 2019). The average temperature is 15.8 °C and the long-term annual average of precipitation is about 151 mm (Ashtiani *et al.*, 2016). The elevation varies from 1309 meters (a.s.l.¹) in the northwest to 1047 meters (a.s.l.) in the southeast. This plain, like other arid and semi-arid regions, is facing with water problem. The water supply is mostly through the groundwater resources (Parhizkar *et al.*, 2015) which are mainly used for the agricultural purposes. Fig 1 shows the study area and location of piezometers and quality monitoring wells in Iran.

2.2. Methodology

In this study, nine physicochemical parameters, including Sodium (Na⁺), Calcium (Ca²⁺), Magnesium (Mg²⁺), Sulfate (SO₄²⁻), Chlorine (Cl⁻), Bicarbonate (HCO₃⁻), Potential of Hydrogen (pH), Total dissolved solids (TDS), Electrical Conductivity (EC), and were used from 21 groundwater samples in Damghan Plain in August 2018 and February 2019. The data of groundwater quality were obtained from the Iran Water Resources Management Company. In Damghan Plain agricultural activities are started in February (wet season) and finished in August (dry season) and the groundwater is used during these activities and charged during the autumn season.

The quality of groundwater assessed for suitability in drinking adopting EWQI and agricultural purposes using physicochemical indices namely Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelley's Ratio (KR), Salinity Hazard (SH), Synthetic Harmful Coefficient (K), Potential Salinity (PS), Total Dissolved Solids (TDS), Chloride (Cl⁻), Permeability Index (PI) and Soluble Sodium Percentage (SSP) based on groundwater data.

In order to generate the maps of adopted indices, Inverse Distance Weighted (IDW) interpolation technique was employed in ArcMap 10.7. This technique is widely used by many researchers to assess the spatial distribution of groundwater physicochemical parameters (Kawo and Karuppannan, 2018; Rostami *et al.*, 2019; Gnanachandrasamy *et al.*, 2020; Verma *et al.*, 2020; Zolekar *et al.*, 2020). In this interpolation technique, the value of un-sampled cells is calculated using surrounding points (Prasanth *et al.*, 2012).

¹ Above sea level



Fig. 1. Study area and location of piezometers and quality monitoring wells

2.2.1. Entropy Weighted Water Quality Index

WQI is widely used for evaluating groundwater suitability for drinking purposes, which its quality depends on physicochemical parameters (Liu et al., 2020). In calculation of WQI, the weights of each parameter are usually determined based on expert opinion, but recently, entropy theory has been used to compute the weight of water quality parameters (Egbueri et al., 2020; Maskooni et al., 2020; Ukah et al., 2020; Adimalla, 2021;). In this study, EWQI, which is presented by Pei-Yue et al. (2010), was used to assess the groundwater quality for drinking purposes. The concept of entropy was initially proposed by Shannon (1948) which expresses the uncertainty degree of a stochastic event (Amiri et al., 2014), or in other words, it shows how much an event can be stochastic (Gorgij et al., 2017).

EWQI provides an unbiased assessment of water quality considering all the measured parameters (Ukah et al., 2020) and its calculation is done in three steps including: calculating entropy weight, quality rating scale for each parameter and classification of the groundwater quality. In the first step, the performance matrix is constructed. The matrix (X) indicates a summary of physicochemical analysis data, as m (i = 1, 2, ..., m) denotes the number of wells that are monitored to assess groundwater quality based on n (j = 1, 2, ..., n) measured parameters. Thus, x_{ij} is the value of j^{th} parameter in the *i*th well.

Then, according to the analyzed data, matrix X can be constructed as follows:

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

$$\mathbf{X} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$
(1)

Since the groundwater quality parameters have different units, the normalized matrix will be computed using the efficiency type normalizing function as (Pei-Yue *et al.*, 2010);

$$y_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}}$$
(2)

Where x is the value of *j*th parameter in the *i*th well and $(x_{ij})_{max}$ and $(x_{ij})_{min}$ are the maximum and minimum values of *j*th parameter, respectively.

Then, the *Y* (normalized) matrix will be constructed as:

$$\mathbf{Y} = \begin{bmatrix} y_{11} & y_{12} & \dots & y_{1n} \\ y_{21} & y_{22} & \dots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \dots & y_{mn} \end{bmatrix}$$
(3)

The *j*th parameter index amount, in i^{th} sample is calculated as;

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{4}$$

Where m represents the number of wells. In the next step, the entropy value of parameter j is computed as follows;

$$e_{j} = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \cdot \ln P_{ij}$$
(5)

The less the value of e_j is, the more effect the *j* index will have (Pei-Yue *et al.*, 2010). The following step is to calculate the entropy weight for each parameter as;

$$w_i = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)}$$
(6)

The second step to determine EWQI value is to compute the quality rating scale (q_i) for each parameter in every sample as;

$$q_{i=}\left(\frac{c_i}{s_i}\right) \times 100\tag{7}$$

Where C_i is the concentration of each physicochemical parameter in each groundwater sample in mg/L except for pH which is defenseless and S_j is the standard of each parameter based on World Health Organization (WHO) Standards (Table 1).

The third step is to calculate EWQI as following formula;

$$EWQI = \sum_{j=1}^{n} w_i \cdot q_i \tag{8}$$

Where n is the number of groundwater quality parameters.

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185

186

| Parameter | Unit | WHO Standard |
|--------------------|------|--------------|
| Na ⁺ | mg/L | 200 |
| Mg^{2+} | mg/L | 50 |
| Ca^{2+} | mg/L | 75 |
| SO4 ²⁻ | mg/L | 250 |
| Cl- | mg/L | 250 |
| HCO ₃ - | mg/L | 120 |
| pH | - | 6.5 - 8.5 |
| TDS | mg/L | 500 |

| Table 1. Groundwater quality limitation for drinking purposes based on |
|---|
| World Health Organization Standards (WHO, 2011) |

According to Pei-Yue *et al.* (2010), the groundwater quality based on EWQI is classified in five ranks for drinking purposes (Table 2).

Table 2. Groundwater quality ranking based on EWQI for drinking purposes

| Groundwater quality | Rank | EWQI | |
|---------------------------------|------|-----------|---|
| Excellent drinking quality | 1 | < 50 | |
| Good drinking quality | 2 | 50 - 100 | |
| Moderate drinking quality | 3 | 100 - 150 | |
| Poor drinking quality | 4 | 150 - 200 | |
| Extremely Poor drinking quality | 5 | 200 | |
| | | | - |

2.2.2. Evaluation of Groundwater Quality for Irrigation Purposes

There are several parameters and indices for assessing the groundwater status for agricultural purposes, which provide comprehensive results to recognize the groundwater suitability for irrigation. In the present study, Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelly's ratio (KR), Salinity Hazard (SH), Synthetic Harmful Coefficient (K), Potential Salinity (PS), Total Dissolved Solids (TDS), Chloride (Cl⁻), Permeability Index (PI) and Soluble Sodium Percentage (SSP) were adopted in order to assess the suitability of quality of groundwater for agricultural activities (Table 3). All the cations and anions are in meq/L to calculate these indices.

After determining the groundwater quality, Land Use-Land Cover (LULC) using Landsat OLI 8 images and groundwater level fluctuations map during the study period were generated for the study area to better understanding of the groundwater uses for various purposes. The methodology applied in this research is summarized in Fig 2.

3. Result

For assessing the groundwater suitability for drinking and irrigation purposes, physicochemical compounds of groundwater samples were measured. The statistical summary of the physicochemical of groundwater samples parameters are presented in Table 4.

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

| Index | Equation | References | |
|-------------------------------|--|--------------------------|--|
| Sodium Adsorption Ratio | $SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}}$ | Ravikumar et al. (2011) | |
| Magnesium Hazard | $MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100$ | Szabolcs (1964) | |
| Kelley's Ratio | $KR = \frac{Na^+}{(Ca^{2+}+Mg^{2+})}$ | Kelley (1963) | |
| Salinity Hazard | $SH = EC \ (\mu S/cm)$ | Tahmasebi et al. (2018) | |
| Synthetic Harmful Coefficient | $K = 12.4 \times TDS + SAR$ | Zhou et al. (2009) | |
| Potential Salinity | $PS = Cl^- + \frac{SO_4^{2-}}{2}$ | Doneen (1962) | |
| Total Dissolved Solids | TDS (mg/L) | Davis and DeWiest (1966) | |
| Chloride | $Cl^{-}(meq/L)$ | Stuyfzand (1989) | |
| Permeability Index | $PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Na^+ + K^+ + Ca^{2+} + Mg^{2+})} \times 100$ | Doneen (1964) | |
| Soluble Sodium Percentage | $SSP = \frac{Na^+}{Na^+ + Ma^{2+} + Ca^{2+}}$ | Wani et al. (2014) | |

Table 3. Groundwater quality indices for irrigation purposes



Fig. 2. Flowchart of the adopted methodology

187

188

| Parameter | Unit | Minimum | Maximum | Mean | Standard Deviation |
|--------------------|---------|---------|---------|---------|--------------------|
| Na^+ | mg/L | 168.29 | 533.37 | 301.48 | 73.32 |
| Mg^{2+} | mg/L | 35.24 | 125.15 | 57.60 | 16.08 |
| Ca^{2+} | mg/L | 48.10 | 166.33 | 80.83 | 23.13 |
| SO_4^{2-} | mg/L | 109.99 | 403.93 | 232.41 | 85.26 |
| Cl | mg/L | 328.98 | 917.45 | 451.68 | 113.24 |
| HCO ₃ - | mg/L | 125.10 | 326.46 | 226.28 | 62.08 |
| pН | - | 7.14 | 7.95 | 7.61 | 0.22 |
| TDS | mg/L | 1022.00 | 2600.00 | 1379.05 | 282.86 |
| EC | µmhos/L | 1532.00 | 3930.00 | 2070.57 | 428.36 |

Table 4. Statistical summary of physicochemical parameters

3.1. Geochemical Characterization of Groundwater

3.1.1. Ions Concentration

Statistically investigation of the ions results in each sample is necessary to realize groundwater conditions. Based on mean value of cations and anions, the order of cations is followed by Na⁺ > Ca²⁺ > Mg²⁺ and the anions are ordered as Cl⁻ > HCO₃⁻ > SO₄²⁻. Na⁺ and Cl⁻ have the most concentrations, compared to other cations and anions. So high concentration of these ions increases the salinity of groundwater, so that gives salty taste to it and has the greatest effect on the high values EC. Also, high concentration of sodium can cause high blood pressure in humans as well as kidney and heart disease. It has been reported by Ehteshami (*et al.*, 2015) as well. Parhizkar (*et al.*, 2015) reported that the main agricultural product in the region is pistachios, which can be due to the high concentration of these ions and high salinity in groundwater. The standard deviation of pH was 0.22 which indicates that its value does not change too much all over the plain. Maximum and minimum values of TDS exceeded standard value (Table 1), which its high value could be due to water-rock interaction (mineral dissolution) and evaporation (Xu *et al.*, 2019).

Correlation analysis of physicochemical parameters was applied to present the degree of relation of them. The results showed the highest correlation was between all cations and all anions, while, in terms of individual ions, Na⁺ and Cl⁻ had the strongest correlation with a correlation coefficient of 0.629, and there were the least correlation between Ca²⁺ and SO₄²⁻ with a correlation coefficient of 0.001, approximately (Fig 3). The relationship between Ca²⁺ and SO₄²⁻ indicates that gypsum is not a primary processes of groundwater chemistry (Chen *et al.*, 2019) as well as, the weak relationship of Ca²⁺ + Mg²⁺ and HCO₃⁻ + SO₄²⁻ reflects that carbonates and sulfate cannot be dissolved in groundwater (Li *et al.*, 2018). Totally, it can be said that, the hydrochemical process in the Damghan Plain are not influenced by one process and it is mainly influenced by several items including ions exchange, ions concentration and evaporation.

3.1.2. Durov Diagram

Durov diagram is employed in order to display a useful relationship for groundwater samples having similar physicochemical parameters compound. Durov diagram disclosed that cations were dominated by Na⁺, while anions were dominated by Cl⁻ and there are not significant differences between the concentration of ions, TDS and pH values in both months August, 2018, and February, 2019. In the middle square, it is clearly observed that Na⁺-Cl⁻ type is more dominant than other types. The values of pH, raged from 7.14 to 7.95 with an average of 7.61 which indicates that the groundwater has slightly alkaline nature and there are slight changes in the plain. TDS varied between 1022 and 2600 mg/L, with a mean value of 1379.05 (Table 4).



Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

Fig. 3. Bivariate diagrams of ionic concentrations in groundwater samples (Red: August; Blue: February)

189

190



Fig. 4. Classification of groundwater samples based on Durov diagram

3.2. Entropy Weighted Water Quality Index

The most important step in computing EWQI is to determine the entropy weight, which is considered as a coefficient for calculating the WQI. Entropy weight of each parameter reflects the relative importance of that parameter in groundwater quality. A parameter with high entropy weight has little change in groundwater quality and has reached stability in the aquifer environment. Conversely, if the entropy weight of a parameter is low, its quality changes are high and it plays the major role in affecting groundwater quality.

After initial investigations, entropy weight was computed for each parameter. The higher the entropy weight of a parameter is, the greater the effectiveness of that parameter is. The results of parameters' entropy weight revealed that the effectiveness of the parameters follows $Cl^- > Mg^{2+} > SO_4^{2-} > TDS > Ca^{2+} > HCO_3^- > Na^+ > pH$ order, in August, 2018, while, in February, 2019, the order is as $Cl^- > SO_4^{2-} > Ca^{2+} > TDS > Mg^{2+} > HCO_3^- > pH > Na^+$. As it is shown in Fig 5, Cl^- has the highest entropy weight among the parameters and there is no significant difference between them (with value of 0.176 in August and 0.173 in February). Therefore Cl^- has the most effect on groundwater quality in the study area.

After computing the entropy weight of parameters and water quality rating scale, based on the standards of the World Health Organization (WHO, 2011), the groundwater quality for drinking purposes was estimated in study area for both months. The values of EWQI map ranged from 111.74 to 175.47, with mean value of 149.47 in August, 2018, while, in February, 2019, they were found between 113.02 and 189.08, with mean value of 147.26. The results revealed that groundwater quality is classified as moderate to poor.

According to the spatial distribution maps of EWQI, the value of this index was lower in eastern parts than western parts and the classified maps clearly depicted two moderate and poor zones in August, 2018, and February, 2019 (Fig 6). These maps represented that the groundwater quality changes from Moderate class in the west to "Poor" class in the east. The comparison of the classified EWQI maps of two months showed that the quality of groundwater for drinking purpose become a little bit better in south parts, while in the north parts it was a

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

little deteriorated. This is also consisting with the hydraulic slope of the area as groundwater moves from northwest to southeast. Groundwater in 275.57 Km² area (37.62 %) in August and 358.65 Km² area (48.96 %) in February had moderate quality, while 456.94 Km² area (62.38 %) in August and 373.86 Km² area (51.04%) in February had poor quality.



Fig. 5. The entropy weight of physicochemical parameters



Fig. 6. Spatial distribution maps of drinking water quality based on EWQI

3.3. Groundwater Quality for Irrigation Purposes

The suitability of groundwater quality for irrigation purpose in the region was assessed using SAR, MH, KR, SH, K, PS, TDS, Cl⁻, PI, SSP indices. Physicochemical parameters of groundwater were adopted to calculate these indices and the spatial distribution maps of indices developed by Geographic Information System (GIS) based on IDW spatial analysis technique (Fig 7).

191

192



Fig. 7. Maps of groundwater quality indices for irrigation purpose

Sodium Adsorption Ratio

SAR shows the sodicity hazard and if water has high concentration of sodium and calcium, it may change the structure of the soil (Adimalla, 2020). According to the results, SAR values ranged from 5.04 to 8.51 in August, 2018, and from 4.39 to 8.65 in February, 2019. Groundwater in all samples was categorized into "Excellent" class in both months (Table 5). The average of SAR values in these months are 6.37 and 6.41. These maps represented that SAR values totally are higher in eastern parts of the study area than western parts in both month (Fig 7).

DESERT, 28-2, 2023

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

| SAD | Croundwater Quality | Number of Samples (%) | |
|---------|----------------------|-----------------------|--------------|
| SAK | Groundwater Quanty – | August | February |
| < 10 | Excellent | 21 (100.00%) | 21 (100.00%) |
| 10 - 18 | Good | 0 (0.00%) | 0 (0.00%) |
| 15 - 26 | Injurious | 0 (0.00%) | 0 (0.00%) |
| 26 < | Unsuitable | 0 (0.00%) | 0 (0.00%) |

Table 5. Groundwater quality classification based on SAR (Ravikumar et al., 2011)

Magnesium Hazard

Magnesium normally exchanges with sodium in the irrigated soil (Keesari *et al.*, 2016) and its high concentration increases the soil aggregation (Zhou *et al.*, 2020). The results showed that 4 samples in August and 5 sample in February had groundwater which were classified into suitable class and groundwater in the rest of the samples were classified into unsuitable status (Table 6). The maps of MH presented that the groundwater in central parts of the plain had better conditions than northern and southern parts in terms of this index. The mean value of MH during the study period decreased from 54.43 to 52.61.

 Table 6. Groundwater quality classification based on Magnesium Hazard (Szabolcs, 1964)

| MH (%) | Groundwater Quality – | Number of Samples (Percent) | |
|--------|-----------------------|-----------------------------|-------------|
| | | August | February |
| < 50 | Suitable | 4 (19.00%) | 5 (24.00%) |
| 50 < | Unsuitable | 17 (81.00%) | 16 (76.00%) |

Kelley's Ratio

KR is defined to determine the concentration of sodium against the concentration of magnesium and calcium (Gaikwad *et al.*, 2020). The results indicated that the most of the groundwater samples (90.50%) were categorized into unsuitable class in both months and only 2 groundwater samples (9.50%) had suitable condition (Table 7). The maps of this index represented KR value in August is higher in west and in February in south and its value a little increased from 1.58 to 1.59 from August, 2018, to February, 2019.

 Table 7. Groundwater quality classification based on Kelley's Ratio (Kelley, 1963)

| KR | Crowndwiston Quality | Number of Samples (Percent) | |
|-----|----------------------|-----------------------------|-------------|
| | Groundwater Quanty — | August | February |
| < 1 | Suitable | 2 (9.50%) | 2 (9.50%) |
| 1 < | Unsuitable | 19 (90.50%) | 19 (90.50%) |

Salinity Hazard (SH)

Salinity is one of the most crucial parameter which uses to distinguish the groundwater quality for irrigation and determines the existence of salt in groundwater, which its high concentration can affect on osmotic process of plants (Subramani *et al.*, 2005). SH index value ranged between 1532.15 and 2529.82 in August, and between 1541.14 and 2729.73 in February. In August, groundwater was classified into "Doubtful" class in 15 samples, while in 6 samples was classified into "Unsuitable" class and in February, groundwater was classified into

193

| 194 | DESERT, 28-2, 2023 |
|-----|--------------------|
| | |

"Doubtful" class in 15 samples and "Unsuitable" class in 5 samples (Table 8). The average values of SH in August and February were 2036.99 and 1996.70, respectively. These maps indicated that the SH values were lower in western parts of the study area than eastern parts in both month (Fig 7).

| EC(umohs/am) | (µmohs/cm) Groundwater Quality | SH Class | Number of Samples (Percent) | |
|--------------------------|--------------------------------|----------|-----------------------------|-------------|
| $EC(\mu \text{mons/cm})$ | | SITClass | August | February |
| < 250 | Excellent | C1 | 0 (0.00%) | 0 (0.00%) |
| 250-750 | Good | C2 | 0 (0.00%) | 0 (0.00%) |
| 750–2250 | Doubtful | C3 | 15 (71.00%) | 16 (76.00%) |
| 2250 < | Unsuitable | C4 | 6 (29.00%) | 5 (24.00%) |

Table 8. Groundwater quality classification based on Salinity Hazard (Tahmasebi et al., 2018)

Synthetic Harmful Coefficient

Synthetic Harmful Coefficient mainly indicates the salt and alkalis hazards (Xu *et al.*, 2019). Based on the results, the groundwater in the most samples had excellent condition (15 samples in both months). The maps of this index showed that the value of K was higher in eastern parts than western parts, with average value of 23.20 in August and 22.91 in February (Fig 7).

Table 9. Groundwater quality classification based on Synthetic Harmful Coefficient (Zhou et al., 2009)

| V | Groundwater Quality | Number of Samples (Percent) | | |
|---------|----------------------|-----------------------------|-------------|--|
| K GIOU | Groundwater Quanty – | August | February | |
| < 25 | Excellent | 15 (71.00%) | 15 (71.00%) | |
| 25 - 36 | Good | 5 (24.00%) | 6 (29.00%) | |
| 36 - 44 | Injurious | 1 (5.00%) | 0 (0.00%) | |
| 44 < | Unsuitable | 0 (0.00%) | 0 (0.00%) | |

Potential Salinity

PS index is primarily related to the content of chloride and sulfate. The total groundwater samples were within injurious to unsatisfactory class in both month based on PS values, which ranged from 10.61 to 20.87 (with an average of 14.93) in August and from 10.47 to 20.90 (with an average of 14.65) in February. In both months the values were higher in southeastern than other parts (Fig 7).

Total Dissolved Solids

TDS estimates the total organic and inorganic substances which are dissolved in water (Pan *et al.*, 2019). That the groundwater in all samples was classified within slightly saline class in both months and the maps illustrated that TDS value were found from 1022.10 1682.88 mg/L in August and from 1026.09 to 1821.82 mg/L in February. The TDS value was totally higher in eastern parts than other parts in both months (Fig 7).

Chloride

Chloride may originate from various sources such as weathering, seawater infiltration and leaching of sedimentary rocks (Rout and Sharma, 2011). High concentration of this anion can

| Application of Entropy Weighted Water | Quality Inday and Dahahan Dahimahadi at al | 105 |
|---------------------------------------|---|-----|
| Application of Entropy weighted water | Quality index and / Denghan Kammabadi <i>et al.</i> | 195 |

be a sign of excessive organic pollution (Yogendra and Puttaiah, 2008). The results indicated the groundwater in all samples was categorized into brackish class in both months (Table 12). The western parts had lower value of Cl⁻ than eastern parts in both months (Fig 7) and mean value of Cl⁻ was 12.42 meq/L and 12.26 meq/L in August and February, respectively.

| DS (mag/L) | Groundwater Quality | Number of Samples (Percent) | |
|------------|-----------------------------|-----------------------------|--------------|
| rs (meq/L) | | August | February |
| < 3 | Excellent to Good | 0 (0.00%) | 0 (0.00%) |
| 3 – 5 | Good to Injurious | 0 (0.00%) | 0 (0.00%) |
| 5 < | Injurious to Unsatisfactory | 21 (100.00%) | 21 (100.00%) |

Table 10. Groundwater quality classification based on Potential Salinity (Doneen, 1962)

Table 11. Groundwater classification based on Total Dissolved Solids (Davis and DeWiest, 1966)

| TDS(ma/I) | Groundwater Class | Number of Samples (Percent) | |
|--------------|-------------------|-----------------------------|--------------|
| TDS (IIIg/L) | Gloundwater Class | August | February |
| < 1000 | Non Saline | 0 (0.00%) | 0 (0.00%) |
| 1000 - 3000 | Slightly Saline | 21 (100.00%) | 21 (100.00%) |
| 3000 - 10000 | Moderately Saline | 0 (0.00%) | 0 (0.00%) |
| 10000 < | Very Saline | 0 (0.00%) | 0 (0.00%) |

Table 12. Classification of groundwater based on Chloride (Stuyfzand, 1989)

| Dangas (mag/L) | Catagorias | Number of Samples (Percent) | |
|-----------------|-----------------|-----------------------------|--------------|
| Ranges (meq/L) | Categories | August | February |
| < 0.14 | Extremely Fresh | 0 (0.00%) | 0 (0.00%) |
| 0.14 - 0.85 | Very Fresh | 0 (0.00%) | 0 (0.00%) |
| 0.85 - 4.23 | Fresh | 0 (0.00%) | 0 (0.00%) |
| 4.23 - 8.46 | Fresh Brackish | 0 (0.00%) | 0 (0.00%) |
| 8.46 - 28.21 | Brackish | 21 (100.00%) | 21 (100.00%) |
| 28.21 - 282.06 | Brackish - Salt | 0 (0.00%) | 0 (0.00%) |
| 282.06 - 564.13 | Salt | 0 (0.00%) | 0 (0.00%) |
| 564.13 < | Hypersaline | 0 (0.00%) | 0 (0.00%) |

Permeability Index

Irrigation water can affect the soil permeability in long term (Ramesh and Elango, 2012). The results of PI showed that groundwater in most samples ranged between 25 and 75 (class II) (Table 13). In both months, PI value was lower in southeastern than other parts (Fig 7) and its mean value increased from 69.61 to 70.02 during the study period.

196

| DI (0/) | Crowndwistor Quality | Class | Number of Sar | of Samples (Percent) | |
|---------------|----------------------|-----------|---------------|----------------------|--|
| PI(%) Groundy | Groundwater Quanty | Class | August | February | |
| 75 < | Suitable | Class I | 1 (5.00%) | 3 (14.00%) | |
| 25 - 75 | Suitable | Class II | 20 (95.00%) | 18 (86.00%) | |
| < 25 | Unsuitable | Class III | 0 (0.00%) | 0 (0.00%) | |

Table 13. Groundwater quality classification based on Permeability Index (Doneen, 1964)

Soluble Sodium Percentage

SSP is an important index for assessing the sodium hazard and shows the dominant of sodium to the total cations (Peiyue *et al.*, 2011). 19 groundwater samples were classified into unsuitable class (Table 14) and its value was totally higher in central parts than other parts in both months (Fig 7) and its mean value increased from 60.83 to 60.93 from August, 2018, to February, 2019.

Table 14. Groundwater quality classification based on Soluble Sodium Percentage (Wani et al., 2014)

| SSD | Groundwater Quality | Number of San | nples (Percent) |
|------|----------------------|---------------|-----------------|
| 551 | Groundwater Quanty — | August | February |
| < 50 | Suitable | 2 (9.50) | 2 (9.50) |
| 50 < | Unsuitable | 19 (90.50) | 19 90.50) |

3.4. Groundwater table changes and Land Use Land Cover

Groundwater table changes map was produced to show the changes in groundwater table during study period and its effect on groundwater quality using groundwater table data. Changes of groundwater table during the study period were investigated using groundwater table data for two studied month. The map of groundwater level fluctuations (Fig 8, Left) illustrated that groundwater table decreased in the northern parts of the region, while in the southern parts has increased from August, 2018, to February, 2019. The changes of groundwater table range from -0.69 to +0.32 meter, with the average of -0.19 meter, which generally indicates the groundwater table depletion in south of the plain during study period.

For better understanding the suitability of groundwater, which provides the required water for different types of land use, the Land Use/Land Cover (LULC) map was generated by LULC map of Natural Resources and Watershed Management Organization of Iran (Fig 8, Right). According to this map, the most part of plain is bareland (56.8%) and followed by agricultural lands (15.85%), poor range (12.29%), urban area (9.02%), saltland (3.99%), and agriculturefallow (2.05%) (Table 15). Saltland area is located in the east side of the plain and rangeland is in the north and west side and bareland is between them, which indicate that natural vegetation is decreasing from west to east. Due to the presence of saltland in the east side the amount of salinity is higher in this area, and value of EC, SAR KR and PS indices is higher.

4. Discussion

In the present study, EWQI, as a novel method, and various physicochemical indices were employed through GIS to determine the groundwater suitability for drinking and irrigation purposes, respectively.

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.



Fig. 8. The maps of groundwater table changes from August, 2018 to February, 2019 (Left) and LULC for Damghan Plain (Right)

| LULC Type | Area (Km ²) | Area (%) |
|--------------------|-------------------------|----------|
| Urban | 66.05 | 9.02 |
| Saltland | 29.23 | 3.99 |
| Bareland | 416.06 | 56.8 |
| Agriculture | 116.14 | 15.85 |
| Poor Range | 90.01 | 12.29 |
| Agriculture-Fallow | 15.02 | 2.05 |
| Sum | 732.51 | 100.00 |
| | | |

Table 15. Area of LULC types in Damghan Plain

The initial study of groundwater characteristics represented that Na⁺ and Cl⁻ have the highest concentrations in groundwater among cations and anions, respectively, and are exceeding the permissible limits of WHO standards in both months August, 2018, and February, 2019. Moreover, the strong relationship between these two ions based on bivariate diagram reflected salinity status of groundwater. On the other hand, the relationship between other cations and anions are weaker than their relationship. Despite this issue along with high levels of TDS, precautions should be taken for drinking. Additionally, groundwater quality for salinity-sensitive crops is poor and plants which are more resistant to salinity should be cultivated in the studied plain.

The results of evaluation of groundwater quality using the EWQI highlighted that among the all parameters, Cl⁻ has the highest entropy weight in both months which indicated this ion has the highest effect on groundwater quality and less changes. EWQI maps implied groundwater totally had moderate status in west and poor status in east of the area. The mean value of this

index become a little lower from 149.47 in August to 147.26 in February, which reflected that the groundwater quality has not changed much and has just slightly improved for drinking purpose. The reason of this decreasing can be increasing the groundwater level in the southern parts of the area, which shows that with the decrease of groundwater level, its quality decreased and in the southern parts, with the increase of groundwater level (increase of groundwater quantity), its quality slightly increased.

The assessment of groundwater quality for irrigation showed that although SAR, KR, PI and SSP indices had slightly increased in their mean value, but groundwater is suitable in terms of SAR, K and PI in both months and has not limitation for using in agricultural sectors. This result indicates that the concentration of Na⁺ was more appropriate than other ions used in these indices. Conversely the groundwater has not good status in terms of SSP, MH, SH, K, PS, TDS and Cl⁻ indicating groundwater has high concentration of solid materials and other ions.

The evaluation of groundwater suitability for irrigation purposes revealed that SAR, KR, PI and SSP indices had slightly increased in their mean value, which indicated the groundwater quality become worse in terms of these indices. On the other hand, the mean value of MH, SH, K, PS, TDS and Cl⁻ indices have slight decrease during the study period. SH, PS and Cl⁻ values in the southern parts have been increased from August to February. This can be due to rising groundwater table.

LULC map was employed to show which groundwater consumption is appropriate with its quality. This map indicated that the most urban areas were located in the north parts, in which groundwater has both moderate and poor quality, in west side has moderate quality while in east side has poor quality. Agricultural lands are located in the middle and south of the plain, in which the groundwater has mainly suitable quality in terms of SAR, K and PI and unsuitable in terms of MH, KR, SH, PS, TDS, Cl⁻ and SPP. The suitable condition in terms of SAR, K and PI is due to the high concentration of Mg^{2+} and Ca^{2+} (Table 4). Thus, groundwater is not suitable for irrigation in agriculture sector.

5. Conclusion

The results of groundwater quality for drinking purpose showed that Cl- has the most effect on its quality and has less change among all used physicochemical parameters. Base on EWQI, the quality of groundwater is totally moderate in western parts of Damghan Plain, while in the eastern parts it has poor status. The evaluation of groundwater suitability for irrigation purposes revealed that SAR, KR, PI and SSP indices had slightly increased in their mean value, which indicated the groundwater quality become worse in terms of these indices. On the other hand, the mean value of MH, SH, K, PS, TDS and Cl- indices have slight decrease during the study period. SH, PS and Cl- values in the southern parts have been increased from August to February. This can be due to rising groundwater table.

The results of the present study provide guidance to decide for appropriate management. It is recommended that relevant organizations adopt the suitable strategies to save by sustainable use and to enhance the quality of groundwater in Damghan Plain to make more usable the groundwater and which is mainly used for agricultural purposes.

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198

Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

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| 202 | 2 | DESERT, 28-2, 2023 |
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Application of Entropy Weighted Water Quality Index and ... / Dehghan Rahimabadi et al.

Appendix

Ca²⁺ UTM UTM Mg²⁺ SO_4^2 HCO₃ TDS Na Cl Row Month pН (mg/lit) (mg/lit) (mg/lit) (X) (Y) (mg/lit) (mg/lit) (mg/lit) (mg/lit) 236000 116.232 1 3986300 333.355 43.74 226.7016 128.142 7.74 1341 529.2685 2 240800 3989200 195.415 37.665 52.104 132.5628 328.976 192.213 7.9 1022 3 243800 3984200 223.2329 44.955 52.104 225.741 328.976 164.754 1088 7.6 4 247300 44.955 64.128 218.0562 352.0185 164.754 7.46 1131 3992300 244.8435 5 247700 3978500 366.4606 61.3575 80.16 398.649 456.596 170.856 7.59 1614 249100 279.5346 6 3996600 317.262 65.61 84.168 403.421 274.59 7.47 1467 7 249200 4000400 266.684 42.525 96.192 149.3733 367.971 305.1 7.89 1213 8 251400 3987900 251.9704 37.665 80.16 174.8292 401.6485 158.652 7.82 1121 9 252700 3982300 340.9417 74.115 77.154 318.9192 483.1835 244.08 7.41 1607 Aughust, 2018 10 252900 3997000 410.3715 58.32 80.16 273.2907 529.2685 256.284 7.39 1575 11 259000 3998100 314.5032 61.965 76.152 172.4277 474.321 274.59 7.5 1369 12 259800 280.7079 63.18 98 196 294.4239 454.8235 7.74 1387 3978600 146.448 13 260900 3985200 375.8865 46.17 90.18 272.8104 639.1635 134.244 7.24 1683 14 261200 4009400 375.6566 57.105 90.18 150.8142 573.581 302.049 7.58 1592 7.46 15 262300 254.2694 71.685 55.11 327.5646 412.2835 125.091 1310 3981100 263400 3992300 277.0295 54.108 155.6172 1226 16 46.17 403.421 268 488 7.86 17 60.75 259.335 264000 3996400 311.7444 65.13 146.4915 488.501 7.65 1382 18 265100 4004800 168.2868 72.9 79.158 139.7673 359.1085 216.621 7.54 1082 19 333.355 72.144 403.421 241.029 7.46 1375 266600 3995100 53.46 277.1331 20 266800 4004200 227.8309 70.47 94.188 200.7654 382.151 305.1 7.91 1305 533.368 21 269300 3998400 125.145 136.272 399.6096 917.446 265.437 7.49 2600 7.92 22 545.221 128.142 1392 236000 3986300 325.7683 54.675 80.16 206.529 23 35.235 7.41 1026 240800 3989200 180.4715 70.14 109.9887 330.7485 213.57 24 243800 3984200 235.8774 43.74 66.132 152.7354 345.6375 207.468 7.47 1060 25 247300 3992300 258.4076 48.6 65.13 226.7016 355.5635 186.111 7.78 1137 26 247700 65.61 78.156 403.9323 454.8235 195.264 7.39 1614 3978500 364.6214 27 249100 70.47 54.108 1395 3996600 358.644 355.422 385.696 286.794 7.21 28 256.3385 94.188 249200 4000400 46.17 126.3189 381.0875 326.457 7.95 1261 29 251400 3987900 256.7983 35.235 84.168 157.5384 408.7385 180.009 7.93 1130 252700 7.5 30 3982300 319.561 37.665 62.124 267.5271 344.9285 176.958 1126 February, 2019 31 252900 3997000 393.5888 61.965 82.164 250.2363 545.221 237.978 7.66 1590 32 259000 3998100 299.7896 59.535 88.176 171.9474 472.5485 298.998 7.71 1381 1479 33 259800 3978600 325.7683 57.105 90.18 317.4783 469.7125 7.7 158.652 34 260900 354.7357 47.9925 166.332 208.9305 699.4285 1822 3985200 158.652 7.14 35 261200 4009400 55.89 117.234 177.2307 579.6075 320.355 7.83 1608 326.6879 36 262300 3981100 255.8787 64.395 64.128 318.9192 411.22 155.601 7.78 1290 37 263400 48.096 7.8 1235 3992300 271.9717 51.6375 134.9643 407.675 286.794 38 264000 3996400 308.9856 61.3575 70.14 166.1838 451.2785 280.692 7.77 1320 39 265100 4004800 172.8848 68.04 94.188 200.2851 241.029 7.63 1095 362.6535 40 266600 3995100 400.026 61.965 60.12 311.2344 433.5535 280.692 7.37 1449 41 4004200 225.7618 162.3414 389.241 298.998 7.21 1321 266800 66.825 96.192 42 269300 3998400 366.2307 85.05 70.14 399.6096 506.226 286.794 7.86 1699

Table 616: Data table of physicochemical parameters