A comparative study on the performance of NSFWQI$_m$ and IRWQI$_{sc}$ in water quality assessment of Sefidroud River in northern Iran

G. Ebraheim · M. Hasani Zonoozi · M. Saeedi

Abstract Local water quality indices (WQIs) are usually developed by modifying internationally recognized indices, which are considered reference index. In previous works on WQIs, the performance of local and reference indices has not been compared with each other. Therefore, the question crosses the mind whether using local or international indicators individually can show all qualitative aspects of a water resource. In this study, it was aimed to make this comparison between NSFWQI$_m$ (National Sanitation Foundation Water Quality Index) as the reference index and IRWQI$_{sc}$ (Iranian Water Quality Index for Surface Water Resource-Conventional Parameters) as the local one through a case study (Sefidroud River in northern Iran). Based on the results, the indices' performance in representing the seasonal and spatial fluctuations of the river water quality was almost similar. However, the water quality scores obtained by the two indices were somewhat different. Based on NSFWQI$_m$, the average water quality score of the river was about 49.0, by which the water was categorized in "bad" class, while IRWQI$_{sc}$ represented an average score of 56.1, which corresponds to "fairly good" class. Therefore, NSFWQI$_m$ identified the water quality with stricter criteria than IRWQI$_{sc}$, regarding the public health. On the other hand, according to relative standard deviations (0.17 for NSFWQI$_m$, 0.21 for IRWQI$_{sc}$) of the obtained water qualities, IRWQI$_{sc}$ better distinguished between high and low water qualities of the river. Accordingly, in order to better interpret the quality conditions of surface water resources in Iran, it is necessary to use both indices since NSFWQI$_m$ (reference index) attracts attention to stricter international standards and requirements, while IRWQI$_{sc}$ (local index) causes more focus on seasons or locations with the worst water quality.

G. Ebraheim · M. H. Zonoozi (✉) · M. Saeedi
Department of Civil Engineering, Iran University of Science and Technology (IUST), Narmak, Tehran 16846-13114, Iran
e-mail: mhzonoozi@iust.ac.ir

G. Ebraheim
e-mail: ebraheim.ghazal@gmail.com

M. Saeedi
e-mail: msaeedi@iust.ac.ir

Introduction

Water resources are essential for common urban activities and agricultural, industrial, and recreational uses. Increase in water demand by the ever increasing population; release of huge amounts of pollutants from agricultural, industrial, and urban areas into the natural water bodies; and frequent drought periods are considered the main causes of the water scarcity and contamination (Alexakis et al. 2012; Cerqueira et al. 2020). Usage of polluted water for various purposes can result in destructive effects on human health, depending upon the pollution level. Besides, water pollution and depletion of dissolved oxygen concentration can severely

disturb the biological activities of aquatic ecosystems. Therefore, analysis of water quality and evaluation of polluting factors is of high importance for water resources.

In this regard, Water Quality Indices (WQIs) have been developed and applied as useful tools for monitoring and evaluating the quality of water resources. A WQI collects and integrates various physical, chemical, and biological water quality parameters into a single dimensionless number which reflects the water status (Saeedi et al. 2010; Ewaid et al. 2018). Water quality classification using WQIs helps the researchers to assess the effects of the entering pollutants which finally makes it possible for the decision- and policy-makers to manage and develop water resources more effectively and sustainably and directs them to select a proper source of water for a special use, as well (Saeedi et al. 2010; Alexakis et al. 2012; Ewaid et al. 2018). These indices are also useful for the purpose of comparing the quality of water resources (Saeedi et al. 2010). Large number of water quality indices has been formulated all over the world during the last decades. In this regard, the US National Sanitation Foundation Water Quality Index (NSFWQI) (Brown et al. 1970), Oregon Water Quality Index (OWQI) (Dunnette 1979), Smith index (Smith 1990), Wilcox index (Wilcox 1948), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) (CCME 2001), and many others can be mentioned. Each index has its own parameters, parameters' weights, and aggregation formula according to which, unique applications can be defined for the index. For example, NSFWQI and Oregon indices are applied for the general assessment of the state of water quality (Terrado et al. 2010; Sutadian et al. 2016). CCMEWQI in its original format is applied for general water quality assessment (Terrado et al. 2010; Sutadian et al. 2016). Later modified versions of CCMEWQI are developed for specific uses such as assessing impact of forestry related activities on water quality, suitability for drinking water supply, and aquaculture (Sutadian et al. 2016). Smith index is also used for specific purposes including assessing suitability for bathing, fish spawning, and water supply (Terrado et al. 2010; Sutadian et al. 2016), and Wilcox index evaluates the water quality for irrigation use (Wilcox 1948). Among all developed indices, NSFWQI is known as a universal and generally applicable index which has been widely used by specialists for classification of surface water resources under the patronage of its comprehensiveness, ease of use,

and less complexity (Baghapour and Shooshtarian 2017; Noori et al. 2019).

Up until present, several researches regarding water resource quality have been performed using WQIs. Some of these studies are based on the pre-developed indices and some others are about to generate updated versions of the pre-developed indices to suit them for specific local conditions. Akkoyunlu and Akiner (2012), in a part of their research, investigated the stream water quality in Sapanca Lake Basin (Turkey) using NSFWQI, CCMEWQI, and OWQI. They found CCMEWQI and OWQI highly pessimistic in the prediction of the rivers' water quality. As they described, NSFWQI was more appropriate than the two others for reflecting the water quality of the rivers in their study area (Akkoyunlu and Akiner 2012). Hoseinzadeh et al. (2015) investigated the water quality in Aydughmush River in Iran at eight stations for 1 year using NSFWQI and FWQI (Forestry Water Quality Index). As they explained, the water quality in most stations was classified as "medium class" and "borderline class," respectively (Hoseinzadeh et al. 2015). Medeiros et al. (2017) assessed the quality of Amazonian rivers (Brazil) in industrial areas using NSFWQI. They described that the Arapiranga River was more preserved than the Murucupi River, due to its less-inhabited environment and further distance from the urban and industrial areas (Medeiros et al. 2017). Terrado et al. (2010) compared five indices including NSFWQI and CCMEWQI for the physico-chemical evaluation of a surface water body according to data from automated sampling networks. They found CCMEWQI as the most suitable index due to its flexibility in selecting parameters and the possibility of modifying the objectives to be met by each variable according to the specific end use of the water (Terrado et al. 2010). Gao et al. (2016) also used CCMEQWI to assess the water quality status of Three Gorges Reservoir, China. Their results showed that the state of the reservoir water quality was intricate but stable and acceptable between 2008 and 2013 (Gao et al. 2016). Gikas et al. (2020) comparatively applied the CCMEWQI and the Water Framework Directive (WFD) methodology, proposed by the Ministry of Environment and Energy of Greece (WFDMEEG), to evaluate the chemical status of a major transboundary river. As they reported, the WFDMEEG methodology classified the river water quality as "good," while based on CCMEWQI, the quality ranged between "marginal" and "good" category. Therefore, Gikas et al. (2020)

concluded that CCMEWQI was stricter than WFDMEEG. Tiri and Boudoukha (2010) investigated the water quality of the Koudiat Medouar dam in Algeria for agricultural usages on the basis of Wilcox index and showed that the water quality was changed between high salinity and low sodium hazard to medium salinity and low sodium hazard. They categorized the water as the low water quality for agricultural purposes and attributed this almost low quality to the type of rocks of the studied basin and high levels of nitrate, ammonium, and sodium due to urban pollution (Tiri and Boudoukha 2010). Alexakis (2011) used the Piper trilinear diagram, the US Salinity Laboratory diagram, and the Wilcox diagram to assess surface and ground water quality in the Messolonghi-Etoliko and Neochorio region (West Greece) for irrigation uses. By comparing the values of the water quality parameters with the water quality limits established by Canadian Council of Minister of the Environment, Alexakis (2011) concluded that 75% of the surface water and that all the groundwater samples were chemically suitable for irrigation use.

As there is no worldwide-accepted methodology for developing a WQI, the development of precise indices that suit specific local conditions and regional water quality requirements has always been of great interest (Sutadian et al. 2016). Due to a lot of subjectivity and uncertainty involved in the steps for developing and applying a WQI, Sutadian et al. (2016) recommended that the opinion of local water quality experts is taken. In this regard, some local indices are developed on the basis of pre-developed internationally recognized indices as reference indices. NSFWQI is one of these reference indices based on which most of the water quality indices have been developed (Said et al. 2004; Şener et al. 2017). For example, Akkoyunlu and Akiner (2012) prepared a modified WQI adopted particularly from NSFQWI to assess the stream water quality in Sapanca Lake Basin (Turkey). They aimed to decrease the number of pollution parameters and to reduce the money required to measure them, as well. For this reason, they generated a new index called WQI_{min} (minimum) using a least number of the most predominant or easily measurable parameters and also developed an alternative index, named WQI_{eut} (eutrophication) using eutrophication related parameters (Akkoyunlu and Akiner 2012). A modified version of NSFWQI has also been applied in India. The modification was performed through changing weights and the equation for the sub-indices (MPCB 2014). IRWQI$_{sc}$

(Iranian Water Quality Index for Surface Water Resource-Conventional Parameters) is another local WQI which has been developed on the basis of NSFWQI and is commonly used in Iran (Aazami et al. 2015; Baghapour and Shooshtarian 2017).

IRWQI$_{sc}$ has been used by some researchers to assess the quality status of Iran's water resources. Hamedi et al. (2015) used IRWQI$_{sc}$ to evaluate the effects of urban pollutants on the water quality of Sorkhe-Hessar Watercourse, a big urban watercourse in southeast of Tehran, Iran. As they reported, the water quality score of the watercourse was 15–29.9 showing poor qualitative conditions (Hamedi et al. 2015). Samadi (2016) studied the pollution and spatial-temporal impact of land use wastewaters on water quality of Choghakhor wetland in Chahar-Mahal Bakhtiari province, Iran, using IRWQI$_{sc}$. According to their results, IRWQI$_{sc}$ represented an annual average score of 70, corresponding to "fairly good" status, for the wetland (Samadi 2016). Makhlough et al. (2017) investigated the water quality of Azad Dam in Sanandaj (Iran) using IRWQI$_{sc}$ which classified the water quality as an "Excellent" class.

Although the development and use of local indices has become very common, using them regardless of their reference indices will not be reassuring. According to our best knowledge, in the previous works on water quality indices, comparison between the performance of local indices and their reference international indices has not been made. Therefore, the questions that remain unanswered are either whether using only local or international indicators alone is adequate or whether it can show all the qualitative aspects of a water resource and helps the decision-makers to better manage their local water resources. Accordingly, making a precise comparison between local and reference indices using appropriate methods would be of high importance. Regarding the mentioned gap in the literature, it was aimed, in the present study, to precisely investigate the subject through a case study (Sefidroud River in northern Iran) by using NSFWQI as the reference index and IRWQI$_{sc}$ as the local one, with the same aggregation formula for both indices. The two indices were compared in terms of their performance in describing the river water quality, their strictness, and their capability of discriminating between high and low water qualities. For this purpose, the Sefidroud River water quality was calculated according to both indices for four seasons and four stations located on the river. The average and the relative standard deviation (RSD) values of the indices,

the entropy weight of the parameters, the overall data entropy effect (DEE), and the overall effect of sub-indices changing rates (ESCR) on the indices values were estimated and discussed in details.

Materials and methods

Study area

Sefidroud River is one of the largest and most important surface water resources in northern Iran. This river, which is formed by the confluence of the rivers Qezelowzan and Shahroud at the north slope of the Alborz mountain system, finally enters the Caspian Sea (Fig. 1). The river is located in Gilan province which is limited to the Caspian Sea from north, Ardebil province from west, Zanjan and Qazvin provinces from the south, and Mazandaran province from the east. The river catchment area between the Sefidroud Dam and its discharge point to the Caspian Sea is about 980 km^2 (Noori et al. 2019).

Several point and non-point sources of pollution are located within the river catchment area. Agricultural fields, rice fields in particular, are the main non-point sources from which large quantities of drainage water are discharged into the river body. The most important point sources of pollution include industrial and residential effluents from riverside industrial and urban areas. The dominant industries located within the river catchment area are textile, leather, food, cellulose, and metallic and non-metallic minerals (Mirmoshtaghi et al. 2011; Jamshidi et al. 2016; Mahab Ghodss Co., 2010). Release of different types of pollutants from these point and non-point sources deteriorates the river water quality and makes it a high priority to assess the river water quality (Noori et al. 2019). The present study was conducted based on a previously performed research (Moravatdoust Anarkoli et al. 2015) on a 35-km span of the Sefidroud River between outlet of Sefidroud Dam and a place right after Rustamabad, close to Tarik Dam.

Data of water quality parameters

The data of the water quality were adopted from the previous research (Moravatdoust Anarkoli et al. 2015) in which four sampling stations have been selected and studied. The sampling stations have been located over 35 km along the Sefidroud River between outlet of

Sefidroud dam and the point after Rustamabad village, close to Tarik Dam. Samples were taken during four seasons of the year 2013. The location of the study area and the information of the sampling stations are presented in Fig. 1. The flow rate values for the four stations are presented in Table 1 (Moravatdoust Anarkoli et al. 2015).

Water quality indices

In this study, NSFWQI and IRWQI$_{sc}$ were selected as the water quality indices to investigate the overall water quality of Sefidroud River and to compare the performance of the indices as well. The indices are briefly introduced below.

NSFWQI

The NSFWQI is among the earliest and most widely used indices for the general assessment of the state of water quality (Alexakis et al. 2016; Sutadian et al. 2016). For the original NSFWQI, (NSFWQI$_a$, Eq. 1) weighted arithmetic mean was used for index aggregation. But due to the eclipsing problem of the arithmetic formulation, the multiplicative aggregation (weighted geometric mean) was used in the modified NSFWQI (NSFWQI$_m$, Eq. 2) (Sutadian et al. 2016). The 9 parameters involving NSFWQI and their weights are presented in Table 2 (Sutadian et al. 2016).

$$\text{NSFWQI}_a = \sum_{i=1}^{n} I_i W_i \tag{1}$$

$$\text{NSFWQI}_m = \prod_{i=1}^{n} I_i^{W_i} \tag{2}$$

$$\sum_{i=1}^{n} W_i = 1 \tag{3}$$

$$0 \leq I_i \leq 100 \tag{4}$$

where I_i and W_i are the sub-index value and the weight coefficient of the parameter i, respectively, and n is the number of water quality parameters. To calculate the NSFWQI$_m$ values, the sub-index value of each parameter was determined using the sub-index rating curves of the NSFWQI$_m$ available in previous reports (Singh and Saxena 2018). After calculating the index value for 4 stations and 4 seasons, the final index interpretation with the aim of grading the water quality was performed
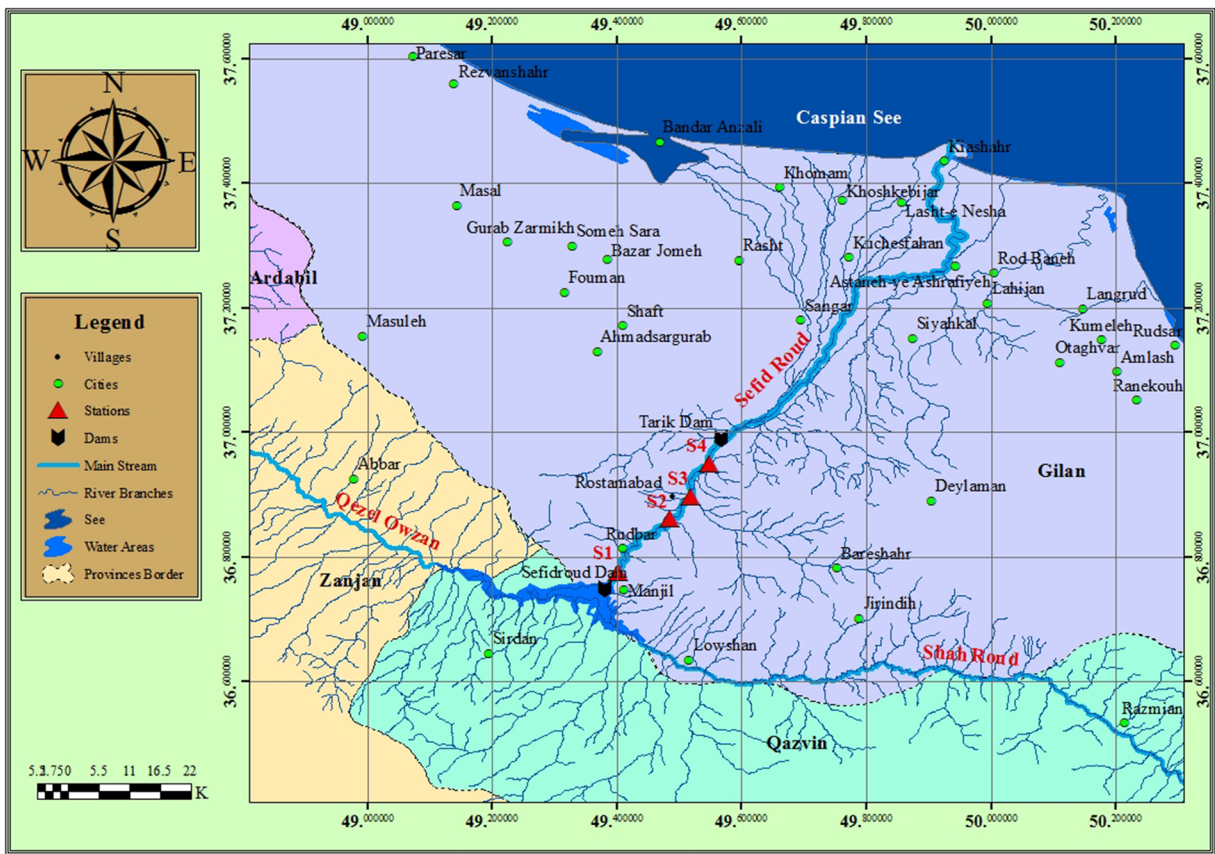
Fig. 1 Location of Sefidroud River in northern Iran and sampling stations

according to the previously suggested classification of the index scores (Table 3) (Sutadian et al. 2016).

IRWQI$_{sc}$

IRWQI$_{sc}$ was developed by the Department of Environment of Iran through modifying the NSFWQI according to the local condition of Iran in order to assess general

water quality of domestic resources (Sutadian et al. 2016; Baghapour and Shooshtarian 2017). Eleven water quality parameters (Table 2) have been aggregated to

Table 1 Flow rate values in the year of study (according to Moravatdoust Anarkoli et al. 2015)

Sampling points	Flow rate (m^3/s)				
	Spring	Summer	Fall	Winter	Average
Station 1	121.97	54.24	9.86	18.13	51.05
Station 2	119.43	54.43	14.08	20.16	52.03
Station 3	117.9	54.93	23.93	24.91	55.42
Station 4	114.74	55.22	28.72	27.12	56.45
Average	118.51	54.71	19.15	22.58	

Table 2 Water quality parameters and parameter weights according to NSFWQI$_m$ and IRWQI$_{sc}$

NSFWQI$_m$		IRWQI$_{sc}$	
Parameter	Parameter weight	Parameter	Parameter weight
DO$_{sat}$	0.17	DO$_{sat}$	0.097
pH	0.11	pH	0.051
Turbidity	0.08	Turbidity	0.062
Nitrate	0.1	Nitrate	0.108
Phosphate	0.1	Ammonium	0.090
FC	0.16	Phosphate	0.087
BOD	0.11	FC	0.14
TS	0.07	BOD	0.117
T	0.1	COD	0.093
		EC	0.096
		TH	0.059

form the IRWQI$_{sc}$ structure (Eq. 5). According to the index formulation and as described in Guideline for Calculating Water Quality Index in Iran (DOE) n.d.), in case the numbers of parameters measured are less than 11 parameters presented in Table 2, Eq. 5 is applicable and does not require any correction.

$$\mathrm{IRWQI_{SC}} = \left[\prod_{i=1}^{n} I_i^{W_i}\right]^{\frac{1}{\gamma}} \qquad (5)$$

$$\gamma = \sum_{i=1}^{n} W_i \qquad (6)$$

$$0 \le I_i \le 100 \qquad (7)$$

where I_i and W_i are the sub-index value and the weight coefficient of the parameter i, respectively; γ is the sum of the weights; and n is the number of water quality parameters. The sub-index values were determined using the sub-index rating curves of the IRWQI$_{sc}$ presented by the Department of Environment (DOE) of Iran. The classification of the index scores for grading the water quality is presented in Table 3.

Comparison of the water quality indices

Relative standard deviation

As the first comparison measure, relative standard deviation (RSD) was used to calculate the relative variability of the indices. The RSD values of the water qualities obtained by the indices distinguish the more robust index with higher capability of discriminating between high and low water qualities. The formulas of standard deviation (SD) and relative standard deviation (RSD) are presented as follows:

$$\mathrm{SD} = \sqrt{\frac{\sum_{j=1}^{N} \left(x_j - \bar{x}\right)^2}{N+1}} \qquad (8)$$

$$\mathrm{RSD} = \frac{\mathrm{SD}}{\bar{x}} \qquad (9)$$

where x_j represents the calculated values for a specific index, $\bar{x}$ is the mean value of the index, and N is the number of calculated values for the index.

Shannon entropy analysis

As another comparison method, Shannon entropy analysis (Shannon 1948) was performed on the water quality parameters included in the indices to determine the uncertainty amount of each parameter and subsequently to evaluate the overall data entropy effect (DEE) on the indices' values. The steps for calculating entropy values of the parameters are the same as described by Ding and Shi (2005). Assuming m water samples ($i = 1, 2, …, m$) and n quality parameters ($j = 1, 2, …, n$), eigenvalue matrix X can be constructed as follows:

$$X = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \qquad (10)$$

In order to eliminate the impact of difference of various units and various ranges of parameters, the parameter values in matrix X should be normalized by using the normalization function presented in Eq. 11. After this transformation, the standard-grade matrix Y (Eq. 12) can be obtained.

$$Y_{ij} = \frac{x_{ij} - \left(\min x_{ij}\right)_i}{\left(\max x_{ij}\right)_i - \left(\min x_{ij}\right)_i} \qquad (11)$$

$$Y = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{m1} & \cdots & Y_{mn} \end{bmatrix}, Y_{ij} \in [0, 1] \qquad (12)$$

By defining P_{ij} as the ratio of the jth parameter value in ith sample (Eq. 13), the information entropy of each parameter (e_j) can be calculated as follows:

Table 3 Water quality classification according to NSFWQI$_m$ and IRWQI$_{sc}$

NSFWQI$_m$		IRWQI$_{sc}$	
Score	Classification	Score	Classification
0–24	Very bad	Less than 15	Very bad
25–49	Bad	15–29.9	Bad
50–69	Medium	30–44.9	Relatively bad
70–89	Good	45–55	Moderate
90–100	Excellent	55.1–70	Relatively good
0–24	Very bad	70.1–85	Good
25–49	Bad	More than 85	Very good
50–69	Medium	Less than 15	Very bad

$$P_{ij} = y_{ij} / \sum_{i=1}^{m} y_{ij} \tag{13}$$

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} P_{ij} \ln P_{ij} \tag{14}$$

The smaller value of e_j corresponds to the more uncertainty and consequently higher effect of parameter j (Ding and Shi 2005). The entropy weight of the parameter j (EW_j) can be calculated using Eq. 15.

$$EW_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} \tag{15}$$

Overall data entropy effect

The overall data entropy effect (DEE) on the indices' values was estimated according to the following procedure:

$$RPW_i = \frac{PW_i}{\sum_{i=1}^{n} PW_i} \tag{16}$$

$$DEE = \prod_{i=1}^{n} EW_i^{RPW_i} \tag{17}$$

In the above equations, RPW_i is the relative weight of parameter i. The greater the relative weight of the parameters with higher entropy weight, the greater the ability of the index to distinguish between high and low water qualities.

Overall effect of sub-indices changing rates

To determine the overall effect of sub-indices changing rates (ESCR), the normalized changing rate of the sub-indices (NCR, changing rate of sub-indices versus the changes of the corresponding parameters) was first calculated according to Eq. 18. Then ESCR was calculated using Eq. 19.

$$NCR_i = abs \left[\frac{I_{i(max)} - I_{i(min)}}{P_{I_{i(max)}} - P_{I_{i(min)}}} \right] \tag{18}$$

where $I_{i(max)}$ and $I_{i(min)}$ are respectively the highest and the lowest obtained values of sub-index i and $P_{I_{i(max)}}$ and $P_{I_{i(min)}}$ are the corresponding parameter values.

$$ESCR = \prod_{i=1}^{n} NCR_i^{RPW_i} \tag{19}$$

To better understand the concept of the NCR, a schematic is presented in Fig. 2. As seen, the NCR for the sub-index of index A is $\frac{58}{6}$, while it is $\frac{68}{6}$ for index B. Therefore, sub-index of index B has a higher normalized changing rate which lets it to better discriminate between high and low water qualities.

Results and discussion

Evaluation of Sefidroud River quality according to $NSFWQI_m$ and $IRWQI_{sc}$

Ten qualitative parameters which include turbidity, pH, TDS, SS, BOD, nitrate, phosphate, fecal coliform, DO, and temperature were accessible using which the indices could be calculated. The results of $NSFWQI_m$ and $IRWQI_{sc}$ water quality indices for four stations of Sefidroud River are presented in Fig. 3. According to $NSFWQI_m$ and $IRWQI_{sc}$ indices, the average water quality score of Sefidroud River was about 49.0 and 56.1, which are categorized in bad and fairly good classes, respectively. According to both indices, station 1 (outlet of Sefidroud Dam) and station 3 (after Rustamabad village) represented the highest and the lowest average index values. Besides, according to both indices, the highest qualities belonged to spring and winter depending upon the station, while fall season demonstrated the worst water quality mostly due to the higher levels of turbidity and fecal coliform in this season. The water quality for fall season in all stations
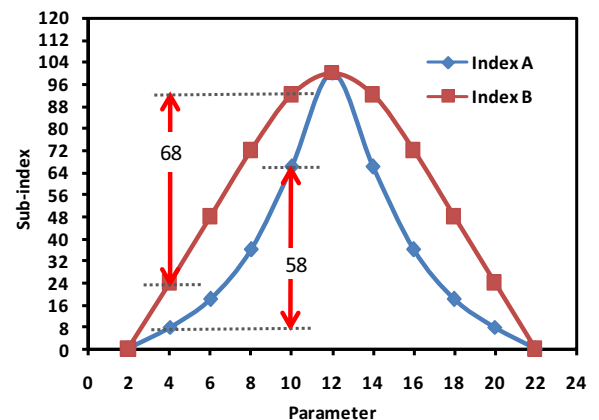

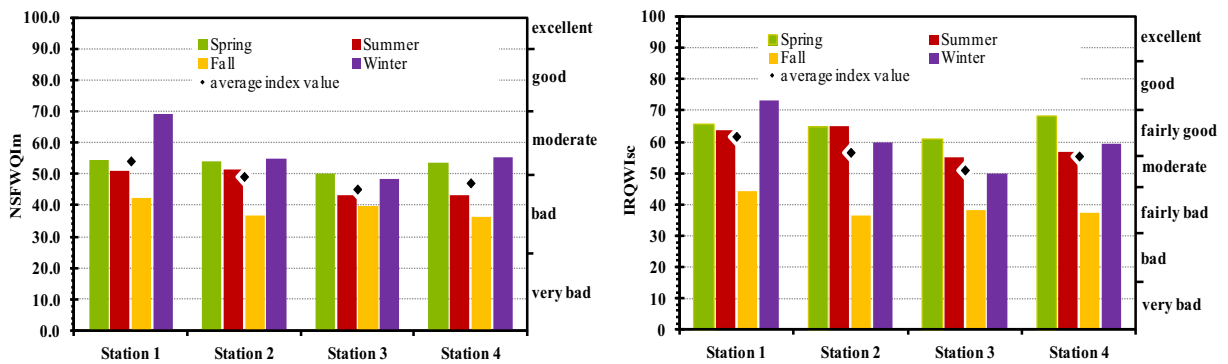**Fig. 2** Schematic for concept of NCR

Fig. 3 Sefidroud River water quality at four stations according to NSFWQI$_m$ and IRWQI$_{sc}$

was classified in the bad and fairly bad categories according to NSFWQI$_m$ and IRWQI$_{sc}$, respectively. Ewaid et al. (2018) who investigated the Tigris River water quality within Baghdad (Iraq) reported that the worst water qualities were recorded during winter and spring and the best qualities belonged to summer and fall. They also attributed the low water quality in the mentioned seasons to the higher values of turbidity in the water (Ewaid et al. 2018). The difference between the results of the two studies, according to which the introduced seasons with the worst quality was various, might be attributed to the source of the turbidity in the river.

Based on the results, the indices performed almost similar in representation of the overall changing trends of the river water quality vs. season and station. However, much more optimistic water quality score and classifications were obtained using IRWQI$_{sc}$. In other words, NSFWQI$_m$ was stricter and much more conservative than the IRWQI$_{sc}$ regarding the public health. In general, the difference between the final scores obtained by using the two indices depends simultaneously on three factors including type of parameters involved in the indices' formula, weights of the parameters, and corresponding values of the sub-indices. It seems that the most important factor that has caused the difference in the scores obtained by NSFWQI$_m$ and IRWQI$_{sc}$ is the existence of temperature and turbidity parameters in NSFWQI$_m$ and the fact that the mean sub-index value of both parameters is very low (equal to 30.8 and 20, respectively). According to the calculations made by the authors, by removing these two parameters from NSFWQI$_m$, the scores from the two indices become very close together. Therefore, the absence of these two parameters in the IRWQI$_{sc}$ is a major reason for the difference in scores obtained by the two indices.

It is also worth mentioning that even if the same average scores (e.g., 49.0) was obtained by the two indices the Iranian index would still categorize the water quality in a higher class (moderate for IRWQI$_{sc}$ against bad for NSFWQI$_m$). This is because of the differences in the descriptive classification of the two indices. Lumb et al. (2011) who compared some WQIs in the United States of America (USA) and Canada explained that not only the yielded scores of the WQIs but also the classification of the index scores influence the final description of water quality and determination of its suitability for a particular use (Lumb et al. 2011).

Another functional difference between the two indices is their ability for discriminating between high and low water qualities. This can be realized from Fig. 3 according to which, IRWQI$_{sc}$ exhibited higher index values for spring, summer, and winter while lower index values for fall, compared with NSFWQI$_m$. In order to make more clarifications, average index values, standard deviations (SD) and relative standard deviations (RSD) of the individual stations, and the total data were calculated for each index and presented in Table 4. As seen, the RSD values of the data from stations 2, 3, and 4 and the mean RSD of the total data are comparatively larger for IRWQI$_{sc}$. This indicates that IRWQI$_{sc}$ better distinguishes between high and low water qualities of the river. The mentioned characteristic, which can be considered a blessing of the IRWQI$_{sc}$, leads to focus more precisely on the season or the location with the worst water quality. As there is no worldwide consensus on the methodology for implementing the steps used for constructing WQIs regarding the selection of parameters, generation of sub-index values, generation of parameter weights, and final index aggregation process (Sutadian et al. 2016), such functional differences of the indices are inevitable.

Table 4 Average index values, standard deviations, and relative standard deviations of the index values for NSFWQI and IRWQI$_{sc}$

Index	Parameter	Location				Total data
		Station 1	Station 2	Station 3	Station 4	
NSFWQI$_m$	Average index value	54.2	49.3	45.3	47.2	49.0
	SD	11.24	8.47	4.79	8.93	8.49
	RSD	0.21	0.17	0.11	0.19	0.17
IRWQI$_{sc}$	Average index value	61.7	56.6	50.9	55.4	56.1
	SD	12.32	13.60	9.54	13.18	11.66
	RSD	0.20	0.24	0.19	0.24	0.21

The indices' ability to distinguish between high and low water qualities can be mainly attributed to two factors: First, the scatteredness of each parameter besides the amplifying effect of the corresponding relative parameter weight (RPW), and second, the changing rate of each sub-index versus the changes of the corresponding parameter (normalized changing rate, NCR). These factors are discussed in details in the "Analysis of information entropy" section and the "Normalized changing rate of the indices" section, respectively.

Analysis of information entropy

Shannon entropy analysis was performed in order to determine the parameters with the highest scatteredness and to find out if the data entropy was one of the influencing factors on the indices ability to discriminate between low and high water qualities as well. The entropy values of all used parameters are illustrated in Fig. 4. Besides, the entropy weights of parameters for

both NSFWQI$_m$ and IRWQI$_{sc}$ are presented in Fig. 5. As seen in Fig. 4, turbidity, TS, FC, TP, and nitrate, respectively represented the lowest values of data entropy. Putting together Figs. 4 and 5, it can be found the lower the data entropy, the higher the data scatteredness, and entropy weight.

To estimate the overall data entropy effect on the indices' values, DEE was calculated for each index according to the pre-explained procedure ("Overall data entropy effect" section). As seen in Table 5, the DEE is slightly larger for the IRWQI$_{sc}$ (0.110) compared with the NSFWQI$_m$ (0.089). Therefore, it can be concluded that assigning higher RPWs to the parameters with higher EWs is one of the reasons that the IRWQI$_{sc}$ performed better in discriminating between low and high water qualities ($\frac{0.110}{0.089} = 1.24$). In developing conventional WQIs, assignment of weights to parameters is carried out on the basis of personal judgments and expert opinion (Amiri et al. 2014; Fagbote et al. 2014; Singh et al. 2019). This can be considered the main

Fig. 4 The entropy values of the used parameters in NSFWQI and IRWQI$_{sc}$
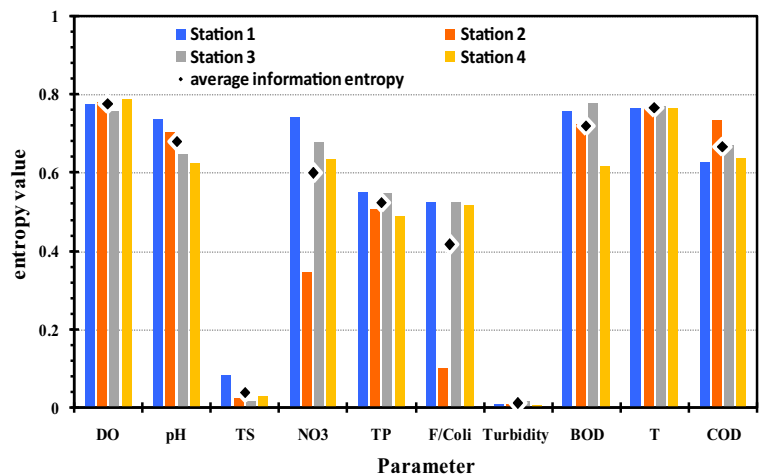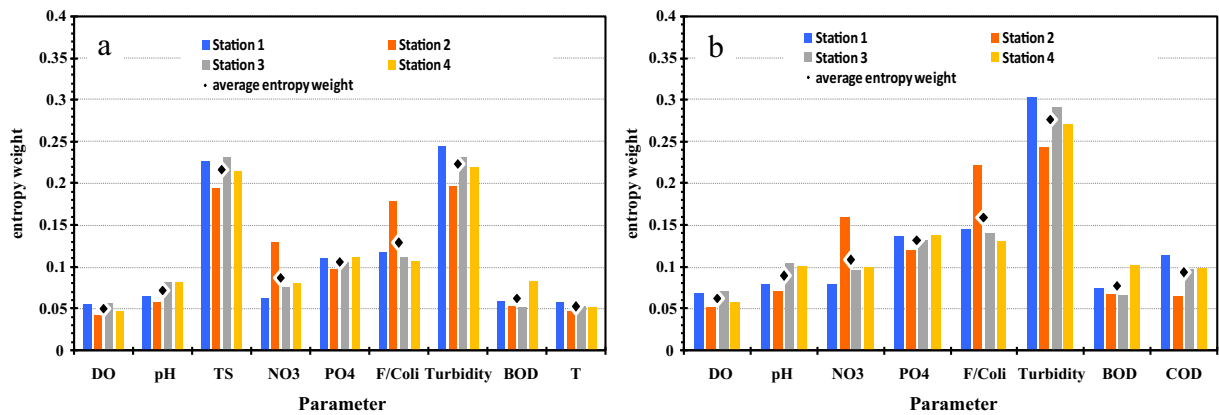
Fig 5 The entropy weights of the used parameters in NSFWQI (**a**) and IRWQI$_{sc}$ (**b**)

reason for obtaining different values for the data entropy effect for the two indices.

Normalized changing rate of the indices

After determining the highest and the lowest values of each sub-index and the corresponding parameter values, the normalized changing rates of the sub-indices (NCR) and their weighted values (NCR^{RPW}) were calculated and presented in Table 6. The overall effect of the sub-indices changing rates (ESCR) on the indices values was estimated by the geometric mean of the weighted NCRs. As seen in the table, the ESCR for IRWQI$_{sc}$ is 1.146

which is higher than that of NSFWQI$_m$ (0.732). It can be even concluded that the changing rate of the sub-indices affected the indices' values more severely than the entropy weight of the parameters, in terms of their ability in discriminating between low and high qualities ($\frac{1.146}{0.732} = 1.57$).

Conclusion

The main aim of the present work was to precisely investigate and compare the performance of IRWQI$_{sc}$ as the local index and the NSFWQI$_m$ as the reference

Table 5 Calculation of DEE

Index		Parameter									
		DO$_{sat}$	pH	TS	Nitrate	TP	FC	Turbidity	BOD	T	COD
NSFWQI$_m$	PW$_i$	0.17	0.11	0.07	0.1	0.1	0.16	0.08	0.11	0.1	-
	RPW$_i$	0.17	0.11	0.07	0.1	0.1	0.16	0.08	0.11	0.1	-
	EW$_i$	0.050	0.072	0.216	0.088	0.107	0.129	0.223	0.063	0.052	-
	EW$_i$ ^{RPW_i}	0.602	0.749	0.898	0.784	0.799	0.720	0.887	0.737	0.745	-
	DEE $= \prod_{i=1}^{n}$ EW$_i$ ^{RPW_i}	0.089									
IRWQI$_{sc}$	PW$_i$	0.097	0.051	-	0.108	0.087	0.14	0.062	0.117	-	0.093
	RPW$_i$	0.128	0.068	-	0.143	0.115	0.185	0.082	0.155	-	0.123
	EW$_i$	0.063	0.089	-	0.109	0.132	0.159	0.277	0.077	-	0.094
	EW$_i$ ^{RPW_i}	0.701	0.849	-	0.728	0.792	0.712	0.900	0.673	-	0.747
	DEE $= \prod_{i=1}^{n}$ EW$_i$ ^{RPW_i}	0.110									

Table 6 Calculation of ESCR

Index			DO_{sat}	pH	TS	Nitrate	TP	FC	Turbidity	BOD	T	COD
$NSFWQI_m$	Sub-index$_i$	Min. value	99	60	20	93	56	10	5	34	16	-
		Max. value	94	87	20	96	100	65	69	95	56	-
	Corresponding parameters		100.5	8.67	553.5	1.276	0.581	11,826	4344	10	24.3	-
			112.78	7.89	54,857	2.396	0.006	17	13.96	1	7.93	-
	NCR$_i$		0.407	34.62	N.A	2.68	76.5	0.0047	0.00148	6.78	2.44	-
			0.858	1.477	N.A	1.104	1.543	0.424	0.594	1.234	1.093	-
	NCR$_i$ ^{RPW_i}											
	$ESCR = \prod_{i=1}^{n} NCR_i^{\ RPW_i}$		0.732									
$IRWQI_{sc}$	Sub-index$_i$	Min. value	99	53	-	70	33	12	2	35	-	48
		Max. value	89	96	-	52	100	88	65	96	-	87
	Corresponding parameters		100.5	8.67	-	1.276	0.581	11,826	4344	10	-	27
			91.00	8.01	-	2.396	0.006	17	13.96	1	-	5.6
	NCR$_i$		1.052	65.15	-	16.07	116.5	0.0064	0.00145	6.78	-	1.822
	NCR$_i$ ^{RPW_i}		1.007	1.328	-	1.488	1.728	0.393	0.585	1.345	-	1.077
	$ESCR = \prod_{i=1}^{n} NCR_i^{\ RPW_i}$		1.146									

one in evaluating the Sefidroud River water quality for general uses. According to the obtained results using both indices, stations 1 and 3 showed the highest and the lowest average annual quality, respectively. Besides, fall season showed the worst water quality, while the highest qualities belonged to spring and winter, depending upon the station. Therefore, the indices had similar performance in determining the overall trend of seasonal and spatial changes in water quality. On the other hand, $NSFWQI_m$ identified the water quality with a stricter and more conservative measure regarding the public health, because $NSFWQI_m$ put water quality in a lower class compared with $IRWQI_{sc}$ (bad versus fairly good, respectively). From another point of view, $IRWQI_{sc}$ better distinguished between high and low water qualities of the river as it exhibited higher index values for spring, summer, and winter while lower index values for fall, compared with $NSFWQI_m$. Better performance of $IRWQI_{sc}$ in discriminating between low and high water qualities was mostly attributed to higher values of both DEE and ESCR for this index compared with $NSFWQI_m$. On the whole, to have a more comprehensive evaluation of the quality of surface water resources of Iran, both $NSFWQI_m$ and $IRWQI_{sc}$ are required. The former attracts the attention of decision-makers to stricter international standards and regulations and the latter causes more focus on the season or the location with the worst water quality.

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