



Establishing a Suitable Soil Quality Index for Semi-arid Rangeland Ecosystems in Northwest of Iran

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Abstract

Establishing soil quality index (SQI) is a common procedure in assessing soil capacity function. Various SQIs can be designed and used in soil evaluations upon the aspects including data set, efficiency, and sensitivity. This study was conducted to distinguish a representative soil minimum dataset (MDS) among 16 total dataset (TDS) properties in semi-arid rangeland ecosystems of north-west Iran. Appropriate SQIs were calculated applying the models of integrated quality index (IQI) and Nemoro quality index (NQI). IQI by simple additive and weighted additive approaches and also NQI were calculated for both MDS and TDS based on linear transformation of soil parameters. Totally, different SQIs including simple additive IQI, weighted additive IQI, and NQI were separately established to TDS and MDS. Sensitivity index (SI) and efficiency ratio (ER) of each SQI were then calculated for prioritizing and selecting suitable index. Principal component analysis (PCA) revealed that seven indicators are appropriate MDS for accounting 70.27% of data variations. Maximum and minimum SI belonged to MDS-NQI and TDS-weighted additive IQI, with values of 2.597 and 2.056, respectively. MDS-NQI has the highest value of ER (85.71), while TDS (both weighted and simple additive)-IQI has received the lowest value of ER (71.43). Final prioritizing according to ranks of SI and ER showed that MDS-NQI is the most suitable approach in soil quality assessment of semi-arid rangelands. Therefore, it could reduce cost due to measuring fewer indicators in the laboratory on contrary premise to have more dense soil samples in the field.

Keywords Soil quality index · Soil indicators · Minimum dataset · Principal components analysis · Rangelands

1 Introduction

Natural rangelands cover about half the area of Iran where they have economic, cultural, and environmental importance (Rezaei et al. 2006). The soil is the vital factor of rangeland

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ecosystems which has encountered various deterioration problems that attract the researcher’s attention (Stark et al. 2015). Soil erosion, productivity reduction, deprecation health of rangeland, and desertification are threats that happen in many regions as a result of non-proper utilization and greater demand on soil resources (Mofidi et al. 2013). In order to avoid the destruction of the environment and to facilitate proper management strategies, the determination of rangeland soil quality and capability is necessary. Therefore, in the recent years, public knowledge for finding out and evaluation of environmental changes have been quickly increased and the attempts are ongoing to obtain appropriate indicators for soil quality evaluation (Andrews et al. 2002a).

Although, various soil characteristics are known as available indicators, it is clear that interpreting a large number of properties may result in huge, complex, and confusing information (Marzaioli et al. 2010). On the other aspect, the soil indicators often include high correlation, also, their measurements are too expensive and time consuming, and finally, individual soil properties sometimes are not specific and adequate in determining rangeland soil capability and quality (Rezaei et al. 2006).

Bünemanna et al. (2018) expressed that explicit assessment of soil quality regarding particular soil hazards and soil services has rarely been applied, and numerable contexts support obvious explanation scheme of property values. Regarding the above-mentioned description, in practice, there is a need for comprehensive and science-based tools to monitor soil quality information. Based on usage, in standard procedures for choosing soil properties minimum data set (MDS) and integrating various indicators, it is possible to prepare the essential knowledge for rangeland managers to decide knowingly. Likewise, the soil quality indices might have sufficient susceptibility to display both temporal and spatial scales variation through various managements and environmental conditions (Nakajima et al. 2015).

In this regard, the term soil quality index (SQI) has been proposed and developed for simplifying soil analyzing outcomes (Andrews et al. 2002a). Soil quality implies to soil's potential to operate within an ecosystem, to strengthen biological chain, to provide resources quality, and to improve organism's safety (Doran and Parkin 1994). Establishing a SQI must include three steps of selection: a representative indicators set, scoring and standardizing candidate indicators, and finally, the combination or formulation of indicators into a SQI (Qi et al. 2009). Two kinds of data collection including total data set (TDS) and minimum data set (MDS) are applied in assessing soil quality. The TDS includes a series of indicators chosen based on particular soil analyzing scheme linking to soil functions, whereas the MDS is a set of indicators elected regarding statistical analysis (Andrews et al. 2002a). In current research, it is aimed to relate the contribution of soil quality to vegetation production, so soil properties were selected upon their effects on plant growth based on previous researches (Li et al. 2013; Zornoza et al. 2007). Various methods are used to score and combine the indicators into indices. In the scoring stage, indicators are transformed into unit less dimension by linear and nonlinear methods (Askari and Holden 2015). Also, many procedures including additive, multiplicative, and weighed mean techniques can be utilized to integrate dimensionless indicators into quality indices (Andrews et al. 2002a). These procedures can be calculated by the integrated quality index (IQI) and Nemoro quality index (NQI) methods (Qi et al. 2009).

The IQI index incorporates the weighted and unweighted (simple) values of all selected properties into a new index (Qi et al. 2009) using the SQI expanded by Doran and Parkin (1994). Unlikely, the NQI, introduced by Nemoro, is calculated from the minimum indicator and the average score, neglecting of their quota (Qi et al. 2009).

Findings revealed that the efficiency of various SQIs differs in the ecosystems and there is less research works in rangelands compared to cultivated and forest ecosystems (de Melo Filho et al. 2007). In spite of various soil quality assessment methods developed in former researches, there are fewer

attempts for establishing soil quality and selecting suitable soil quality index and sensitive index, especially in semi-arid rangelands. However, collecting the minimum data set indicators, scoring the indicators, formulation and selecting the suitable SQI remain as problems on the establishing SQI in natural ecosystems (Guo et al. 2017). Accordingly, it is necessary to develop an assessment tool for quantifying soil quality in semi-arid areas, such as the rangelands of northwest Iran. For this purpose, the objectives of the current study were the following: (i) to determine minimum data set indicators (MDS) among 16 total soil measurements dataset (TDS) for soil quality using PCA; (ii) to develop two soil quality indices including integrated soil quality (IQI) and Nemoro soil quality (NQI) applying two approaches of soil indicators in choosing (TDS and MDS); (iii) to select the most suitable and appropriate soil quality index using mathematical procedures of sensitivity index (SI) and efficiency ratio (ER) criteria.

2 Materials and Methods

2.1 Study Area and Soil Sampling

This study was done in natural semi-arid rangelands in northwest of Iran between $45^{\circ} 7'$ to $48^{\circ} 20'$ eastern longitude and $36^{\circ} 45'$ to $39^{\circ} 26'$ northern latitude (Fig. 1). All the sampling rangelands are traditionally used as grazing of sheep and goat. The 20-year annual average precipitation varies spatially from 220 to 350 mm. The mean yearly temperature in coldest area is -20°C while the mean yearly temperature in warmest area is 38°C . According to the De Martonne climate classification, the area has cold and arid to ultra-cold and semi-arid conditions (Iranian organization of forests, rangelands and watershed management 2004). Soil sampling was conducted in stratified random sampling scheme; points are assigned to predefined groups or strata and a simple random sample was chosen from each stratum (Carter and Gregorich 2008). For this purpose, based on heterogeneity of land units, landforms, and vegetation types as strata, a total of 98 mixed soil samples (0–30-cm depths) after removing the litter and humus layer of the ground surface were collected from rangeland sites during June to July (flowering period of dominant rangeland plants). They were then transported to the laboratory. To prepare mixed soil samples, three samples within 1000 m^2 of each rangeland sites were collected and then composited.

2.2 Soil Analysis

A set of 16 physical and chemical soil properties were measured. Soil pH was analyzed in a saturated soil paste, electrical conductivity (EC, dS m^{-1}) was obtained from an extract of

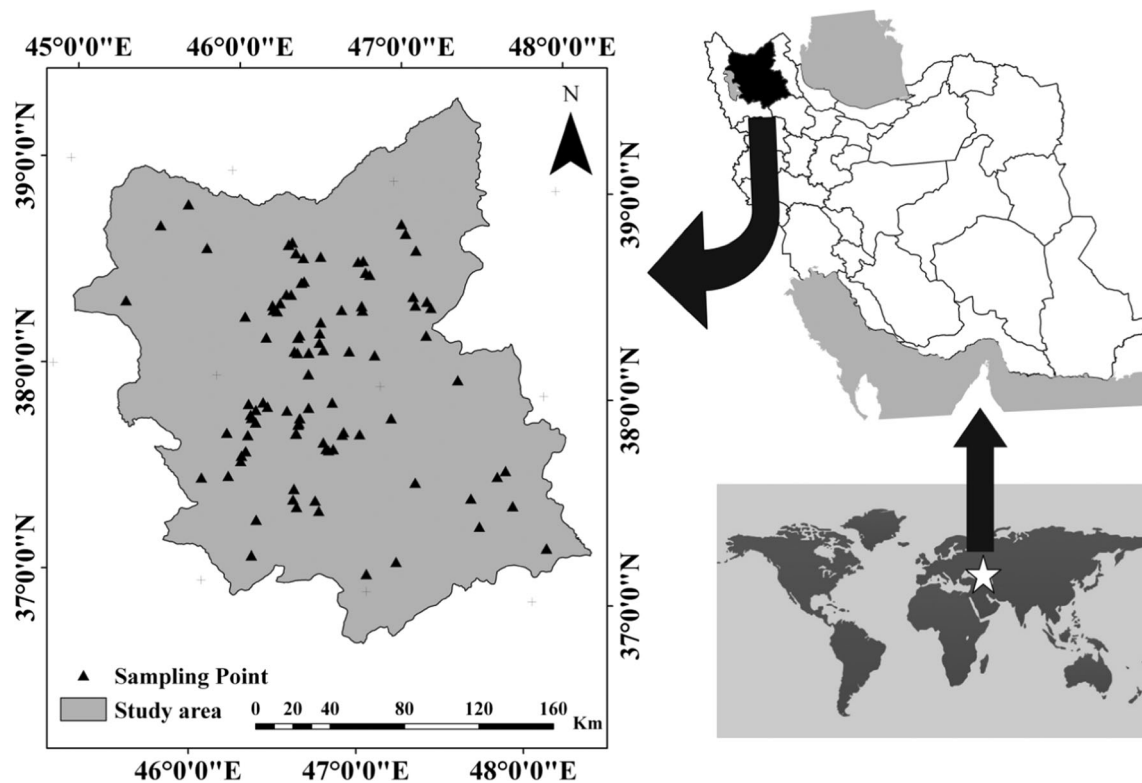


Fig. 1 Location of study area and sampling points

saturated soil paste. Fine particles size (clay, silt, and sand content, %) were determined by the Bouyoucos method (Gee and Or 2002). Soil rock fragment content (RF, %) was measured by sieving soil and separating and weighting particles larger than 2 mm. Soil organic matter (OM, %) was measured by wet oxidation method (Carter and Gregorich 2008). Cation exchange capacity (CEC, %) was determined by the method described by Carter and Gregorich (2008). Total nitrogen (TN, %) by the Kjeldahl method and then total nitrogen mass (TNM, $\text{gm}^{-2}\text{soil depth}^{-1}$) was calculated based on the procedure described by Ellert and Bettany (1995). Soil bulk density (BD, g cm^{-3}) and soil water saturation percentage (SWP, %) were measured by the core method and gravimetric method respectively (Carter and Gregorich 2008). Soluble Ca^{2+} , Mg^{2+} , and K^{+} of saturated paste extracts (meq l^{-1}) were measured according to Carter and Gregorich (2008). Calcium carbonate equivalent (CCE, %), was determined by back titration (Carter and Gregorich 2008). Finally, sodium adsorption ratio (SAR) was calculated with the method reported by Richards (1954).

2.3 Developing Soil Quality Indices Method

A framework with three steps (Fig. 2) was used to develop various soils quality indices (SQIs).

2.3.1 Selection of Minimum Data Set (MDS)

As the initial step for assessing soil quality indices, a principal component analysis (PCA) in statistical software of SPSS, version 23, was employed on the total data set (TDS) to select the most appropriate indicators to act as a minimum dataset (MDS) for developing a SQI. After varimax rotation, only the principal components (PCs) with eigenvalues greater than 1 were considered for distinguishing of MDS (Flury and Riedwyl 1988). The varimax rotation will maximize the factor loadings (correlation between factors and measured soil parameters), assuming no correlations among PCs. Varimax rotation implies on rotating the factor axes orthogonally, in maximizing the variance of the squared loadings of a factor (column) on all the variables (rows) in a factor matrix, which has the effect of differentiating the original variables by extracted factor.

Under a special PC, a factor weight is given for every soil indicator which displays the share of the indicator to the derivation of that PC. Within each PC, the indicators with a high absolute loading value were considered as important indicators (Andrews et al. 2002a). If two or more indicators were selected in any PC, their correlation was observed and one must be selected. Finally, only greatly weighted independent indicators were kept for MDS (Andrews et al. 2002b).

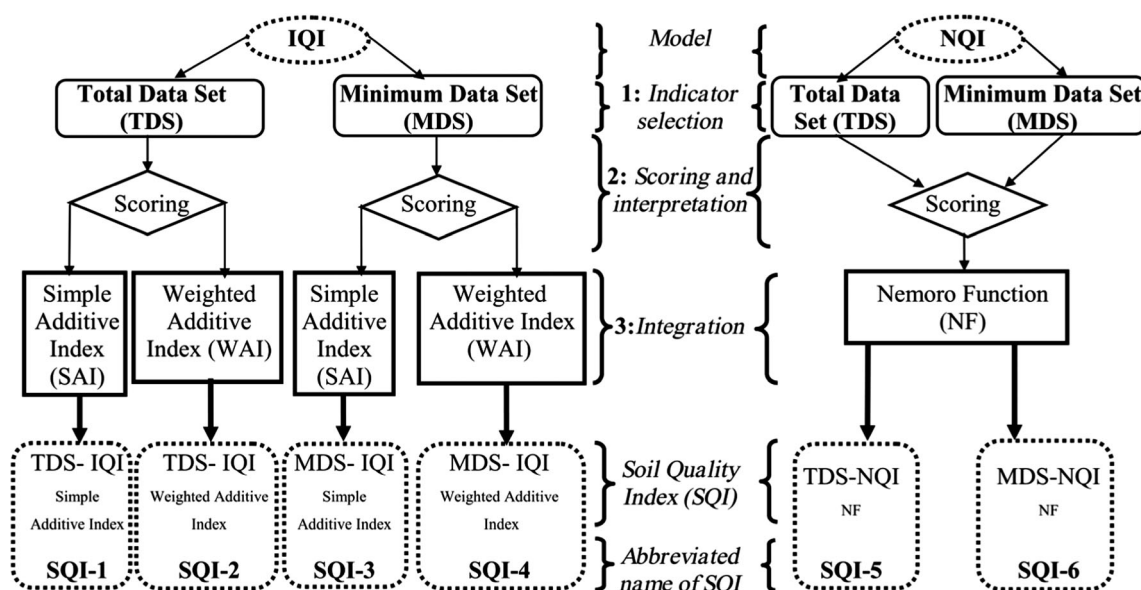


Fig. 2 Conceptual scheme showing the three steps for calculating soil quality indices (SQIs)

2.3.2 Transformation of Indicators

Because of different parameter units, indicators were converted into unit less scores ranging from 0 to 1 using linear scoring function that reflects soil quality (Qi et al. 2009). The scores were allocated via functions including more is better, less is better, and optimum functions to the data sets of TDS and MDS. For the “more is better” properties, each observation was divided by the highest observed value. Therefore, the highest measured value received a score of 1 while all others received a lesser score than 1. For “less is better” properties, the lowest measured value (in the numerator) was divided by each value (denominator) and thus the lowest measured value received a score of 1. For “optimum is better” indicators, the observation values were arranged as “higher is better” up to a threshold value and then arranged as “lower is better” above the threshold value (Liebig et al. 2001).

The conversion type of each indicator was specified based on environmental soil functions in ecosystems, literature survey, and also expert’s opinion (Tesfahunegn 2014; Raiesi 2017). Detailed scoring functions have mentioned the following. The “more is better” scoring function was used to saturated soil water-holding capacity, OM and CEC, on the basis of their role and function in soil productivity and water accessibility (Marzaioli et al. 2010). It has been found that adding the organic matter to the soil will have more positive impacts on soil quality, ecosystem yield, and root growth stimulating (Martínez et al. 2018). This function was also defined for K^+ , Ca^{2+} , and Mg^{2+} because they are necessary and crucial to plant growth (Lima et al. 2013). In addition, according to Tesfahunegn (2014), the “more is better” function was allocated to silt and clay similarly. On the contrary, the “less is better” function was considered for BD because its high value has a limitation

restrictive effect on growth of plant roots, soil organisms, soil infiltration, and porosity (Andrews et al. 2002a) and to CCE, since its richness, in semi-arid areas, have an adverse impact on soil acidity and soil nutrient cycling. Moreover, reversed scoring (“less is better” function) was supposed for rock fragment due to low potentially preservation of soil moisture and habitat for flora and fauna and also to SAR because of increasing soil sodicity risk for soil and plant in high values (Ghaemi et al. 2014). Finally, “optimal range” procedure was used to soil acidity, sand, and EC. In this case, threshold values or optimal spans were distinguished: 7 for acidity (Liebig et al. 2001), 0.2–2 $dS\ m^{-1}$ for EC and 30% for sand (Tesfahunegn 2014) based on plant’s needs. Thus, scores were allocated using the “more is better” or the “less is better” function according to indicators type. These indicators have positive impact on the soil health with increased levels before the threshold and are harmful beyond the optimum levels; hence, they can be transformed by the “mid-point optimum” function (Raiesi 2017).

2.3.3 Integrating Indicators and Calculating Soil Quality Indices

For developing soil quality indices (SQIs) per sample points, scored soil indicators in both of MDS and TDS were integrated by two models including NQI (Qi et al. 2009) and IQI (Doran and Parkin 1994). The formulation of SQIs was conducted in spreadsheet software of Microsoft Excel version 2010. Finally, the high values of SQI display better soil quality. The Nemoro quality index (NQI) was calculated on scored indicators employing Eq. 1.

$$NQI = \sqrt{\frac{P_{ave}^2 + P_{min}^2}{2}} \times \frac{n-1}{n} \tag{1}$$

Where n is number of indicators, P_{ave} is the average, and P_{min} is the minimum of the values of particular properties in any soil sample (Qi et al. 2009).

For calculating the integrated quality index (IQI), after scoring soil parameters in each data set (TDS and MDS), the scores were integrated into simple additive IQI and weighted additive IQI (Doran and Parkin 1994) using Eqs. 2 and 3 separately. For calculating weighted additive IQI, after converting the measured values of each property into score, the PCA results were used to the weighting of indicators. For both TDS and MDS, weight values were applied considering indicator communalities. The communality for a given variable can be explained as the share of variation in that variable illustrated by the PCs. In other words, the communality for each variable is obtained by taking the sum of the squared factor loadings for that variable and the relative explained importance of each soil indicator, in terms of its contribution to all of the factors, is judged by its communality value. It varies between 0 and 1, and the high value of the communality represents the high quota of that indicator to explain the phenomenon examined (Johnson and Wichern 1992; Rahmanipoura et al. 2014). Another PCA was done once again for MDS and the new weights for each indicator in the new dataset were extracted by its communality and were equivalent to the ratio of its communality with the sum of communalities of all MDS indicators.

$$\text{Simple additive IQI} = \frac{\sum_{i=1}^n S_i}{n} \quad (2)$$

$$\text{Weighted additive IQI} = \sum_{i=1}^n W_i S_i \quad (3)$$

Where S_i is the variables score, n is the indicators number, and W_i is the communalities weight of each indicator extracted from the PCA.

2.4 Evaluation of Soil Quality Indexing Methods

Sensitivity index (SI) and efficiency ratio (ER) were used as two criteria to select suitable and best IQIs (Tsefahunegn 2014).

2.4.1 Sensitivity Index

Sensitivity index (SI) was used for evaluating the performance of SQ indexing methods as Eq. 4:

$$\text{Sensitivity index (SI)} = \frac{SQI_{(\max)}}{SQI_{(\min)}} \quad (4)$$

Where SQI (max) and SQI (min) are the maximum and minimum value of each SQI. The SQI with higher value of sensitivity is more superior susceptible to turbulences,

environmental conditions, and management plans. In fact, this index shows the variability potential of the SQIs in the data set and however it has more dynamic.

2.4.2 Efficiency Ratio

Efficiency ratio (ER) criterion was applied to represent the efficiency of each SQI in explaining totally soil status. In other words, this criterion shows to what extent the SQI is representative of the total data set. To this end, Pearson correlation was performed between the value of specified SQI values and individual soil indicators. So ER was obtained through dividing significant correlation number between a specified soil quality index and all indicators by the all feasible correlation number between specified SQI and all indicators number, expressed as percentage (Eq. 5). Increasing ER expresses that the subjected soil quality index is more efficient in representing soil total condition.

$$\text{Efficiency ratio (ER)} = \left(\frac{K}{N}\right) 100 \quad (5)$$

Where K is the number of significant paired correlations between a specific SQI and all indicators; N is the number of all feasible paired correlation in data set which it equals 7 and 16 for MDS and TDS respectively in this study.

Finally, to prioritize the SQIs based on two criteria, the ranks of both criteria were summed and then made appropriate decision.

3 Results

3.1 Soil Properties

Descriptive statistics of sixteen soil characteristics were presented in Table 1.

3.2 PCA Analysis

Principal component analysis as a method for reducing data was performed to choose the most suitable properties and so to calculate SQI (Andrews et al. 2002a). All the bold-faced and italicized soil parameters in Table 2 were selected in the final MDS. The first five PCs explained 73.27% of changes in the selected MDS indicators.

Boldface factor loadings are considered highly weighted value within 10% of the greatest factor loadings. Italicized factor loadings were selected to include as the indicators in the MDS

Table 1 Descriptive statistics of soil parameters in study area

Indicator	Unit	Min.	Max.	Mean	SD	Indicator	Unit	Min.	Max.	Mean	SD
RF	%	0.99	51.02	19.1	11.72	BD	gcm ⁻¹	0.75	1.88	1.34	0.16
Clay	%	4.00	59.00	29.2	11.56	SWP	%	20.03	116.24	44.77	15.93
Silt	%	7.50	45.00	26.67	8.033	K ⁺	meq l ⁻¹	0.05	0.8	0.28	0.16
Sand	%	11.0	83.50	44.13	16.04	Ca ²⁺	meq l ⁻¹	0.78	14.7	2.09	2.4
pH	–	5.71	8.12	7.62	0.38	Mg ²⁺	meq l ⁻¹	0.61	4.07	1.4	0.63
EC	dsm ⁻¹	0.31	2.10	0.6	0.36	CEC	meq l ⁻¹	4.96	87.64	24.22	13.43
CCE	%	2.25	40.00	13.38	9.37	SAR	–	0.13	3.76	0.43	0.43
OM	%	0.12	18.66	3.63	2.99	TNM	g m ⁻² depth ⁻¹	28.59	2520.0	808.63	552.79

SD standard deviation

More than 21% of the variation among all dataset was represented under the PC1 in the PCA. Soil organic matter and total nitrogen mass are the two highly weighted variables with values of 0.94 and 0.86, respectively (Table 2). Both indicators imply that first PC is mostly related to organic matter. Also, two mentioned indicators had high correlation ($r = 0.95, p < 0.01$). Therefore, TN was eliminated from final MDS and OM was retained as one of the MDS indicators. EC and Ca²⁺ were chosen to represent the highest factor loading in the PC2. The coefficient correlation of current indicators is significant ($r = 0.96, p < 0.01$). Both of the attributes relate mainly to soil chemical condition and soluble soil ions. According to Andrews et al. (2002b), because of its higher factor loading

(0.95) and higher correlation with Ca²⁺ (more than 0.70), EC was selected as the most important factor for collecting MDS. In the PC3, CCE, silt, and sand were within 10% of the highest factor loading. Obviously, from the schema of current factors, it seems that current PC is mostly related to soil texture and infiltration. To avoid any redundancy in indicator selection, the sand was removed because of having significantly high correlation with silt ($r = -0.73, p < 0.01$) and also due to its lower absolute loading factor (-0.76) rather than silt. The correlation of CCE and silt was 0.42. Therefore, due to less possibility of redundancy between CCE and silt, both indicators were considered as representatives of the PC3 for inclusion in MDS. Likewise, accordingly, this was same for the

Table 2 Results of PCA indicating those properties selected as the MDS

PCs parameters	Components					Communalities
	PC1	PC2	PC3	PC4	PC5	
Eigenvalues	3.48	2.568	2.29	2.27	1.12	
% of Variance explained	21.78	16.051	14.30	14.16	6.97	
Cumulative variance explained%	21.78	37.827	52.13	66.29	73.27	
Indicators	Eigenvectors/factor loadings					
RF	-0.22	-0.23	-0.16	0.43	-0.33	0.41
Clay	0.00	0.06	0.52	-0.69	-0.07	0.75
Silt	0.38	-0.00	0.77	-0.11	-0.03	0.75
Sand	-0.19	-0.05	-0.76	0.55	0.07	0.93
pH	-0.78	0.00	0.29	0.05	0.08	0.69
EC	0.01	0.95	-0.08	-0.04	0.09	0.93
CCE	-0.30	-0.07	0.79	0.12	-0.08	0.75
OM	0.94	0.03	0.11	-0.08	0.06	0.91
BD	-0.53	-0.10	-0.13	0.44	0.01	0.51
SWP	0.74	0.18	0.10	-0.43	-0.01	0.78
K ⁺	-0.02	0.50	0.01	0.55	-0.15	0.58
Ca ²⁺	-0.00	0.94	-0.03	-0.08	-0.11	0.91
Mg ²⁺	0.23	0.62	0.09	0.11	0.28	0.54
CEC	0.18	-0.09	-0.07	-0.76	-0.09	0.63
SAR	-0.03	0.04	-0.17	0.05	0.92	0.88
TNM	0.86	0.02	0.12	-0.01	0.07	0.77

PC4 that both indicators of CEC and clay were selected as another member of MDS, which have correlation coefficient of 0.36 ($p < 0.001$). In the last PC, only SAR had the highest loading factor within 10% of the highest factor loading and was selected for retaining in MDS. Finally, the indicators recommended for MDS, including OM, EC, silt, CCE, clay, CEC, and SAR. However, the majority of MDS indicators are counted as chemical soil properties. Communalities results (Table 2) for the soil attributes indicated that EC had the maximum communality (93%) and RF had the minimum communality (41%).

The selected MDS subjected another one for PCA, and the MDS communalities were obtained for weighting the scores in soil quality indices related to MDS. Weights values of TDS and MDS, for each indicator, were derived from the ratio of communality of each indicator to sum of all indicators communalities in the first and second PCA respectively (Table 3). The rank of the weight values of MDS was as follows: CCE, silt, EC, CEC, OM, clay, and SAR.

3.3 Soil Quality Index

Soil quality indices were calculated for all 98 observations under the framework of developing soil quality indices and using proposed formulas (Table 4). Sensitivity index shows that MDS-NQI (SQI-6) is the most sensitive index with value of 2.597 for evaluation soil quality in rangelands. Developed IQI with TDS (SQI-2) also have the lowest sensitivity to variation in studied rangelands soil.

Efficiency ratios (ER) were calculated to specify the power of each SQI being as representative index for whole soil parameters set. For this purpose, firstly, the correlation coefficient between soil parameters and each SQI and its significance was computed. Secondly, as the efficiency ratios, the ratio of significant relationships to number of all relationships was calculated. The calculated efficiency ratios of six developed soil quality indices are presented in Table 5. Regarding the ER of NQI_{MDS} (85.71), it is obviously deduced that this

developed SQI correlates with much indicators than other indices. It has more efficiency ratio (ER %) and therefore represents the soil overall condition highly.

In order to make decision, final prioritizing of different indices was conducted by summation ranks of two criteria with an assumption that two selected criteria's of SI and ER have equal quota on final decision (Fig. 3).

In the view point of mixing both criteria for selecting suitable soil quality index to use in rangeland soil assessments, it is determined that the priority A belongs to NQI-MDS (SQI-6) and E as last priority belongs to simple additive TDS-IQI (SQI-2). Generally, the selection of MDS has caused that related indices to be desired.

4 Discussion

The maintenance of soil quality is critical for ensuring the sustainability of the biosphere. Soil quality indices are comfortable indicators of soil that benefit ecosystem managers to understand the impacts of their management plans on ecosystem sustainability (Lima et al. 2013). Nevertheless, an appropriate SQI, based on statistical procedures, can represent precious information for assessing the interactions between SQIs and ecosystem potential (Nakajima et al. 2015). Therefore, the method described in this research has been designed for selecting the most appropriate soil properties to establish the most suitable SQI of rangelands in semi-arid areas of north-west Iran. Study soils had low to moderate OM, showing typical semi-arid soils (Baldoek and Nelson 2000). According to amount of EC (range 0.31–2.1 dsm^{-1}), pH (range 5.71–8.12), and SAR (range 0.13–3.76), the soils are classified as non-saline. Regarding the CCE amount, soils were categorized into low to moderate calcareous, whereas the range of pH showed that soils varied from fairly acidic to strongly alkaline (Soil Survey Division Staff 1993).

Some researchers have evaluated soil quality based on available soil properties to conform the total dataset (TDS)

Table 3 Results of estimated communality and weight of soil quality indicators in both TDS and MDS

Indicator	TDS		MDS		Indicator	TDS		MDS	
	Com.*	Weight	Com.	Weight		Com.	Weight	Com.	Weight
RF	0.41	0.03	–	–	BD	0.51	0.04	–	–
clay	0.75	0.06	0.49	0.11	SWP	0.78	0.07	–	–
silt	0.75	0.06	0.72	0.16	K ⁺	0.58	0.05	–	–
sand	0.93	0.08	–	–	Ca ²⁺	0.91	0.08	–	–
pH	0.69	0.06	–	–	Mg ²⁺	0.54	0.04	–	–
EC	0.93	0.08	0.64	0.14	CEC	0.63	0.05	0.64	0.14
CCE	0.75	0.06	0.85	0.19	SAR	0.88	0.07	0.49	0.11
OM	0.91	0.08	0.61	0.13	TNM	0.77	0.06	–	–

*Com.: Communality

Table 4 Descriptive statistics and sensitivity index of soil quality indices

Model	Dataset	Integration	Soil quality index	Mean	Min	Max	Sensitivity index (SI)	Rank
IQI	TDS	IQI-TDS Simple Additive Index	SQI-1	0.44	0.32	0.66	2.058	5
		IQI-TDS Weighted Additive Index	SQI-2	0.46	0.33	0.68	2.056	6
	MDS	IQI-MDS Simple Additive Index	SQI-3	0.46	0.29	0.68	2.318	2
		IQI-MDS Weighted Additive Index	SQI-4	0.46	0.31	0.71	2.268	3
NQI	TDS	NQI-TDS	SQI-5	0.29	0.21	0.44	2.091	4
	MDS	NQI-MDS	SQI-6	0.29	0.18	0.47	2.597	1

indicator method (Doran and Parkin 1994). Other researchers believe that few representative indicators, called minimum data set (MDS) should be used (Andrews et al. 2002a). The used PCA approach in current research has presented a feasible tool for assessing rangelands soil quality via elimination redundant data. There are two approaches that are mainly found for indicator selection in the literature including the opinion of experts and mathematical-statistical systems such as regression equations and PCA (Doran and Parkin 1994). The PCA method has been applied as a method for data reduction in various researches (Qi et al. 2009; Raiesi 2017). This method chooses fewer soil indicators by data reduction

and increasing accuracy. Data reduction is suitable for a developing country where the measurement of more indicators may be inexpensive and time consuming. In the current study, based on statistical technique of PCA, in 98 rangeland sites, 7 soil parameters were selected from 16 candidate soil physical and chemical parameters as MDS. These MDS parameters are the most susceptible soil indicators to analyze soil quality. Among selected MDS indicators, OM, silt, clay, EC, CEC, CCE, and SAR have been applied in traditional MDSs for evaluating soil quality (Marzaioli et al. 2010; Qi et al. 2009). Moreover, in similar climatic condition of the current study area, OM was contained in established MDS by Nosrati

Table 5 Efficiency ratio and correlation matrix between each SQI value and soil indicators

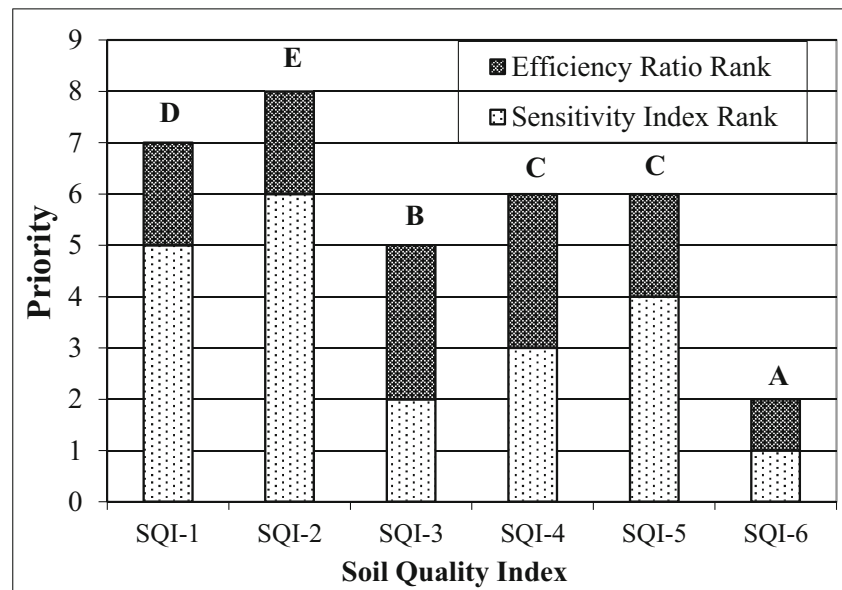
Indicators/ indices	IQI				NQI	
	TDS		MDS		TDS	MDS
	Simple additive (SQI-1)	Weighted additive (SQI-2)	Simple additive (SQI-3)	Weighted additive (SQI-4)	NQI _{TDS} (SQI-5)	NQI _{MDS} (SQI-6)
RF	-0.43**	-0.41**	-	-	-0.47**	-
Clay	0.44**	0.46**	0.59**	0.49**	0.44**	0.52**
Silt	0.53**	0.54**	0.56**	0.53**	0.52**	0.52**
Sand	-0.58**	-0.60**	-	-	-0.57**	-
pH	-0.51**	-0.51**	-	-	-0.51**	-
EC	0.39**	0.37**	0.02 ^{ns}	0.01 ^{ns}	0.39**	0.00 ^{ns}
CCE	-0.14 ^{ns}	-0.12 ^{ns}	-0.14 ^{ns}	-0.26**	-0.15 ^{ns}	-0.22*
OM	0.75**	0.77**	0.65**	0.68**	0.76**	0.71**
BD	-0.54**	-0.54**	-	-	-0.54**	-
SWP	0.75**	0.75**	-	-	0.75**	-
K ⁺	0.11 ^{ns}	0.07 ^{ns}	-	-	0.10 ^{ns}	-
Ca ²⁺	0.44**	0.42**	-	-	0.43**	-
Mg ²⁺	0.44**	0.40**	-	-	0.44**	-
CEC	0.37**	0.37**	0.62**	0.59**	0.36**	0.57**
SAR	-0.15 ^{ns}	-0.18 ^{ns}	-0.26**	-0.19 ^{ns}	-0.15 ^{ns}	-0.25*
TNM	0.71**	0.73**	-	-	0.72**	-
Efficiency ratio (%)	81.25	81.25	71.43	71.43	81.25	85.71
Rank	2	2	3	3	2	1

^{ns} is not significant

**Correlation is significant ($p < 0.01$)

*Correlation is significant ($p < 0.05$)

Fig. 3 Prioritizing of various SQIs (A is first, B is second, C is third, D is fourth, and E is fifth priority)



(2012) in evaluation of soils in croplands, rangelands, and urban regions of Tehran Province, Iran. It is obvious that the accuracy of soil quality assessment is raised by increasing indicator numbers because of variety in soil physical, chemical, and biological properties. Nonetheless, this research showed that a few properties, i.e., 7 out of the 16 properties, provided enough information on soil quality. This finding is in accordance with the finding of Lima et al. (2013) who declared 8 out of 29 indicators as MDS could present adequate information. The results showed that MDS method could adequately demonstrate TDS method with respect to saving time and money. Principal component analysis was found, therefore, to be an appropriate approach for selecting more advantageous indicators, which have vital roles in soil sustainability (Ghaemi et al. 2014). Using MDS method in order to select the parameters which better represent the TDS, time and money can be saved (Qi et al. 2009).

A MDS including silt, clay, OM, EC, CEC, CCE, and SAR was established for calculating soil quality of rangeland soils in the region. OM and CEC act as the fundamental role in soil productivity in viewpoint of its capability to hold and release soil nutrient, as well as to progress soil physical condition. They are highly associated with many soil properties that they can show the majority of the information. In the current research, OM had a higher role in soil quality and contributed more to establish SQI, as was found in similar researches (Zhang et al. 2019). The role of other selected variables including clay and silt content as controlling OM preservation have effectively been taken into MDS in other studies in rangeland ecosystems for establishing soil quality index (Rezaei et al. 2006). Calcium discharge has been identified as a menace to ecosystem productivity (Huntington 2000). SAR and EC are important indicators that have adverse impact in controlling soil quality and plant growth (Richards 1954).

The entrance of the EC and SAR into the SQI will decline the final values of the SQI. For instance, some of the mentioned indicators are considered to be one of the most important parameters to evaluate soil quality in natural ecosystems in north of Tanzania (Ndakidemi and Semoka 2006) and to assess soil quality of rangeland potential in Iran (Rezaei et al. 2006). Raesi (2017) found that soil particles such as clay and silt were significantly associated with soil quality and they highly impress soil nutrients cycling. The relative importance of each soil indicator, in viewpoint of their share to all of the factors, is determined by its communality value, “a value that represents the residual variance of the indicator in comparison to a critical convergence value of confidence” (Johnson and Wichern 1992). Results show that CCE has high communality value of 0.854 in the second PCA.

Additionally, in this research, linear transformation was selected in lieu of non-linear transformation suggested by other researches (Andrews et al. 2002a) to convert the value into the range from 0 to 1. Liebig et al. (2001) emphasized ease of design a linear scoring technique that determines the highest possible score for each indicator and needs less former information about the ecosystem. The integrated soil quality index (IQI) and Nemoro quality index (NQI), which were based on a mathematical-statistical system were used to assess the soil quality of the rangelands. Nemoro index method showed highest sensitivity among other analyzed methods, which is in line with former obtained results of Rahmanipoura et al. (2014) in croplands of Qazvin province of Iran and Bo et al. (2014) in soil quality assessment of micro-topography in semi-arid Loess Plateau of China. The lowest sensitivity values were associated with simple additive index IQI-TDS. Also, the highest and lowest ER belongs to MDS-NQI and also to both simple additive index IQI-MDS and weighted additive IQI-MDS respectively. Overall results of the

prioritization soil quality indices imply that the MDS-NQI have the most efficiency and sensitivity for variation in rangeland, so it is suggested to use this quality index for further and comprehensive soil assessments plans such as assaying relationship of rangeland vegetation properties, effect of land management and grazing intensity and monitoring soil quality index. This SQI was selected based on the SI and ER criteria and it can be used by land managers for evaluating soil quality. However, in the case of using the SQI for predicting ecosystem service, it is obvious that a soil quality index should be established in regard to special soil functions. An overall soil quality index is often desired and favorable but it is not very operational, since soil quality is best evaluated in relation to particular soil functions (Bünemann et al. 2018). In addition, the Nemoro index method uses relatively the uncomplicated mathematics and is very simple to apply; it requires only basic mathematical knowledge and is easy to understand (Bo et al. 2014).

In summary, regardless of IQI and NQI models, derived SQIs from MDS have higher priorities than TDS-derived SQIs. This was in agreement with the findings obtained by Qi et al. (2009) for cropland soils of China and with findings of Andrews et al. (2002a), who proposed a reduction of indicator number could adequately provide suitable soil quality. It seems that removing some non-important indicators from TDS has caused increasing sensitivity of indices (Rahmanipoura et al. 2014). Furthermore, simple additive indexing has similar trend compared to weight indexing in IQI models of both MDS and TDS. This trend could be illustrated by the use of indicator weight as discriminating factor in weighted simple additive IQI model in contrast with simple additive IQI model that alter score and importance of different indicators. This could shift the results (Andrews et al. 2002b).

In this study, due to some limitations on soil sampling and transporting and analysis cost, the soil biological indicators were neglected to incorporate in establishing the SQIs. However, to assess soil quality more comprehensively and accurately, soil biological properties such as enzymes (Adetunji et al. 2017) and fungal communities (Marin et al. 2017) should also be considered for SQI in future researches. Our study focused on the surface soil quality but for the comprehensive evaluations in the future researches; it is needed to work on establishing SQIs for the entire soil profile. Additionally, the results could be applied as a starting point for further studies in developing countries such as Iran, where the measurement of indicators might be inexpensive and time-consuming. Therefore, because of lacking related studies in rangeland ecosystems, it is needed to conduct more research to test the suitability of this approach in time or different managements of rangelands such as grazing intensity. Also investigating the relationship of this soil quality index with other rangeland functions such as forage production and biodiversity is another recommended approach of future evaluations.

Meanwhile, in this research, the indices are not evaluated through productivity potential like other studies, therefore it is recommended to examine the indices by this approach in future researches.

However, there is not any global approach to evaluate soil quality, although scientists have offered conceptual schemes to assess soil quality (Doran and Parkin 1994). Credible, authentic, susceptible, and achievable indicators must be distinguished and the plan for overall evaluation of soil quality must be expanded. Hard laboring to improve a SQI approach is required to use knowledge of soil science in solving natural resource problem (Nakajima et al. 2015).

5 Conclusions

Soil physical properties had fewer effects on the establishment of soil quality index compared to the chemical parameters of rangeland soils. Minimum data set selection using principal component analysis as a multivariate statistical method could adequately represent total data set method. Therefore, it seems to be an appropriate approach for choosing more effective indicators with respect to saving time and money in the developing countries such as Iran which has vast rangelands. The established indices based on minimum data set are more useful than those established by total data set. Furthermore, simple additive indexing has similar trend compared weighted indexing in integrated quality index models, regardless of data set type. Finally, this study demonstrated that using Nemoro quality index for selected minimum data set is more suitable for detecting soil quality rather than other integrated quality indices. Therefore, it is suggested to use Nemoro quality index–minimum data set in rangelands soil assessments due to its high-efficiency ratio and sensitivity index.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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