Assessing the soil quality index as affected by two land use scenarios in Miandoab region

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Abstract

In this research, the physical, chemical and biological properties of 19 soil indicators using 80 samples (0–25 cm) were quantified to measure the soil quality index (SQI) in Miandoab region, Iran, across different land uses. These properties include aggregate stability (AS), bulk density (BD), soil moisture content (θ_m), saturation percentage (SP), particle size fractions (clay, silt, sand), pH, EC, available P and K, OC, total N, C/N, CaCO_3 , sequestration of organic carbon (SOC), CEC, microbial respiration (MR) and microbial population (MP). Principal component analysis (PCA) was used as a dimension reduction method to separate farmlands and orchards as two different land uses. The linear SQI and nonlinear SQI were calculated, and the results showed a clear difference in SQI as affected by the aforementioned land uses. The specific contribution of each minimum data set also showed that soil OC, N, MR, MP, silt, CaCO_3 , AS and BD had the highest importance to SQI. The linear SQI value was more significantly affected by the physical properties than the chemical and biological ones. It varies from the maximum value of 35.17% in the farmland to 37.74% in the orchard. On the other hand, the nonlinear SQI showed the highest contribution of biological SQI in the farmland (73.94%) followed by the orchard (64.15%). Finally, both linear and nonlinear equations may be acceptable for assessing SQI using the aforementioned soil properties. Furthermore, it is the biological properties that have the main role in terms of evaluating the effect of land use conversion on soil quality.

Keywords Farmland · Orchard · Principal component analysis

1 Introduction

According to the United States Department of Agriculture Natural Resources Conservation Service, “Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation” [1]. This capacity is an inherent characteristic [2], which varies from one to another soil and consists of physical, chemical and biological properties, namely the soil quality indicators that reflect the soil condition [3]. The dynamic soil

properties such as soil organic matter and microbial attributes are sensitive to agricultural activities and land use changes [4], and land use alterations can have an adverse impact on soil function [5]. In addition, soil properties are often interdependent but under various agricultural and management activities may affect the soil quality and productivity and respond differently, so the interpretation of their effects under different management will be confusing [6].

Notwithstanding the interpretation of soil quality based on the individual microbial properties is a challenge, and soil quality relies on soil nutrients that can be affected by

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land use changes and management activities [7]. They can inherently be the potential indicators of the soil quality, because of their higher sensitivity compared to the physical and chemical properties [8]. Therefore, based on different environmental conditions there are several tools and techniques which are needed for a competent assessment of these changes based on the concept of soil quality [9]. Since the definition of soil quality by several properties is complicated, the necessity of individual index is clear. But, it should be mentioned that the unified soil quality indices derived by different soil properties can be a better representative index for soil quality than an individual index [10].

The high value of soil quality indices shows that soil quality has a better function toward different aspects such as long-term productivity [2]. Based on Doran and Parkin [11] reports, the properties with information about soil function will make the minimum data set (MDS) as well as results favorable soil quality indices. The MDS was achieved using mathematical techniques and scoring functions (linear and nonlinear). Principal component analysis (PCA) is one of the most commonly used techniques for selecting MDS which reduces the data redundancy and makes a facility to select the indicators by classifying the soil properties into different principal components (PC) [12, 13]. Based on the importance of the SQI assessment in both farmland and orchard, it is possible to have clear discrimination between mentioned land uses to see how the land use conversion can affect the soil quality. So our hypothesis was that the SQI is a proper tool to evaluate the effect of different land use on soil quality. Therefore, the main objectives of this research work were to (i) identify the minimum data set (MDS) including the most important soil quality indicators for soil quality assessment, (ii) develop the linear and nonlinear scoring function for different land uses and (iii) investigate the effect of farmland and orchard land uses on the soil quality.

To our awareness, this research is the first report which is done in the vicinity of the Urmia lake area regarding the assessment of the SQI by physical, chemical and biological properties in different land uses, where the land use change in this area is growing fast and the lake is in the danger of being dried because of the mismanagement and inappropriate agriculture activities, the importance of this kind of research seems more necessary.

2 Materials and methods

2.1 Study area

The study area with farmland and orchard was located in Miandoab region, West Azerbaijan province of Iran. It lies

between a latitude of 36° 52' to 37° 02' N and a longitude of 46°00' to 46°14' E covering about 7000 ha (Fig. 1). The synoptic station of Miandoab climatic data showed an average annual, maximum and minimum temperatures of 12.8, 19.9 and 7.5 °C, respectively. Also, the average annual rainfall and evapotranspiration were recorded as 272.3–733.3 mm, respectively. The area has a Mesic soil temperature regime and Aridic moisture [14].

2.2 Soil data

For determining the location of the sampling points, grid surveying was carried out based on the size of the lands and aim of the study which is a commonly used approach [15]. The entire study area covers with a grid of 1000 × 700 m, and in total, 80 samples (0–25 cm) were collected, transported to the laboratory and after air drying were prepared with passing through a 2 mm sieve for physical and chemical analysis. Field moist soil samples were also maintained at 4 °C and prepared for microbial analysis.

All the measured properties as soil quality indicators were selected based on [16] list. Soil physical properties such as aggregate stability (AS) [17], bulk density (BD) [18], soil moisture content (θ_m) [19], saturation percentage (SP) [20] and texture [21] with chemical properties of soil reaction (pH) [22], electrical conductivity (EC) [23], available phosphor (P) [24], absorbing potassium (K) [25], organic carbon (OC) [26], total nitrogen (N) [27], the ratio of carbon to nitrogen (C/N), calcium carbonate equivalent (CaCO_3) [28], sequestration of organic carbon (SOC) and cation exchange capacity (CEC) [29] were determined. Also, microbial respiration (MR) [30], and microbial population (MP) [31] were calculated as microbial properties in this research.

2.3 Scoring the soil quality index

Soil quality index (SQI) was computed through the three steps: (i) selecting sensitive indicators for an MDS, (ii) scoring the MDS indicators and (iii) unifying the scores into an index [32, 33]. For the matter, a total of 19 soil physical, chemical and biological properties were measured based on their sensitivity and ability for expressing the complexity and functionality of soils [34].

The principal component analysis (PCA) was carried out using the SPSS software v20.0 for determining the MDS indicators. This way causes to select the most important indicators as well as to reduce the dimension of the data set without losing any information [35]. Based on the eigenvalue of the PC, the indicator with eigenvalue > 1 was accounted as the best representative indicator for the soil quality which can explain at least 5% of

Fig. 1 The location of the study area in Miandoab region, northwest of Iran

the data variation. In other words, the highly weighted indicators with > 0.50 factor loading value were considered as soil quality indicators [36]. Whenever there was more than one indicator in each factor, the multivariate correlation coefficient would decide if the indicator could remain in the factor or it should be omitted from the MDS; indeed, it will decrease the redundancy. In a case that indicator was highly weighted with no correlation between PC and soil properties, each accounted as an important one and remained in the MDS [36]. After selecting the MDS, the linear and nonlinear scoring functions were applied for scoring them between 0 and 1 because the aforementioned soil indicators consist of different units [6]. Based on the effects of indicators on the soil quality, they were scored as "more is better" for one with a positive effect on the soil quality, "less is better" for one with negative effects and "optimum" for one which can have a positive effect on increasing part and negative effect on decreasing part [37]. In this study, the bulk density was scored as "less is better", silt and CaCO_3 was scored as "optimum" and the rest of the indicators maintained in the MDS were scored as "more is better." The following linear scoring functions (Eqs. 1 and 2) were used as "more is better" and "less is better," respectively.

$$L = \frac{x}{x_{\max}} \quad (1)$$

$$L = \frac{x_{\min}}{x} \quad (2)$$

where L is the linear score varying from 0 to 1, x is the value of soil property, and $x_{\max}$ and $x_{\min}$ are the maximum and minimum values of each observed soil property [38]. The nonlinear scoring function was also used in the sigmoidal-type curve (Eq. 3).

$$NL = \frac{a}{\left(1 + \left(\frac{x}{x_0}\right)^b\right)} \quad (3)$$

where NL is the nonlinear score of each indicator (between 0 to 1), a stands for the maximum value (in this study $a = 1$) reached by the function, x is the value of the selected indicator, x_0 is the mean value of each indicator, and b is the slope of the equation which was set as -2.5 for "more is better" and 2.5 for "less is better" functions [38].

Notwithstanding the linear scoring is easier to be calculated [39], the nonlinear scoring technique can determine the function better than a linear one. Moreover, the

nonlinear technique needs pre-knowledge and skill for interpreting the behavior of each indicator in the system. However, in most cases, both linear and nonlinear functions show almost similar results [36]. The last step for the soil quality assessment was to combine the selected indicators into a single index using Eq. 4.

$$SQI = \sum_{i=1}^n W_i S_i \quad (4)$$

where W_i is the weighting factor of each indicator derived by factor analysis and S_i is the linear and nonlinear scores calculated via Eqs. 1–3 [40]. In final, according to the value of SQI, the effects of land use on the soil function have been evaluated. It assumes that the higher SQI value relates to the better soil quality [6].

2.4 Statistical analyses

The data were checked for normality distribution. For this, the paired t-test method applied at the $P < 0.05$ significance level by SPSS software v20.0. Then, the significance level of SQI was tested based on the relative importance of scoring methods. Finally, the ordinary kriging method was applied to interpolate the value of unsampled points as it minimized the error variance [41]. Before mapping, spherical, Gaussian, stable and exponential models were tested for experimental semivariogram calculation and the stable model was chosen based on the lowest RMSE and highest

R^2 . The maps of SQI were created based on the linear and nonlinear scoring functions by ArcGIS software v10.2.

3 Results and discussion

3.1 Soil analyses

Table 1 shows the statistical characteristics of the measured properties of the 80 samples in the study; the samples exhibited a large variation in most of the soil properties. The normal distribution was tested based on the Kolmogorov–Smirnov method and the value of the kurtosis and skewness, and the non-normal parameters ($P < 0.05$) were normalized by the log transformation technique. This non-normality can be attributed to the changes in the sedimentation environments and the effect of pedogenic and hydrologic processes. On the other hand, agricultural management activities can also cause heterogeneous distribution among the soil properties [42]. The pH coefficient of variation (CV%) and standard deviation (Std. deviation) had the lowest and the second-lowest values, respectively, which can be related to the dominant parent material in the study area, whereas the high CV% in N, P, K and EC indicated the strong spatial variation of their content in the study area. These strong variations may be due to the variations in land use, soil types and the effect of management factors such as applying fertilizer in the field, topographic changes and the drainage condition in the study area (Table 1).

Table 1 Statistical characteristics of all data set

Variable	Minimum	Maximum	Mean	Std. deviation	CV%	Kurtosis	Skewness
pH	7.09	8.73	7.92	0.28	3.59	−0.17	0.93
EC (dS.m ^{−1})	0.66	11.93	2.63	2.48	94.25	2.34	5.55
P (mg.kg ^{−1})	0.44	41.50	5.85	6.39	109.11	3.23	13.23
K (mg.kg ^{−1})	5.00	872.00	187.30	179.70	95.94	2.07	4.19
AS (%)	2.62	19.53	11.39	3.56	31.33	−0.12	−0.23
BD (gr.cm ^{−3})	1.08	1.78	1.43	0.40	23.10	0.62	−0.26
θ m (%)	0.51	1.55	1.05	0.08	8.45	−0.77	28.66
SP (%)	31.30	91.77	54.98	11.63	21.16	0.44	0.92
Clay (%)	7.27	44.97	23.57	9.68	41.06	0.23	−0.85
Silt (%)	5.00	66.00	39.12	12.72	32.52	−0.41	−0.38
Sand (%)	5.00	81.00	37.30	17.29	46.35	0.58	−0.27
OC (%)	0.04	3.16	1.79	0.68	38.42	−0.98	0.29
N (%)	0.00	0.55	0.13	0.08	62.51	1.98	6.95
C/N	0.03	5.18	1.64	0.94	0.57	0.94	1.21
CaCO ₃ (%)	2.25	12.50	6.45	3.76	58.29	0.88	−0.98
SOC (ton ha ^{−1})	1.68	179.69	95.23	42.86	45.00	−0.31	−0.31
CEC (meq.100 gr ^{−1})	4.17	31.65	16.42	6.13	37.31	0.48	−0.11
MR (mg kg ^{−1})	1.67	9.28	4.39	1.97	44.86	0.65	−0.47
MP (10 ^{−5} gr ^{−1})	139.32	274.93	187.88	35.11	18.68	0.65	−0.47

3.2 Selecting indicators

Different properties cause changes in the soil condition under different land uses. The factor analysis tries to select the most important ones with a high variation for getting more information about soil and assessing the land use effect on soil quality, and it also prevents some of the time-consuming and high-cost activities in large-scale area where they have the same ecosystem and condition [43]. Communalities define the contribution of variance in each soil property which are illustrated by the PCA; in other words, high communalities in the properties show the high value of variance by PCA [44].

The selected 19 soil profiles properties, relevant to the soil quality, were accounted for the PCA. The results are summarized in Table 2. Seven factors revealed the eigenvalues greater than 1, which indicate the soil quality and its diversity. They explain more than 5% of the data variation and jointly about 79% of the total variance. The first factor shows 13.1% of the total variation, while factors 2 to 7 represent 12.63%, 11.91%, 11.83%, 11.56%, 10.85% and 7.15% of the variations, respectively (Table 2). In the first factor, the high loading values belong to the chemical properties of SOC (0.881) followed by OC (0.855) and

C/N (0.615). Carbon was reported as a key property for SQI evaluation, which can have different effects on the soil chemical, physical and biological properties [45, 46]. The second factor was associated with chemical and physical properties including N and SP with the highest loading value of 0.886 and 0.758, respectively. Both MR and MP as two biological properties are recorded with the most highly weighted ones in the third factor. Silt with a positive high loading value (0.882) and sand with negative high loading value (−0.864) are identified as two important properties in the fourth factor. The most important properties in factor 5 are relevant to chemical properties and fertility and include CaCO_3 (0.802), CEC (0.740) and K (0.711). Finally, the highly weighted properties in factor 6 are AS (0.865) and clay (0.716), while EC (0.689) is distinguished in factor 7 (see Table 2). The commonality values for all variables are recorded more than 0.50, which explains the high variance of soil properties and the expansion of factor analysis. For an instant, four soil properties of sand, SOC, MR and MP could explain more than 90% of the variance in this work.

The vector loading plot (Fig. 2) shows the effects of each variable on the components. The loading ranged from −1 to 1. If it is closer to −1 or 1, the effect of the

Table 2 Results of principal component analysis (PCA) of soil quality indicators

Soil properties	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Commonality ^a
pH	0.25	−0.29	0.38	0.49	0.01	−0.17	0.00	0.58
EC (dS.m^{-1})	−0.18	0.29	0.07	0.05	−0.14	−0.04	0.68	0.62
P (mg.kg^{-1})	−0.08	0.58	0.01	−0.01	0.55	−0.36	0.10	0.80
K (mg.kg^{-1})	−0.41	−0.05	0.03	−0.05	0.71	0.01	0.09	0.69
AS (%)	−0.10	0.19	−0.19	−0.08	0.03	0.86	−0.01	0.84
BD (gr.cm^{-3})	0.33	−0.21	0.09	−0.03	−0.03	0.10	0.76	0.76
θ_m (%)	−0.04	0.20	0.41	0.21	−0.14	0.42	−0.23	0.51
SP (%)	0.09	0.75	−0.05	0.44	0.05	0.23	0.04	0.85
Clay (%)	0.10	0.08	−0.05	0.38	0.14	0.71	0.16	0.73
Silt (%)	0.05	0.17	0.00	0.88	0.00	−0.01	−0.04	0.81
Sand (%)	−0.09	−0.17	0.02	−0.86	−0.08	−0.39	−0.06	0.95
OC (%)	0.87	0.18	0.13	0.16	−0.21	0.02	−0.13	0.90
N (%)	0.06	0.88	−0.06	0.07	−0.07	0.21	0.00	0.85
C/N	0.61	−0.51	0.19	0.00	−0.17	−0.27	0.00	0.78
CaCO_3 (%)	−0.24	−0.03	−0.07	0.04	0.80	−0.02	−0.11	0.72
SOC (ton.ha^{-1})	0.88	−0.00	0.17	0.11	−0.17	0.06	0.29	0.93
CEC (meq.100gr^{-1})	0.13	0.10	0.15	0.14	0.74	0.30	−0.22	0.76
MR (mg.kg^{-1})	0.14	−0.06	0.94	−0.00	0.04	−0.09	0.09	0.92
MP ($10^{-5}.\text{gr}^{-1}$)	0.14	−0.06	0.94	−0.00	0.04	−0.09	0.09	0.92
Eigenvalue	3.90	3.66	2.31	1.54	1.32	1.19	1.05	15.00
Variance (%)	13.01	12.63	11.91	11.83	11.56	10.85	7.15	78.97
Cumulative variance (%)	13.01	25.64	37.56	49.40	60.97	71.82	78.97	

Bold loading values (>0.50) indicate the highly weighted factors

Bold-underlined values were the factors included in the MDS

Fig. 2 A vector loading plot of the first and second factors in farmland and orchard land uses

variable on the component will be larger until it is close to 0, the variable has a weak influence on the component [47]. The results show that SOC in factor 1 and N in factor 2 have maximum influence among the tested variables, so they should be considered as the main indicators in soil quality evaluation under farmland and orchard land uses.

Table 3 represents the correlation of the measured soil properties. Under the first factor, SOC, OC and C/N are all significantly correlated ($P < 0.01$) with each other, but only the SOC with the highest loading (0.881) is selected in the MDS. This shows that any changes in the SOC content will affect the other soil properties, which are significantly correlated. Therefore, if there are more than one highly correlated variable, one will remain in MDS and the rest will be omitted [48]. Nitrogen and SP are also highly correlated ($r = 0.70$, $P < 0.01$) in factor 2, and N is selected for MDS with 0.886 loading value. MR and MP with more than 11% of the total variation were the most important properties in factor 3 which are highly correlated ($r = 1.0$, $P < 0.01$), and both are kept in MDS; these two properties can replace each other as a soil quality indicator when one of them is not measured. Under factor 4, silt and sand are highly correlated ($r = -0.83$) with 0.882 and -0.864 loading value, respectively, but the silt is kept in MDS. Although the CaCO_3 (0.802), CEC (0.74), K (0.711) and P (0.553) in factor 5 are all significantly correlated, the CaCO_3 due to its high loading value remained in MDS. Under factor 6, the AS and clay with 0.865 and 0.716 loading value, respectively, are significantly correlated ($r = 0.53$, $P < 0.01$) and AS is kept in MDS. In factor 7, BD (0.768) and EC (0.689) do not have high correlation ($r = 0.18$, $P < 0.01$) and BD is considered as an indicator in MDS. Overall, the indicators retained in MDS include SOC, N, MR, MP, silt, CaCO_3 , AS and BD which are

considered as the most important variables in creating the SQI under different land uses.

3.3 The scores of indicators

The linear and nonlinear functions were applied for scoring the MDS indicators. They were classified into three groups: 1) SOC, N, AS, MR and MP indicators as “more is better” functions due to their positive influence on soil quality (i.e., management purposes and crop productivity); 2) BD as “less is better” function demonstrates a negative effect on the soil quality [37]; and 3) other soil properties of silt and CaCO_3 as “optimum” function due to both positive and negative effects on soil quality. The summary of criteria used by the scoring functions for all MDS indicators entire of the study area is represented in Table 4.

3.4 Soil quality index

The SQI was calculated using the weighting factor of each indicator derived by factor analysis and the linear as well as nonlinear scores (Fig. 3). The results showed that the SQI values in farmland were greater than the orchard, which may be resulted by the presence of plant residues on the soil surface. Besides, in addition, fertilization of farmland increases soil nutrients of SOC, N and P due to an increase in organic matter input [13], so they affect the microbial activity, organic carbon content and other soil properties [49]. In this study, the values of SQI using the linear function are also greater than the nonlinear function in both land uses (Fig. 3).

Based on the contribution of each MDS to SQI (Fig. 4), the MP contributes with the highest score using both linear (17.84% in the farmland and 16.93% in the orchard) and nonlinear functions (18.16% and 17.33% in the farmland and orchard, respectively). It was found as the highest loading value in factor analysis (Table 2). The second highest contributor to linear SQI is related to SOC and silt in farmland and orchard, respectively. They had a high loading value (13.01%) and variance (11.83%) in the factor analysis (Table 2). The high contribution of SOC in farmland SQI shows the importance of SOC as an important indicator, which can be explained by the low amount of SOC in the soil that can have an effect on soil functions and processes such as nutrient cycling and microorganism. In addition, obtained result by Yao et al. [50] with a similar climate condition and low amount of SOC reported the same properties as the main indicator, which is influenced by soil management, land use and the lower contribution of other properties in SQI, plus it can be also related to less correlation of these properties. Furthermore, recovery of the crop biomass to the farmland than orchard can improve the soil labile carbon sequestration [13]. In

Table 3 Correlation matrix of measured soil attributes across the study area

Variable	pH	EC	P	K	AS	BD	θ_m	SP	Clay	Silt	Sand	OC	N	C/N	CaCO ₃	SOC	CEC	MR
EC	0.02																	
P	-0.07	0.19																
K	-0.21	0.02	0.36**															
AS	-0.34**	0.00	-0.15	0.05														
BD	0.12	0.18	-0.16	-0.08	-0.03													
θ_m	0.14	0.07	-0.08	0.00	0.18	-0.09												
SP	-0.02	0.24*	0.33**	-0.10	0.33**	-0.10	0.23*											
Clay	0.11	0.14	-0.01	-0.02	0.53**	0.05	0.24*	0.43**										
Silt	0.20	-0.04	0.02	0.01	0.01	0.01	0.19	0.49**	0.17									
Sand	-0.21	-0.04	-0.01	0.00	-0.31**	-0.03	-0.28*	-0.61**	-0.68**	-0.83**								
OC	0.24*	-0.05	-0.11	-0.45**	-0.07	0.07	0.20	0.23*	0.14	0.22*	-0.24*							
N	-0.22*	0.16	0.30**	-0.11	0.33**	-0.07	0.22*	0.70**	0.19	0.26*	-0.30**	0.21						
C/N	0.37**	-0.04	-0.31**	-0.29**	-0.40**	0.18	-0.09	-0.38**	-0.17	-0.08	0.16	0.52**	-0.53**					
CaCO ₃	-0.09	-0.12	0.34**	0.56**	0.02	-0.20	-0.08	0.00	0.03	0.05	-0.06	-0.33**	-0.08	-0.33**				
SOC	0.28*	0.04	-0.19	-0.39**	-0.10	0.59**	0.12	0.11	0.12	0.18	-0.20	0.83**	0.08	0.53**	-0.33**			
CEC	0.21	-0.13	0.29**	0.375	0.23*	-0.12	0.20	0.29**	0.32**	0.12	-0.26*	0.00	0.12	-0.11	0.46**	-0.07		
MR	0.35**	0.00	0.01	0.00	-0.24*	0.21	0.14	-0.08	-0.08	0.04	0.01	0.20	-0.12	0.30**	-0.05	0.29**	0.09	
MP	0.35**	0.00	0.01	0.00	-0.24*	0.21	0.14	-0.08	-0.08	0.04	0.01	0.20	-0.12	0.30**	-0.05	0.29**	0.09	1.00**

**Correlation coefficients are significant at $P < 0.01$, *correlation coefficients are significant at $P < 0.05$

Table 4 Summary of average and range values normalized linear and nonlinear equations of the scoring functions for all MDS

	SOC	N	MR	MP	Silt	CaCO ₃	AS	BD
Minimum	1.68	0.01	5.79	139.31	5	2.25	2.62	1.08
Maximum ($x_{\max}$)	179.68	0.54	32.23	274.92	66	12.5	19.53	2.78
Average (x_0)	95.23	0.13	15.26	187.88	39.12	6.45	11.39	1.75
Curve type (scoring function)	More is better	More is better	More is better	More is better	Optimum	Optimum	More is better	Less is better
Weighting factor ^a	0.13	0.12	0.11	0.11	0.11	0.11	0.10	0.07
Slope (b value)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	2.5
Normal- ized linear equa- tion	$0.13(x/179.68)$	$0.12(x/0.54)$	$0.11(x/32.23)$	$0.11(x/274.92)$	$0.11(x/66)$	$0.11(x/12.5)$	$0.10(x/19.53)$	$0.07(x/2.78)$
Normal- ized	$0.13 \times 1/$	$0.12 \times 1/$	$0.11 \times 1/$	$0.11 \times 1/$	$0.11 \times 1/$	$0.11 \times 1/$	$0.10 \times 1/$	$0.07 \times 1/$
Nonlinear equa- tion	$(1 + (x/95.23)^{-2.5})$	$(1 + (x/0.13)^{-2.5})$	$(1 + (x/15.26)^{-2.5})$	$(1 + (x/187.88)^{-2.5})$	$(1 + (x/39.12)^{-2.5})$	$(1 + (x/6.45)^{-2.5})$	$(1 + (x/11.39)^{-2.5})$	$(1 + (x/1.75)^{2.5})$

^a Derived from factor analysis (please see Table 2)

Fig. 3 The average linear and nonlinear SQI in farmland and orchard

nonlinear SQI, the MR and N have the highest contribution in farmland and orchard, respectively, following MP. These results represent the effect of the weighting factor in factor analysis.

The contributions of physical, chemical and biological indicators were affected by two land use scenarios are illustrated in Fig. 5. Applying the linear function showed that soil physical properties had a higher contribution compared with the chemical and biological ones with the 35.17% value in farmland and 38.74% in the orchard. But the application of nonlinear function revealed that the biological properties had the highest value in both land uses (73.94% and 64.15% for farmland and orchard, respectively). The factor analysis had also shown the same

Fig. 4 The contribution of the MDS indicators to the SQI using linear and nonlinear scoring functions for both farmland and orchard land uses

Fig. 5 The contribution of the chemical, physical and biological indicators to the SQI by linear and nonlinear scoring functions in farmland and orchard

results in which the biological indicators (MP and MR) had a high loading value and variance (Table 2).

Additionally, the contribution of biological indicators in farmland was larger than the orchard, using both linear and nonlinear functions (Fig. 5), which may be caused by more agricultural activities such as tillage in farmland. These activities can easily alter the soil condition favored to microbial growth by providing more substrate. The

biological properties are sensitive to any management practice or any other agricultural activity [49]. On the contrary, the physical and chemical properties need long-term and intensive activity to be changed, so their impact on soil quality is less than the biological properties [51]. Furthermore, the relationship between soil quality and different land uses is influenced by different factors like climate, soil type, crop varieties and other factors that are

Fig. 6 The SQI maps by **a** linear and **b** nonlinear scoring functions in the study area

not evaluated in this research [47]. Figure 6 represents the SQI maps by the linear and nonlinear scoring function in the study area and shows almost the same range of SQI in both linear and nonlinear scoring functions.

4 Conclusions

In this research work, the practical usage of the SQI assessment is reported to define the effect of land use conversion on soil quality. Therefore, some physical, chemical and biological properties of soil were quantified using 80 samples to measure the soil quality index (SQI) in the Miandoab region, Iran. The results represented that soil SOC, N, MR, MP, silt, CaCO_3 , AS and BD had a high contribution to SQI and SOC made the highest variation to SQI (13.01%) followed by N (12.63%) and MR and MP (11.91%). The linear SQI values were more significantly affected by physical properties, while the nonlinear SQI showed the highest contribution of biological properties. Generally, the most sensitive indicators as affected by land use were the biological properties, which showed a high contribution to SQI in both linear and nonlinear functions. This confirms that agricultural activities like tillage have increased microbial activity and soil quality. In addition, there was no clear difference between linear and nonlinear equations to evaluate SQI. Furthermore, it should be considered in the future studies that although the SQI is a simple and flexible method, measured by different soil properties for monitoring the soil health, it is the biological properties that have the main role in terms of evaluating the effect of land use conversion on soil quality.

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Compliance with ethical standards

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

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