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SOIL QUALITY ASSESMENT OF UPPER TIGRIS BASIN

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Abstract: Economic life of the Tigris basin, part of the Mesopotamian depends heavily on agricultural production for thousands of years. Sustainability of agricultural production in this ancient region may only be possible by conserving and improving the ability of soils to function. Therefore, soil quality indexes were computed to evaluate and monitor functioning ability of pasture lands, forest lands, orchard and arable lands in the upper Tigris Basin of Mesopotamian. Soil samples were collected from (0–20 cm) at 134 locations from approximately the corners of 5km*5km size grid cells within 2.450 km^2 research site. Twelve soil properties were measured as potential indicators of soil quality. A minimum data set (MDS) for each of land use was determined by means of principal component analysis (PCA) and expert opinion (EO) techniques. The weightages of each indicator were calculated using PCA and analytical hierarchy process (AHP). Soil quality index (SQI) for every sampling locations was calculated by weighted additive method following the use of linear scoring functions to obtain unitless indicator scores. The organic matter (OM), aggregate stability (AS) and slope were considered the most powerful and common soil attributes for distinguishing land uses in regard to soil quality and they can be used to monitor and assess the soil quality in this semi-arid environment. The SQI values of four land uses were significantly different ($P<0.01$) from each other. The highest SQI value was obtained for forest land with EO (SQI_{EO}=0.974) and the lowest SQI value was for orchards with PCA (SQI_{AHP}=0.793). The results indicated that PCA and EO methods produced comparable results in assessment of soil quality.

Keywords: Soil quality, soil fertility, linear scoring, expert opinion, PCA, AHP.

1. INTRODUCTION

As one of the world's major ecosystems and a cradle of civilization, humans settled and developed agricultural practices in Mesopotamian for 10.000 years ago (Evans, 2011). Tigris Basin located in the upper Mesopotamian is under a severe land degradation problem. Due to the human settlement for thousands of years, lands exposed to increasing anthropogenic impacts, with detrimental effects on functions of soils. The upper Mesopotamian region, south eastern Anatolia is highly susceptible to land degradation, which is exacerbated by the increased cultivation of arable lands and poor management of rangelands. Managements can be evaluated and if causing to degradation can be corrected by the assessment of soil quality. Marzaioli et al., (2010) indicated that determining the appropriate soil conservation measures and crop yield improvements would be possible by evaluating soil quality. However, studies about the characterization of soils and assessment of soil quality in Tigris basin are rather insufficient.

Although soils have already been used for thousands of years and significantly degraded, precautions have to be urgently taken to prevent from further degradation. Soil quality assessment is to determine the performances of soil biological, chemical, and physical functions compared to its inherent potential (Veum et al., 2017). Soil quality is important to understand if functioning ability of a soil under different land uses and management practices is aggrading, sustaining, or degrading (Karlen et al., 2003). Quantification of soil quality is important to establish an early warning tool of adverse impacts from change in land use type. The impacts of land use on functioning ability of soils can only be understood before it's being too late by the assessment of the soil characteristics that are indicative of susceptibility to degradation accurately. Since soil quality cannot be measured directly, determination of sensitive soil attributes is the most important step to preserve and improve the quality of soils (Brejda et al., 2000), and provide appropriate soil conservation measures to sustain improvements in soil functions and perform ecosystem services.

Combination of individual soil attributes is used in assessment of soil quality to evaluate the effects of management decisions in a region or in a particular land use. Because soil quality is a soil and site-specific concept and controlled by site-specific factors, such as climate, land use or inherent soil properties (Karlen et al., 2006). However, huge spatial variation of soil characteristics does not allow to set a universal list of indicators suitable for all regions, land uses and ecosystem functions (Seybold et al., 1997). Therefore, indicator lists which represent the highest variability within the data set should be determined as site, region or land use specific in order to provide necessary information for land user to make sustainable decisions about their lands (Rezaei et al., 2006; Rezaei et al., 2015). Dynamic soil attributes such as organic matter (OM), aggregate stability and some of biological attributes are considered highly responsive to management practices and land use changes (Masto et al., 2008a).

Consistent and accurate assessment of soil quality requires a reliable method to interpret and measure soil properties. Since individual soil indicator may not reflect the functioning ability of soils under different land uses (Mukherjee & Lal, 2014), assessment of soil quality can be performed by characterization of soil properties, determining the minimum data set (MDS) and calculating the soil quality index (SQI) for a given region or land use type (Andrews et al., 2004). Redundancy in data set is reduced using principal component analysis (PCA) in defining a MDS (Andrews et al., 2002; Govaerts et al., 2006; Rezaei et al., 2006). The MDS is defined as the smallest number of soil attributes which are needed to define basic soil functions i.e., resistance and resilience to physical degradation, water and nutrient supply for plants and other living organisms in soil, and supporting plant growth (Rezaei et al., 2006). SQI can be obtained by integrating the soil properties within MDS into a single index which is a three-step process: (i) indicator selection, (ii) indicator interpretation and scoring and (iii) integration of individual indicator scores into SQI (Andrews et al., 2002).

Irrigation investments financed by the Turkish state in the Tigris basin are about to be completed, though contemporary studies on soil resources are not sufficient to support future management decisions to maintain the sustainability of agricultural production. Unfortunately, improper management decision in Harran Plain, the first largest (160.000 ha) irrigation project in the southeastern Turkey resulted in severe decline in soil fertility (Günal et al., 2015). The impact of management decisions on functioning ability of soils can be monitored and the decisions can be evaluated in a reasonable manner by soil quality assessments. The objectives of this study were to characterize variability of some physical and chemical properties of soils under different land uses, and to develop a soil quality index of different land use types in Tigris basin of upper Mesopotamian for establishing a benchmark for the upcoming soil quality evaluations in the same area.

2. MATERIALS AND METHODS

2.1. Study Area

134 soil samples representing pasture lands (20), forests (13), orchards (8) and arable cultivated lands (93) were collected from an area of about 2.450 km^2 located in upper Tigris Basin (between latitude 37°97' N and 38°29' N; longitude 39°75' E and 40°54' E), southeast Anatolia Region of Turkey (Figure 1). Study area was divided into 5km*5km size grids and soil samples were collected from 0-20 cm depth of the corners. The study area is located between the southeastern Taurus Mountains forming the northern and western borders and the Karacadag forming the south and south-western borders. The altitude ranges from 621 m to 1241 m. The study area is highly fragmented by rivers and deformed by tectonism. The south and southwest parts of the study area consist of flat areas covered by Karacadağ basalts. The lowlands located in the vicinity of the Karacadağ foothills are highly stony. Andisols are found in the vicinity of Karacadağ hillslopes. Entisols, Inceptisols and Vertisols are the commonly encountered soil ordos of the study area. The clay content of soils formed on Karacadağ basalts is quite high (average 66%) and smectite is the predominant clay mineral (Uzun, 2013).

The region is characterized by a hot

Mediterranean/dry-summer subtropical climate. The total annual average rainfall of the area 474,90 mm and mean air temperature is 15.8°C (1970-2011) (Çelik & Toprak, 2016).

Crop production of arable lands at the time of soil sampling was dominated by cereals, especially wheat (*Triticum aestivum L.*), barley (*Hordeum vulgare L.*), corn (*Zea Mays L.*) and lentil (*Lens culinaris*). Minimum or no-till systems does not invert the soil and keep the crop residues at the surface are almost not applied in the region, and conventional tillage with the use of rotary plough which invert soil is commonly practiced in crop production. Orchards were dominated by vineyards and followed by apple, apricot and cherry plantations. Farmers intensively tilled soils for weed management and moldboard is used in tillage operations. In forests of the study area, *Quercus infectoria* is especially common among the oak species. There are also locally distributed species such as *Quercus brantii*, *Quercus libani* and *Quercus cedrorum* (Sozer, 1984).

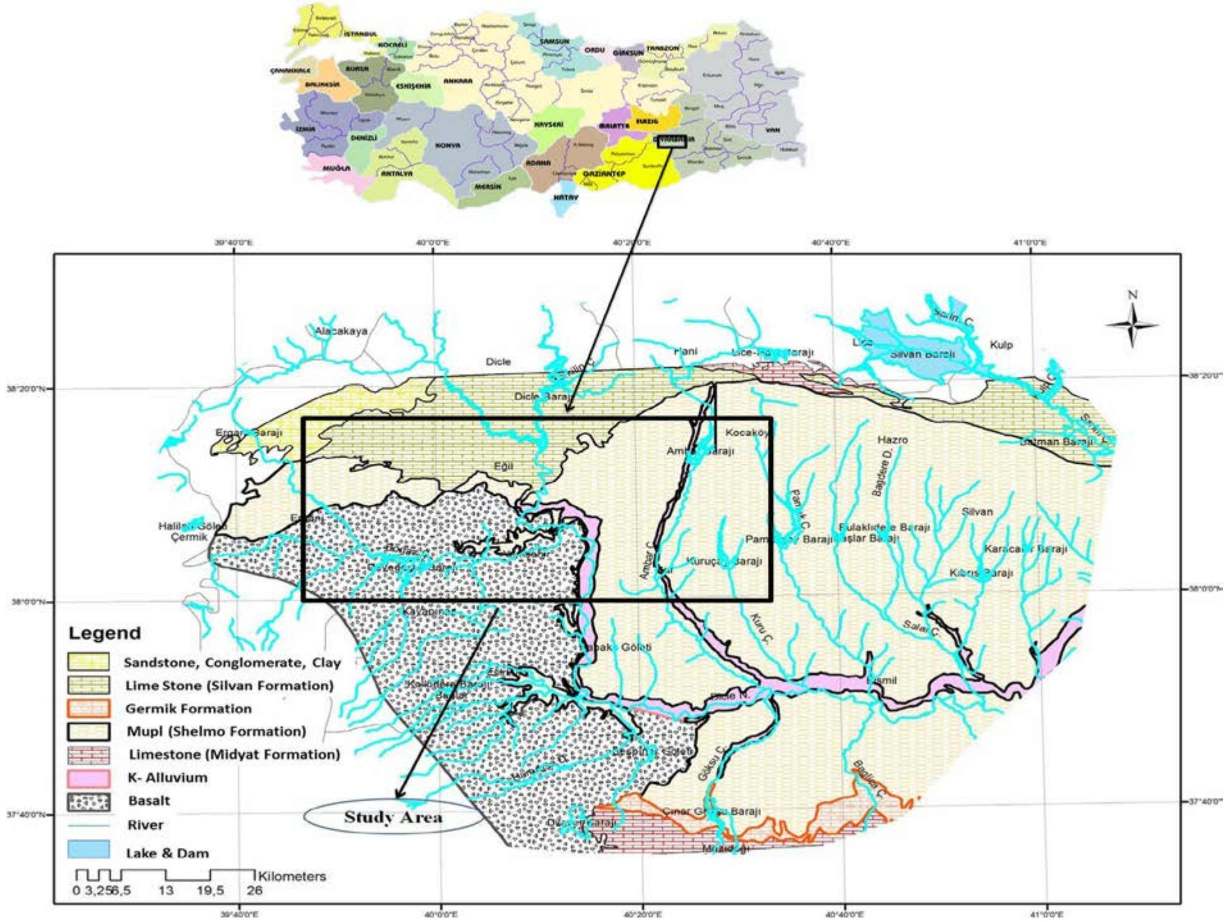

Figure 1. Location and geological map of the study area (Çelik, 2015)

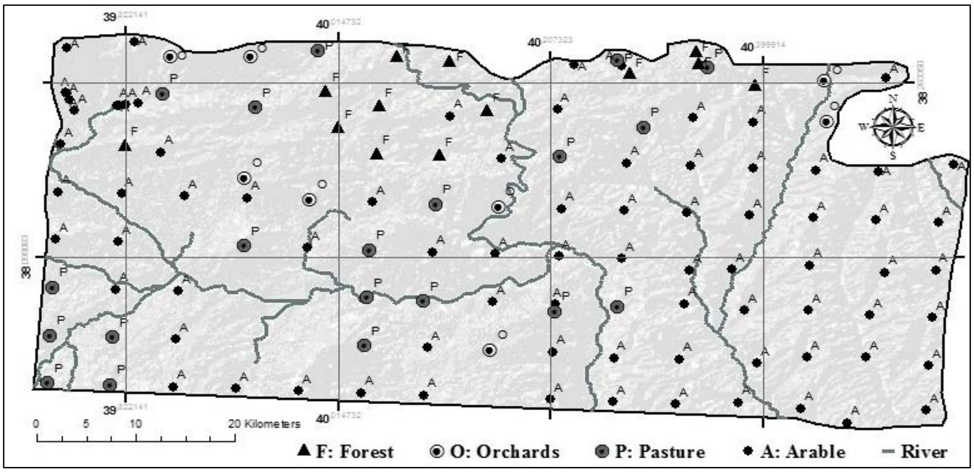

Figure 2. Distribution of sampling points in the study area

Soils in study area formed over various geological roots. Basalt is dominated on majority of the south and south-western part of the study area. The entire eastern and the upper part of the Ergani district formed over the Upper Miocene–Pliocene Şelmo formation. The Şelmo formation is alluvial in nature and is composed mainly of clay, silt, sandstone, gravel and marl bands. In addition, the Silvan formation rich in limestone is located in the north and the Mardin formation rich in limestone is located on the north of the study area (Figure 1) (Çelik, 2015). Old and new alluviums at Quaternary age deposited by the Tigris River and its tributaries over this formation (Doğan, 2005). Another highly common formation of study area is Germik which is divided into two separate sections as limestone and evaporite members. The Gemlik formation is divided into five facies which are; 1.) brown yellow colored, porous limestone facies, 2.) cream-beige colored dolomitic limestone facies, 3.) cream-beige colored gypsiferous limestone facies, 4.) gray colored gypsum, clayey gypsum facies and 5.) pink-beige colored muddy gypsum facies (Yeşilova & Helvacı, 2011).

2.2. Laboratory Analysis

Physical and chemical soil properties were measured using standard laboratory methods. Particle size distribution was determined by the hydrometer method in a sedimentation cylinder, using sodium hexamethaphosphate as the dispersing agent (Gee et al., 1986). The soil reaction (pH) and electrical conductivity (EC) were measured in a saturated paste (Rhoades, 1982). In pH measurements, an electrode of pH meter calibrated with standard solutions at pH 3, 7 and 10. $CaCO_3$ was determined by using calcimeter method as mentioned by Allison et al., (1965). Organic matter (OM) was determined using the technique described by Walkley and Black (1934). Organic carbon was converted to soil organic matter content multiplying by the conversion factor of 1.72 (Nelson & Sommer, 1982). Aggregate stability (AS) was determined wet sieving method (Eijkelkamp 08. 13, Netherlands). Plant available phosphorus content was analyzed by the modified Olsen's method (Olsen & Sommers, 1982), available potassium was determined by atomic absorption spectrophotometer after extraction using 1M ammonium acetate at pH 7.0 (Thomas, 1982). Sodium adsorption ratio (SAR) was calculated from saturated paste extracts of Na^+, Ca^{++} and Mg^{++} in milliequivalents per liter (U.S. Salinity Lab. Staff, 1954). The slope of each sampling point was obtained from the digital elevation model (DEM) of the study area. In order to produce DEM, SRTM digital elevation data with a resolution of 90 m was used.

2.3. Assessment of Soil Quality

Soil quality assessment is a three-step process that is composed of determination of indicators for MDSs, scoring of indicators selected or indicator interpretation and integration of individual indicator scores into the soil quality index (Andrews et al., 2004).

2.4. Determination of Indicators

For each of land use type in study area, two different MDSs were determined by means of principal component analyses (PCA) and expert opinion (EO). In order to reduce the number of indicators while minimizing the loss of information to assess soil quality index and represent the highest variability of the original data set, PCA was performed using SPSS (version 21.0) for nine attributes. For the data set of each land use type, principal components (PC) with high eigenvalues ($\geq$1.0) (Kaiser, 1960) were considered the best representatives explaining the variability of the original data. Varimax rotation was employed for the retained PCs to maximize the correlations between PC and the soil properties by distributing the variance (Waswa et al., 2013). Under each PC with eigenvalues $\geq$1.0, variable with the highest loading value and the variables within the 10% of the highest loading value were selected as soil quality indicators. The higher factor loading is considered a greater contribution to the variability in particular PC (Andrews et al., 2002; Govaerts et al., 2006; Askari & Holden, 2015). In some cases, more than one variable from each PC fitted to the indicator selection criteria, thus the redundancy among variables were analyzed by multivariate correlation. If the correlation of variables is higher than 0.60, then variable with the highest correlation sum was retained as soil quality indicator, otherwise both were retained within the MDS (Andrews & Carroll, 2001; Lin et al., 2017).

The expert opinion (EO) approach allows to select easily determined soil characteristics into the MDS. If the expert who knows the soils in the study area, crops in rotation and management practices applied on the land determines the indicators to be used, soil quality assessment will be more reliable and meaningful (Andrews et al., 2002).

2.5. Scoring the Soil Quality Indicators

The data obtained for the indicators were transformed into the unitless values ranging from 0 to 1 using linear scoring curves (Liebig et al., 2001).

Three types of scoring curves were used in transformations which are “more is better” (Fig. 3a), “less is better” (Fig. 3b) and “mid-point is optimum” (Fig. 3c). ‘More is better’ is used for positive slopes as in organic matter and aggregate stability. Masto et al., (2008b) reported that the validity of a soil quality index primarily associated to the appropriate critical limits (threshold values) used for individual soil properties. Threshold values used in calculation of indicator scores were gathered from the published literature (Table 1). Following the decision of the shape for the expected response, each indicator value was divided by the threshold value such that the value equal or higher than the threshold received a score of 1.0. For ‘less is better’, the threshold value was divided by each data value such that the data equal or lower than the threshold value received a score of 1.0. For indicators like pH, EC and $CaCO_3$ “mid is optimum” threshold values are taken into consideration for indicator score calculations.

2.6. Integration into a Soil Quality Index

The summary of SQI calculation is presented in Figure 4. The SQI for each sampling point was calculated using the weighted additive approach. The weightages of indicators selected in MDS obtained by PCA and EO were calculated using the PCA and analytical hierarchy process (AHP) techniques. In PCA approach; each PC with an eigenvalue ≥ 1.0 explained certain amount of variation in the total data set, and this variation was divided by the total variation of the PCs with an eigenvalue ≥ 1.0 (Andrews et al., 2002). Analytical hierarchy process is a technique that developed to organize and analyze complex decisions based on mathematics and psychology (Saaty, 2008).

Table 1. Indicators list and threshold values used in scoring

Indicators	**Threshold value**	**Scoring Curve**	**Reference**
pH	5.5-7.2	Optimum is better	Mukherjee & Lal, 2014
EC	0.2-0.5 dS m^{-1}	Optimum is better	Mukherjee & Lal, 2014
SAR	<3.0	Less is better	Mutlu, 2015
OM	2.50 %	More is better	Lima et al., 2013
$CaCO_3$	4.0-8.0 %	Optimum is better	Mutlu, 2015
Potassium	200 mg kg^{-1}	More is better	Andrews et al., 2004
Phosphorus	15-60 mg kg^{-1}	Optimum is better	Andrews et al., 2004
AS	> 60.0 %	More is better	Andrews et al., 2004
Slope	< 6.0 %	Less is better	Kosmas et al., 1999

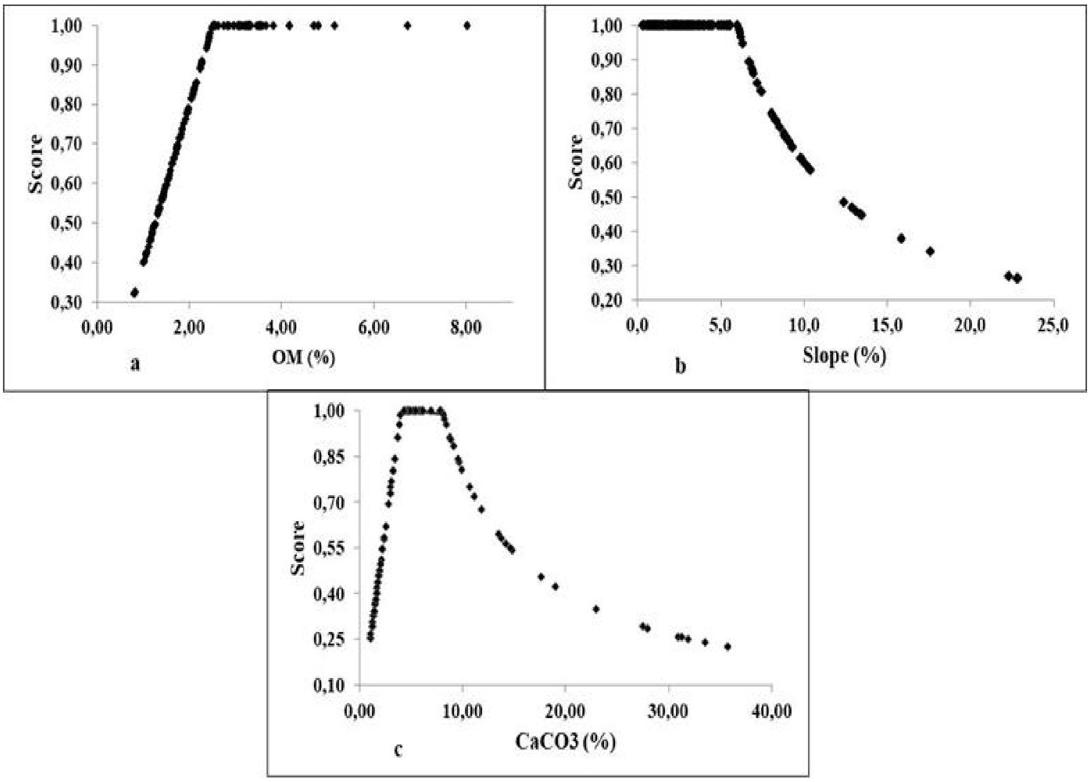

Figure 3. Scoring curves for less is better (slope), mid point optimum ($CaCO_3$) and higher is better (organic matter).

The AHP method is used to calculate weighting factors by help of a preference matrix where all identified relevant criteria are compared against each other with reproducible preference factors (Mohammed & Mohd, 2014). The weights of soil quality indicators in the AHP were primarily based on experts' opinion or experience on soils studied and the type of land use considered.

Scored soil indicators were multiplied by the weightage of indicator in MDS and all weighted indicator scores were integrated into a single index value for each of sampling point (Eq. 1) (Andrews et al., 2002).

$$SQI = \sum_{n=0}^{i} WiSi \quad \textbf{(Eq.1)}$$

where W is the weightage of soil indicator derived from the PCA or AHP and S is the indicator score obtained by linear scoring curve. The higher SQI value indicates better functioning of a soil.

2.7. Statistical Analyses

All the data were tested for normality and equal variance prior to the statistical analyses and were transformed if needed. The differences in soil properties, soil quality indicators and SQI values among land use types were statistically analyzed by one-way analysis of variance (ANOVA) using SPSS 21.0. The PCA and related tests were also conducted using SPSS software.

3. RESULTS AND DISCUSSIONS

Twelve soil properties (Table 2) were determined as indicators for functioning capacity of soils. Since components of soil texture are inherent characteristics, they were not included into the soil quality indicator data set.

3.1. Arable Lands in Upper Tigris Basin

Descriptive statistics of indicators and scores for arable lands are presented Table 2. Arable lands were characterized by a lower soil OM content than other land uses. The highest coefficient of variation (CV) (127.96%) is occurred for the P content in arable lands. The variability of $CaCO_3$ is very high with 119.97% of CV. Although the mean $CaCO_3$ content is not high (5.39%) and in some areas very low (1.02%), it reaches to 35.72% depending on the parent material of the soils. Soils are mostly heavy clayey with a mean clay content of 62.12%.

The soils of Tigris Basin, in south eastern Turkey, have a historical importance in Turkish agricultural productivity and have been subjected to intensive agricultural production and danger to decline quality of soils. In order to select soil attributes to best represent the soil quality of arable lands in upper Tigris Basin, the PCA reduced the total data set to four PCs that explained 64.43% of the total variance of the original data (Table 3).

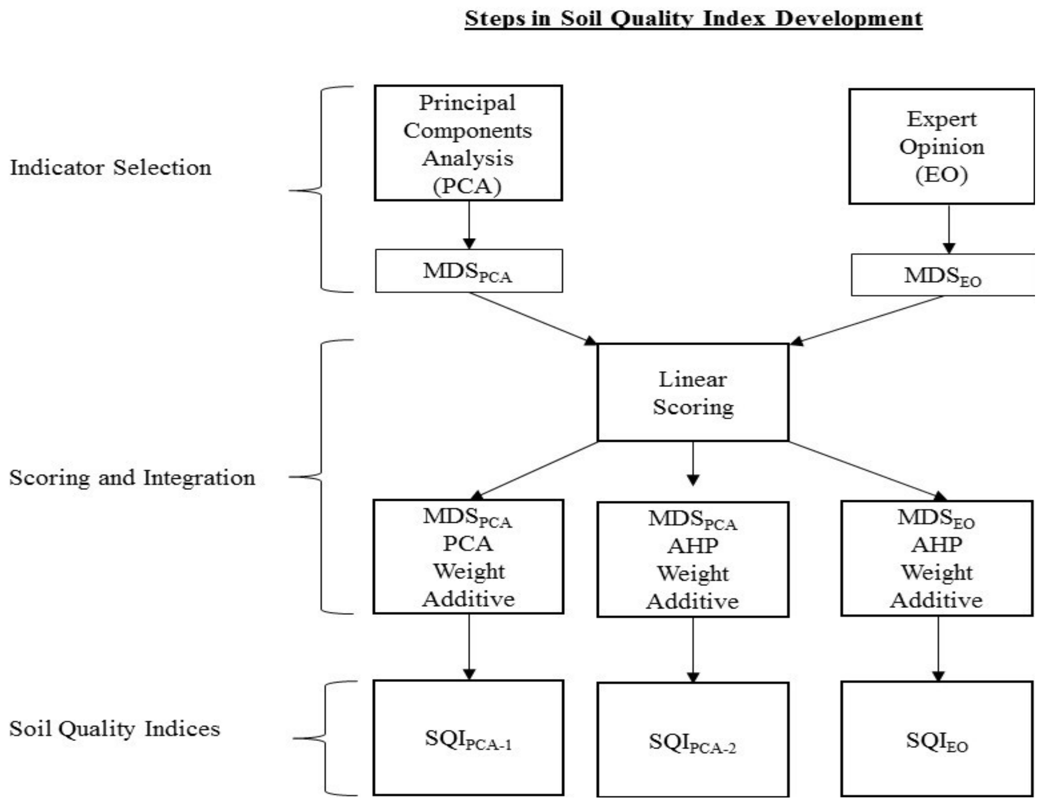

Figure 4. Steps in soil quality assessments

Table 2. Descriptive statistics of soil properties used for soil quality assessment of arable lands in upper Tigris Basin.

		Laboratory Data					Indicator scores	
N=93		**Min.**	**Max**	**Mean**	**SD**	**CV**	**Mean**	**SD**
Clay	(%)	32.70	77.70	62.12	12.11	19.50	-	-
Sand		7.10	47.30	18.67	9.70	51.99	-	-
Silt		7.50	40.00	19.22	6.53	33.95	-	-
AS	(%)	9.80	96.97	83.80	13.59	16.22	0.99	0.08
pH		6.41	8.19	7.48	0.40	5.32	0.95	0.04
EC	($dS\ m^{-1}$)	0.36	1.97	0.82	0.30	37.15	0.66	0.17
$CaCO_3$	(%)	1.02	35.72	5.39	6.46	119.97	-	-
OM		0.81	8.02	1.95	0.96	49.00	0.72	0.20
SAR		0.05	1.05	0.28	0.18	65.80	-	-
Potassium	($mg\ kg^{-1}$)	5.90	1512.39	327.73	232.27	70.87	0.87	0.24
Phosphorus		2.85	172.04	15.43	19.74	127.96	0.67	0.28
Slope	(%)	0.32	22.81	4.50	4.33	96.31	0.90	0.18

*SD: Standard Deviation; CV: Coefficient of variation

Table 3. Principal components and properties selected for the minimum dataset (MDS) for arable lands.

	PC1	**PC2**	**PC3**	**PC4**
Eigen Values	1.87	1.66	1.17	1.10
% Variance	20.82	18.45	12.94	12.22
Cumulative Variance	20.82	39.27	52.21	64.43
Phosphorus	**0.884**	0.258	-0.055	-0.048
OM	**0.881**	-0.236	-0.069	0.013
Slope	0.049	**-0.760**	0.118	0.114
EC	0.083	0.656	0.185	0.120
AS	-0.186	-0.109	**0.766**	0.180
$CaCO_3$	-0.017	-0.173	**-0.684**	0.420
SAR	0.350	0.319	0.476	0.403
Potassium	0.012	0.125	0.014	**-0.665**
pH	-0.038	0.436	0.067	**0.637**

Boldface loadings were considered highly weighted and underlined loadings were retained in MDS from the PCs after correlation analysis.

The soil parameter with the greatest loading value and the other parameters had a loading value within the 10% of the greatest loading value were selected considered for minimum data set (MDS) in each of the PCs. Organic matter and P were highly weighted variables from PC1, but were significantly correlated (r=0.62) to each other (Table 4). Plant available P was selected to MDS due to the its higher correlation coefficient sum, thus OM did not contribute to the SQI of arable lands because of high correlation with P. Slope from PC2, AS and $CaCO_3$ from PC3 and K and pH from PC4 were highly weighted and considered for the MDS of the arable lands in upper Tigris Basin (Table 3).

The PCA method has been preferred to establish MDS in soil quality assessments (Andrews et al., 2002; Govaerts et al., 2006; Lima et al., 2013; Mukherjee & Lal, 2014; Askari & Holden, 2015; Cherubin et al., 2016; Lin et al., 2017) due to being a less subjective method of soil quality indicator selection. Although the PCA can help to assess unbiased soil quality and to remove the redundancy in data set, the indicators considered for MDS may not be as important or meaningful as the indicators excluded from data set.

Table 4. Correlation matrix for the dataset of arable lands

	pH	EC	$CaCO_3$	OM	AS	SAR	Potassium	Phosphorus	Slope	Sum of Corr.
pH	1.00									3.04
EC	0.17	1.00								3.24
$CaCO_3$	0.05	-0.07	1.00							2.76
OM	-0.06	-0.15	0.06	1.00						3.24
AS	0.08	0.11	-0.21	-0.11	1.00					2.94
SAR	0.36	0.26	-0.15	0.12	0.16	1.00				3.40
Potassium	-0.12	-0.04	-0.07	-0.03	-0.07	-0.05	1.00			2.40
Phosphorus	0.02	0.26	-0.02	**0.62**	-0.17	0.25	0.02	1.00		3.50
Slope	-0.19	-0.19	0.13	0.08	0.03	-0.06	0.02	-0.14	1.00	2.83

Cherubin et al., (2016) indicated that a large number of indicators are needed to run the PCA which is not convenient to adopt for farm or regional scale soil quality assessments. The soil quality indicator list for the regional scale soil quality assessment of arable lands in Tigris Basin based on common decisions of the authors (expert opinion, EO), and land use types comprised of slope, P, AS, pH, EC and OM.

Organic matter or organic carbon is the most commonly used indicator of soil quality for various types of soils around the world particularly for the arid and semi-arid regions (Vasu et al., 2016; Raiesi, 2017). Organic matter stores and supplies nutrient and water for soil organisms and plants, improves resistance to degradation through holding soil particles together and reducing the negative impact of erosion and prevents to form undesired physical conditions such as compaction and surface crust. Therefore, organic matter was considered as one of the soil quality indicators in this study, and included into the MDS by EO for the assessment of soil quality of arable lands. Soil pH is an important soil quality indicator due to the significant effect on solubility and availability of plant nutritions. Nutrients are found either as cation or anion forms in soils and bound to charged surfaces called anion or cation exchange sites of soils. The status of hydrogen ions bound to the charged surface or free in soil solution largely determines the charge of the soil particles and availability of nutrients (McCauley et al., 2009).

The phosphorus is frequently deficient (<4.5 mg kg^{-1} in 58% of the country) in alkaline soils of Turkey (Eyüpoğlu, 1999), thus the P indicator is important to present the P supply potential of soils to plant growth, and therefore included into the MDS of arable lands and orchards by EO. Plant available P is considered one of the major plant nutrients and also a primary factor limiting yields due to its weak mobility, thus Liu et al., (2017) used P for soil diagnosis and fertility assessment of *Camellia oleifera* grown soils in mid-subtropical China. The phosphorus was scored by a mid-point optimum approach. The left side of the P scoring curve reflects the P concentration for crop requirements, and the right side express the hazardous impact of excess P such as P runoff to surface water (Andrews et al., 2004).

Potassium is an essential plant nutrient for plant growth and considered one of the soil quality indicators of arable lands with PCA, however soils in Turkey as well as the Tigris basin contain adequate amount of K, thus not included to the MDS by EO.

3.2. Pasture Lands in Upper Tigris Basin

Descriptive statistics of indicators and scores for pasture lands are presented Table 5. Soil properties belonged to different land use types were presented in separate tables.

Four PCs were identified with eigenvalue ≥1.0 for pasture lands and explained 75.0% of the total variance of the data set (Table 6). The first PC explained 26.59% of the total variance and pH and EC were highly weighted variables within 10% of the highest factor loading value (Table 6). The correlation between pH and EC (r=0.57) was less than 0.60, thus both included into the MDS (Table 7). Plant available potassium, AS and P had the highest factor loadings from PC2, PC3 and PC4, respectively. The indicators considered for MDS had low correlations between each other and the MDS of pasture lands in upper Tigris basin were thus comprised of pH, EC, K, AS and P. However, the expert opinion for the soil quality indicators of pasture lands MDS was consisted of AS, EC, OM and slope.

3.3. Orchards in Upper Tigris Basin

Descriptive statistics of indicators and scores for orchards are presented Table 8. Orchards in study

Table 5. Descriptive statistics of soil properties used for soil quality assessment of pasture lands in Upper Tigris Basin.

N=20		**Laboratory Data**					**Indicator Scores**	
		Min.	**Max.**	**Mean**	**SD**	**CV**	**Mean**	**SD**
Clay	(%)	26.45	77.70	60.70	11.28	18.58	-	-
Sand		4.80	52.10	15.24	10.85	71.22	-	-
Silt		17.50	35.00	24.06	4.97	20.65	-	-
AS	(%)	48.72	98.11	80.33	11.86	14.76	1.00	0.01
pH		6.67	7.90	7.22	0.33	4.60	0.98	0.03
EC	($dS\ m^{-1}$)	0.38	1.15	0.75	0.20	26.32	0.70	0.17
$CaCO_3$	(%)	1.31	27.96	4.92	6.94	141.19	-	-
OM		0.80	5.14	2.71	1.18	43.69	0.85	0.21
SAR		0.05	0.45	0.18	0.12	66.39	-	-
Potassium	($mg\ kg^{-1}$)	85.53	723.59	325.15	189.94	58.42	0.90	0.19
Phosphorus		2.52	49.90	15.05	15.22	101.14	0.62	0.33
Slope	(%)	0.90	17.62	5.24	4.85	92.51	0.88	0.22

*SD: Standard Deviation; CV: Coefficient of variation

Table 6. Principal components and properties selected for the minimum dataset (MDS) for pasture lands.

	PC1	**PC2**	**PC3**	**PC4**
Eigen values	2.39	1.79	1.444	1.127
% Variance	26.59	19.84	16.05	12.52
Cumulative Variance	26.59	46.43	62.48	75.00
pH	**<u>0.867</u>**	-0.004	-0.054	0.284
EC	**<u>0.832</u>**	-0.074	0.178	-0.394
SAR	0.608	0.316	0.531	0.079
$CaCO_3$	0.457	0.125	-0.081	-0.251
Potassium	-0.061	**<u>0.858</u>**	0.094	-0.007
Slope	0.299	0.734	-0.327	0.044
AS	0.053	-0.189	**<u>0.900</u>**	-0.189
Phosphorus	0.014	-0.063	-0.277	**<u>0.863</u>**
OM	-0.258	0.331	0.467	0.625

Boldface loadings were considered highly weighted and underlined loadings were retained in MDS from the PCs after correlation analysis.

Table 7. Correlation matrix for the dataset of pasture lands

	pH	EC	$CaCO_3$	OM	AS	SAR	Potassium	Phosphorus	Slope	Sum of Corr.
pH	1.00									3.80
EC	0.57	1.00								4.64
$CaCO_3$	0.12	0.41	1.00							3.09
OM	-0.09	-0.36	-0.12	1.00						3.55
AS	-0.04	0.28	0.04	0.23	1.00					3.71
SAR	0.46	0.48	0.16	0.12	0.33	1.00				4.08
Potassium	-0.04	-0.07	0.03	0.18	-0.09	0.31	1.00			3.11
Phosphorus	0.16	-0.35	-0.02	0.30	-0.36	-0.08	0.03	1.00		3.32
Slope	0.32	0.12	0.17	0.15	-0.35	0.15	0.37	-0.02	1.00	3.64

area were mainly vineyard (5 of 8 orchards) and mixed fruits (apple, cherry and apricot) and moldboard plow has been used in soil tillage. The OM content was significantly lower compared to the other land uses due to the intensive tillage operations. Although soils in orchards have high clay content (58.33%), it was slightly lower than the soils of other land use types. Aggregate stability similar to OM is one of the key indicators of soil quality, and low AS is considered to be a sign of degradation of soils. The positive influence of OM and clay content on stability of aggregates have been documented (Muneer & Oades, 1989; Šimansky & Jonczak, 2016). The lower OM and clay contents of orchard soils along with the lower AS values compared to the land uses support the interaction of OM and clay content with AS.

The PCA indicated three PCs with eigenvalues ≥1.0 for orchards of upper Tigris Basin, and these three PCs explained 82.16% of the variance of the data set. The PC1 explained 41.03% of the variance and P had the highest factor loading value.

Table 8. Descriptive statistics of soil properties used for soil quality assessment of orchards in Upper Tigris Basin.

		Laboratory Data					**Indicator Scores**	
N=8		**Min.**	**Max**	**Mean**	**SD**	**CV**	**Mean**	**SD**
Clay	(%)	45.20	75.20	58.33	9.91	16.99	-	-
Sand		4.80	27.10	15.61	6.78	43.45	-	-
Silt		17.70	35.00	26.06	6.44	24.70	-	-
AS	(%)	42.81	89.42	73.70	15.76	21.39	0.98	0.05
pH		6.61	7.85	7.19	0.42	5.81	0.98	0.03
EC.	(dS m^{-1})	0.55	0.91	0.73	0.13	17.94	0.70	0.13
$CaCO_3$	(%)	1.22	33.59	10.95	13.48	123.11	0.73	0.63
OM		1.10	2.82	1.87	0.57	30.39	0.73	0.20
SAR		0.05	0.45	0.18	0.14	77.87	-	-
Potassium	(mg kg^{-1})	71.03	591.23	285.16	191.26	67.07	-	-
Phosphorus		3.89	132.72	27.62	43.06	155.9	0.60	0.32
Slope	(%)	1.42	8.53	4.67	2.51	53.83	0.96	0.10

*SD: Standard Deviation; CV: Coefficient of variation

Table 9. Principal components and properties selected for the minimum dataset (MDS) for orchards.

	PC1	**PC2**	**PC3**
Eigen values	3.69	2.04	18.42
% Variance	41.03	22.72	15.58
Cumulative Variance	41.03	63.74	82.16
Phosphorus	**0.935**	0.199	0.058
Slope	**<u>0.841</u>**	-0.471	-0.063
$CaCO_3$	0.743	0.073	-0.463
SAR	-0.033	**<u>0.940</u>**	0.279
pH	0.056	**0.925**	-0.096
AS	-0.166	0.144	**0.764**
OM	-0.291	0.392	**<u>-0.753</u>**
EC	-0.287	0.530	**<u>0.696</u>**
Potassium	-0.503	0.251	0.584

Boldface loadings were considered highly weighted and underlined loadings were retained in MDS from the PCs after correlation analysis.

The slope had a factor loading value within 10.0% of the highest factor loading value (Table 9). The correlation analyses revealed that P and slope were significantly correlated (r>0.60), thus the P having the highest correlation sum (slope) was selected for the MDS (Andrews and Carroll, 2001; Lin et al., 2017). SAR and pH were the highly weighted variables from PC2 and considered for MDS. These two variables explained 22.72% of the variance. SAR was selected from PC2 for MDS due to the higher correlation coefficients sum compared to that of pH (Table 10). Organic matter had the highest factor loading value from PC3 and factor loading values of OM and EC were within the 10.0% of the highest factor loading.

The correlation analyses revealed that correlation coefficient of OM with AS and EC was low, therefore included into the MDS. But, AS and EC were significantly correlated to each other (r=0.68), EC was considered for MDS due to its higher correlation coefficient than AS. Similarly, EC and SAR had significant correlation (r=0.71) and EC had a greater correlation coefficient sum than SAR (Table 10), thus included in the MDS (Table 9). The AS and SAR did not contribute to the SQI of orchards due to the high correlations with EC. Therefore, the final MDS_{PCA} of orchards in upper Tigris Basin was comprised of slope, OM and EC. The researchers' opinion (MDS_{EO}) on the indicators to be used in regional scale soil quality assessment of orchards is substantially different from MDS_{PCA}. The salinity is not a limiting factor in the pasture lands of the upper Tigris basin, thus excluded from the MDS, instead pH, plant available P, $CaCO_3$ and AS were included to the MDS.

3.4. Forest Lands in Upper Tigris Basin

Descriptive statistics of indicators and scores for forest land are presented Table 11. Although clay content did not differ among land uses, clay content (64.05%) of forest land was slightly higher compared to other land use types (Table 11). The lowest mean sand, $CaCO_3$, K and P contents were obtained in forest land soils, whereas clay, silt and OM contents were comparable higher than the soils of other land uses.

The first four PCs had eigenvalues ≥1.0 and explained 81.16% of the variance of the data set (Table 12). The highly weighted variables under PC1 were EC and OM, and they were significantly correlated (r=0.62) to each other (Table 13).

Table 10. Correlation matrix for the dataset of orchards

	pH	EC	$CaCO_3$	OM	AS	SAR	Potassium	Phosphorus	Slope	Sum of Corr.
pH	1.00									4.29
EC	0.31	1.00								5.56
$CaCO_3$	0.05	-0.46	1.00							5.02
OM	0.31	-0.15	0.35	1.00						3.98
AS	0.06	**0.68**	-0.28	-0.28	1.00					4.46
SAR	**0.80**	**0.71**	-0.08	0.15	0.28	1.00				5.15
Potassium	0.06	0.59	-0.48	-0.13	0.51	0.47	1.00			5.15
Phosphorus	0.25	-0.14	0.58	-0.32	-0.22	0.18	-0.39	1.00		4.70
Slope	-0.44	-0.51	**0.74**	-0.28	-0.16	-0.48	-0.51	**0.63**	1.00	5.76

Table 11. Descriptive statistics of soil properties used for soil quality assessment of forest lands in Upper Tigris Basin.

		Laboratory Data					Indicator Scores	
N=13		**Min.**	**Max.**	**Mean**	**SD**	**CV**	**Mean**	**SD**
Clay	(%)	45.20	75.20	64.05	7.88	12.30	-	-
Sand	(%)	4.80	22.30	9.23	4.71	51.01	-	-
Silt	(%)	17.50	32.70	26.73	3.98	14.90	-	-
AS	(%)	44.57	94.33	81.01	12.83	15.84	0.99	0.03
pH		6.67	7.81	7.22	0.43	5.89	-	-
EC	(dS m^{-1})	0.39	0.93	0.54	0.14	26.96	-	-
$CaCO_3$	(%)	1.07	31.91	4.64	8.38	180.71	-	-
OM	(%)	3.06	6.73	3.68	1.00	27.24	1.00	0.00
SAR		0.07	1.43	0.32	0.36	113.03	1.00	0.00
Potassium	(mg kg^{-1})	41.04	282.27	101.62	66.69	65.62	0.98	0.06
Phosphorus	(mg kg^{-1})	2.90	59.90	22.10	18.74	84.85	-	-
Slope	(%)	2.17	22.83	7.72	5.51	71.36	0.81	0.25

*SD: Standard Deviation; CV: Coefficient of variation

Table 12. Principal components and properties selected for the minimum dataset (MDS) for forest lands.

	PC1	**PC2**	**PC3**	**PC4**
Eigen values	2.88	2.11	1.24	1.08
% Variance	32.04	23.40	15.68	11.96
Cumulative Variance	32.04	55.45	69.20	81.16
EC	**0.883**	0.047	-0.005	-0.108
OM	**<u>0.852</u>**	-0.011	0.210	0.226
Phosphorus	0.790	0.241	-0.091	0.034
$CaCO_3$	-0.113	**-0.957**	0.063	-0.023
AS	0.159	**<u>0.880</u>**	-0.138	0.249
SAR	0.007	0.030	**<u>0.912</u>**	0.022
pH	0.101	0-.371	0.763	-0.288
Slope	0-.218	0.035	0.274	**<u>-0.811</u>**
Potassium	-0.116	0.354	0.088	**<u>0.781</u>**

Boldface loadings were considered highly weighted and underlined loadings were retained in MDS from the PCs after correlation analysis.

Table 13. Correlation matrix for the dataset of forest lands

	pH	EC	$CaCO_3$	OM	AS	SAR	Potassium	Phosphorus	Slope	Sum of Corr.
pH	1.00									4.61
EC	0.18	1.00								3.98
$CaCO_3$	0.38	-0.07	1.00							4.13
OM	0.21	**0.62**	-0.15	1.00						4.17
AS	-0.37	0.27	**-0.86**	0.11	1.00					4.73
SAR	0.54	-0.05	0.03	0.12	-0.15	1.00				3.16
Potassium	-0.31	-0.11	-0.26	0.09	0.44	0.02	1.00			3.66
Phosphorus	-0.27	0.57	-0.29	0.59	0.22	0.07	0.06	1.00		4.20
Slope	0.35	-0.11	0.09	-0.27	-0.32	0.18	-0.35	-0.13	1.00	3.80

Organic matter had the highest correlation coefficient sum and thus, was retained for the MDS. The $CaCO_3$ and AS were highly weighted variables from PC2 and significantly correlated (r=-0.86) to each other, AS was considered for MDS due to its higher correlation coefficient sum. Under PC3, SAR was the only highly weighted variable and selected for MDS. The slope and K were highly weighted variables from PC4 and both were retained for the MDS because they were not well correlated. The final MDS for forest land in upper Tigris Basin were comprised of OM, AS, SAR, slope and K. The MDS_{EO}, based on experts' opinions was composed of only OM, slope and AS.

3.5. Soil Quality Assessment

The mean values of pH, EC, OM, P, K, sand and silt significantly (P<0.01) varied among four land use types evaluated. However, one way

ANOVA revealed that only pH, EC, OM and P indicator scores were significantly differed among land use types (Table 14).

Table 14. Results of one-way analysis of variance (ANOVA) for different land uses in terms of soil attributes

Attributes	Sig.	
	Lab. Data	**Indicator Score**
pH	0.006	0.006
EC	0.007	0.000
SAR	0.086	-
OM	0.000	0.000
AS	0.178	0.952
$CaCO_3$	0.192	0.286
P	0.000	0.047
K	0.000	0.365
Slope	0.110	0.257
Clay	0.692	-
Sand	0.007	-
Silt	0.000	-

The indicator lists and the weights used to calculate final SQI of four land uses were presented in Table 15. The PCA and EO revealed that different set of indicators would be required for soil quality assessment of each land use. However, the OM along with slope and AS are considered as the most important and common indicators by the EO to assess and monitor the soil quality of four land uses in upper Tigris basin. The weights of indicators revealed the potential contribution rate of indicators in soil quality assessment. The indicator of OM was given the highest weightage for all land uses by the researchers due to the significant contribution to ability of soils to form stable aggregates, adsorb and release nutrients and water on its surface which sustain and support plant growth and biodiversity in soils (Seybold et al., 1997; Brejda et al., 2000).

In MDS_{PCA} of orchards, slope had the highest weightage (0.526) while OM had the greatest contribution (0.339) to SQI in MDS_{EO}. Due to the significant influence on soil quality affecting water retention, formation of stable aggregates, lowering bulk density, buffering soil pH, increasing cation exchange capacity providing suitable surfaces for pesticide adsorption and heavy metals, enhancing infiltration, aeration and creating habitat for soil biota (Seybold et al., 1997), Brejda et al., (2000) reported that total organic carbon of soils alone could be used to monitor soil quality.

In the SQI_{EO} where the weightages of indicators were determined by AHP, the contribution of pH, OM, EC and slope to overall SQI of arable lands was 25.2%, 22.4%, 20.0% and 17.4%, respectively (Table 15). The OM indicator in forest land, similar to pasture and orchards, had the highest weightage (0.668) suggested that OM may be considered the primary constraint limiting the functioning potential of soils in these land uses.

Table 15. The weightages of soil quality indicators for minimum data sets (MDS) selected by principal component analyses (PCA) and expert opinion (EO)

PCA MDS				EO MDS	
Land Use		**PCA weight**	**AHP weight**		**AHP weight**
Arable Lands	P	0.271	0.099	P	0.072
	Slope	0.241	0.259	Slope	0.174
	AS	0.169	0.139	AS	0.077
	pH	0.159	0.449	pH	0.252
	K	0.159	0.054	EC	0.200
				OM	0.224
Pasture Land	AS	0.158	0.476	AS	0.102
	EC	0.262	0.196	EC	0.127
	pH	0.262	0.194	OM	0.519
	K	0.195	0.051	Slope	0.253
	P	0.123	0.085		
Orchards	Slope	0.526	0.285	Slope	0.112
	OM	0.237	0.577	OM	0.339
	EC	0.237	0.139	pH	0.255
				P	0.103
				$CaCO_3$	0.097
				AS	0.095
Forest Land	OM	0.344	0.488	OM	0,668
	AS	0.251	0.113	AS	0.157
	Slope	0.128	0.238	Slope	0.175
	SAR	0.148	0.118		
	K	0.128	0.044		

Table 16. Soil quality index values for different land uses

Land Use	SQI_{PCA-1}	SQI_{PCA-2}	SQI_{EO}	ANOVA for Methods
Arable Lands	0.857±0.100	0.914±0.061	0.817±0.074	0.000
Pasture Lands	0.849±0.092	0.903±0.057	0.856±0.131	0.171
Orchards	0.846±0.089	0.793±0.130	0.830±0.097	0.605
Forest Lands	0.969±0.036	0.953±0.061	0.974±0.037	0.456
ANOVA for Land Uses	0.000	0.000	0.000	

Three different SQI values were calculated as SQI_{PCA-1}, SQI_{PCA-2} and SQI_{EO}. The SQI_{PCA-1} is calculated by multiplying the scores of indicators determined by PCA with the weightages obtained by PCA. The SQI_{PCA-2} is calculated by multiplying the scores of indicators determined by PCA with the weightages obtained by AHP. The SQI_{EO} is calculated by multiplying the scores of indicators determined by EO with the weightages obtained by AHP. The SQI values of four land uses were significantly different at $P<0.01$ for each of the three different methods. The methods only yielded a significantly different result for arable lands and SQI values were not different from each other for the other three land uses. The SQI values were significantly ($P\leq0.01$) higher in the following order for SQI_{PCA-1} and SQI_{PCA-2}: Forest Lands > Arable Lands > Pasture Lands > Orchards, and for SQI_{EO}: Forest Lands > Pasture Lands > Orchards > Arable Lands, indicating that land use type has a significant effect on soil quality. The highest SQI value was obtained for forest land with EO (SQI_{EO}=0.974) and the lowest SQI value was for orchards with PCA (SQI_{AHP}=0.793). The significant difference in SQI among land use types is resulted from the difference in indicators selected for the MDS to compute the SQI and the weightages obtained by PCA and AHP. Brejda et al., (2000) explained that variation of soil quality between soil and geographic regions is a consequence of the differences in major soil forming factors such as parent material, climate, vegetation and topography and anthropogenic factors such as land use practices in each region.

In the orchards, conventional tillage with the use of moldboard plow resulted in reduction of OM content due to the increased mineralization rate which promoted aggregate destruction (Bronick & Lal, 2005). In addition to the negative influence of OM loss, breaking of macro aggregates into small and less stable aggregates by tillage equipment decreased the AS of orchards which consequently lowered the functioning ability of soils.

The mean SQI_{PCA-1} value (0.849) of pasture lands was slightly lower than SQI_{PCA-2} (0.914) and SQI_{EO} (0.856) of pasture, though there was no statistical difference (P=0.171) among values of SQI (Table 16).

Spatial distribution of SQI values obtained by three different methods were mapped and presented in Figure 5, 6 and 7, respectively. Since the SQI values of different methods were similar except for arable lands, the maps produced were also very similar to each other. The best soils are located on the northern and southeastern part of the study area, while soils with the lowest soil quality were on the south west and north-east part of the upper Tigris basin.

The SQI value of forest land was significantly higher compared to the other land uses in upper Tigris Basin. The SQI_{EO} (0.974) was slightly higher than the SQI_{PCA-1} (0.969) and SQI_{PCA-2} (0.953) due the indicators in MDS and the weightages of indicators. The forest lands were mostly located in sloppy areas (mean slope 7.72%) of northern part of the study area (Figure 5, 6 and 7) and less affected by the anthropogenic impacts. The fallen litters of the trees increased the organic matter content of the surface soils in forest lands and sustained the high soil quality despite the slope. High OM content of soils in forest land increased the AS and resulted in higher SQI values among the land uses in upper Tigris basin.

4. CONCLUSIONS

Soil quality indicators for four land use types in upper Tigris Basin were determined by PCA and EO and used in calculation of SQI to learn how soil quality of soils changed by different land uses. The SQI values of lands uses were significantly differed from each other. The difference in SQI values was mainly due to the changes in indicators used and the weights of each indicator because of the differences in land use types. Soil organic matter, AS and slope were considered to be the key indicators of MDSs determined by EO for the soil quality assessment of all four land uses, these indicators significantly affected the computed SQI values. Since OM is the key element of soil fertility and fulfills an important role in sustaining productivity, it had the highest weightages in land uses (except arable lands) with AHP technique. However, the data reduction technique, PCA, used to determine MDS revealed some differences in indicator lists which resulted in significant differences in SQI values of arable lands ($P<0.01$) and forest lands ($P<0.05$).

The SQI values for pasture and orchard lands obtained with three methods were significantly similar to each other. The similarity in spatial patterns of the soil quality indicators and SQI values confirm the applicability of the methods in assessment of soil quality in Tigris Basin as well as the regions which have similar characteristics.

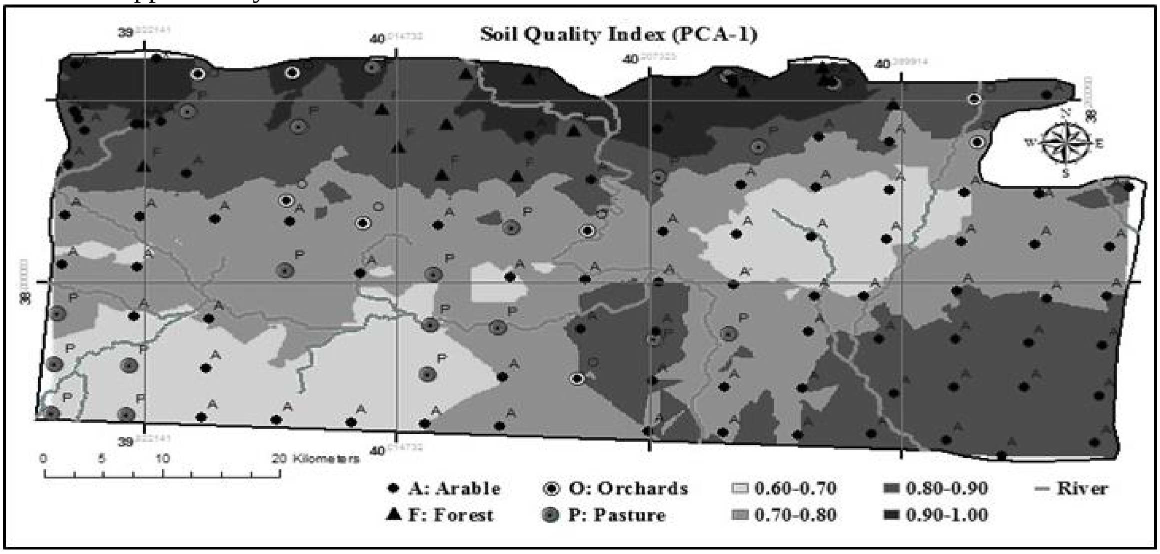

Figure 5. Spatial distribution of SQI_{PCA-1} values in upper Tigris basin

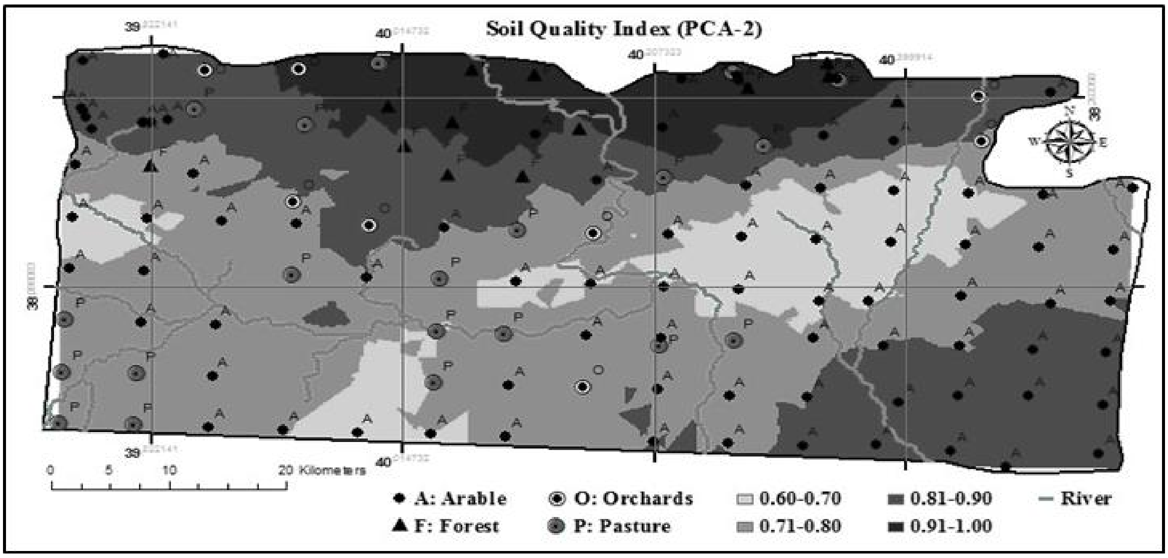

Figure 6. Spatial distribution of SQI_{PCA-2} values in upper Tigris basin

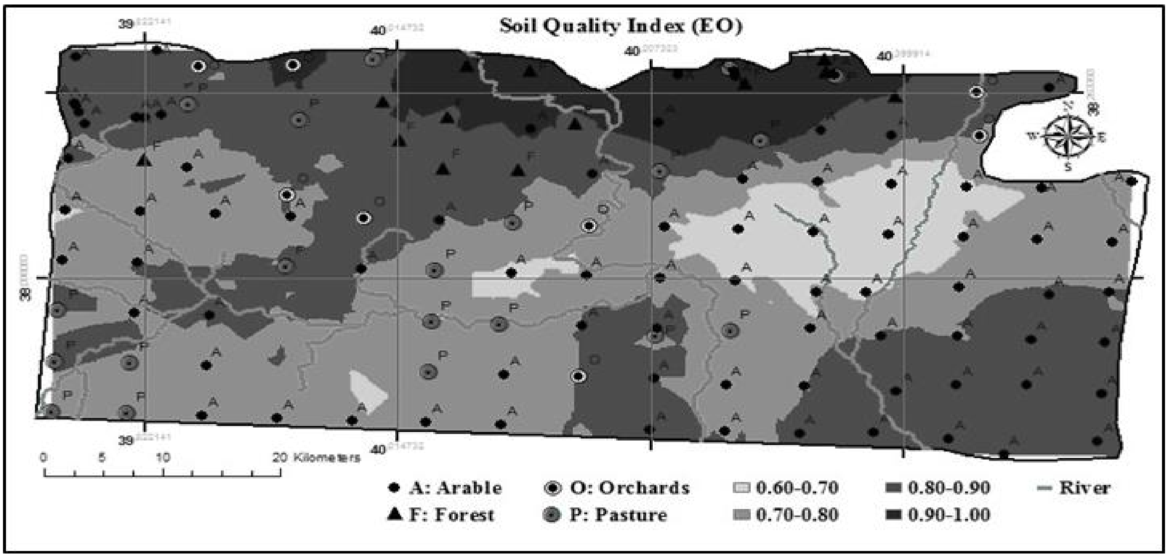

Figure 7. Spatial distribution of SQI_{EO} values in upper Tigris basin

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