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KS Niranjana
Research Scholar, Department of P.G. Studies & Research in Environmental Science, Kuvempu University, Jnana Sahyadri, Shankaraghatta, Shivamogga, Karnataka, India

K Yogendra
Associate Professor, Department of P.G. Studies & Research in Environmental Science, Kuvempu University, Jnana Sahyadri, Shankaraghatta, Shivamogga, Karnataka, India

KM Mahadevan
Professor, Department of PG Studies & Research in Chemistry, Director, P.G centre, Kadur, Kuvempu University, Chikmagaluru, Karnataka, India

Correspondence
KS Niranjana
Research Scholar, Department of P.G. Studies & Research in Environmental Science, Kuvempu University, Jnana Sahyadri, Shankaraghatta, Shivamogga, Karnataka, India

Assessment of soil quality index under coffee land use system of hilly zone of Karnataka, India

KS Niranjana, K Yogendra and KM Mahadevan

Abstract
Soil quality degradation is a major problem in recent times. Coffee is the major plantation crop in the majority of the areas of Chikkamagaluru and Kodagu districts which falls under hilly zone of Karnataka where it is mostly grown on slope terrains. To determine the sustainability of soil and land management practices prevalent in this region, a study on soil quality assessment was done through minimum data set. About 150 soil samples at 0-30 cm depth were collected from different locations of coffee growing plantations of Chikkamagaluru and Kodagu districts. Soil quality index (SQI) was assessed through identifying minimum data set (MDS) by employing principal component analysis. Twenty four soil attributes were subjected to principal component analysis (PCA) which yielded seven principal components with Eigen value >1 and explaining at least 5 % of total variance in the entire data set. The seven PCs together explained 77.86 per cent of total variance. Based on the rotated factor loadings, the selected MDS were exchangeable Mg from PC-1, maximum water holding capacity (MWHC) from PC-2, pH from PC-3, earthworm population density (EWPD) from PC-4, sand from PC-5, available P_2O_5 from PC-6, and available boron (B) from PC-7.The selected indicators were transformed into scores (linear scoring method) to calculate the SQI. The assessed SQI was 0.44forChikkamagaluru and the0.43 for Kodagu district under coffee land use system of hilly zone of Karnataka and showed non-significant difference between them. The overall contribution of different PCs in the determination of SQI was in the order of Mg – 22.15%, MWHC – 18.63%, pH – 17.45%, EWPD – 16.81%, sand – 11.37%, P_2O_5 – 7.72% and B – 5.88%.

Keywords: Soil quality index, coffee land use, hilly zone, principal component analysis, minimum data

Introduction

With the increasing degradation of agricultural lands, there is a great need of sustaining soil resources and to maintain thesoil quality. Human pressure, in recent times, especially under hilly slopes, has modified land use with production systems, which resulted in ecological effects. (Sharma, 2004) [20]. Inappropriate land use and soil management have cause severe degradation of soil quality in the tropics (Lal, 1990) [15]. Soil quality is the degree of suitability to the specific functions that soils perform in a given system. It can be defined as "the capacity of the soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and to promote plant and animal health (Doran and Parkin, 1994) [10]. In order to achieve higher productivity, there have been many changes in soil and land use and management practices, which have led to deterioration of soil and environmental quality. However, such changes and associated impacts are not uniform across the region. Therefore, to determine the sustainability of the land management systems prevalent in a region, quantitative assessment of soil quality on a regional scale is necessary.

Karnataka, which is one of the South Indian state, is divided into ten agro climatic zones. The hilly zone (Zone 9) is characterized by heavy rainfall, extreme forms of soil acidity, high rate of top soil erosion, loss of nutrients through leaching *etc*., which pose major constraint for higher productivity. Apart from this, only a few types of cropping systems are restricted in these areas. Major parts of Chikkamagaluru and Kodagu districts are prevailed by these conditions and where coffee is the major planation crop grown by the farmers. Karnataka accounts for 70 per cent coffee production in India. It is cultivated in an area of 0.88 lakh hectares with a production of 0.78lakh metric tonsin Chikkamagaluru and 1.03 lakh hectares with a production of 1.09 lakh metric tons in Kodagu disrict (Sunanda and Nagaraja, 2014) [25]. In these areas, coffee is being cultivated mostly on slope terrains. Thus, soil and nutrient management is an important aspect in these kind of lands. Though farmers of this region adopt some practices like liming, fertilization, mulching *etc*., still there is decline in the productivity. Hence, the present study was undertaken to assess the soil quality of coffee land use of Chikkamagaluru and Kodagu districts of hilly zone of Karnataka, India.

Material and Methods

The study area comprises of Sringeri, Koppa, N.R. Pura and Mudigere talukas of Chikkamagalur district; Virajpete, Madikeri and Somwarpet talukas of Kodagu district. About 150 surface samples (0-30 cm depth) from 30 different locations from coffee plantations of the area were selected for the study. The soil samples collected were analysed for 24 different physical, chemical and biological properties by following standard procedures as outlined in table 1.

Table 1: Methods followed to measure the different soil parameters

Sl. No.	Soil attribute	Abb.	Method	Reference
1.	Mechanical analysis (% sand, silt and clay)	Sand, Silt, Clay	International pipette method	Piper,1966
2.	Bulk density, maximum water holding capacity, porosity	B.D., MWHC, Porosity	Keen's Cup method	Bernard A. Keen & Raczkowski,1921
3.	pH, Electrical Conductivity	pH, E.C.	1:2.5 soil:water using meters	Jackson, 1973
4.	Soil organic carbon	SOC	Wet digestion method	Walkley and Black, 1934
5.	Cation exchange capacity	CEC	Sodium saturation method	Jackson, 1973
6.	Available nitrogen	N	Alkaline $KMnO_4$ method	Subbiah and Asija, 1956
7.	Available phosphorus	P_2O_5	Spectrophotometric method	Bray and Kurtz, 1945
8.	Available Potassium	K_2O	Flame photometric method	Jackson, 1973
9.	Exchangeable calcium & Magnesium	Ca, Mg	Versinate titration method	Tandon, 1989
10.	Available sulfur	S	Extraction with 0.15 % $CaCl_2$, estimation by Turbidometric method	William and Steinberg,1959
10.	Exchangeable iron, manganese, copper and zinc	Fe, Mn, Cu, Zn	Atomic absorption spectrophotometric method	Lindsay and Norwell,1978
11.	Available boron	B	Hot water soluble method	Berger and Trough, 1984
12.	Earthworm population density	EWPD	Manual collection	Anderson and Ingrem, 1993
13	Soil microbial biomass carbon	SMBC	Chloroform fumigation method	Jenkinson and Powlson, 1976
14	Dehydrogenase enzyme activity	DHEA	Reduction of TTC to TPF	Page *et al*., 1982

Statistical analysis

The data were subjected for normality of distribution and ANOVA was performed using SPSS (version 16) to assess the effect of different soil attributes among different districts. Strength of different soil parameters were determined by Pearson's correlation coefficient. For determination of SQI, three steps were followed as developed by Andrews *et al.*, (2002) [2] as follows. (1) Selection of most critical soil quality indicators, i.e. minimum data set (MDS) of indicators that best represents the soil function, (2) scoring of MDS indicators into scores based on their performance of soil functions, (3) integrating of indicator scores into a comparative index of soil quality. For selection of MDS, principal component analysis (PCA) was performed using SPSS (version 16) (Andrews *et al.*, 2002) [2]. Principal components (PCs) are defined as linear combinations of variables that account for maximum variance within the entire dataset. It was assumed that PCS with eigen values >1 (Brejda *et al*. 2000) [8] and those that explained at last 5 per cent of the variation in the data (Sharma *et al*., 2005) [21] were selected and subjected to varimax rotation to maximize correlation between PCs and the measured attributes (Shukla *et al.*, 2006) [22]. Within each PC, the attribute with highest factor loading (positive or negative) or the attribute with highest correlation sum, were selected for further scoring.

Every observation of selected indicators was transformed into scores of 0 to 1 using linear scoring method. The equations proposed by Diack and Stott (1994) [13] were used to convert the soil data into scores as follows: y = (x-s) / (1.1*t-s) for 'more is better', y=1-{(x-s) / (1.1*t-s)} for 'less is better', where y is the score of the soil data, x is value of the soil property, s is the lowest value and t is the highest value.

The third step was to calculate the soil quality index (SQI). After transforming the observed values into scores, the indicators were weighted using PCA results. The percentage of variation in the total data set was divided by total percentage of variation explained by all the selected PC's gives the weighted factor (W) for attributes selected under a given PC. The SQI was calculated using the formula SQI $=\sum_{i=1}^{n} WiSi$, where W is the weighting factor derived from PCA, S is the indicator score. Higher scores of SQI indicates better soil quality and vice versa.

Results and Discussion

The data on the mean values of different soil attributes across three different districts with standard deviation are presented in table 2. The soils were sandy loam to sandy clay loam in texture with bulk density varying from 1.39to 1.46 Mg m^{-3}. The study revealed that the majority of the soils were medium to highly acidic with low EC values and high in soil organic carbon status. The available nitrogen, phosphorus and potassium were medium in fertility status. The exchangeable calcium and magnesium contents were marginal to adequate and available sulphur ranged from 12.40 to 32.40ug g^{-1}. The soils were substantially high in iron, manganese, Copperand zinc contents and low in boron content. Among the biological properties, the EWPD and DHE Ashowed less variation whereas the SMBC showed wide variation between the two districts.

The correlation matrix of 24 soil attributes across three districts were presented in table 3. It clearly indicates that the soil attributes has tendency to respond in groups between the two districts. Therefore, to reduce the redundancy of the data, PCA was performed on the measured soil attributes. The results of PCA showing PCs with their eigen values and proportion of variance (in per cent) explained along with the rotated factor loadings and communalities are presented in table 4. The PCA provided 7 PCS with eigen value > 1 and explaining at least 5 per cent of variance in the data set. The 7 PCS together explained 77.86 percent of total variance. Based on the rotated factor loadings, the selected MDS were exchangeable Mg from PC-1, maximum water holding capacity (MWHC) from PC-2, pH from PC-3, earthworm population density (EWPD) from PC-4, sand from PC-5, available P_2O_5 from PC-6, and available boron (B) from PC-7.Under PC-1, Mg and Zn were the two attributes with highest factor loadings. Since these two were highly correlated, only Mg with the highest factor loading of

0.855was retained in the PC-1. It has accounted for 20.60 percent of variation with an eigen value of 4.61. Coffee being an exhaustive crop, which gives away lot of photosynthates and nutrients through beans and litter removes lot of calcium and magnesium from the soil (Alwar *et al*., 1991) [1]. In PC-2, MWHC and BD were the for soil properties with highest factor loadings. Since these were highly correlated, only MWHC with a factor loading of 0.844 with an Eigen value of 4.48 which accounted for 18.67 percent variation was selected. In PC-3, only the soil pH was the soil attributes with highest factor loading. It accounted for 12.42 per cent of the variance with an eigen value of 2.98.Soil reaction plays a major role in determining the soil quality of a given area (Singh *et al*., 2013) [23]. EWPD was the selected soil attribute from PC-4 with a highest factor loading of 0.775. PC-4 accounted for 8.95 per cent of variance with an eigen value of 2.15. High organic matter content due continuous fall of litter under coffee plantations combined with pepper-silver of Silvi-Horti system might have resulted in high population of earthworms which in turn contributed to MDS indicator selection. Sand and silt were the two attributes with highest factor loadings from PC-5 which are significantly correlated. Thus, sand was the selected attribute from PC-5 (0.884 factor loading) which accounted for 6.14 per cent variation with 1.47 eigen value. In many studies, soil texture (proportion of sand, silt and clay) reported as a component of MDS indicators (Brejda and Moorman, 2001, Cho *et al*., 2004) [8, 9]. Similarly, available phosphorus was the lonely attribute with the highest factor loading of 0.682 with an eigen value of 1.42 accounting for 5.92 per cent of total variance. From PC-7, boron was the major attribute (0.745 factor loading) contributing 5.16 per cent of total variance with an eigen value of 1.17. Available phosphorus in the MDS indicator is explicable given that the soil of coffee land use are medium to strongly acidic in reaction, where P2O5 deficiency due to fixation as Fe and Al phosphate is considered as the key constraint (Kumar, 2011) [14]. Boron is the important micro nutrient in mineral nutrition of plants, thus have a major role in ascertaining the soil fertility of a given area. The relationship between eigenvalue and principal component was depicted through screw plot as shown in Figure 1.

From the above PCs, ‘more is better’ approach was followed for all soil attributes except for sand where ‘less is better approach’ was followed to compute the scores using the formula which was explained earlier. The individual scores from each PCs from all observations were multiplied by the weighting factor derived from PCA to obtain the soil quality index under coffee land use between the two districts. The weighting factor for the selected MDS varied from 0.266 for PC-1, 0.241 for PC-2, 0.160 for PC-3, 0.115 for PC-4, 0.079 for PC-5, 0.076 for PC-6 and 0.063 for PC-7. The SQI assessed by linear scoring method under coffee land use for Chikkamagalur, was 0.44 ± 0.08 and 0.43 ± 0.06 for Kodagu district (Figure 2).

Table 2: Physical, chemical and biological properties as influenced by coffee land use system

Sl. No.	Soil attribute	Chikkamagaluru		Kodagu	
		Mean	Std. Dev.	Mean	Std. Dev.
1	pH (1:2.5)	5.51	±0.11	5.45	±0.29
2	E.C. (dS m^{-1})	0.09	±0.03	0.21	±0.27
3	S.O.C. (g kg^{-1})	19.86	±2.47	15.94	±2.24
4	C.E.C.(c mol(p^+)kg^{-1}	17.59	±1.89	18.66	±1.47
5	Avl. N (kg ha^{-1})	396.63	±78.72	294.39	±43.25
6	Avl.P_2O_5 (kg ha^{-1})	28.62	±9.53	22.86	±6.28
7	Avl.K_2O (kg ha^{-1})	249.24	±30.51	242.80	±25.23
8	Ex.Ca (c mol(p^+)kg^{-1}	4.37	±1.35	5.08	±1.60
9	Ex.Mg(c mol(p^+)kg^{-1}	1.56	±0.26	1.53	±0.39
10	Avl. S (mg kg^{-1})	24.28	±5.56	16.92	±3.56
11	DTPA Fe (mg kg^{-1})	89.43	±18.59	80.71	±11.05
12	DTPA Mn (mg kg^{-1})	44.27	±11.40	52.21	±13.51
13	DTPA Cu (mg kg^{-1})	11.99	±2.91	6.51	±4.98
14	DTPA Zn (mg kg^{-1})	1.08	±0.61	1.83	±0.48
15	Avl. B (mg kg^{-1})	0.50	±0.11	0.39	±0.09
16	Sand (%)	46.41	±6.35	48.61	±6.14
17	Silt (%)	21.54	±5.50	21.48	±4.01
18	Clay (%)	29.99	±7.15	29.91	±5.21
19	Bulk Density(Mg m^{-3})	1.42	±0.02	1.43	±0.01
20	MWHC (%)	30.21	±1.47	29.71	±0.95
21	Porosity (%)	44.88	±0.74	44.46	±0.34
22	EWPD(individuals m^{-2})	95.00	±22.98	90.29	±16.13
23	SMBC ((ug g^{-1} soil)	719.88	±76.12	576.33	±83.61
24	DHEA(ugTPFg^{-1}soil day^{-1})	33.52	±4.96	35.68	±4.69

Table 3: Correlation among soil attributes in different districts under coffee land use system

	pH	EC	SOC	CEC	N	P2O5	K2O	Ca	Mg	S	Fe	Mn	Cu	Zn	B	Sand	Silt	Clay	BD	MWHC	Porosity	EWPD	SMBC
EC	-0.153																						
SOC	-0.036	-0.283																					
CEC	0.334	-0.045	-0.199																				
N	-0.114	-0.132	.500**	-.569**																			
P2O5	0.066	-0.199	0.305	.420*	-0.008																		
K2O	.508**	0.079	-0.146	0.298	-0.148	.466**																	
Ca	.620**	-0.108	-0.212	.598**	-.362*	0.346	.457*																
Mg	0.307	0.154	-.440*	.625**	-.603**	0.101	0.295	.687**															
S	-0.068	-0.263	.369*	-0.278	.445*	0.352	0.148	-0.133	-.447*														
Fe	-0.192	-0.057	0.047	-.516**	0.132	-0.08	-0.024	-0.252	-0.331	.367*													
Mn	0.229	0.266	-0.328	-0.111	-0.288	-0.189	0.158	0.331	0.273	-0.142	0.197												
Cu	.534**	-0.339	.510**	0.281	0.243	.400*	0.352	.424*	0.043	0.263	0.013	-0.184											
Zn	-0.061	0.202	-.547**	.380*	-.483**	0.055	0.178	.465**	.590**	-0.247	-0.153	.462*	-0.17										
B	0.117	0.064	.538**	-0.105	.480**	.364*	0.225	0.049	-0.203	.376*	0.021	-0.094	.401*	-0.078									
Sand	0.267	-0.051	0.014	0.109	-0.03	-0.239	-0.15	0.33	0.312	-0.104	-0.19	-0.058	0.284	0.089	-0.178								
Silt	0.105	0.141	-0.206	0.112	-0.148	0.064	0.231	0.04	0.039	-0.213	0.061	0.24	-0.074	0.09	0.122	-.740**							
Clay	-.455*	-0.02	-0.074	-0.343	0.036	-0.036	-0.173	-.381*	-0.344	0.182	0.313	0.034	-.491**	-0.082	-0.321	-.378*	-0.129						
BD	-0.349	-0.04	-0.177	-0.284	-0.087	-.511**	-.419*	-0.353	0.012	-0.036	0.203	0.014	-0.344	-0.013	-0.345	0.101	-0.145	0.094					
MWHC	0.236	0.112	0.124	.372*	-0.023	.374*	0.331	0.154	-0.115	0.06	-0.25	-0.322	0.326	-0.034	0.297	-0.066	0.091	-0.168	-.627**				
Porosity	0.262	0.025	0.275	0.242	0.131	.569**	.387*	0.241	-0.073	0.106	-0.135	-0.246	.412*	-0.181	.453*	-0.099	0.153	-.394*	-.758**	.607**			
EWPD	-0.092	0.041	0.207	-0.269	0.137	-0.013	-0.259	0.014	-0.329	.376*	0.277	0.348	-0.03	-0.016	0.275	-0.041	-0.054	0.03	-0.133	-0.058	0.086		
SMBC	-0.075	0.344	-0.019	0.091	-0.328	0.265	0.107	-0.064	-0.062	0.151	0.001	0.191	-0.157	0.082	0.097	-.395*	0.246	0.208	-0.14	.392*	0.055	0.191	
DHEA	-0.221	0.198	-0.265	-0.165	-0.19	-0.017	0.056	0.027	0.229	0.1	0.318	.549**	-0.241	.521**	0.081	-0.222	0.285	-0.032	0.178	-0.233	-0.148	0.166	0.176

Table 4: The results of principal component analysis and communalities to evaluate the soil quality index

	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7	Communalities
pH	0.090	0.165	**0.910**	-0.032	-0.057	-0.046	0.098	0.879
E.C.	0.154	0.237	-0.227	0.242	0.117	-0.671	0.049	0.656
S.O.C.	-0.529	0.209	-0.084	0.029	-0.190	0.391	0.410	0.688
C.E.C.	0.645	0.396	0.193	-0.451	-0.081	0.084	0.014	0.827
Avl. N	-0.711	-0.076	-0.066	0.094	-0.043	0.184	0.421	0.737
Avl.P_2O_5	0.224	0.586	-0.012	-0.06	0.15	0.682	0.138	0.864
Avl. K_2O	0.272	0.34	0.529	-0.003	0.358	0.243	0.03	0.658
Exch. Ca	0.638	0.189	0.598	0.046	-0.164	0.134	0.133	0.866
Exch. Mg	0.855	-0.092	0.238	-0.201	-0.072	-0.104	0.086	0.861
Avl. S	-0.303	0.124	-0.091	0.436	-0.051	0.670	0.048	0.759
Exch. Fe	-0.271	-0.313	0.027	0.523	0.247	0.290	-0.172	0.620
Exch. Mn	0.389	-0.206	0.29	0.676	0.192	-0.270	-0.112	0.856
Exch. Cu	-0.083	0.227	0.536	-0.084	-0.176	0.443	0.458	0.790
Exch. Zn	0.853	-0.05	-0.114	0.189	0.039	-0.083	0.043	0.790
Avl. B	-0.198	0.355	-0.034	0.262	0.153	0.194	0.745	0.807
Sand	0.161	-0.181	0.248	-0.053	-0.884	-0.096	0.166	0.916
Silt	0.077	0.081	0.133	-0.028	0.870	-0.199	0.091	0.860
Clay	-0.217	-0.05	-0.351	0.165	0.104	0.192	-0.741	0.797
B.D.	0.021	-0.767	-0.32	-0.053	-0.060	-0.04	-0.129	0.716
MWHC	-0.045	0.844	0.091	-0.149	0.005	-0.03	0.058	0.750
Porosity	-0.106	0.702	0.222	-0.075	0.111	0.095	0.395	0.737
EWPD	-0.157	0.146	-0.078	0.775	-0.189	-0.013	0.086	0.695
SMBC	0.139	0.567	-0.253	0.322	0.237	-0.079	-0.316	0.671
DHEA	0.460	-0.268	-0.244	0.523	0.398	0.022	0.192	0.811
Eigen values	4.94	4.48	2.98	2.15	1.47	1.42	1.17	
Variance (%)	20.60	18.67	12.42	8.95	6.14	5.92	5.16	
Cum. Variance (%)	20.60	39.27	51.69	60.64	66.78	72.70	77.86	

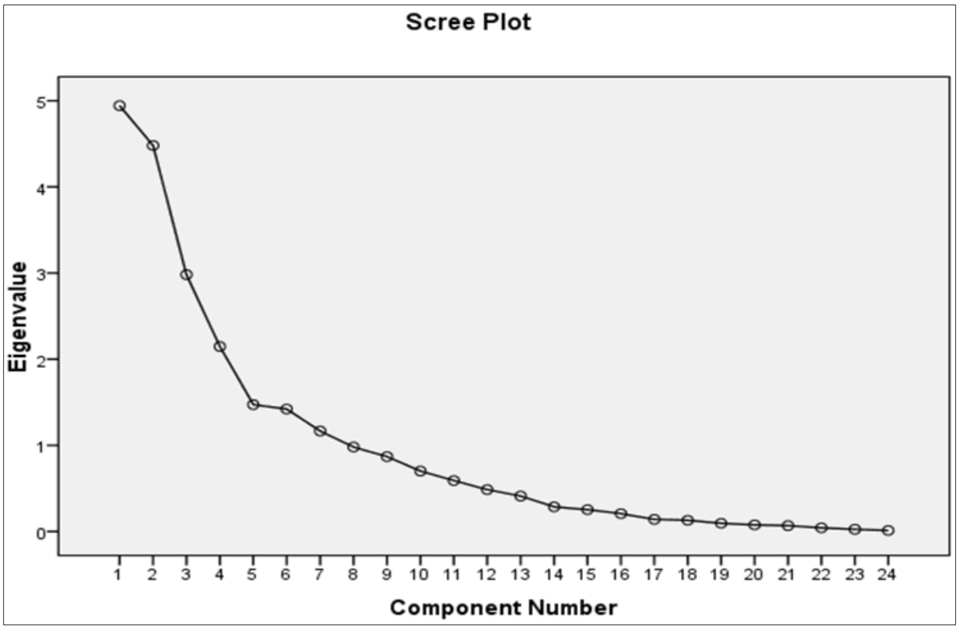

Fig 1: Screw plot showing the relationship between Eigen values and the principal components

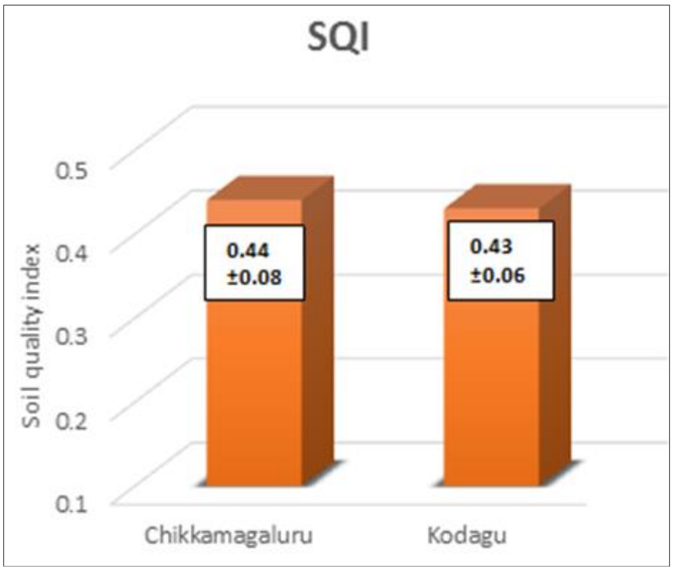

Fig 2: Soil quality index of Chikkamagaluru and Kodagu districts under coffee land use

The SQI of both the districts fell under low category (Low=SQI < 0.50) as per classification given by Xu *et al.*, (2006) [28]. The lowest SQI rating for Chikkamagaluru and Kodagu may be attributed to the exhaustive nature of the coffee crop combined with geological and climatic characteristics of the hilly region. The overall contribution of different PCs in the determination of SQI was in the order of Mg – 22.15%, MWHC – 18.63%, pH – 17.45%, EWPD – 16.81%, sand – 11.37%, P_2O_5 – 7.72% and B – 5.88%. The results of SQI clearly indicated that the values for coffee of Chikkamagaluru and Kodagu were on par with each other. The Mg content, the water retention capacity, the soil reaction, the earthworm population, sand - the textural component, the available phosphorus and boron played a major role in determining the SQI.

Conclusion

From the present study, it can be concluded that seven different soil attributes (indicators), *viz*: sand and MWHC from physical attributes; pH, Mg, P_2O_5, and B from chemical attributes; and EWPD from biological attributes were identified, which reliably explain the soil quality of the study area. The SQI of both the districts: Chikkamagaluru and Kodagu fell under low category and on par with each other. Hence, there is a wide scope for improving the SQI by managing the identified attributes and introducing more appropriate management techniques in both the districts. To address the declining or low category of the SQI, the management practices should be examined and more of soil, water and nutrient conservation practices should be implemented in the study area which represents major parts of hilly zone of Karnataka.

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