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Geo-spatial Assessment of Soil Quality Index of Alirajpur District of Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Information regarding spatial variability and distribution of soil properties is critical for stakeholders attempting to increase nutrients use efficiency and crop productivity. The soils of Alirajpur district having the bulk density, pH, EC, OC and $CaCO_3$ varied from4.70 to 8.40, 0.03 to 0.90 dSm^{-1}, 0.47 to 12.92 g kg^{-1} and 5.0 to 115.0 g kg^{-1} soil, respectively. Available N, P, K and S content in soils of Alirajpur district ranged from 76.0 to 382.0 kg ha^{-1}, 1.34 to 62.13 kg ha^{-1}, 53.52 to 529.85 kg ha^{-1} and 0.55 to 33.90 mg kg^{-1} soil, respectively. Zn, Cu, Fe, Mn and B contents in soil varied from 0.03 to 1.98, 0.06 to 3.74, 1.07 to 36.0, 1.34 to 43.0 and 0.03 to 4.76 mg kg^{-1} soil, respectively. The categories of the soil fertility status were made with respect to N, P, K and S as medium, high, medium and low (M-H-M-L). The 64.71%, 93.01% and 25.37% soil samples were observed to be low in S, Zn and Fe, respectively. The results revealed that none of the samples were tested low in Cu and Mn and these are not a major problem in Alirajpur district. Correlation analyses among the above highly weighted variables were done to remove the redundant variables, accordingly OC and N, Fe and Mn, CaCO3 and Zn were highly correlated, and finally OC, Fe and Zn were retained owing to their high factor loading. The sensitive indicators (Minimum dataset) under the soils of Alirajpur District in descending order of importance as revealed by factor analysis were as follows: OC > Fe > Zn > B > EC > K > MBC.

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The sensitive indicators under the soils of Alirajpur district in descending order of importance as revealed by factor analysis were as follows: OC > Fe > Zn > B > EC > K > MBC. This suggests that these indicators may be used in future for characterizing the state of soil conditions of district. Soil quality index rating ranged from 0.22 to 0.31 under the different blocks and 0.22 for district as whole with l parameter soil quality index 0.31 for Alirajpur district.

Keywords: Alirajpur district; geo-statistical approach; soil properties; SQI; spatial variability.

1. INTRODUCTION

Information regarding spatial variability and distribution of soil properties is critical for stakeholders attempting to increase nutrients use efficiency and crop productivity. Application of fertilizers on the basis of soil characteristics maps associated with fertilizers recommendation may aid to curtail fertilizers inputs without affecting the crop yield. The present study was focused on geo-spatial assessment of soil quality index of Alirajpur district of Madhya Pradesh India using geo-statistical approach. 272 GPS based surface (0-15 cm) soil samples were collected from six blocks (Alirajpur, Bhabra, Jobat, Kathiwara, Sondwa, and Udaigarh) of Alirajpur district after harvest of crops during rabi season 2016-17. The samples were processed and analyzed for fertility parameters, spatial variability maps generated using GIS, correlations between nutrient content in soil and were workout and soil quality index was analyzed using PCA. Geo-statistics is an useful tool and extensively used for analyzing spatial variability, interpolating between point observation and ascertaining the interpolated values with specified error using a minimum number of observations. Spatial variability in pH, organic matter, total and available NPK and micronutrients has been studied by different researchers in various soils under contrasting management systems across the world. Geographical maps of soil properties help accurate soil survey. These maps are required to understand the patterns and processes of soil spatial variability, which is the combined effect of soil physical, chemical and biological processes operating at different spatio-temporal scales combined with anthropogenic activities. Fertilization based on large scale maps with recommendations related to soil fertility may also lead to reduced fertilizer inputs without surrendering productivity.

Soil is one of the key components of sustainable agricultural production system and its quality is governed by physico-chemical characteristics and nutrient supplying capacity which ultimately reflected through crop productivity. Soil quality was defined as the capacity of specific kind of soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality and promote plant growth as well as human health [1]. The concept of soil quality was introduced for proper stratification and allotment of agricultural inputs [2]. It can be conceptualized in two aspects viz., inherent soil quality shows little change over time whereas dynamic soil quality changes with respect to soil management [3]. Doran et al. [4] and Karlen et al. [1] recommended that the soil quality should be evaluated based on soil functions. Subsequently, soil quality gained importance as a tool to assess various agricultural production systems around the world [5, 6]. Soils are inherently heterogeneous in nature because many factors contribute to their formation and the complex interactions of these factors [7]. Characterizing spatial variability of soil nutrients in relation to site properties, including climate, land use, landscape position and other variables, is important for understanding how ecosystems work and assessing the effects of future land use change on soil nutrients [8]. It is well established that change of land use, long-term cultivation and mineral fertilization can cause significant variations in soil properties [9]. The nature and characteristics of soils are mainly dependent on geological formations, topography and climate of the region in which the soil occurs. Soil enzyme activities are crucial for biological and biochemical processes such as organic matter degradation, litter mineralization and recycling of such macro nutrients as N, P, S and some micro elements and enzymatic activity in soil varies in relation to microbial population in soil which is also influenced by inorganic and organic sources of nutrients [10,11]. However, dehydrogenase which are respiratory enzymes and integral part of all soil organism give a measure of biological activity of soil at a given time.

2. MATERIAL AND METHODS

2.1 Description of Study Area

Geographically, the Alirajpur district is situated 22°18’19” latitude and 74°21’09” longitude and at

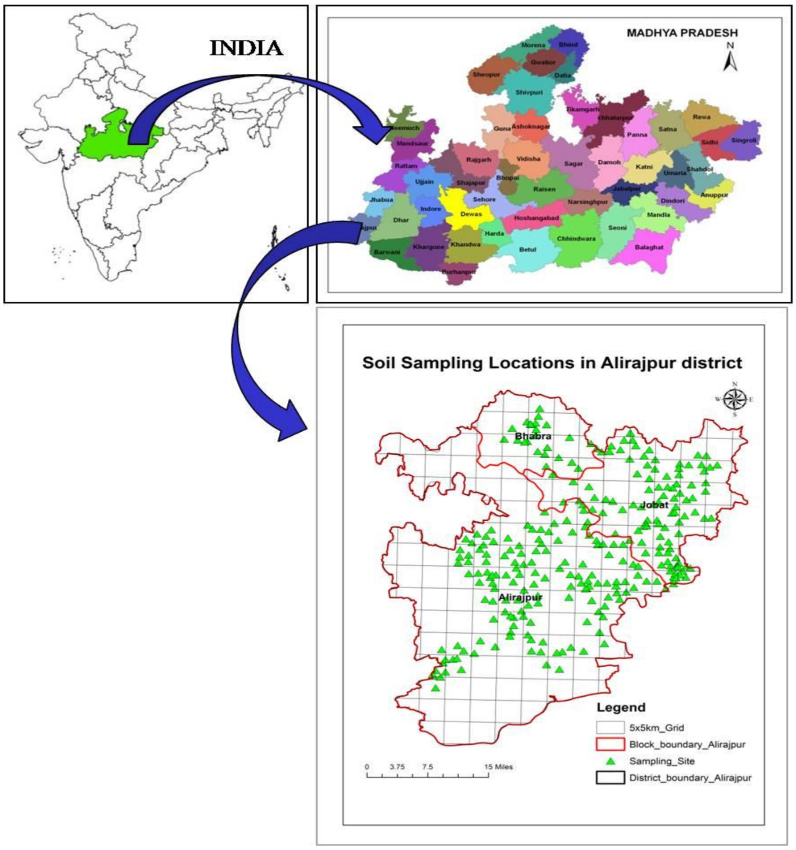

Fig. 1. Location map of study area

an altitude of 315 m above mean sea level. Administratively, district covers an area of 2165 km^2 and divided into six blocks name as Bhabara, Jobat, Sondwa, Kathiwara, Alirajpur and Udaigarh. Location and sampling site maps of study area is given in Fig. 1.

2.2 Soil Sampling and their Processing

GPS based two hundred seventy two surface soil samples were collected across all the blocks of Alirajpur district of Madhya Pradesh (India). Composite soil sample was collected and kept into properly labeled sample cloth bags. Soil samples were brought to the laboratory and air dried, crushed with wooden pestle and mortar, sieved through 2 mm stainless steel sieve.

2.3 Laboratory Analysis

The color parameters of soil were recorded by using Munsell color chart (1994 Rivsed Edition). The soil samples were collected with manually operated core sampler up to 15 cm depth and oven dried at 105 ^{0}C for 24 hours [12]. The particle size analysis (i.e., sand, silt and clay percent) of soil was determined by Bouyoucous hydrometer method (Bouyoucous, 1962). The CEC of soil was analyzed by leaching it with 1N neutral NH_4OAc solution as described by Jackson [13]. Soil pH, electrical conductivity (EC), soil organic carbon [14], calcium carbonate was determined using standard procedure described by Jackson [13]. Available N was determined as per the method is given by Subbiah and Asija [15]. Available P was determined by 0.5 M sodium bicarbonate procedure as described by Olsen et al. [16] using Spectrophotometer. Available K was extracted with 1 N NH_4OAc and then measured by Flame Photometer [13]. The available Sulphur was extracted by 0.15% $CaCl_2$ solution and the concentration of Sulphur was determined by the turbidimetric method using spectrophotometer [17]. Available micro-nutrients were extracted by DTPA-$CaCl_2$ solution and analyzed using atomic absorption spectrophotometer [18]. Hot water soluble boron in soil was analyzed by azomethine-H method as outlined by Berger and Truog [19]. Biomass carbon was determined by the fumigation extraction method as per the procedure of Brookes et al. [20]. The dehydrogenase activity in soil was determined by method given by Burns RG.1978). the soil respiration was estimated by closed jar method [21]. The nutrient index (NI) values for available nutrients present in the soils was calculated utilizing the formula suggested by Parker et al. [22] and classified this index as low (<1.67), medium (1.67 to 2.33) and high (>2.33).

2.4 Geo-statistical Analysis in Arc GIS Environment

Geo-statistical methods were used to analyze the spatial correlation structures of soil properties and spatially estimate their values at unsampled locations using geo-statistical tool in GIS 9.3.1 software.

Ordinary Kriging was used for the spatial interpolation because it is best at providing an unbiased prediction for specific unsampled locations and minimizing the influence of outliers. According to Cambardella et al. (1994) the nugget to sill ratio was used to define different classes of spatial dependence for the soil properties. Nugget/sill ratio of 25%, 25-75% and >75% were classified as having strong, moderate and weak spatial dependence, respectively.

2.5 Statistical Analysis

The data of soil properties were analyzed by plotting various charts and diagrams/graph tables, average, Pearson correlation and PCA analysis using SPSS software (version 21.0 for windows).

2.6 Soil Quality Index (SQI) Estimation Using Principal Component Analysis

A statistics-based model was used to estimate SQI using principal component analysis (PCA) [23, 24] Jha and Mohapatra 2012; and Mukherjee and Lal [5]. The PCA-model is used to create a minimum data set (MDS) to reduce the indicator load in the model and avoid data redundancy [23, and 4]. The preliminary function of PCA is to reduce the dimensionality of the entire data set consisting of a large number of interrelated variables, while retaining as much as possible of the variations present in the data set. This is achieved by transformation to a new set of variables, the principal components (PCs), which are uncorrelated, and ordered so that the first few retain most of the variation present in all of the original variables. In other words, the PCA method was chosen as a data reduction tool to select the most appropriate indicator(s) to represent and estimate SQI.

All the original observations (untransformed data) of each soil were included in the PCA model using SPSS, version 21.0. The PCs with high eigenvalues represented the maximum variation in the dataset [23, 24], (Li et al., 2013). Under a given PC, each variable had corresponding eigenvector weight value or factor loading. Only the 'highly weighted' variables were retained to include in the MDS. The 'highly weighted' variables were defined as the highest weighted variable under a certain PC and absolute factor loading value within 10% of the highest values under the same PC. Thus, the bold-face values were considered highly weighted eigenvectors and therefore were initially selected in the MDS. However, when more than one variable was retained under a particular PC, multivariate correlation matrix was used to determine the correlation coefficients between the parameters [23]. If the parameters were significantly correlated (r=0.60, p=0.05), then the one with the highest loading factor was retained in the MDS and all others were eliminated from the MDS to avoid redundancy.

The non-correlated parameters under a particular PC were considered important and retained in the MDS [25]. All the bold-faced and underlined soil parameters were selected in the final MDS. After selection of parameters for the MDS, all selected observations were transformed using linear scoring functions (less is better, more is better and optimum). Once the selected observations were transformed in numerical scores (ranged 0–1), a weighted additive approach was used to integrate them into indices for each soil [23]. Each PC explained a certain amount of variation in the dataset, which was divided by the maximum total variation of the all PCs selected for the MDS to get a certain weightage value under a particular PC [23]. For example, the % variance (30.87) was divided by total cumulative variance (63.83) to obtain the weight value of 0.48 for PC-1. Thereafter, the weighted additive SQI was computed using Equation:

$$SQI=\sum weight * individual\ soil\ parameter\ score$$

3. RESULTS AND DISCUSSION

During the course of investigations two hundred seventy-two GPS based surface soil samples (0-

15 cm) were collected from almost all the fields of different location of the Alirajpur district and analyzed for various physical, chemical and biological properties. The details results are presented in below.

3.1 Physico-chemical Properties and Nutrients Content in Soils of Alirajpur District

Results pertaining to physico-chemical properties of soils of Alirajpur district showed that the soil pH of Alirajpur district as whole, varied from 4.7 to 8.4 with mean value of 6.5 and under different blocks variation in soil pH ranged from 4.7 to 8.4 with mean values varied from 5.8-7.1. Variation in soil pH under different blocks and district as whole might be due to variations in parent material of soil, management practices and land uses. Similar variations in soil pH under different regions were also reported by Raghuvanshi et al. [26], Dubliya [27], Singh et al. [28] and Baishya and Sharma [29].

However, electrical conductivity of soils across different blocks of Alirajpur district ranged from 0.03 to 0.90 dS m^{-1} at 25°C with average of 0.09 dS m^{-1} which was in normal range (< 1 dSm^{-1} at 25°C). The low electrical conductivity in soil under study area might be due to high rainfall received and deep water table. Similar results for different soils were also reported by Tomar [30], Singh [31], Dilliwar et al. [32] and Singh et al. [28]. Whereas, organic carbon in soils of different blocks of Alirajpur district was varied from 0.47 to 12.92 g kg^{-1} with mean values ranged from 3.24 to 7.27 g kg^{-1}, while for Alirajpur district as whole OC varied from 0.47 to 12.92 g kg^{-1} with average value of 5.2 g kg^{-1}. Variation in organic carbon content in soil samples was may be due to variation in land use pattern, addition of organic matter in soil. Mandal et al. (2007) also found that crop species and cropping systems may play an important role for variations in soil organic carbon. Findings of Singh et al. (2014) also support the findings of present study. Calcium carbonate content in soils of different blocks of Alirajpur district ranged from 5 to 115 g kg^{-1} with average values varied from 26.83 to 47.16 g kg^{-1}. Results also indicated that lowest and the highest values of $CaCO_3$ in soil were obtained in Sondwa and Udaigarh blocks, respectively might be due to calcareous parent materials and lower leaching process. Similar results were reported by Dilliwar et al. [32] and Singh et al. [28]. Available N, P, K and S content in soils of Alirajpur district ranged from 76.0 to 382.0 kg ha^{-1}, 1.34 to 62.13 kg ha^{-1}, 53.52 to 529.85 kg ha^{-1} and 0.55 to 33.90 mg kg^{-1} with mean value of 186.36 kg ha^{-1}, 21.01 kg ha^{-1}, 201.39 kg ha^{-1} and 8.99 mg kg^{-1}, respectively. Zn, Cu, Fe, Mn and B contents in soil varied from 0.03 to 1.98, 0.06 to 3.74, 1.07 to 36.0, 1.34 to 43.0 and 0.03 to 4.76 mg kg^{-1} with mean values of 0.30, 0.96, 9.92, 14.54 and 1.67 mg kg^{-1}, respectively. Similar results were reported by Dilliwar et al. [32] and Singh et al. [28] (Table 1).

The coefficient of variation (CV), ratio of the standard deviation to mean, expressed in percentage is a useful measure of overall variability. Coefficient of variation less than 10%, 10 to 100%, and more than 100% was considered as low, moderate, and high variability, respectively. The pH had least variability (CV = 13.49 %), while EC, $CaCO_3$ and OC had moderate variability (CV = 88.91, 54.24 and 60.32 %, respectively). Macronutrients were found moderately variable which ranged from 39.85 to 77.79 per cent. Micronutrients were also found moderately variable which ranged from 68.80 to 83.26 per cent in Alirajpur district. The available K in soil had lowest variability (CV=39.85 %) followed by available N (43.68 %), available P (69.80 %), and S had the highest variability (77.79 %). Among the micronutrients, Cu was found highly variable (CV = 83.26 %) followed by Zn (79.09%), Fe (73.85%) and Mn (70.45 %) and lowest in B (68.80%). Overall pH had low variability where as other soil properties showed moderate variability.

3.2 Fertility Status in Soils of Alirajpur District

The result are clear showed Table 1 and Fig. 2 indicated that in Alirajpur district about 52.91 and 47.09 per cent soil samples were found medium and high in organic carbon, respectively. However, 73.9, 26.1, 77.57 and 64.71 per cent soil samples were deficient and 26.10, 34.56, 20.59 and 29.04 per cent soil samples were medium in N, P, K and S, respectively. While, soil samples high in available P, K and S were 39.34, 1.84 and 26.25 per cent, respectively. Nutrient index (NI) was found to be 1.26, 2.13, 1.24 and 1.42 for N, P, K and S, respectively (Fig. 3).

The deficiency of Zn, Cu, Fe and B in soil collected from Alirajpur district was found in 93.01, 7.35, 25.37 and 20.22 per cent samples, respectively. None of the soil sample was found deficient in Mn. However, Zn, Cu, Fe, Mn and B were found to be medium in 5.88, 23.90, 31.99, 8.46 and 15.44 per cent soil samples, respectively. Whereas, Zn, Cu, Fe, Mn and B were found to be sufficient in 1.10, 68.75, 42.65, 91.54 and 64.34 per cent soil samples, respectively. Overall in Alirajpur district all micronutrients were found sufficient.

3.3 Correlation between Physico-chemical Properties and Available Nutrients in Soil of Alirajpur District

Relationship of physico-chemical properties with macro and micronutrients in soils of study area are presented in (Table 2) revealed that the pH had significant positive correlation with EC (r=0.355**), OC (r=0.162**), $CaCO_3$ (0.129*) N (r=0.168**), Cu (r=0.196**), but significant negative relationship with Fe (r= -0.322**), Mn(0.306**). The EC had significant positive correlation with OC (r=0.142*), P (r=0.162**), Cu (0.171**). The OC had significant positive correlation with N (r=0.980**), available P (r=0.193**). The $CaCO_3$ had significant positive correlation with Zn (r=0.131*), Cu (r=0.165**).

The available N showed positive relationship with P (r=0.170**). The available P showed positive relationship with Cu (r=0.120**). The DTPA-extractable Zn showed positive relationship with Cu (r=0.267**), Fe (r=0.253**) and Mn (r=0.326**). The DTPA-extractable Cu was positively correlated with Fe (r=0.313**) and Mn (r=0.322**). The DTPA-extractable Fe showed a positive correlation with Mn (r=0.687**). The DTPA-extractable Mn showed a positive correlation with B (r=0.148*).

Table 1. Descriptive statistics of physico-chemical properties and fertility status of soils of Alirajpur district (n=272)

Parameters	Min	Max	Mean	SD	CV	PSD	PSM	PSH	NI
pH	4.70	8.40	6.53	0.88	13.49				
EC(dSm^{-1})	0.03	0.90	0.09	0.08	88.91				
OC(gkg^{-1})	0.47	12.92	5.20	3.14	60.32				
$CaCO_3$(gkg^{-1})	5.00	115.00	34.82	18.89	54.24				
N ($kgha^{-1}$)	76.00	382.00	186.36	81.40	43.68	73.90	26.10	0.00	1.26
P ($kgha^{-1}$)	1.34	62.13	21.01	14.66	69.80	26.10	34.56	39.34	2.13
K ($kgha^{-1}$)	53.52	529.85	201.39	80.26	39.85	77.57	20.59	1.84	1.24
S ($mgkg^{-1}$)	0.55	33.90	8.99	6.99	77.79	64.71	29.04	6.25	1.42
Zn ($mgkg^{-1}$)	0.03	1.98	0.30	0.23	79.09	93.01	5.88	1.10	1.08
Cu ($mgkg^{-1}$)	0.06	3.74	0.96	0.80	83.26	7.35	23.90	68.75	2.61
Fe ($mgkg^{-1}$)	1.07	36.00	9.92	7.32	73.85	25.37	31.99	42.65	2.17
Mn ($mgkg^{-1}$)	1.34	43.00	14.54	10.24	70.45	0.00	8.46	91.54	2.92
B ($mgkg^{-1}$)	0.03	4.76	1.67	1.15	68.80	20.22	15.44	64.34	2.44

SD- Standard deviation, CV- Co-variance, PSD- Percent samples Deficient, PSM- Percent samples Medium, PSH- Percent Samples High, NI- Nutrient Index

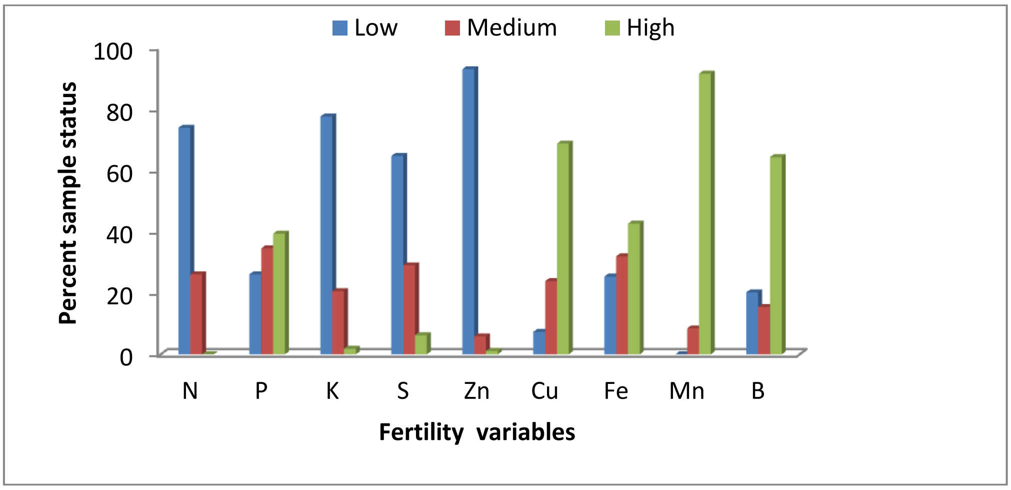

Fig. 2. Fertility status in soils of Alirajpur District

3.4 Correlation between Physical, Physico-chemical and Biological Properties and Available Nutrients in Soil of Alirajpur District

Relationship of physical, physico-chemical and biological properties with macro and micro nutrients in soils of study area are presented in Table 3 which revealed that the BD had significant positive correlation with Zn (r=0.483**) but significant negative relationship with Mn (r=-0.457*), DHA (r=-0.425*). The pH had significant positive correlation with EC (r=0.419*), $CaCO_3$ (r=0.411*). The OC had significant positive correlation with N (r=0.986**), available P (r=0.375*), Cu (r=0.383*), CO_2 (0.483**). The $CaCO_3$ had significant positive correlation with Zn (r=0.635**).

The available N showed positive relationship with CO_2 (r=0.465*). The available S showed positive relationship with Mn (r=0.454*). The DTPA-extractable Zn showed positive relationship with Cu (r=0.441*). The DTPA-extractable Cu was positively correlated with MBC (microbial biomass carbon) (r=0.395*) and CO_2 (r=0.454*). The DTPA-extractable Fe showed a positive correlation with Mn (r=0.653**). The MBC had showed a significant positive correlation with CO_2 (r=0.430*). The Pearson's' correlation matrix was worked out and results revealed that pH was significantly and positively correlated with EC, OC, $CaCO_3$, N and Cu whereas negatively related with Fe and Mn. While, EC had significant and positive correlation with OC, P and Cu, and OC showed significant and positive correlation with N and P. Whereas, $CaCO_3$ content in soil had significant positive relation with Zn and Cu. Results also showed that available N in soil showed significant positive relationship with available-P in soil and available-P in soil was significantly and positively correlated with Cu-content in soil. Available- B had significant and positive correlated with Mn in soil. The available Zn in soil showed significant positive correlation with available Cu, Fe and Mn in soil [33,34]. The available Cu in soil showed significant positive relationship with Fe and Mn and available Fe in soil had significant and positive relation with Mn in soil.

3.5 Selection of Sensitive Indicators and Development of Soil Quality Index (SQI)

Multivariate data sets due to their multidimensionality are difficult to interpret. In such circumstances, use of principal component analysis is very useful. The analysis requires the computation of Eigen values and Eigen vectors of correlation matrix with many variables.

The direction of maximum variability was estimated by Eigen vectors while the eigen values specifies the variance of the vector. The entire data set was subjected to PCA to identify the critical soil parameters under different Farms that can be considered as soil indicators. Results of PCA of soil variables-Factor loadings, communalities and total variance explained by different component in Table 4 and 5.

3.6 Principle Component Analysis (PCA)

Principal component analysis performed to examine the pattern of variations in the data sets resulted in four components, which explained 70.63% of the total variance (Table 4). The first four PCs had eigen values >1.0. Of these, the first principal component (PC-1) had highest positive loadings of Mn & Fe accounted for 18.07% of the variance. PC-2 had high positive loadings of OC and N accounted for 16.72% of the variance. PC-3 had high positive loadings of pH & EC accounts for 11.67% of the variance. PC-4 had high positive loadings of S accounted for 8.90% of the variance. From PCA results, the highly weighted variables under PC-1: Mn and Fe, PC-2: OC and N, PC-3: pH and EC, and PC-4: available S. Correlation analyses among the above highly weighted variables were done to remove the redundant variables, accordingly Mn and Fe, OC and N, pH and EC were highly correlated, and finally Fe, OC and pH were retained owing to their high factor loading. The sensitive indicators (Minimum dataset) under the soils of Alirajpur District in descending order of importance as revealed by factor analysis were as follows: Fe > OC > pH > S. This suggests that these indicators may be used in future for characterizing the state of soil conditions of this district.

Principal component analysis performed to examine the pattern of variations in the data sets resulted in four components, which explained 70.63% of the total variance (Table 5). The first four PCs had Eigen values >1.0. Of these, the first principal component (PC-1) had highest positive loadings of OC & N accounted for 22.67% of the variance. PC-2 had high positive loadings of Fe and Mn accounted for 14.56% of the variance. PC-3 had high positive loadings of $CaCO_3$ & Zn accounts for 12.71% of the

Table 2. Correlation between physico-chemical properties and available nutrients in soil of Alirajpur district

Parameters	pH	EC	OC	$CaCO_3$	N	P	K	S	Zn	Cu	Fe	Mn
EC	0.355**	1										
OC	0.162**	0.142*	1									
$CaCO_3$	0.129*	0.103	-0.015	1								
N	0.168**	0.118	0.980**	-0.020	1							
P	0.077	0.162**	0.193**	0.103	0.170**	1						
K	-0.106	-0.028	-0.090	-0.050	-0.088	-0.001	1					
S	0.107	0.089	-0.010	0.001	-0.006	-0.101	0.067	1				
Zn	0.008	0.062	0.059	0.131*	0.063	0.061	0.022	-0.04	1			
Cu	0.196**	0.171**	0.010	0.165**	-0.015	0.120*	0.062	0.042	0.267**	1		
Fe	-0.322**	-0.008	-0.058	0.053	-0.065	0.082	0.001	0.050	0.253**	0.313**	1	
Mn	-0.306**	0.002	-0.107	0.036	-0.115	0.024	-0.035	0.037	0.326**	0.322**	0.687**	1
B	-0.065	0.017	0.063	-0.025	0.047	0.022	-0.058	0.044	0.071	0.036	0.102	0.148*

*** Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed)*

Table 3. Correlation between physical, physico-chemical and biological properties and available nutrients in soil of Alirajpur district (n=28)

Parameters	BD	pH	EC	OC	$CaCO_3$	N	P	K	S	Zn	Cu	Fe	Mn	B	DHA	MBC
pH	0.076	1														
EC	0.051	0.419*	1													
OC	-0.067	0.122	0.164	1												
$CaCO_3$	-0.192	0.411*	0.157	0.120	1											
N	-0.083	0.128	0.186	0.986**	0.093	1										
P	0.269	0.074	0.127	0.375*	0.030	0.352	1									
K	0.153	0.329	0.144	0.070	-0.005	0.098	0.251	1								
S	-0.041	0.058	0.120	-0.294	-0.248	0.237	0.235	0.013	1							
Zn	0.483**	0.221	0.277	0.315	0.635**	0.335	0.113	0.048	0.084	1						
Cu	-0.168	0.297	0.307	0.383*	0.233	0.347	0.139	0.078	0.143	0.441*	1					
Fe	-0.366	-0.280	0.236	0.146	-0.233	0.346	0.073	0.190	0.181	0.251	0.306	1				
Mn	-0.457*	0.030	0.003	0.201	-0.051	0.264	0.097	0.053	0.454*	0.353	0.369	0.653**	1			
B	-0.130	-0.260	0.093	-0.087	0.039	-0.150	0.22	0.056	0.049	0.049	0.054	0.146	0.094	1		
DHA	-0.425*	0.317	0.005	-0.165	-0.016	-0.180	-0.19	-0.350	0.009	0.309	0.159	0.010	-0.010	0.320	1	
MBC	-0.363	0.114	0.069	0.053	0.071	0.012	0.018	0.114	0.011	0.071	0.395*	0.155	0.256	0.174	0.017	1
CO_2	-0.193	0.080	0.175	0.483**	0.130	0.465*	0.123	0.058	0.076	0.314	0.454*	0.226	0.364	0.081	0.012	0.430*

*** Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed).*

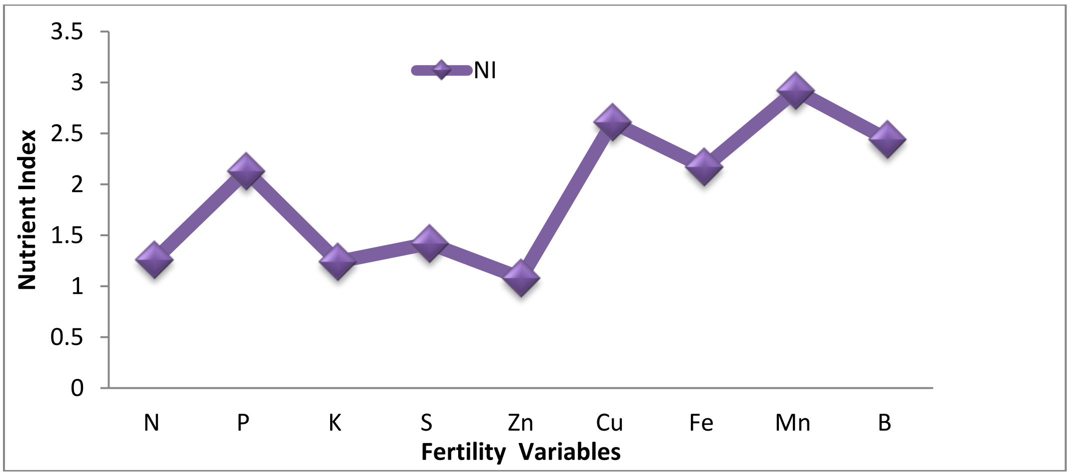

Fig. 3. Index of nutrient availability in soils of Alirajpur district

variance. PC-4 had high positive loadings of B accounted for 10.35% of the variance. PC-5 had high positive loadings of EC accounts for 7.42% of the variance. PC-6 had high positive loadings of K only accounted for 7.05% of the variance. PC-7 had high positive loadings of MBC accounts for 6.03% of the variance From PCA results, the highly weighted variables under PC-1: OC and N, PC-2: Fe and Mn, PC-3: $CaCO_3$ and Zn, and PC-4: HWS B, PC-5 EC, PC-6 available K and PC-7 MBC.

Correlation analyses among the above highly weighted variables were done to remove the redundant variables, accordingly OC and N, Fe and Mn, $CaCO_3$ and Zn were highly correlated, and finally OC, Fe and Zn were retained owing to their high factor loading. The sensitive indicators (Minimum dataset) under the soils of Alirajpur District in descending order of importance as revealed by factor analysis were as follows: OC > Fe > Zn > B > EC > K > MBC. This suggests that these indicators may be used in future for characterizing the state of soil conditions of this district.

3.7 Sensitive Indicators and Conversion of Data into 0-1 Scale and Soil Quality Rating Value

Furthermore, in order to develop the soil quality index for Alirajpur and to assess relative degradation status amongst the different land uses, the selected indicators were normalized to 0-1 scale by using the scoring function i.e. more is better and less is better concept After that the soil quality index was computed using the additive model (by averaging the 0-1 scale value of sensitive indicators). It is important to note that the SQI is based on the results obtained in soils from Alirajpur District. Data presented in Table 6 and depicted in Figs. 2 and 3 as a whole Alirajpur district, the SQI was 0.22 and the soil quality index of Alirajpur district 10% with biological parameter, the SQI 0.32. The lowest score of 0.22 was recorded in without biological parameter.

3.8 Selection of Sensitive Indicators and Development of Soil Quality Index

Results pertaining to principal component analysis (PCA) for whole Alirajpur district showed variation in the data set were explained 55.35 % of the total variance by principal components. PCs had eigen values >1.0 and the sensitive indicators (minimum dataset) under the soils of different block of Alirajpur district in descending order of importance as revealed by factor analysis were as follows: pH > OC > S >Fe. This suggests that these indicators may be used in future for characterizing the state of soil conditions of this district.

Considering Alirajpur as a whole principal component analysis for 10% samples with biological parameter performed to examine the pattern of variations in the data sets resulted in five components, which explained 80.80 of the total variance. The sensitive indicators (minimum dataset) under the soils of whole Alirajpur district in descending order of importance as revealed by factor analysis were as follows: EC > MBC > K > Zn > B > Fe > OC. The results are well supported by those reported by Jha and Mohapatra (2012) and Wang et al. [35].

Table 4. Results of PCA of Alirajpur district (n=272)

Variables	PC-1	PC-2	PC-3	PC- 4
pH	-0.377	0.121	***0.714***	0.191
EC	-0.01	0.123	**0.637**	0.142
OC	-0.031	***0.977***	0.049	0.054
$CaCO_3$	0.127	-0.088	0.507	-0.168
N	-0.046	**0.974**	0.033	0.057
P	0.16	0.303	0.325	-0.406
K	-0.028	-0.115	-0.116	-0.473
S	-0.016	-0.086	0.092	***0.739***
Zn	0.536	0.093	0.245	-0.073
Cu	0.5	-0.041	0.533	0.075
Fe	***0.846***	-0.043	-0.091	0.045
Mn	**0.863**	-0.097	-0.08	0.097
B	0.244	0.141	-0.146	0.356
Eigen values	**2.349**	**2.174**	**1.517**	**1.157**
% of Variance	**18.067**	**16.724**	**11.666**	**8.899**

Table 5. Results of PCA of Alirajpur district (n=28)

Variables	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
BD	0.026	-0.542	-0.498	-0.195	0.211	0.295	0.198
pH	0.030	-0.247	0.277	-0.576	0.484	-0.170	0.252
EC	0.094	-0.058	0.152	-0.032	0.834	0.099	0.028
OC	0.956	0.090	0.103	-0.074	0.053	0.041	0.045
$CaCO_3$	0.028	-0.231	0.872	-0.084	0.141	0.093	0.133
N	0.941	0.152	0.100	-0.129	0.070	0.055	0.029
P	0.497	-0.282	-0.181	0.366	0.192	0.433	0.108
K	0.014	0.167	0.035	0.078	0.025	0.887	0.184
S	-0.408	0.567	-0.324	-0.138	0.433	0.025	0.009
Zn	0.237	0.315	0.816	0.076	0.235	0.142	0.048
Cu	0.347	0.295	0.179	0.043	0.523	0.153	0.373
Fe	0.317	0.774	-0.053	0.198	0.124	0.162	0.064
Mn	0.118	0.861	0.075	-0.138	0.073	0.026	0.200
B	-0.098	-0.075	0.048	0.811	0.025	0.025	0.195
DHA	-0.114	0.161	0.178	0.614	0.076	0.631	0.217
MBC	-0.026	0.150	0.073	0.104	0.003	0.048	0.918
CO_2	0.485	0.272	0.057	-0.059	0.182	0.107	0.497
Eigen values	**3.853**	**2.479**	**2.16**	**1.76**	**1.261**	**1.199**	**1.025**
% of Variance	**22.667**	**14.583**	**12.705**	**10.351**	**7.415**	**7.054**	**6.03**

Table 6. Sensitive indicators and conversion of data into 0-1 scale and soil quality rating value

Alirajpur	Sensitive indicators	SQI
Alirajpur (n=272)	pH(0.30), OC(0.24), S(0.24), and Fe (0.08)	**0.22**
10% sample of Alirajpur district with biological parameter	EC(0.69), OC(0.11), K(0.33), Zn (0.13), Fe (0.25), B (0.23), and MBC (0.48)	**0.31**

4. CONCLUSIONS

Based on the findings of present investigation it can be concluded that: Soils of Alirajpur district were found neutral to slightly acidic in reaction, safe in electrical conductivity, low to medium in organic carbon, non-calcareous in nature and extent of N, P, K, S, Zn, Cu, Fe and B deficiencies in soils samples were to the extent of 73.9, 26.1, 77.6, 93.0, 7.4, 25.4 and 20.2 %, respectively.PCA analysis showed that most sensitive factors governing variation in soil composition were OC, Fe, Zn, B, EC, K, and MBC. The finally calculated SQI are 0.22 to 0.31 which show moderate to good quality of soil in Alirajpur.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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