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# Soil quality of cultivated land in urban and rural area on the basis of both minimum data set and expert opinion

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**ABSTRACT**

Soil quality assessment is a significant approach for arable land, especially in a coastal region to gain a better understanding of soil productivity and effect of agricultural systems on soil resources. This study aimed to determine the quality of cultivated soil of both urban (Noakhali) and rural areas (Kabirhat and Subarnachar) of Noakhali, Bangladesh. The soil quality was evaluated as soil quality index by using 117 soil samples data, collected from three different sites within the Noakhali District. Among 14 soil parameters (total data set), only six parameters namely organic matter, Phosphorous, Boron, potassium, and iron were selected for the minimum data set, based on a combination of principal component analysis, norm values and expert opinion. Four soil quality index calculation methods, namely: linear weighted additive; linear simple additive; nonlinear weighted additive and nonlinear simple additive; were calculated based on the minimum data set. A significant positive correlations (P <0.001, P <0.05) among the four methods were observed. The soil quality of the three sampling regions followed the order of Kabirhat> Subarnachar> Noakhali indicating the better quality soil in rural areas. In Noakhali, the major contributors to soil quality were organic matter (2.94–64.85%) followed by Boron (4.69-58.22%), iron (4.77–50.00%), electrical conductivity (3.48–32.53%), phosphorous (0.36–39.44%) and potassium (1.77–27.76%) whereas in Kabirhat, Boron (31.70%) and iron (23.83%) were the major contributors, and in Subarnachar, organic matter (28.98%) contributed the most.

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## INTRODUCTION

The human being is dependent on food crops grown in soil, but the quantity and quality of that food are prominently influenced by soil the quality (Wall *et al.,* 2015). Soil quality can be reduced through imbalanced fertilizer use, acidification, changes in alkalinity, changes in salinity, unsustainable and intensive agricultural activities and, most undesirably, by soil erosion (Masto *et al.,* 2008; Bilgili *et al.,* 2017). Additionally, declining soil quality results in the interruption of basic soil functions, including retaining plant nutrients which attenuate the harmful

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effects of contaminants (Masto *et al.,* 2008). Therefore, maintaining soil quality - maintaining maximum productivity without decreasing soil quality, is crucial for ensuring a sustainable agricultural development (Askari and Holden, 2014). To ensure high soil quality it is necessary to quantify the term and it is believed that a reliable and accurate soil quality measurement can confirm the soil quality of a particular area (Guo *et al.,* 2017). Soil quality is the capacity of a soil to sustain biological productivity, maintain environmental quality, and promotes plant, animal, and human health (Doran and Parkin, 1994). The term soil quality index (SQI) has evolved from this concept (Armenise *et al.,* 2013) and at the present time SQI is given importance because it gives better understanding about soil ecologies across a certain area allowing more efficient soil management facilities (Wang & Gong, 1998). However, the determination of a SQI is quite difficult, and different from air and water quality as soil is not directly consumed (Doran *et al.,* 1996.). Additionally, soil quality does not depend on a single factor; various physical, chemical and biological factors have to be considered for the quantification of a SQI (Shekhovtseva *et al.,* 2015). Many models have been developed by many researchers for the quantification of a SQI (Andrews *et al.,* 2004; Karlen *et al.,* 1997), but there is no universal method for such quantification because the various aspects of the study area have to be considered in this process (Andrews *et al.,* 2004; Rangel-Peraza *et al.,* 2017). Some researchers have adopted SQI methods at both regional and on-farm scales (Glover *et al.,* 2000; Masto *et al.,* 2008), but we think that for consistent and accurate evaluation of soil quality at both regional and national levels there needs to be further analysis (Yu *et al.,* 2018). There are two possible data set approaches for SQI determination – the total data set approach (TDS) and the minimum data set (MDS) approach. The MDS approach is considered more suitable due to the extra cost of a TDS system (Rezaei *et al.,* 2006). The choice of a MDS comprises of various techniques, for example, PCA (Andrews and Carroll, 2001), factor analysis (Shukla *et al.,* 2006), correlation analysis (Andrews *et al.,* 2001), norm value analysis (Yemefack *et al.,* 2006) and expert opinion (EO) (Andrews *et al.,* 2002). Although both linear and nonlinear methods can be used for scoring MDS, but nonlinear scoring is preferable than the linear method (Larson and Pierce 1994; Andrews *et al.,* 2002). Finally, additive and weighted additive methods were used to convert the indicators into Soil Quality Indices (SQIa and SQIw) (Yu *et al.,* 2018). Noakhali district is one of the most important agricultural areas of Bangladesh due to its geographical location. The district of Noakhali is one of the most important agricultural areas of Bangladesh due to its geographical location. In Noakhali Upazila about 48,248, 35,595, and 34,490 hectors of land was cultivated during 2013-14, 2014-15 and 2015-16 fiscal year with an annual production of 112,330, 119,764, and 108,233 metric ton respectively. In Subarnachar Upazila about 44,815 hector land was cultivated and the total production was 133,900 metric ton in the same fiscal years. Agricultural activities contributed to 30% of the regional GDP and about 45% of the native population working in the sector although flooding, soil erosion and salinity problem are existing for many years. Therefore in order to ensure the consistent agricultural production in this area it is necessary to assess the quality of soil. However as the district consists of both rural and urban areas, we took the sample from both areas to get an overall soil quality scenario of the district. Taking SQI is an effective tool for soil quality determination as a hypothesis, the objectives of this study were to: i) create an MDS to isolate key indicators of soil quality, ii) score the soil quality indicators based on linear and nonlinear methods, iii) determine and compare additive and weighted additive SQIs in the study area. This study has been carried out in Noakhali, Bangladesh during the year of 2017-2018.

## MATERIAS AND METHODS

*Study area description*

The study area is about 175 kilometer (km) away from the city of Dhaka, Bangladesh. The study area comprised of three Upazilas (regions) of the Noakhali District, namely Noakhali (urban area), Kabirhat (rural area) and Subarnachar (rural area). The man growing season of this area is post-monsoon (October-January), although some lands are also cultivated during the monsoon season (June-September). This is a lowland area where cultivation is mostly dependent on surface water such as river or lakes, although ground water is also used in some areas, particularly in the Noakhali Upazila. As it is a coastal area there are salinity problems in some areas, predominantly in the Subarnachar Upazila. The location map is shown in Fig. 1 and the characteristics of these areas along with the main cultivated crops are shown in Table 1.

*Soil sampling and analysis*

The soil samples were collected at depths of 0–15 cm from 22 different sites during September to December of 2017, before the agricultural cycle. The site history and characteristics of the soil in the three Upazilas are shown in Table 1. For each sampling point, three subset samples were collected and mixed thoroughly. We maintained a distance of about 6 cm apart for each subsample (Yu *et al.,* 2018). The mixed samples were first air-dried, ground, mixed thoroughly, sieved through a mesh of 2 mm sieve and finally stored in a clean plastic container for analysis. Soil pH values were determined using a glass electrode pH meter (HI 3220) with soil–water ratio of 1:2.5 as described by Jackson (1962). The amount of organic matter in the soil was calculated by multiplying the organic carbon value (Walkley and Black (1934) with the Van Bemmelen factor 1.724 (Piper, 1950). Total nitrogen (TN) in the soil was determined using the Kjeldahl method which involves digesting the soil samples at 390 °C in a digestion tube with 5 ml 98% conc. HCl (Page *et al.,* 1982). Available phosphorus determined by shaking with a 0.03 M $NH_4F$–0.025 M HCl solution mixture maintaining the pH at <7.0 followed by analysis with a UV-Vis spectrometer (Lambda 365 UV/Vis, Perkin Elmer, USA) following the Bray and Kurtz method and also by the Olsn method for soil of pH >7 (Latrou *et al.,* 2014). Exchangeable cations such as potassium (K),

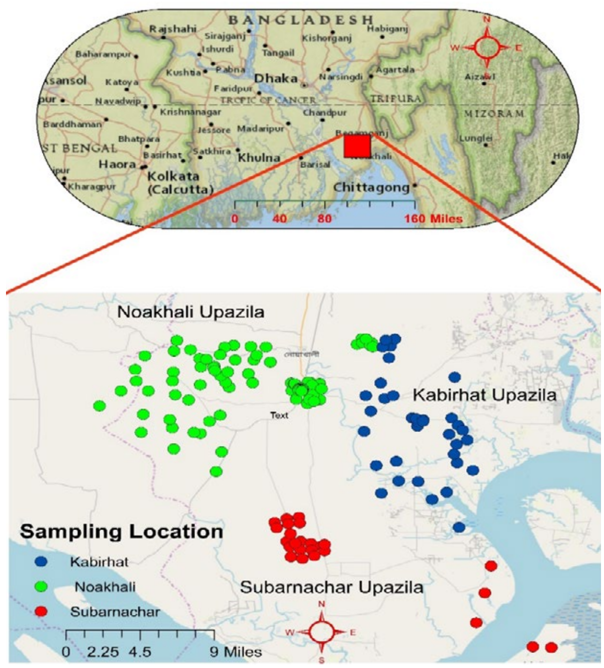


Fig. 1: Geographic locations of the study area along with the sampling site in Noakhali District, Bangladesh

Table 1: Site History and features of soil in three different Upazila

| | | Sampling Site | | |
|---|---|---|---|---|
| | | Noakhali | Kabirhat | Subarnachar |
| Temperature (°C) | | | 22.25-30.95 | |
| Rainfall (mm/y) | | | 75.35 | |
| Soil color | Upper layer | Grayish brown- grayish dark brown | Grayish brown- dark grayish brown | Grayish brown-light grayish brown |
| | Mid layer | Light brownish gray-grayish light brown | Grayish light brown- dark grayish brown | Light brownish gray |
| Main crops | | Paddy (Boro rice), red amaranth, cowpea, jute, wheat, corn | Corn, paddy (Aman rice), banana, peanut, eggplant | Soya bean, peanut, paddy (Aman rice), pea (Khesari), mustard, chili, watermelon, pumpkin, cucumber |

Calcium (Ca) and Magnesium (Mg) were determined by extraction with 1 M ammonium acetate (Black, 1965; Schollenberger and Simon, 1945). The available sulfur content of the soil samples was determined with a sulfur-extracting solution described by Fox *et al.* (1964). The concentration of iron (Fe), Zinc (Zn), copper (Cu), and manganese (Mn) of the soil samples were determined by using diethylenetriaminepentaacetic acid (DTPA) solution extraction (Petersen, 2010). Boron was determined by digestion of the samples with $CaCl_2$ in a nitrogen atmosphere followed by analysis of the absorbance by spectrophotometer (Lambda 365 UV/Vis, Perkin Elmer, and USA) (Petersen, 2010).

*Soil quality evaluation*

*Indicator selection*

To evaluate the SQI of the samples we followed three major steps, starting with selecting the indicators that formed the MDS. First of all, the coefficient of variation was used to lessen the length of the data, which indicates the quantity of substantial difference of the factor that exists among the sampling stations. If the coefficient of variation is less than 10% among the sampling stations we have eliminated that factor from consideration (Xu *et al*., 2005; Dong *et al.,* 2013). Then the principle component analysis (PCA) method was used to reduce the length of data while minimizing loss of information (Armenise *et al.,* 2013). PCs having eigenvalues greater or equal to 1 were selected, because PCs with eigenvalues of less or equal to 1 make up fewer deviation than generated by a sole variable (Andrews *et al.,* 2002). For each PC, soil properties with factor loadings of ≥0.50 were selected (Zhang *et al.,* 2016). Afterwards, Pearson correlation (r) analysis was utilized to reduce the redundancy of data on the basis of relationship analysis. The variables having correlation value of r ≥ 0.70 with highest factor loading was considered as an indicator from the well-correlated variables (Andrews *et al.,* 2001). Finally, norm values (Nik) were utilized to finalize the MDS because a solitary incentive inside 10% of the most astounding incentive in every PC can't mirror the data of multi-dimensional space (Andrews *et al.,* 2001; Yemefack *et al.,* 2006). The norm values were calculated using Eq. 1 (Chen *et al.,* 2013).

$$N_{ik} = \sqrt{\sum_{1}^{n}\left(U_{ik}^{2} \; X \; \lambda_k\right)} \quad (1)$$

$N_{ik}$ indicates the inclusive loading of soil variable i in the first k PCs, $\lambda_k$ represents the eigenvalue of the PC, and $U_{ik}$ is the loading of soil variable i in PCk.

*Indicator Scoring and SQI Calculation*

The indicators were scored as dimensionless values (ranging from 0 to 1) using both a linear and a nonlinear scoring method for the preparation of MDS (Liebig *et al.,* 2001). In the case of the linear scoring, the 'more is better' indicator was calculated by dividing it by the highest value, so that the highest score become 1 as Eq. 2 and the 'less is better' indicator was identified by dividing the lowest value by each data such that the lowest score become 1 as Eq. 3. The indicator like EC, was scored as 'higher is better' up to a threshold value (e.g. EC 1.4 dS/m) and 'lower is better' above the threshold (Andrews *et al.,* 2002).

$$S_{iL} = \frac{X}{X_{max}} \quad (2)$$

$$S_{iL} = \frac{X_{min}}{X} \quad (3)$$

Where, $S_{iL}$ indicates the linear score of the soil indicator, X is the individual soil indicator value, and Xmax and Xmin are the top and least value of each soil indicator observed among the sampled stations (Askari and Holden, 2014; Raiesi, 2017). For nonlinear scoring using Eq. 4.

$$SiNL = \frac{a}{1+\left(\frac{X}{Xm}\right)^{b}} \quad (4)$$

SiNL indicates the nonlinear score, "a" means the maximum score which is one (1) for this study, X represents the soil indicator value, Xm is the mean value of each soil indicator, and b is the slope of the equation which is scored as -2.5 for 'more is better' curve and 2.5 for 'less is better' curve (*Table 5*) (Raiesi, 2017; Yu *et al.,* 2018). The data obtained from both the linear and nonlinear methods were given weightage value on the basis of PCA. The weightage value (Wi) was calculated by dividing the total percentage of variance from each PC by the percentage of cumulative variance (Ray *et al.,* 2014). From both the values the SQI index is calculated by using additive Eq. 5 and weighted additive as Eq. 6.

$$SQI_A = \frac{\sum_{i=1}^{n} S_i}{n} \quad (5)$$

$$SQIw = \sum_{i=1}^{n} W_i \; S_i \quad (6)$$

Si represents the indicator score (both linear and nonlinear); n is the total number of variables selected for MDS and Wi their weighing value. Based on the above results we determined four different SQIs on the basis of additive integration method and weighted additive integration method using both linear and non-linear score values. In case of weighted additive method, SQI values ranged from 0 to 1 and a value between 0.8 and 1.0 could be considered to represent very high quality soils, while values between 0.0 and 0.19 indicate very low quality soils (Rangel-Peraza *et al.,* 2017; Ngo- Mbogba *et al.,* 2015). In the case of additive SQIs, SQI values greater than 0.2 could be considered to indicate good quality soils (Andrews *et al.,* 2004).

*Statistical analysis*

Statistical analyses were performed by using SPSS 17.0 and Microsoft Excel. The comparisons of measured values between stations and variables were conducted using the Tukey HSD test. All tests were done at the 0.05 or 0.01 significance level. The coefficient of variance was used to determine the major variation of the soil parameters among the sampling stations.

## RESULTS AND DISCUSSIONS

*Statistics description*

Table 2 showed the descriptive statistics of the laboratory-analyzed soil quality parameters, representing the mean and standard error of the data of both urban and rural area of Noakhali District. The pH of the soil samples from Noakhali Upazila ranged from 6.30–7.66, 6.05–7.92 from Kabirhat Upazila, and 6.00–7.26 from Subarnachar Upazila , all of which which are within the range suggested by the Food and Agriculture Organization (FAO 2013). From the observed data it can be anticipated that the soil of these three Upazilas is moderately acidic to moderately alkaline in nature (Motsara *et al*., 2008) which may be due to the salinity effect in these areas. However, the soil pH of samples from Noazpur, Ghoshbag, Batya, Char Bata and Chaprashirhat were significantly different ($P < 0.05$) from the other sampling sites. Among all the soil sampled that from Chaprashirhat had the highest pH value (a mean of 7.92) while Char Bata had the lowest observed value (a mean of 6.00). Soil pH is considered a vital factor because plant nutrient availability is greatly influenced by the soil pH. The best pH range for maximum plant nutrient availability is 5.5–7 (Firdous *et al.,* 2016). In our present study most soil pH values were within this range. Electrical conductivity is the indirect measurement of soluble salt and salinity in soil. In our present study the range of EC was between 0.59–4.83 dS/m. From Table 2 it is clear that there were no significant differences ($P<0.05$) among the various sampling sites, except Narottompur and Goshbhag of Kabirhat Upazila. Nevertheless, the maximum EC was observed at Char Clerk of Subarnachar Upazila due to the highest possibility of salt intrusion from the nearby Meghna River, whereas the lowest EC was observed at Goshbhag of Kabirhat Upazila. The negative correlation between pH and EC as observed by our PCA analysis ($r = -0.11$) has also been suggested by many other researchers (Ouhadi and Goodarzi 2007; Shabbir *et al.,* 2014). This may be due to higher EC values indicating higher ion contents; these ions push away the hydrogen ions in the soil resulting in a decreased pH value. The standard range of soil EC is 0.2–1.4 dS/m. The lower value indicates nutrient scarcity and higher values either indicate the use of higher salt fertilizer or a salinity problem in the soil (Hartsock *et al.,* 2000). In our study about 64% of the total soil had EC values higher than the standard range, indicating that the soils of these areas are affected by salinity problems. Furthermore, among all Upazilas, the soil of Subarnachar Upazila had higher salinity values, followed by Kabirhat Upazila and Noakhali Upazila. The U.S. Salinity Laboratory suggests that EC values over 4 dS/m may be toxic to the plants (Nell *et al.,* 2014). Organic matter (OM) is considered a vital parameter for soil quality because it allows air and water to enter the soil, protect the soil from erosion and improve soil fertility (Peraza *et al.,* 2017). The standard OM content of good quality soil is >1.29% as proposed by Akram *et al.* (2014). From Table 2 it is clear that more than 95% of the sampled soil had OM contents of more than the standard limit. Usually the soil of these Upazila are clay to loamy types; these types of soils are likely to retain OM as clay soil can form temporary bonds with the organic matter (Krull *et al.,* 2003). The highest OM content was observed at Ewazbalia of Noakhali Upazila while the lowest content observed at Narottompur of Kabirhat Upazila. Among the three Upazila, the OM content of Subarnachar Upazila is slightly lower than others because the soil of this area is loose in consistency, even in wet conditions. The exchangeable cations determined were dominated

Table 2: Descriptive statistics of soil properties at different sites of three Different Upazila used for soil quality assessment

| Sampling Area | pH | EC (dS/m) | OM (%) | TN (%) | P (µg/g) | K (meq/100g) | S (µg/g) | Zn (µg/g) | B (µg/g) | Mg (meq/100g) | Ca (meq/100g) | Cu (µg/g) | Fe (µg/g) | Mn (µg/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noakhali Region (urban area) | | | | | | | | | | | | | | |
| Noakhali (n=5) | 7.66±0.38$^{AB}$ | 2.44±1.30$^{AB}$ | 1.71±1.03$^{AB}$ | 0.08±.034$^{B}$ | 51.33±45.08$^{A}$ | 0.19±0.02$^{ABC}$ | 36.18±29.70$^{C}$ | 0.66±0.12$^{DE}$ | 0.32±0.18$^{BCD}$ | 1.80±0.56$^{DEF}$ | 8.86±3.15A | 2.84±0.44$^{A}$ | 27.40±6.35$^{A}$ | 8.40±4.72$^{AB}$ |
| Noannai (n=9) | 6.59±0.65$^{AB}$ | 1.61±2.09$^{AB}$ | 2.29±0.58$^{AB}$ | 0.11±0.24$^{B}$ | 6.34±5.12$^{B}$ | 0.14±0.04$^{ABC}$ | 20.10±8.90$^{C}$ | 0.69±0.11$^{DE}$ | 0.40±0.29$^{BCD}$ | 1.83±0.65$^{DEF}$ | 5.73±0.75$^{A}$ | 2.63±0.82$^{A}$ | 97.50±57.36$^{A}$ | 26.25±8.53A$^{B}$ |
| Binodpur (n=10) | 6.58±1.09$^{AB}$ | 1.17±1.95$^{AB}$ | 2.38±1.27$^{AB}$ | 0.11±0.04$^{B}$ | 30.10±31.62$^{AB}$ | 0.18±0.10$^{ABC}$ | 28.29±25.73$^{C}$ | 0.73±0.12$^{CD}$ | 0.37±0.28$^{BCD}$ | 1.82±0.55$^{DEF}$ | 6.10±1.78$^{A}$ | 3.33±0.23$^{A}$ | 71.00±37.99$^{A}$ | 23.33±11.72$^{AB}$ |
| Dharmapur(n=12) | 6.96±0.69$^{AB}$ | 0.99±0.62$^{AB}$ | 2.18±1.00$^{AB}$ | 0.11±0.04$^{B}$ | 20.33±27.53$^{AB}$ | 0.18±0.08$^{ABC}$ | 17.36±12.67$^{C}$ | 0.75±0.09$^{CDE}$ | 0.20±0.18$^{CD}$ | 1.60±0.33$^{EF}$ | 11.4±11.21$^{A}$ | 2.95±0.79$^{A}$ | 76.75±70.79$^{A}$ | 11.53±8.67$^{AB}$ |
| Char Matua (n=11) | 7.39±0.53$^{AB}$ | 1.87±0.83$^{AB}$ | 1.68±0.62$^{AB}$ | 0.09±0.03$^{B}$ | 13.27±11.63$^{AB}$ | 0.12±0.02$^{C}$ | 39.95±45.54$^{C}$ | 0.76±0.09$^{CDE}$ | 0.74±0.36$^{ABCD}$ | 2.05±0.59$^{DEF}$ | 7.43±1.23$^{A}$ | 6.50±10.75$^{A}$ | 28.63±16.31$^{A}$ | 7.68±7.01$^{AB}$ |
| Ashwadia (n=3) | 7.19±0.16$^{AB}$ | 1.87±0.48$^{AB}$ | 1.93±0.53$^{AB}$ | 0.10±0.02$^{B}$ | 23.30±18.70$^{AB}$ | 0.13±0.01$^{BC}$ | 53.61±37.73$^{C}$ | 0.75±0.07$^{CDE}$ | 0.43±0.10$^{BCD}$ | 1.87±0.72$^{DEF}$ | 7.10±2.01$^{A}$ | 3.73±1.01$^{A}$ | 79.67±60.58$^{A}$ | 29.67±20.21$^{AB}$ |
| Ewazbalia (n=6) | 6.54±0.52$^{AB}$ | 1.73±1.41$^{AB}$ | 3.08±0.76$^{A}$ | 0.14±0.02$^{B}$ | 7.16±10.36$^{B}$ | 0.14±0.04$^{ABC}$ | 55.39±48.01$^{C}$ | 0.75±0.06$^{CDE}$ | 0.48±0.16$^{BCD}$ | 1.89±0.51$^{DEF}$ | 6.20±1.43$^{A}$ | 3.00±0.49$^{A}$ | 27.33±4.18$^{A}$ | 7.83±3.06AB |
| Dadpur(n=7) | 7.00±0.16$^{AB}$ | 1.09±0.26$^{AB}$ | 2.35±0.37$^{AB}$ | 0.11±0.02$^{B}$ | 3.45±4.38$^{B}$ | 0.12±0.02$^{C}$ | 26.60±5.07$^{C}$ | 0.73±0.07C$^{DE}$ | 0.59±0.16$^{ABCD}$ | 1.99±0.63$^{DEF}$ | 5.85±0.95$^{A}$ | 3.33±1.26$^{A}$ | 64.50±26.06$^{A}$ | 28.25±7.76$^{AB}$ |
| Kaladarap (n=10) | 7.06±0.57$^{AB}$ | 1.02±0.32$^{AB}$ | 2.17±0.36$^{AB}$ | 0.11±0.02$^{B}$ | 5.69±4.25$^{B}$ | 0.13±0.02$^{BC}$ | 39.61±16.73$^{C}$ | 0.71±0.10$^{CDE}$ | 0.52±0.24$^{BCD}$ | 0.21±0.98$^{CDEF}$ | 6.67±1.15$^{A}$ | 2.28±1.05$^{A}$ | 34.88±11.72$^{A}$ | 10.00±6.76$^{AB}$ |
| Kadir Hanif (n=10) | 6.97±0.63$^{AB}$ | 1.14±.0.65$^{AB}$ | 2.51±1.51$^{AB}$ | 0.11±0.04$^{B}$ | 9.91±11.07$^{AB}$ | 0.17±0.11$^{ABC}$ | 21.61±14.95$^{C}$ | 0.77±0.10$^{CDE}$ | 0.34±0.37BCD | 1.70±0.31$^{EF}$ | 4.87±0.71$^{A}$ | 2.83±0.85$^{A}$ | 69.00±35.55$^{A}$ | 25.33±7.23$^{AB}$ |
| Noazpur (n=3) | 6.20±0.92$^{B}$ | 1.83±0.72$^{AB}$ | 2.65±0.96$^{AB}$ | 0.13±0.02$^{B}$ | 1.92±1.12$^{B}$ | 0.16±0.11$^{ABC}$ | 83.30±43.30C | 0.98±0.30$^{BCDE}$ | 0.52±0.16$^{BCD}$ | 3.75±2.19$^{CD}$ | 8.63±3.73$^{A}$ | 3.67±1.22$^{A}$ | 55.67±43.39$^{A}$ | 13.00±11.93$^{AB}$ |
| Kabirhat Upazila (rural area) | | | | | | | | | | | | | | |
| Sundalpur (n= 3) | 7.20±0.29$^{AB}$ | 2.36±1.72$^{AB}$ | 1.55±0.53$^{AB}$ | 0.08±0.02$^{B}$ | 1.74±1.07$^{B}$ | 0.18±0.06$^{ABC}$ | 34.71±22.62$^{C}$ | 0.71±0.29$^{CDE}$ | 0.45±0.30$^{BCD}$ | 2.33±0.19$^{CDEF}$ | 4.40±0.53$^{A}$ | 3.57±1.12$^{A}$ | 99.00±37.24$^{A}$ | 31.33±14.57$^{A}$ |
| Dhan Siri (n= 3) | 6.72±1.68$^{AB}$ | 3.19±3.19$^{AB}$ | 2.06±0.62$^{AB}$ | 0.10±0.03$^{B}$ | 18.57±27.12$^{AB}$ | 0.19±0.11$^{ABC}$ | 24.61±18.19$^{C}$ | 0.80±0.36$^{CDE}$ | 1.01±0.83$^{ABC}$ | 6.11±0.20$^{AB}$ | 8.37±2.45$^{A}$ | 6.07±2.00A | 52.33±24.42$^{A}$ | 25.00±7.55$^{AB}$ |
| Narottampur (n= 3) | 7.26±0.62$^{AB}$ | 0.68±0.2$^{B}$ | 0.98±0.21$^{B}$ | 0.05±0.01$^{B}$ | 8.65±2.65$^{B}$ | 0.14±0.04$^{ABC}$ | 26.68±23.55$^{C}$ | 0.70±0.17$^{CDE}$ | 0.99±0.89$^{ABC}$ | 3.48±1.95$^{CDE}$ | 4.27±0.61$^{A}$ | 4.40±2.05$^{A}$ | 104.00±74.08$^{A}$ | 29.67±0.58$^{AB}$ |
| Ghoshbag (n= 3) | 6.05±1.20$^{B}$ | 0.59±0.12$^{B}$ | 2.10±0.28$^{AB}$ | 0.11±0.01$^{B}$ | 4.05±3.21B | 0.15±0.02$^{ABC}$ | 27.14±10.59$^{C}$ | 1.30±0.17$^{B}$ | 0.60±0.09$^{ABCD}$ | 1.43±0.93$^{F}$ | 5.47±2.70$^{A}$ | 3.47±1.39$^{A}$ | 51.00±41.07$^{A}$ | 7.67±6.35$^{AB}$ |
| Dhan Salik (n= 3) | 7.43±0.51$^{AB}$ | 2.04±0.42$^{AB}$ | 1.97±0.31$^{AB}$ | 0.10±0.01$^{B}$ | 30.09±37.75$^{AB}$ | 0.33±0.16$^{A}$ | 56.16±45.72$^{C}$ | 0.94±0.14$^{BCDE}$ | 0.85±0.59$^{ABCD}$ | 3.07±1.67$^{CDEF}$ | 5.40±1.18$^{A}$ | 3.50±0.10$^{A}$ | 111.33±37.43$^{A}$ | 23.33±6.66$^{AB}$ |
| Chaprashirhat (n= 3) | 7.92±0.52$^{A}$ | 1.57±0.71$^{AB}$ | 1.60±0.69$^{AB}$ | 0.08±0.03$^{B}$ | 19.24±13.14$^{AB}$ | 0.32±0.20$^{AB}$ | 26.22±31.92$^{C}$ | 1.30±0.26$^{B}$ | 0.64±0.16$^{ABCD}$ | 2.60±1.56$^{CDEF}$ | 5.83±2.56$^{A}$ | 3.90±1.49$^{A}$ | 88.67±67.25$^{A}$ | 11.00±9.64$^{AB}$ |
| Batya (n= 3) | 6.25±0.80$^{AB}$ | 1.03±0.87$^{AB}$ | 2.10±0.35$^{AB}$ | 0.12±0.03$^{B}$ | 7.86±5.85$^{B}$ | 0.16±0.04$^{ABC}$ | 52.02±32.75$^{C}$ | 1.13±0.12$^{BC}$ | 0.87±0.10$^{ABCD}$ | 3.23±0.81$^{CDEF}$ | 6.40±2.46$^{A}$ | 2.63±1.12$^{A}$ | 100.33±62.16$^{A}$ | 29.00±13.45$^{AB}$ |
| Subarnachar Upazila (rural area) | | | | | | | | | | | | | | |
| Char Bata (n= 6) | 6.00±0.59$^{B}$ | 3.19±13.37$^{AB}$ | 1.99±0.4$^{AB}$ | 0.10±0.02$^{B}$ | 3.37±0.74$^{B}$ | 0.23±0.08$^{ABC}$ | 87.89±56.24$^{BC}$ | 0.65±0.11$^{DE}$ | 0.13±0.03$^{D}$ | 1.31±0.16$^{F}$ | 8.23±1.12$^{A}$ | 4.10±0.93$^{A}$ | 46.00±7.01$^{A}$ | 18.5±7.53$^{AB}$ |
| Char Jubaly (n= 7) | 7.26±0.50$^{AB}$ | 4.54±2.87$^{AB}$ | 2.48±0.75$^{AB}$ | 0.12±0.04$^{B}$ | 12.81±5.59$^{AB}$ | 0.27±0.14$^{ABC}$ | 80.95±42.63$^{C}$ | 0.61±0.08$^{E}$ | 0.93±0.52$^{ABCD}$ | 3.17±0.83$^{CDEF}$ | 7.17±0.29$^{A}$ | 2.70±0.89$^{A}$ | 24.33±2.08$^{A}$ | 4.33±0.58$^{B}$ |
| Char Jabbar (n= 3) | 6.40±0.46$^{AB}$ | 3.80±1.90$^{AB}$ | 1.80±0.19$^{AB}$ | 0.09±0.01$^{B}$ | 2.33±0.58$^{B}$ | 0.26±0.09$^{ABC}$ | 160.33±15.31$^{A}$ | 1.80±0.87$^{A}$ | 1.40±0.69$^{A}$ | 6.27±0.7$^{A}$ | 8.10±0.56$^{A}$ | 4.00±0.96$^{A}$ | 42.33±7.77$^{A}$ | 19.33±17.04$^{AB}$ |
| Char Clerk (n= 3) | 6.27±0.71$^{AB}$ | 4.83±3.07$^{A}$ | 1.62±0.23A$^{B}$ | 0.38±0.54$^{A}$ | 2.33±0.58$^{B}$ | 0.30±0.07$^{ABC}$ | 158.00±60.23$^{AB}$ | 1.07±0.31$^{BCD}$ | 1.13±0.75$^{AB}$ | 4.13±2.42$^{BC}$ | 7.03±0.81$^{A}$ | 3.33±0.87$^{A}$ | 30.00±4.36$^{A}$ | 14.00±11.53$^{AB}$ |

Data with same letter (A, B, C, D, E, and F) do not show any significant variation ($P<0.05$) in a column.

by K, Ca and Mg. The standard ranges of exchangeable K, Ca and Mg are 0.22–0.30, 4.51–6.00 and 1.13–1.50 meq/100 g respectively (SRDI 2018; Ortega *et al.,* 2015). From Table 2 it can be seen that the quantity of exchangeable cations, particularly Ca and Mg, were higher than the maximum tolerable limit in all Upazilas. But in case of K it was lower than the standard limit in both Noakhali and Kabirhat Upazila and was within the standard range in Subarnachar Upazila.

This is to the higher salinity of Subarnachar Upazila soil compared to the other two Upazila, since the K ion is one of the main contributors of salinity. The micronutrient content, including B, Cu, Fe, Zn and Mn, were also determined for these soils and the results are shown in Table 2. The micronutrient levels were much higher than the maximum standard levels, except for B and Zn. The B content was within the range at about 77% of the sampling sites, whereas only 13% of the soil sample Zn concentrations were within the standard levels and the rest were below the standard levels. Generally, the micronutrient content of soil depends on other soil parameters such as pH, OM and soil moisture content (Peraza *et al.,* 2017). An acid soil results in an increase of Zn, Cu and Fe but an alkaline soil can have nutrient deficiencies of trace elements, in particular Fe and Zn (Lal 2002) and the lower content of Zn at the sampling sites in this study is due to the higher pH of soil. The higher Fe content values at all sampling sites is due to the fact that most of the farmers of these three Upazila depend on lower-depth groundwater-based irrigation systems that draw water containing excess amounts of Fe (BNDWS 2009). Total Nitrogen (TN) consist of all forms of inorganic nitrogen, such as $NH_4$, $NO_3$ and $NH_2$ (urea) and the organic nitrogen compounds such as proteins, amino acids and other products (Motsara *et al.,* 2008). At our sampling sites there were no significant differences in the TN values and all TN values at all sampling sites were lower than the standard limit, except Char Clerk of Subarnachar Upazila. The available phosphorous levels determined at almost all sampling sites of three Upazila were also less than the standard limit (Table 2) which is due to the alkaline condition of the soil (Lal 2002).

*Indicator Selection for the minimum data set*

In general, soil parameters with greater variances are selected for PCA; that is why we initially eliminated the consideration of pH, since its variation in the sampled site was minimal and showed a coefficient of variation of less than 10% (7.81%). The spatial variation of the remaining 13 soil properties showed greater variability (Tables 3 and 4) and were selected for PCA analysis. Table 3 showed that four PCs have Eigen values of ≥ 1, each with a variation of greater or equal to 10% and contribute to a total variation of 72.08%. The first PC explained 30.03% of the total variation and the remaining PCs explained more than 10% variation on average. Based on the factor load value (≥ 0.5), we grouped the variables into four PCs. Group 1 contained EC, TN, K, S, B and Mg, while group 2 contained OM, Fe and Mn and group 3 contained pH and P. Group 4 contained only K and Cu. In group 1, variables TN and K

Table 3: Results of PCA of 14 soil properties and their norm values and groups

| Property | PC1 | PC2 | PC3 | PC4 | Norm Value | Group |
|---|---|---|---|---|---|---|
| pH | -.342 | .335 | .719 | .213 | 1.37 | 3 |
| ECe (dS/m) | .812 | -.130 | .247 | .117 | 1.72 | 1 |
| OM (%) | -.142 | -.676 | -.317 | .009 | 1.21 | 2 |
| TN (%) | .585 | -.336 | -.230 | .323 | 1.40 | 1 |
| P (μg/g) | -.275 | .020 | .778 | .194 | 1.25 | 3 |
| K (meq/100g) | .600 | .179 | .348 | .561 | 1.50 | 1, 4 |
| S (μg/g) | .899 | -.129 | -.125 | .127 | 1.87 | 1 |
| Zn (μg/g) | .599 | .276 | -.188 | .013 | 1.33 | 1 |
| B (μg/g) | .747 | .464 | -.028 | -.089 | 1.71 | 1 |
| Mg (meq/100g) | .745 | .441 | .024 | -.238 | 1.71 | 1 |
| Ca (meq/100g) | .261 | -.496 | .408 | -.319 | 1.18 | - |
| Cu (μg/g) | .216 | .379 | .292 | -.732 | 1.20 | 4 |
| Fe (μg/g) | -.419 | .711 | -.239 | .290 | 1.50 | 2 |
| Mn (μg/g) | -.239 | .667 | -.417 | .038 | 1.32 | 2 |
| Eigen Value | 4.204 | 2.575 | 1.993 | 1.32 | | |
| % of Variances | 30.026 | 18.393 | 14.235 | 9.428 | | |
| Cumulative Variances | 30.026 | 48.418 | 62.653 | 72.081 | | |
| Weightage (Wi) | 0.42 | 0.26 | 0.20 | 0.13 | | |

were eliminated because the values of the norm were not within 10% of the value of the highest norm among the variables in group 1. Again, from the correlation value (Table 4), it is clear that among the variables of group 1, B had a strong correlation with Mg (r = 0.81), and as the absolute value of Mg was greater than B, was also eliminated from group 1. Then, group 1 contains three variables, namely EC, S and B. Group 2 contains OM, Fe and Mn. OM was eliminated since its normal value was far from the highest value of Fe (1.50). In group 2, the norm value of the Mn was 12% of the Fe, but due to its significant correlation with the Fe (r = 0.73) it was not considered for MDS. Since the pH was initially removed from the variables, group 3 contains only P. between K and Cu, K had the highest value of the norm and, for that reason, group 4 contains only the variable K. However, from EO as well as literature studies, OM is also considered a vital factor for soil quality (Bhattacharyya, *et al.,* 2007). Therefore, the MDS contained the following screened indicators for SQI calculations: EC, OC, P, B, K and Fe, which have been used as MDSs by various other researchers (Zhang *et al.,* 2014; Mukherjee *et al.,* 2014). The types of scoring curves, factors for scoring equations and the weights of soil indicators are shown in Table 5.

*Soil quality index*

The gathering of soil quality parameters and their integration into a single index could deliver evidence about soil quality changes of a particular area (Chen *et al.,* 2013; Zhang *et al.,* 2016). In any case, the preparation of MDS data is more preferable than TDS for soil quality calculations because the latter implies high labor costs. However, precautions must be taken when selecting the MDS indicators (Andrews *et al.,* 2004). The selected indicators, such as ECE, OM, P, B, K and Fe, were scored using the Eqs. 2 and 3 for linear score and Eq. 4 for non-linear score of soil indicators. The indicator values were then used to calculate SQI values using additive Eq. 5 and weighted additive Eq. 6 methods respectively. The SQI values determined by various methods are shown in Fig. 2. The soil feature of the studied regions monitored the mandate of Kabirhat > Subarnachar > Noakhali, although insignificant variances were detected among the regions ($p < 0.05$) (Fig. 2). However, the value of

Table 4: Correlation coefficients matrix among 14 soil properties

| | pH | EC | OM | TN | P | K | S | Zn | B | Mg | Ca | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | | | | |
| EC | -0.11 | 1 | | | | | | | | | | | | |
| OM | -0.37* | -0.1 | 1 | | | | | | | | | | | |
| TN | -0.39* | 0.50** | 0.08 | 1 | | | | | | | | | | |
| P | 0.56** | -0.06** | -0.12 | -0.25 | 1 | | | | | | | | | |
| K | 0.16 | 0.61 | -0.22 | 0.31 | 0.175 | 1 | | | | | | | | |
| S | -0.41* | 0.76 | -0.07 | 0.59** | -0.319 | 0.50** | 1 | | | | | | | |
| Zn | -0.27 | 0.14 | -0.17 | 0.13 | -0.242 | 0.40* | 0.51** | 1 | | | | | | |
| B | -0.04 | 0.46* | -0.34 | 0.26 | -0.23 | 0.39* | 0.56** | 0.57** | 1 | | | | | |
| Mg | -0.16 | 0.55** | -0.22 | 0.168 | -0.12 | 0.40* | 0.52** | 0.52** | 0.81 | 1 | | | | |
| Ca | -0.14 | 0.29 | 0.16 | 0.098 | 0.25 | 0.06* | 0.23 | 0.02 | -0.13 | 0.15 | 1 | | | |
| Cu | 0.1 | 0.16 | -0.39* | -0.175 | -0.01 | -0.03 | -0.002 | 0.08 | 0.32 | 0.44* | 0.113 | 1 | | |
| Fe | 0.19 | -0.48* | -0.29 | -0.337 | 0.04 | 0.03 | -0.41* | 0.01 | -0.08 | -0.01 | -0.44* | -0.1 | 1 | |
| Mn | -0.05 | -0.21 | -0.24 | -0.189 | -0.11 | -0.19 | -0.18 | -0.09 | 0.04 | 0.19 | -0.43* | 0.05 | 0.73 | 1 |

* Significant correlation at $p < 0.05$; **Significant correlation at $p < 0.01$

Table 5: Type of scoring curves, the parameters of nonlinear and linear equations, and calculated weights for the indicators in the minimum data set

| Indicators | Scoring curve | Nonlinear | | Linear | | Weight (Wi) |
|---|---|---|---|---|---|---|
| | | Mean (Xm) | Slope (b) | Xmax | Xmin | |
| EC | *More is better* | 2.03 | -2.5 | 9.07 | - | 0.42 |
| | *Less is better* | 2.03 | 2.5 | - | 0.28 | 0.42 |
| OM | *More is better* | 2.03 | -2.5 | 4.82 | - | 0.26 |
| P | *More is better* | 12.90 | -2.5 | 100.26 | - | 0.2 |
| B | *More is better* | 0.63 | -2.5 | 1.90 | - | 0.42 |
| K | *More is better* | 0.19 | -2.5 | 0.56 | - | 0.13 |
| Fe | *More is better* | 62.80 | -2.5 | 180 | - | 0.26 |

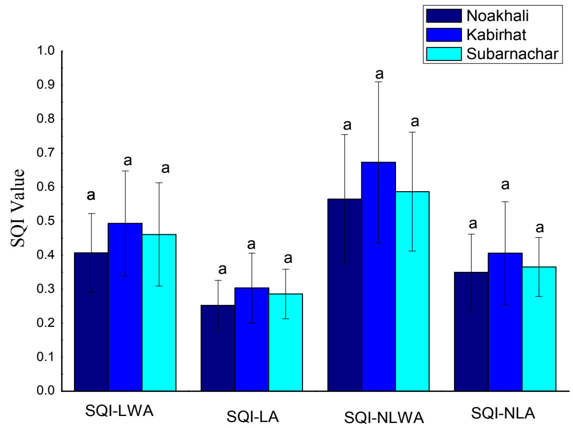

Fig. 2: Soil quality index values of studied areas determined by various methods

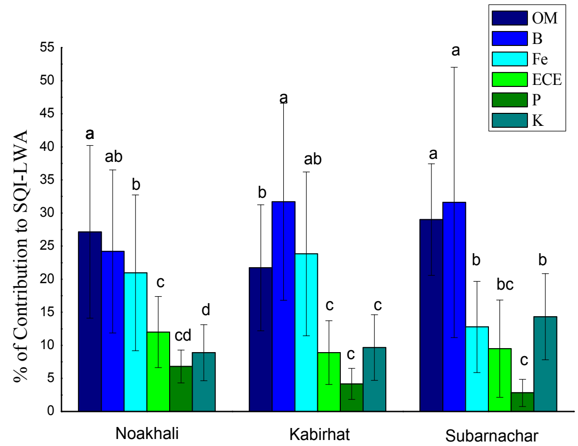

Fig. 3: Major contributors of SQI-LWA in three different Upazila

the weighted average result (SQI-LWA/SQI-NLWA) was found to be higher than the additive method (SQI-LA/SQI-NLA). The SQI-NLWA values ranged from 0.15–0.98 in Noakhali Upazila, 0.39–1.00 in Kabirhat Upazila and 0.24–0.85 in Subarnachar Upazila, whereas SQI-NLA values ranged from 0.11–0.56, 0.24–0.69, and 0.18–0.49 in Noakhali, Kabirhat and Subarnachar respectively. Based on this result it is clear that the soil of Kabirhat Upazila is more suitable for cultivation compared to the soil of Noakhali Upazila and Subarnachar Upazila.

The major contributors of SQI-LWA in three different Upazilas are shown in Fig. 3. The contributions of soil parameters to SQI were significantly different ($p<0.05$) across all sampling areas. In the case of Noakhali the major contributor was OM, which ranged from 2.94–64.85%, followed by B (4.69–58.22%), Fe (4.77–50.00%), EC (3.48–32.53%), P (0.36–39.44%) and K (1.77–27.76%). EC was a major contributor in decreasing the SQI of this area because this area consists of low terrain along with a high degree of mineralization of groundwater and poor drainage conditions. In Kabirhat Upazila, B (31.70%) and Fe (23.83%) were the highest contributors to SQI, followed OM (21.72%). The maximum SQI value was observed in Kabirhat Upazila due to its rich mineral content (Fe, K, B, and P) as compared to the other two areas. OM (28.98%) contributed most to the SQI of Subarnachar Upazila and was responsible for the higher soil quality because it is often considered the largest contributor to soil quality (Shukla *et al.,* 2006). Almost Similar soil quality evaluation results (Fig. 2) and significant positive correlations ($P<0.001$, $p<0.05$) among the four SQIs (Table 6) indicating both the sensitivity and accuracy of the SQ methods. Although the strong positive correlation among various SQIs indicates that

The established MDS was suitable for soil quality assessment of the studied area, but in the meantime it also made it difficult to find out the best approach for the assessment.

## CONCLUSION

The study carried out for superior understanding of the soil conditions in order to take necessary steps to ensure the greater productivity of crops for a sustainable agricultural growth in the studied region. Six (OM, B, Fe, ECE, P and K) out of fourteen indicators were selected for MDS based on PCA, normality factor and EO. Based on the collective contribution of MDS indicators, the study revealed that the soil of Kabirhat Upazila is in good condition (on the basis of both linear and non-linear SQI) for cultivation as compared to other two Upazila due to comparatively lower salinity and higher organic matter content. In overall, the soil quality of rural area is most suitable for agricultural activities as compared to the urban area. However, in almost all Upazila, OM individually played an essential role in soil quality index enhancement. The positive correlation among all of the SQI indexes ensured that the accuracy and eligibility of the SQ methods for these areas soil quality management. The positive correlation among all the SQI indices ensured the accuracy and eligibility of the SQ methods for soil quality management of these areas.

Table 6: Correlation matrix for the four SQIs in three Upazila

| **Noakhali** (urban area) | | | | |
|---|---|---|---|---|
| | SQI -LWA | SQI-LA | SQI-NLWA | SQI-NLA |
| SQI -LWA | 1 | | | |
| SQI –LA | 0.947*** | 1 | | |
| SQI -NLWA | 0.772** | 0.678** | 1 | |
| SQI -NLA | 0.771** | 0.782** | 0.935*** | 1 |

| **Kabirhat** (rural area) | | | | |
|---|---|---|---|---|
| | SQI -LWA | SQI-LA | SQI-NLWA | SQI-NLA |
| SQI -LWA | 1 | | | |
| SQI –LA | 0.957*** | 1 | | |
| SQI -NLWA | 0.901*** | 0.870** | 1 | |
| SQI -NLA | 0.915*** | 0.941*** | 0.968*** | 1 |

| **Subarnachar** (rural area) | | | | |
|---|---|---|---|---|
| | SQI -LWA | SQI-LA | SQI-NLWA | SQI-NLA |
| SQI -LWA | 1 | | | |
| SQI –LA | 0.952*** | 1 | | |
| SQI -NLWA | 0.861** | 0.785** | 1 | |
| SQI -NLA | 0.875** | 0.894** | 0.936*** | 1 |

** $p<0.05$; *** $p<0.001$

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## ABBREVIATIONS

| | |
|---|---|
| *%* | Percentage |
| µg/g | Microgram/gram |
| $\lambda_k$ | Eigen values of PC |
| $^0C$ | Celsius |
| *B* | Boron |
| *Ca* | Calcium |
| *cm* | Centimeter |
| *Cu* | Copper |
| *dS/m* | Deci-Siemens/meter |
| DTPA | Diethylenetriaminepentaacetic acid |
| *EC* | Electrical conductivity |
| *Eq.* | Equation |
| *EO* | Expert opinion |
| *FAO* | Food and agriculture organization |
| *Fig.* | Figure |
| *HCl* | Hydrochloric Acid |
| *K* | Potassium |
| *MDS* | Minimum data set |
| *meq/100 g* | Mili-equivalent/100 gram |
| *Mg* | Magnesium |
| *mm* | Millimeter |
| *mm/y* | Millimeter/year |
| *Mn* | Manganese |
| *n* | No of variables/ no of sample |
| $NH_4F$ | Ammonium fluoride |
| *nm* | Nanometer |
| *OM* | Organic matter |
| *P* | Phosphorous |
| *PC* | Principal Component |
| *PCA* | Principal component analysis |

| | |
|---|---|
| *pH* | Puissance of Hydrogen |
| *r* | Pearson correlation value |
| *S* | Sulfur |
| $S_{iL}$ | Linear score of the soil indicator |
| $S_{iNL}$ | Non-linear score of the soil indicator |
| *SQ* | Soil Quality |
| *SQI* | Soil quality index |
| *SQIa* | Additive soil quality indexes |
| *SQI-LA* | Soil quality index -linear simple additive |
| *SQI-LWA* | Soil quality index -linear weighted additive |
| *SQI-NLA* | Soil quality index -nonlinear simple additive |
| *SQI-NLWA* | Soil quality index -nonlinear weighted additive |
| *SQIw* | Weighted additive soil quality indexes |
| *TDS* | Total data set |
| *TN* | Total nitrogen |
| *USA* | United States of America |
| *Wi* | Weightage value |
| *X* | Individual soil indicator value |
| *Xmax* | Top soil indicator value |
| *Xmin* | Least soil indicator value |
| *Zn* | Zinc |

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