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Assessment of Soil quality in Rural and Peri-urban Areas of Southern Transect of Bengaluru by using Principal Component Analysis

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Abstract: Environmental degradation is caused by urbanization in developing countries affects soil and water quality year by year in the surrounding areas with this our objective was to assess the soil quality of rural and peri-urban areas of southern transect of Bengaluru. Among the different regions, soils of rural areas had recorded significantly higher available N (323.01 kg ha^{-1}), P (28.98 kg ha^{-1}), K (246.16 kg ha^{-1}), exchangeable Ca [9.67 c mol (p^{+}) kg^{-1} soil], Mg [7.22 c mol (p+) kg^{-1} soil], available S (19.32 kg ha^{-1}), Zn (0.73 ppm), B (0.84 ppm) and dehydrogenase activity (DHA) (14.59 µg TPF g^{-1} soil 24 h^{-1}) compared peri-urban. Soils of peri-urban areas were recorded higher Cd (0.041 ppm), Cr (0.049 ppm), Pb (0.033 ppm) and Ni (0.043 ppm). The principal component analysis was used to evaluate the soil quality index of rural and peri-urban areas. The most influenced indicators were: OC, soil pH, S, P and clay. The soils of rural areas had SQI 0.61 and peri-urban 0.54. Conclusively, soil quality of rural and peri-urban areas falls under the medium category of soil quality *viz*., 0.50-0.75.

Keywords: Soil quality, Principal component analysis, Southern transect of Bengaluru

Soil is the most vital and precious natural resource that sustains life on the earth (Kumar Naik et al 2020). Soils degraded year by year due to the pressure exerted by various sectors of society including urbanization and industrialization. Urbanization is an unavoidable trend in human development (Yan et al 2018) that affects soil physico-chemical properties, shifts in input application and the incorporation of imported materials in soil (Stephen et al 2018). Intensification of agriculture by the addition of excess fertilizers, irrigation with contaminated water from industries and application of urban compost would have an adverse effect on the physico- chemical and biological properties of soils and also their potential to synchronise nutrient supply and demand in cropping systems. The major driving forces of soil degradation are deforestation, soil erosion, waste disposal, change in land use, uncontrolled grazing and unscientific land management practices (Vasu et al 2020). Sustainable management of soil and water resource is extremely critical in urban cities, particularly in developing countries and one more challenge in urban cities is the handling and management of municipal wastes and sewage water (Abdel-shafy 2018). Most urban residents in developing counties lack access to adequate management of solid waste and sewerage systems resulting in significant environmental pollution (Navarro and Vincenzo 2019). The assessment of soil quality is necessary to evaluate the degradation status and trends followed in different land use and management techniques (Spandana et al 2013). Soil quality is defined as the continued capacity of soil to function as a vital living system, as it contains biological elements which are key to the ecosystem, within land-use boundaries. The SQI combines both physical and chemical characteristics of soil into a single parameter that may be used as a general measure of soil quality for agricultural purposes (Andrews et al 2002). Bengaluru is an example of many other Indian megacities where urbanization encroaches on traditional land-use systems and their ecosystem services such as soil and water. In this context, the present study was approached to investigate the effect of urbanization on soil quality and to identify the most appropriate indicators that influence soil quality in rural and peri-urban areas of the southern transect of Bengaluru.

MATERIAL AND METHODS

Bengaluru district is divided into two transects one is towards north *i.e.,* the Northern transect (N-transect) and another one *i.e*., the Southern transect (S-transect). The S-transect is a polygon covering a total area of 300 km^2 and it was further divided into three sub-regions *viz*., rural, peri-urban and urban areas based on the survey stratification index (SSI) by Ellen et al (2015) where distance to the city center (Vidhana Soudha) and percentage of built-up area in that village were considered to calculate SSI. If the value comes 1 and 2 then those villages were considered as urban, likewise 3 and 4 for peri-urban, 5 and 6 for rural. The present study is confined only to rural and peri-urban areas. Twenty villages were selected from each rural and peri-urban areas, four representative soil samples were collected from each village then processed and analysed for various physical, chemical and biological properties of soil by adopting standard analytical procedures.

Mechanical analysis of soil was carried out by international pipet method (Piper 1966). Soil pH (1: 2.5) and EC (dS m^{-1}) were analyzed as outlined by Jackson (1973). The method followed for the estimation of SOC by Walkley and Black (1934). The available N by Subbiah and Asija (1956), available P, available K, exchangeable Ca and Mg as outlined by Jackson (1973). The method followed for the analysis of micronutrients and heavy metals by Lindsay and Norwell (1978). In case of biological properties, dehydrogenase activity was analyzed by Casida et al (1964).

Statistical analysis: All data were checked for normality of distribution, and the one-way analysis of variance was performed using SPSS (version 16) to assess the effects of different sub-regions of southern transect on soil properties. Pearson's correlation coefficients were used to determine the strength of relationships among soil attributes. In the present study PCA was performed for the determination of SQI where four steps were followed (Andrews et al 2002). In the first step correlation analysis was carried out to determine whether the soil indicators were redundant, only the significant variables ($p < 0.05$) were included for PCA. In the second step selection of most critical soil quality indicators, for this step: The PCs with eigenvalues >1 (Brejda et al 2000) were selected and subjected to varimax rotation (Shukla et al 2006). The selection of indicators from the PC was done according to Masto et al 2008. In the third step scoring of indicators (S_i). The scoring was done by the linear scoring functions (LS). Each indicator is categorized as "more is better", "less is better", or "optimum is better" according to Masto et al 2008. In the last step scores of individual attributes were added to get final SQI. Once score is assigned to each indicator, weight is computed for them by using the PCA results. The percentage of variation divided by the total per cent variation provide the weighted factor (W_i) for each selected indicator from the PCA (Singh et al 2013). The SQI is computed by integrating score and weight factor of each indicator. This can be explained by the following equation:

$$SQI = \sum_{i=1}^{n} W_i S_i$$

Where S_i is the score for variable i and W_i is the weighting factor derived from the PCA.

RESULTS AND DISCUSSION

Soil physical attributes: The sand (%) and silt content (%) were statistically non-significant among two regions of southern transect of Bengaluru. The highest mean values of sand (55.03 %), silt (16.31 %) were in the peri-urban soils, whereas clay content (30.47 %) was significantly higher in the rural soils (Table 1). The soil texture varies from sandy loam to clay in both rural and peri-urban soils. Pradeep et al 2018 reported that the clay content was high in the rural soils than that of suburban and urban soils. Soils with higher clay contents tend to have greater organic matter which is crucial in determining the microbial biomass, microbial activity, and composition of the microbial community (Mcculley and Burke 2004).

Soil chemical attributes: The soil pH and organic carbon showed significant difference among the two regions of southern transect of Bengaluru. The soil pH ranges from 5.10 to 8.56 in soils rural areas and 4.23 to 8.50 in soils of peri-urban areas (Table 1). The soils of peri-urban were acidic (6.02) and this might be due to excess application nitrogenous fertilizer has resulted in the contribution of H^+ ions and led to soil acidity. Similar results were reported by Sumita et al (2019). The OC content was recorded at 18.64 per cent higher in soils of rural areas compared to peri-urban. The regular application of manures to crops might have added organic matter to soil thereby rural soils recorded higher OC content. The rural soil possessed higher OC (0.44 %) than sub-urban (0.42 %) and urban (0.36 %) soils (Pradeep et al 2018).

Soil available nutrients: Soils of rural areas recorded significantly higher per cent available N (13.30 %), available P (13.95 %) and available K (23.28 %) over the soils of peri-urban areas. This might be due to the continuous application of the judicious level of fertilizers and increased level of organic inputs had led to the increased availability of these nutrients in soils of rural. Pradeep et al (2018) reported that the soils of rural areas had higher levels of macronutrients (N, P, K) than sub-urban and urban soils. The exchangeable Ca and available sulphur varied with different areas of southern transect of Bengaluru. Exchangeable Ca, Mg and available sulphur recorded higher in soils of rural areas (9.67 c mol (p^+) kg^{-1}, 7.22 c mol (p^+) kg^{-1} and 19.32 kg ha^{-1}) compared to soils of peri-urban areas (Table 2). This might be due to the process of urbanization which affected the availability of Ca, Mg and S in peri-urban. Exchangeable calcium and magnesium contents are highly pH dependent and dynamic in their reaction. Since soil reaction is acidic in peri-urban areas of southern transect, exchangeable Ca and Mg content found less in these areas. Higher availability of sulphur in rural areas is mainly attributed to higher soil organic matter content than peri -urban.

The content of DTPA extractable micronutrients (Fe, Zn and B) were significantly varied among the different areas of southern transect of Bengaluru. The Fe was high in soils of peri-urban areas (13.20 ppm) and this might be due to urbanization causes the acidification of soil which resulted in increase of Fe. Generally, the micronutrient content of the soil depends on other soil parameters such as pH, OM, and soil moisture content (Peraza et al 2017). Zn was recorded significantly higher in rural areas (0.73 ppm) than peri-urban (0.63 ppm). Similarly, B content found significantly higher in rural areas (0.84 ppm) compared to peri-urban. Higher availability of Zn and B in rural compared to peri-urban areas is mainly due to the use of crop residues and bulky organic manures in rural areas which is not possible in the vicinity of peri-urban areas. Cu and Mn availability did not vary among the different areas of southern transect of Bengaluru.

Heavy metals: The contents of heavy metals were significantly influenced by the different areas of southern transect of Bengaluru. Soils of peri-urban areas recorded higher Cd (0.041 ppm), Cr (0.049 ppm), Pb (0.033 ppm) and Ni (0.043 ppm). The higher level of heavy metals in peri-urban soils might be due to industrialization and urbanization activities resulted in the accumulation of heavy metals.

Dehydrogenase: The DHA was found significantly different among areas of southern transect of Bengaluru. The dehydrogenase content recorded higher in soils of the rural areas (14.59 µg TPF g^{-1} soil 24 h^{-1}). The high DHA in soils of rural areas might be due to regular application organic manure and agricultural practices. The low DHA is due to strong anthropogenic influences, such as mechanical disturbance, soil sealing, and contamination. These factors have an impact on soil microbial properties (Dobrovolsky and Nikitin 2012).

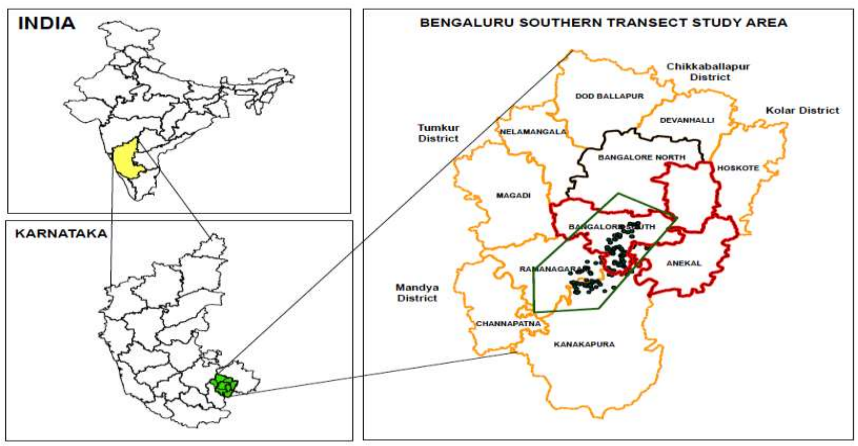

Fig. 1. Base map showing present study area

Table 1. Soil physico-chemical and biological properties of different regions of southern transect of Bengaluru

Treatments	Sand (%)	Silt (%)	Clay (%)	pH	EC (dSm^{-1})	OC (%)	DHS (µg TPF g^{-1} soil 24 h^{-1})
Rural	53.77	15.27	30.47	6.87	0.65	0.70	14.59
Peri -Urban	55.03	16.31	28.19	6.02	0.59	0.59	12.36
CD (p=0.05)	NS	NS	1.64	0.32	NS	0.08	1.96

Table 2. Soil available nutrients of different regions of southern transect of Bengaluru

Treatments	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Ca (c mol (p^+) kg^{-1})	Mg (c mol (p^+) kg^{-1})	S (ppm)
Rural	323.02	28.98	246.16	9.67	7.22	19.32
Peri -urban	285.08	25.43	199.66	8.83	6.84	17.52
CD (p= 0.05)	22.83	2.59	16.74	0.76	NS	1.78

Table 3. Micronutrients and heavy metals in soils of different regions of southern transect of Bengaluru (ppm)

Treatments	Fe	Mn	Cu	Zn	B	Cd	Cr	Pb	Ni
Rural	9.89	7.58	0.60	0.73	0.84	0.031	0.037	0.020	0.030
Peri -urban	13.20	8.24	0.58	0.63	0.63	0.041	0.049	0.033	0.043
CD (p= 0.05)	1.10	1.36	NS	0.10	0.07	0.153	0.153	0.197	0.176

Selection of soil quality indicators: The PCA and per *cent* contribution of each soil attributes towards soil quality indicated by communalities and sowed that among the different soil attributes the SOC (0.911) has contributed high percentage to soil quality followed by N (0.900), dehydrogenase (0.881), soil pH (0.815) and so on (Table 4). The four PC with eigenvalues >1 and explaining at least 5 per cent of the variance in the dataset and which together explains around 67.15 per cent variation in the total data set (Fig. 2). The first PC, second PC, third PC and fourth PC explains around 30.20, 17.76, 10.04 and 9.13 per cent variation, respectively in the data set. Based on rotated factor loadings of soil attributes, selected indicators were: Under PC-1, SOC, available N, and DHA were the three highest weighted variables with the rotated factor loadings of 0.951, 0.949, and 0.937, respectively. Since these three attributes were highly correlated, to avoid redundancy in indicator selection, only SOC was chosen based on its highest correlation sum. Under PC-2, soil pH and Fe were within 10 per cent of the maximum value, so they were considered as highly weighted variables. There was a strong correlation between soil pH and Fe (r = -0.79), therefore the variable with high rotated factor loading was selected *i.e.,* soil pH (0.900). Under PC-3, only sulphur (0.782) was within 10 per cent of the maximum value, so it as considered as a highly weighted variable. Under PC-4, available P (0.681) and clay content (0.649) were within 10 per cent of the maximum value but there was no strong correlation coefficient between these two soil variables (Table 5), so each soil variable as its importance in determination of soil quality that's why both were selected under MDS.

SOC is the most important attribute of soil quality as it improves soil physical, chemical, and biological properties of soil. In the present study, there was a wide gap in the application of organic manure in rural and peri-urban soils. So, the selection of OC as a key indicator of soil quality is advisable (Masto et al 2008, Singh et al 2013, Basak et al

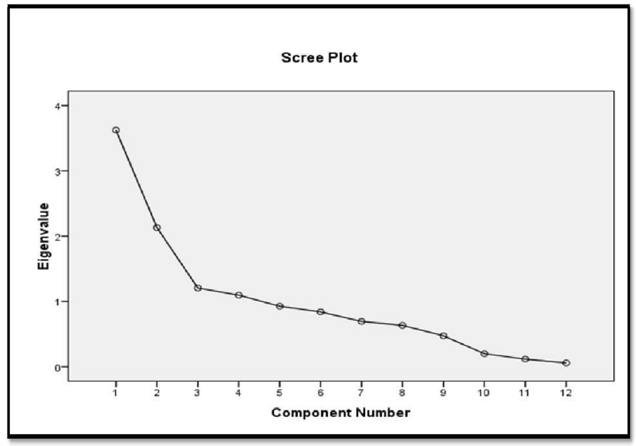

Fig. 2. Relationship between eigenvalue and principal components

Table 4. Principal component analysis and communalities of soil quality parameters to evaluate soil quality index

Soil attributes	PC_1	PC_2	PC_3	PC_4	Communalities
Clay	0.004	0.035	0.465	0.649	0.638
pH	0.051	0.900	-0.034	-0.032	0.815
OC	0.951	0.016	0.065	-0.042	0.911
N	0.949	0.058	0.043	-0.044	0.907
P_2O_5	0.238	0.206	0.146	-0.681	0.585
K_2O	0.659	0.224	-0.115	-0.033	0.499
Ca	-0.011	0.658	0.280	-0.134	0.530
S	0.085	0.045	0.782	0.000	0.621
Fe	-0.074	-0.867	0.059	0.001	0.761
Zn	0.371	0.185	-0.367	0.455	0.513
B	0.240	0.474	-0.331	0.074	0.397
Dehydrogenase	0.937	-0.021	0.030	-0.038	0.881
Maximum value	0.951	0.900	0.782	0.681	
10 per cent of the maximum value	0.0951	0.0900	0.0782	0.0681	
Highly weighted variable	0.856	0.810	0.704	0.613	
Eigenvalues	3.625	2.132	1.206	1.096	
Variance explained (%)	30.20	17.76	10.04	9.13	
Cumulative variance explained (%)	30.20	47.97	58.02	67.15	

Table 5. Correlation coefficients among highly weighted variable

	Clay	pH	OC	N	P_2O_5	Fe	DHA
Clay	1.00						
pH	-0.01	1.00					
OC	0.00	0.09	1.00				
N	0.01	0.13	0.93**	1.00			
P_2O_5	-0.11	0.18*	0.20**	0.23**	1.00		
Fe	0.03	-0.79	-0.10	-0.14	-0.16	1.00	
DHA	-0.03	0.06	0.92**	0.88**	0.18*	-0.07	1.00

* and ** correlations are significant at the 0.05 and 0.01 levels

2016). The measure of soil pH is an important parameter that helps in the identification of the chemical nature of the soil (Shalini et al 2003). P is the second most important macronutrient available in biological systems. S being soil a conditioner helps to reduce the sodium content of soils. The soil texture (clay) was considered another important indicator and it interacts with soil organic matter to form aggregates that protect the organic matter from decomposition. By considering the importance of these indicators in improving soil quality, these indicators such as SOC, soil pH, S, P and clay content were selected as the most appropriable key indicators of soil quality as MDS.

Scoring of indicators: "More is better" approach followed for SOC, available P and available S, while "optimum is better" approach followed for soil pH (6.5-7.5) and clay content (20-35 %). The weight of each PC on the basis of per cent variance to total variance ranges from 0.136 to 0.450 (Table 4). The weighted factor for each PC was: 0.450 (PC-1),0.267 (PC-2), 0.150 (PC-3) and 0.136 (PC-4).

Soil quality index: The per cent contribution of selected soil quality indicators to SQI of rural and peri-urban areas are depicted in Figure 3. Among different indicators, SOC (41.23 %), pH (29.65 %), S (16.49 %), P_2O_5(6.49 %) and clay content (6.49 %) were contributed towards SQI of rural and peri-urban areas of southern transect of Bengaluru. The rural SQI 0.61 and peri-urban 0.54. The high soil quality in rural areas might be due to the high SOC (0.70 %), nearly neutral soil pH (6.8), high S (19.32 kg ha^{-1}), high P (28.98 kg ha^{-1}) and clay content (30.47 %). The low soil quality in peri-urban might be due to the industrialization and urbanization activities resulted in accumulation of heavy metals suppress the availability of other nutrients in soil which leads to deficiency of nutrients in soil. The excess application of nitrogenous fertilisers leads to soil acidity which in turn affects the availability of nutrients. The quality of the soil is altered by imbalance in fertilizer use, acidification, intensive farming activities and most undesirably, soil erosion (Masto et al 2008, Bilgili et al 2017).

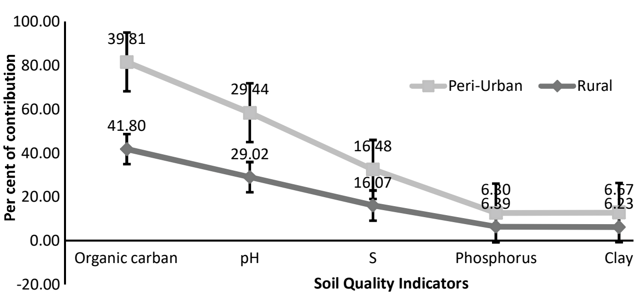

Fig. 3. Per cent contribution of soil key indicators towards soil quality index of rural and peri-urban areas of southern transect of Bengaluru

CONCLUSIONS

Soil organic carbon and soil pH are the most important key indicators of soil quality as they govern the nutrient supplying power of soil and availability of nutrients in soil. Thus, if the soil quality and its productivity is to be improved in the region, appropriate measures need to be taken to improve soil organic carbon, ameliorate soil acidity and improve P and Zn supply. Conservation agriculture, judicious use of chemical fertiliser, soil erosion control measures, organic residues incorporation, *etc*., should be promoted to increase the organic carbon status of the soil. The process of urbanization leads to shift in land use system, farmers instead of growing agriculture crops they started growing commercial crops with injudicious use of fertilizers or dumping of fertilisers to get higher returns, in long run which lead to soil acidity and imbalance of nutrients and further lead to drastic reduction in the productivity of crops and soils become unsuitable for crop production.

REFERENCES

Abdel-Shafy HI 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum* **27**: 1275-1290.

Andrews DL, Karlen and Mitchell JP 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems and Environment* **90**(1): 25-45.

Basak N, Datta A, Biswas S, Mitran T and Mandal B 2016. Organic amendment influences soil quality in farmers' field under rice-based cropping systems in Indo-gangetic plains of India. *Journal of Indian Society of Soil Science* **64**: 138-147.

Bilgili AV, Kucuk C, and Van Es HM 2017. Assessment of the quality of the Harran Plain soils under long-term cultivation. *Environmental Monitoring and Assessment* **189**(9): 460.

Brejda J, Moorman TB, Karlen DL and Dao TH 2000. Identification of regional soil quality factors and indicators I. Central and Southern High Plains. *Soil Science Society of American Journal* **64**(6): 2115-2124.

Casida LE, Klein DA and Santoto T 1964. Soil dehydrogenase activity. *Soil Science* **98**: 371-376.

Dobrovolsky GV and Nikitin ED 2012. Soil ecology. *Moscow University, Moscow*, 412.

Ellen MH, Jose M, Nils N and Thomas M 2015. Construction and use of a simple index of urbanisation in the rural–urban interface of Bangalore, India. *Sustainability* **9**(11): 2146.

Jackson ML 1973. Soil chemical analysis, Prentice-Hall of India Pvt. Ltd, New Delhi, p-498.

Kumar Naik AH, Madhu BM, Sannathimmappa HG, Madhu G, Kiran Kumar N and Hanumantha Naik G 2020. Soil fertility status in Taluks of Chitradurga district under zero budget natural farming of Karnataka. *International Journal of Chemical Studies* **8**(3): 2555-2558.

Lindsay WL and Norwell WA 1978. *Soil Science Society of American Journal* **42**: 421-428.

Masto RE, Chhonkar PK, Singh D and Patra AK 2008. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. *Environmental Monitoring and Assessment* **136**(1-3): 419-435.

Mcculley RL and Burke IC 2004. Microbial community composition across the Great Plains: landscape versus regional variability. *Soil Science Society of American Journal* **68**(1): 106-115.

Navarro F and Vincenzo T 2019. Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health* 1**6**(6): 1060.

Peraza JR, Padilla-Gasca E, López-Corrales R, Medina JR, Bustos-Terrones Y, Amabilis-Sosa LE and Osuna-Enciso T 2017. Robust soil quality index for tropical soils influenced by agricultural activities. *Journal of Agriculture Chemistry and Environment* **6**(04): 199.

Piper CS 1966. *Soil and plant Analysis*, Academic press, New York, p. 367.

Pradeep KR, Anuradha R and Surendra S 2018. Change in soil microbial biomass along a rural-urban gradient in Varanasi (U.P., India). *Geology, Ecology and Landscapes* **2**(1): 15-21.

Shalini K, Devenda HS, Dhindsa S and Singh RV 2003. Studies on causes and possible remedies of water and soil pollution in Sanganer town of Pink city. *Indian Journal of Environmental Science* **7**(1): 47-52.

Shukla MK, Lal R and Ebinger M 2006. Determining soil quality indicators by factor analysis. *Soil and Tillage Research* **87**(2): 194-204.

Singh AK, Bordoloi LJ, Kumar M, Hazarika S and Parmar B 2013. Land use impact on soil quality in eastern Himalayan region of India. *Environmental Monitoring and Assessment* **186**(4): 2013-2024.

Spandana MP, Suresh KR and Prathima B 2013. Developing a soil quality index for Vrishabavathi command area. *International Journal of Engineering Research and Technology* **2**(6): 2278-2281.

Stephen BA, Thorsten Z, Kwabena AN and Daniela S 2018. Urbanization leads to increases in pH, carbonate, and soil organic matter stocks of arable soils of Kumasi, Ghana (West Africa). *Frontiers in Environmental Science* **12**(6): 1-17.

Subbiah BV and Asija CL 1956. A rapid procedure for method for the estimation of available nitrogen in soils. *Current Science* **25**: 259-260.

Sumita C, Hadda MS and Mahal AK 2019. Soil quality assessment through minimum data set under different land uses of submontane Punjab. *Communication in Soil Science and Plant Analysis* **49**(6): 658-674.

Vasu D, Tiwary P, Chandran P and Singh SK 2020. *Soil Quality for Sustainable Agriculture. In Nutrient Dynamics for Sustainable Crop Production*. Springer, Singapore 41-66.

Walkley AJ and Black CA 1934. An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.

Yan W, Yi, Xiao, En-Ming R, Ling J, Yang X and Zhi-YO 2018. An assessment of the impact of urbanization on soil erosion in Inner Mongolia. *International Journal of Environmental Research and Public Health* **15**: 550-555.

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