International Journal of Environment and Climate Change

Volume 14, Issue 9, Page 393-405, 2024; Article no.IJECC.122782
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Effects of Urbanization on Soil Quality in the Rural–Urban Gradient of Bengaluru, India

Karan Sathish [a*], AS Devakumar [b], A Kokila [b], C Vairavan [c], Thrilekha D [d], Chethan Kumar K B [e], Shankar M [e], Narayanaswamy Jeevan [f], Saleemali Kannihalli [g], Moorthy A V [h], V Kousalya [b], Shruthi G S [i] and Shweta Saraswat [a]

[a] *Department of Environmental Sciences, College of Basic Science and Humanities, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand-263 145, India.*
[b] *Department of Forestry and Environment Science, University of Agricultural Sciences, Bangalore, Karnataka-560 065, India.*
[c] *Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharastra-413 722, India.*
[d] *Department of Sericulture, University of Agricultural Sciences, Bangalore, Karnataka-560 065, India.*
[e] *Department of Plant Genetic Resources, ICAR-IARI, New Delhi-110012, India.*
[f] *Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore-641003, India.*
[g] *Department of Entomology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka-560 005, India.*
[h] *Department of Entomology, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand-263 145, India.*
[i] *Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bangalore, Karnataka-560 065, India.*

Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i94424

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/122782

**Corresponding author: E-mail: karansathish555@gmail.com;*

***Cite as:** Sathish, Karan, AS Devakumar, A Kokila, C Vairavan, Thrilekha D, Chethan Kumar K B, Shankar M, Narayanaswamy Jeevan, Saleemali Kannihalli, Moorthy A V, V Kousalya, Shruthi G S, and Shweta Saraswat. 2024. "Effects of Urbanization on Soil Quality in the Rural–Urban Gradient of Bengaluru, India". International Journal of Environment and Climate Change 14 (9):393-405. https://doi.org/10.9734/ijecc/2024/v14i94424.*

Original Research Article

Received: 29/06/2024
Accepted: 31/08/2024
Published: 03/09/2024

ABSTRACT

Understanding the impact of urbanization on soil quality is crucial for sustainable land management practices. This study was conducted in Bengaluru, India, to estimate the soil quality index (SQI) under different rural–urban gradient (RUG) zones. Twenty-four sampling sites were identified along the RUG, and soil samples were collected monthly over five months during the October to February of 2020-2021. The soil quality assessment involved selecting the minimum data set (MDS) via principal component analysis (PCA) and correlation, scoring soil indicators, and combining these scores to create the soil quality index (SQI). PCA was used to identify key soil properties, which included microbial biomass carbon (MBC), SOC, N, manganese (Mn), and urease for different RUG zones derived from the MDS. The rural zones had the highest SQI (0.57), followed by the peri-urban (0.47 and 0.48) and urban (0.45 and 0.47) zones. These findings emphasize the importance of sustainable land management practices to preserve and boost soil quality across diverse regions, particularly in the face of rapid urbanization and industrialization.

Keywords: Soil quality index; rural–urban gradient; urbanization; principal component analysis; minimum data set.

1. INTRODUCTION

The rapid expansion of urban landscapes into surrounding rural areas, a phenomenon known as urbanization, has accelerated globally in recent years [1]. As of 2022, approximately one-third of India's population resided in cities. This reflects an increase in urbanization of more than 4 percent in the past decade, indicating significant migration from rural areas to urban centers for employment and livelihood opportunities. The urbanization of rural areas results in higher resource demands and intensified agriculture, which in turn alters soil microbial dynamics worldwide, particularly in tropical regions [2]. The expansion of urban areas into rural regions has direct and indirect impacts on soil and land use. The most evident effect of urbanization on land usage is urban sprawl [3]. The encroachment of urban areas into rural territories can profoundly alter agricultural dynamics at the rural–urban interface. Recent shifts in land use and land cover patterns driven by human activities have significantly affected urban–rural connections [4]. The rapid expansion of metropolitan systems has had notable repercussions on soil ecosystem services and the land-use systems supporting them. Moreover, the swift increase in population and urbanization influence soil ecosystem services and the land-use patterns that sustain them [5].

Conversely, rapid urban expansion has driven an increased demand for horticulture commodities, prompting a notable shift in agricultural lands toward intensive irrigated multicropping systems. These systems heavily rely on inorganic fertilizers, sporadic urban compost additions, and irrigation. Consequently, this transition has resulted in the accumulation of organic and inorganic residues in the soil, which have been demonstrated to constrain the productivity of agricultural crops. The long-term ramifications of these changes on soil productivity and quality remain poorly understood [5]. Such modifications can exert enduring impacts on soil characteristics [6] underscoring their importance in evaluating soil quality [7]. Hence, soil quality assessments play a vital role in comprehending soil conditions and formulating more effective management strategies [8,9].

The soil quality index (SQI) is a critical tool used to assess and monitor the health and functionality of soils, particularly in agricultural and ecological contexts. Various soil properties are integrated to provide a comprehensive evaluation of soil quality, which is essential for sustainable land management and agricultural practices [10]. According to Karlen et al. [11] it is important to quantify all the aspects of soil properties to assess soil quality because of their significant impact on the ability of soils to accomplish specific functions. Although various assessment techniques are used to determine the quality of SQIs, SQIs developed with a minimum data set (MDS) of characteristics have been shown to reflect soil performance due to changes in management practices, such as alterations in land use patterns [12,9].

However, the impact of urbanization on soil quality has yet to be determined. Hence, to determine the significance of soil quality, this study was undertaken with the following objectives: (1) To evaluate the physicochemical and biological attributes of soil across in the RUG in Bengaluru, India. (2) To establish a MDS of soil parameters for soil quality indexing to evaluate soil quality under distinct RUG zones.

2. MATERIALS AND METHODS

Site description, experimental details, and soil sampling

This study builds upon our previously published work. The detailed site descriptions, and experimental procedures have been comprehensively outlined in in Table 1 [1].

2.1 Soil Analysis

The soil pH was determined using a combination glass electrode immersed in a 1:2.5 soil–water slurry [13]. The electrical conductivity (EC) was measured in a 1:2.5 soil–water suspension using an EC meter [13]. The soil organic carbon (SOC) content was determined using the modified $K_2Cr_2O_7$-H_2SO_4 oxidation method [14]. The alkaline potassium permanganate method was employed to estimate the available nitrogen (N) content in the soil [15]. Available phosphorus (P) was determined using the Bray 1 method [16]. The soil available potassium (K) concentration was measured using a normal neutral 1 N ammonium acetate extractant, the pH was adjusted to 7.0, and a flame photometer was used [13]. Inductively coupled plasma–optical emission spectrometry (ICP–OES) (Spectra Genesis, Germany) was used to estimate the concentrations of iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn).

The bulk density (BD), particle density (PD), and porosity of the soil were determined using the Keen–Raczkowski cup method. The Keen's cup was initially weighed with filter paper, and then an air-dried soil sample was uniformly filled into it by tapping to achieve good compactness and a leveled surface. Subsequently, the cup was submerged in water for 24 hours. After saturation, the cup was removed and oven-dried at 105°C until a constant weight was achieved [17]. The soil moisture content was determined using the gravimetric method by drying the soil to a constant weight at 105°C [18].

Microbial biomass carbon (MBC) [19] and nitrogen (MBN) [20] were measured using the chloroform fumigation extraction technique. Soil dehydrogenase activity was assessed by the reduction of 2,3,5-triphenyl tetrazolium chloride (TTC) [21]. Soil urease activity was analyzed through the incubation method outlined by Kandeler and Gerber [22].

2.2 Assessment of the Soil Quality Index (SQI)

Soil quality assessment entails three primary steps: selecting the MDS through principal component analysis (PCA) and determining the significance difference in correlation ($p<0.05$), scoring soil indicators, and amalgamating scores to formulate the SQI [23,9]. PCA, employing the varimax rotation technique, was also conducted to explore the relationships among these indicators. Principal components (PCs) explaining a minimum of 5% of the variance and possessing eigenvalues >1 was considered for indicator selection. Within each PC, indicators with weighted loading values within 10% of the highest loading were selected for the MDS, irrespective of their sign. Multivariate correlation was used to detect and eliminate redundant data when multiple factors were retained within a single PC. In instances of high correlation ($r >0.60$) among variables, only the variable with the highest correlation was retained for the MDS and considered a "key indicator" used for computing the SQI. Uthappa et al. [9].

A linear scoring method was used to convert the data of each identified critical MDS indicator into scores. The indicators were ranked in ascending order to determine whether a higher or lower value corresponded to better soil function. For indicators where higher values indicated better function, each observation was divided by the highest observed value. Conversely, for indicators where lower values were preferable, the lowest observed value was divided by each observation [5]. This process was performed using the following formula [24]. Linear normalization (S_L) was carried out using the maximum (X_{max}) and minimum (X_{min}) values for each soil indicator (X), as shown in Eqs. 1 and 2.

$$S_L = \frac{X}{X_{max}} \qquad (1)$$

$$S_L = \frac{X_{min}}{X} \qquad (2)$$

Based on the PCA results, the MDS indicators for each observation were weighted following conversion into linear scores. Each PC in the data set represented a certain percentage of variance, and the weighted factor for each MDS indicator was determined by dividing the percentage variance by the cumulative variance for all PCs with eigenvalues >1. Equation 3 was used to calculate the SQI by the weighted scores of the MDS indicators for each observation.

$$SQI = \sum_{i=1}^{n}(Wi \ \times Si) \qquad (3)$$

The subscripted variable's score is denoted as (Si), with its weighting factor from PCA represented as (Wi). The SQI values were standardized to a range of 0 to 1 by dividing all the SQI values by the maximum SQI value. Subsequently, the SQI was calculated as a percentage of the average score for each element in the MDS. According to the classification of Li et al. [25] soils are grouped into five grades based on their SQI values (Table 2).

2.3 Statistical Analysis

A randomized block design (RBD) analysis and Tukey HSD procedure were applied to compare the means of various soil parameters across different RUG zones; these analyses were conducted using Origin (Pro) software, 2024, produced by Origin Lab Corporation, Northampton, MA, USA. Pearson's correlation coefficient was used to assess the relationships among the soil quality properties. PCA was carried out using SPSS 20.0 software, and these results were subsequently used to create the MDS for SQI development. Radar plots depicting the % contribution of each indicator to the SQI were generated using Origin (Pro) software, 2024, by Origin Lab Corporation, Northampton, MA, USA.

Table 1. Details of the experimental sites

Transects	Areas	Code	Latitude (N)	Longitude (E)
North Bengaluru	Urban	NU1	13°08'03.0"	77°34'48.2"
		NU2	13°06'41.64"	77°36'05.94"
		NU3	13°04'56.85"	77°36'32.33"
		NU4	13°07'29.5"	77°33'27.86"
	Peri urban	NP1	13°08'00.77"	77°34'40.77"
		NP2	13°09'39.16"	77°36'31.24"
		NP3	13°09'52.7"	77°36'53.48"
		NP4	13°12'43.55"	77°35'14.95"
	Rural	NR1	13°22'26.76"	77°34'50.12"
		NR2	13°20'10.12"	77°35'39.24"
		NR3	13°15'12.22"	77°35'53.91"
		NR4	13°14'28.53"	77°36'39.09"
South Bengaluru	Urban	SU1	12°50'50.7"	77°35'50.51"
		SU2	12°50'50.7"	77°35'50.51"
		SU3	12°51'25.23"	77°35'50.23"
		SU4	12°50'50.3"	77°30'42.18"
	Peri urban	SP1	12°48'27.41"	77°30'44.91"
		SP2	12°48'46.67"	77°31'28.14"
		SP3	12°48'46.67"	77°31'28.14"
		SP4	12°48'27.38"	77°32'33.21"
	Rural	SR1	12°43'41.59"	77°29'29.03"
		SR2	12°43'26.26"	77°28'53.7"
		SR3	12°44'40.52"	77°26'27.12"
		SR4	12°45'20.6"	77°26'17.68"

Note: NU- North urban, NP- North peri-urban, NR- North rural,
SU- South urban, SP- South peri-urban, SR- South rural.

Table 2. Soil quality grade classification

Indicator	Soil Quality Grade				
	Very High	**High**	**Moderate**	**Low**	**Very Low**
	Grade-I	Grade-II	Grade-III	Grade-IV	Grade-V
SQI	>0.60	0.55–0.60	0.45–0.54	0.38–0.44	<0.38

3. RESULTS

3.1 Effects of Different RUG Zones on Soil Properties

The one-way ANOVA results for 18 soil physicochemical and biological properties across different RUG zones are presented in Table 3.

3.2 Soil Physical Properties

The soil BD, PD, and porosity significantly varied across the RUG zones. BD was highest in urban zones (1.38 and 1.37 Mgm-3), followed by peri-urban zones, and lowest in rural zones (1.33 Mgm-3). PD exhibited a similar trend as BD across the transition zones. The soil porosity reached a maximum in the rural zones (39.72 and 39.71%), followed by that in the peri-urban zones, and reached a minimum in the urban zones (38.02 and 38.87%). The soil moisture content was greater in the urban zones (9.36 and 8.57%) than in the peri-urban and rural zones (8.05 and 7.96%).

3.3 Soil Chemical Properties

The soil pH ranged from neutral to acidic across urban, peri-urban, and rural zones. The pH levels in the urban zones (7.13 and 7.18) were comparable to those in the peri-urban zones (7.08 and 7.16) but significantly differed from those in the rural zones (6.26 and 6.09). The soil EC varied significantly among the RUG zones but remained within the normal range (<0.2 dSm^{-1}). The highest EC was noted in urban zones (0.16 and 0.15 dSm^{-1}), while the lowest EC was reported in rural zones (0.10 and 0.11 dSm^{-1}). The SOC content was highest in rural zones (0.38 and 0.39%), followed by that in peri-urban zones, and was significantly lower in urban zones (0.34%). The available N in the RUG zone was low (<280 kg/ha) and differed significantly. The soil N content increased in the rural zones (165 and 164.54 kg/ha), followed by the peri-urban zone and the significantly low N content in the urban zones (129.10 and 129.97 kg/ha). In urban zones (30.65 and 29.73 kg/ha), P availability was greater than that in peri-urban and rural zones (24.09 and 25.78 kg/ha, respectively). Available K was significantly high in peri-urban zones (184.95 and 183.55 kg/ha) and low in rural zones (147.68 and 147.70 kg/ha).

Significant differences ($p<0.05$) were detected in the micronutrients Zn and Mn across the RUG zones, whereas Fe and Cu exhibited nonsignificant differences ($p>0.05$). The highest available Zn concentration was recorded in rural zones (0.32 ppm), followed by urban (0.30 and 0.31 ppm) and peri-urban zones (0.29 ppm). The Fe concentrations were highest in urban zones (4.11 and 4.02 ppm), followed by peri-urban zones, and lowest in rural zones (3.22 and 3.15 ppm). Compared with urban and peri-urban zones, rural zones exhibited significantly greater Mn concentrations (2.23 and 2.19 ppm) (1.40 ppm). Available Cu was highest in rural zones (0.23 ppm), followed by peri-urban (0.20 and 0.21 ppm) and urban zones (0.18 and 0.19 ppm).

3.4 Soil Biological Properties

In the rural zones (129.35 and 127.67 μg g^{-1}), the soil MBC was significantly greater than that in the peri-urban and urban zones (107.84 and 107.99 μg g^{-1}). The soil MBN status was significantly greater in the rural zones (15.15 and 14.84 μg g^{-1}) than in the peri-urban and urban zones (12.58 and 12.54 μg g^{-1}). Soil dehydrogenase activity was found to be highest in rural zones (99.03 and 95.28 μg TPF g^{-1} soil 24 h^{-1}), followed by peri-urban and urban zones (77.54 and 74.62 μg TPF g^{-1} soil 24 h^{-1}). In rural zones, a significantly greater level of soil urease activity (19.06 and 18.97 μg NH4- N g^{-1}soil h^{-1}) was observed compared to that in peri-urban areas, followed by that in urban areas (13.31 and 13.72 μg NH4- N g^{-1}soil h^{-1}).

3.5 PCA and MDS for Soil Properties in Various RUG Zones

Among the 18 soil properties that exhibited significant variation among the various RUG zones, 13 were chosen for PCA. According to the PCA of the soil indicators in the various RUG zones, only two PCs had eigenvalues > 1 and explained 97% of the cumulative variance (Table

4). PC1 and PC2 are generated depending on the level of significance. PC1, with an eigenvalue of 10.21, explained approximately 78.53% of the variance. The variables included MBC, MBN and N, with the highest positive factor loading of 0.99, followed by urease (0.97) and SOC (0.93). PC2 explained 18.46% of the variation, with an eigenvalue of 2.40. In this PC, soil Mn had the highest factor loading (0.87), followed by Zn (0.81).

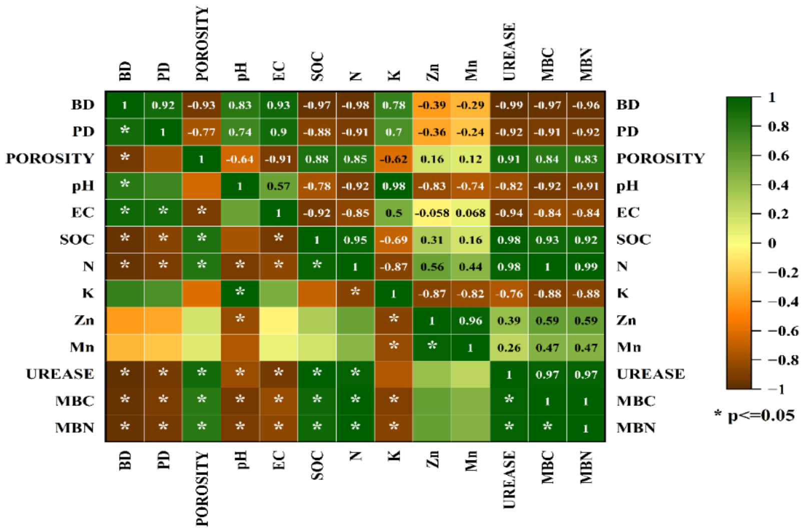
For different RUG zones, two PCs with eigenvalues > 1 were selected for MDS. In the first PC, the MBC, MBN, SOC, N, and urease indices were within 10% of the highest factor loading (Table 4). All five soil properties exhibited significant positive correlations ($r > 0.60$ and $p \leq 0.05$) (Fig. 1). Since MBC and MBN exhibited similar correlations and significance, MBC was ultimately selected for the MDS. The other three parameters represent different aspects of soil, such as soil chemical and biological properties; thus, all three parameters were considered. Soil Mn and Zn were highly weighted variables in PC2. Since Mn and Zn were significantly correlated ($r = 0.96$ and $p \leq 0.05$), only Mn was selected to represent PC2 for the MDS. MBC, SOC, N, Mn, and urease are the soil quality indicators for the different RUG zones derived from the MDS.

3.6 Soil Quality Index (SQI)

Fig. 2 displays the values of the soil quality indices for the different RUG zones. Radar plot diagrams depict the contributions of soil indicators to the SQI under different land-use systems across various rural–urban transition zones (Fig. 3).

3.7 SQI under Diverse RUG Zones

The SQI, calculated using the PCA linear approach across different RUG zones, was highest in rural zones (NR and SR-0.57), followed by peri-urban zones (NP-0.47 and SP-0.48), with the lowest SQI recorded in urban zones (NU-0.45 and SU-0.47). Overall, the southern zones exhibited higher SQIs than did the northern zones, likely due to the comparatively lesser impact of urbanization in the southern zones, with rural zones reporting the highest SQIs among all zones. The rural zone soils displayed a high SQI (0.57), which fell within the range of 0.55–0.60 (Grade II; Table 2). The overall relevance and ranking of the indicators in terms of percent contribution to the SQI were Mn > urease > N > MBC > SOC. The soils in the peri-urban zones (NP-0.47 and SP-0.48) exhibited moderate SQI values, ranging from 0.45–0.54 (Grade III). For the overall SQI, soil urease activity contributed significantly, followed by SOC, while Mn availability made a relatively lesser contribution to peri-urban soils. Finally, in the urban zones (NU-0.45 and SU-0.47), the SQI values ranged from 0.45–0.54 (Grade III), indicating moderate soil quality. In urban zones, the ranking of indicators in terms of percent contribution to the SQI was Mn (23.79 & 23.21%) > SOC (20.46 & 20.34%) > MBC (20.07 & 19.99%) > N (19% & 19.07%) > urease (16.68 & 17.38%).



	BD	PD	POROSITY	pH	EC	SOC	N	K	Zn	Mn	UREASE	MBC	MBN
BD	1	0.92	-0.93	0.83	0.93	-0.97	-0.98	0.78	-0.39	-0.29	-0.99	-0.97	-0.96
PD	*	1	-0.77	0.74	0.9	-0.88	-0.91	0.7	-0.36	-0.24	-0.92	-0.91	-0.92
POROSITY	*		1	-0.64	-0.91	0.88	0.85	-0.62	0.16	0.12	0.91	0.84	0.83
pH	*			1	0.57	-0.78	-0.92	0.98	-0.83	-0.74	-0.82	-0.92	-0.91
EC	*	*	*		1	-0.92	-0.85	0.5	-0.058	0.068	-0.94	-0.84	-0.84
SOC	*	*	*		*	1	0.95	-0.69	0.31	0.16	0.98	0.93	0.92
N	*	*	*	*	*	*	1	-0.87	0.56	0.44	0.98	1	0.99
K				*			*	1	-0.87	-0.82	-0.76	-0.88	-0.88
Zn				*				*	1	0.96	0.39	0.59	0.59
Mn								*	*	1	0.26	0.47	0.47
UREASE	*	*	*	*	*	*	*				1	0.97	0.97
MBC	*	*	*	*	*	*	*	*			*	1	1
MBN	*	*	*	*	*	*	*	*			*	*	1

Fig. 1. Correlation matrix of significant soil indicators under diverse RUG zones

Table 3. Soil physical, chemical and biological properties among the various RUG zones

	NU	**NP**	**NR**	**SU**	**SP**	**SR**
pH	7.13±0.07^{a}	7.16±0.09^{a}	6.26±0.16^{b}	7.18±0.05^{a}	7.08±0.06^{a}	6.09±0.13^{b}
EC (dSm^{-1})	0.16±0.01^{a}	0.11^{bc}	0.11±0.01^{c}	0.15±0.01^{ab}	0.11±0.01^{c}	0.11±0.01^{c}
SOC (%)	0.34±0.01^{b}	0.37±0.01^{ab}	0.38±0.01^{a}	0.34±0.01^{b}	0.37±0.01^{ab}	0.39^{a}
Moisture content (%)	9.36±0.47^{a}	8.61±0.67^{a}	8.05±0.55^{a}	8.57±0.44^{a}	8.55±0.46^{a}	7.96±0.28^{a}
Bulk density (Mgm^{-3})	1.38±0.01^{a}	1.35±0.01^{bc}	1.33^{c}	1.37±0.01^{ab}	1.35^{bc}	1.33^{c}
Particle density (Mgm^{-3})	2.23 ^{a}	2.22 ^{ab}	2.20±0.01^{b}	2.23 ^{a}	2.21±0.01^{ab}	2.21±0.01^{ab}
Porosity (%)	38.02±0.27^{b}	39.53±0.32^{a}	39.72±0.11^{a}	38.87±0.24^{ab}	39.13±0.22^{a}	39.71±0.22^{a}
N (kg/ha)	129.1±5.60^{b}	143.66±4^{ab}	164.54±7.92^{a}	129.97±4.36^{b}	144.61±4.25^{ab}	165.00±7.46^{a}
P (kg/ha)	30.65±1.99^{a}	27.81±2.01^{a}	25.78±1.28^{a}	29.73±3.15^{a}	27.97±1.20^{a}	24.09±0.86^{a}
K (kg/ha)	182.34±3.28^{a}	184.95±4.13^{a}	147.68±3.98^{b}	179.02±3.42^{a}	183.55±3.52^{a}	147.7±5.48^{b}
Zn (ppm)	0.31^{b}	0.29±0.01^{c}	0.32±0.01^{a}	0.3±0.01^{bc}	0.29±0.01^{c}	0.32±0.01^{a}
Fe (ppm)	4.11±0.57^{a}	3.9±0.48^{a}	3.22±0.44^{a}	4.02±0.37^{a}	3.84±0.54^{a}	3.15±0.37^{a}
Mn (ppm)	1.93±0.37^{b}	1.4±0.34^{c}	2.23±0.26^{a}	1.91±0.30^{b}	1.4±0.29^{c}	2.19±0.35^{a}
Cu (ppm)	0.18±0.01^{a}	0.20±0.02^{a}	0.23±0.02^{a}	0.19±0.04^{a}	0.21±0.02^{a}	0.23±0.01^{a}
Dehydrogenase (µg TPF g^{-1} soil 24 h^{-1})	77.54±5.70^{a}	83.21±4.56^{a}	99.03±4.19^{a}	74.62±5.33^{a}	86.24±7.06^{a}	95.28±5.92^{a}
Urease (µg NH_4- N g^{-1} soil h^{-1})	13.31±1.24^{b}	16.83±1.13^{ab}	19.06±1.24^{a}	13.72±0.92^{ab}	16.65±1.56^{ab}	18.97±0.96^{a}
MBC (µg g^{-1})	107.84±0.58^{c}	115.87±1.06^{b}	129.35±0.85^{a}	107.99±0.80^{c}	115.83±1.82^{b}	127.67±0.67^{a}
MBN (µg g^{-1})	12.58±0.07^{c}	13.5±0.13^{b}	15.15±0.13^{a}	12.54±0.09^{c}	13.52±0.21^{b}	14.84±0.05^{a}

Note: NU- North urban, NP- North peri-urban, NR- North rural, SU- South urban, SP- South peri-urban, SR- South rural, EC- Electrical Conductivity, SOC- Soil Organic Carbon, N- Nitrogen, P- Phosphorus, K- Potassium, Zn- Zinc, Fe- Iron, Mn-, Manganese, Cu- Copper, MBC- Microbial Biomass Carbon and MBN- Microbial Biomass Nitrogen.

^{z} *in a row value followed by similar letter specifies no significance.*

Table 4. PCA results for soil quality indicators of various RUG zones

Factors	Rural–Urban Gradient Zones	
	PC1	**PC2**
Bulk density	-0.98	0.2
Particle density	-0.91	0.21
Porosity	0.86	-0.37
pH	-0.92	-0.37
EC	-0.84	0.53
SOC	0.93	-0.28
N	0.99	-0.02
K	-0.88	-0.46
Zn	0.57	0.81
Mn	0.47	0.87
Urease	0.97	-0.22
MBC	0.99	0.01
MBN	0.99	0.01
highest	0.99	0.87
10% of highest	0.90	0.78
Eigenvalue	10.21	2.40
Variance (%)	78.53	18.46
Cumulative variance (%)	78.53	97.00

Note- PC- Principal Component, EC- Electrical Conductivity, SOC- Soil Organic Carbon, N- Nitrogen, P- Phosphorus, K- Potassium, Zn- Zinc, Fe- Iron, Mn-, Manganese, MBC- Microbial Biomass Carbon and MBN- Microbial Biomass Nitrogen.

Principal component analysis (PCA) and selection of minimum data set (MDS)

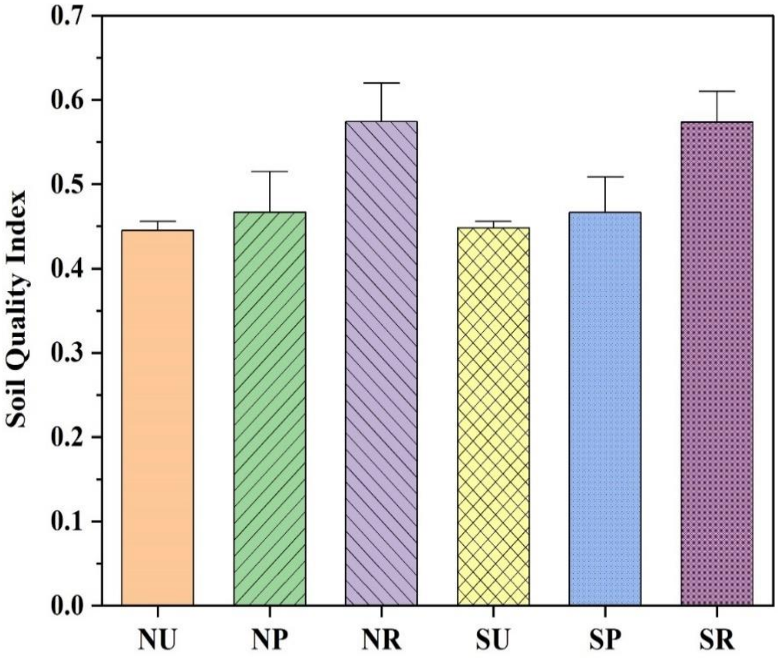


Fig. 2. Soil quality indices in various RUG zones

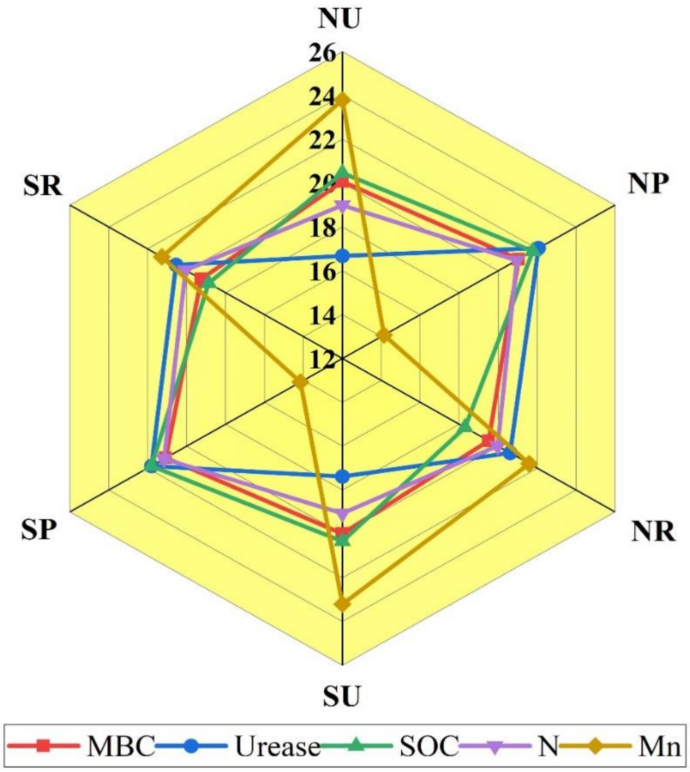


Fig. 3. Radar plot of the percentage contributions of selected soil indicators of the MDS to soil quality indices under different RUG zones

4. DISCUSSION

4.1 Effects of different RUG Zones on Soil Properties

The high BD in urban soils is likely due to the greater soil compaction typically found in urban soils than in peri-urban and rural soils [26]. The use of mechanized irrigation practices in urban and peri-urban areas can aid in maintaining better soil moisture levels. In rural areas, soils tend to be slightly acidic, but with increased urbanization, soils become alkaline [27] likely due to the release of carbonates from calcareous construction waste, which is more prevalent in urban zones. Similar trends across rural–urban zones were reported by Sakandari [28]. Urban soils are likely to accumulate higher concentrations of salts due to increased chemical application in the cultivation process and the use of deeper underground water for irrigation [29]. The high SOC in rural zones may be attributed to the higher clay content in rural soils than in peri-urban or urban soils [30] which aids in better aggregation of soil organic matter [29]. The low N status in urban zones is attributed to the high soil pH, which affects N mineralization and nitrification processes in urban soils [31] causing the urban soil N content to decline in comparison to that in rural and peri-urban zones [32]. Reduced organic inputs and intensive cultivation of crops in urban and transition zones require high P inputs. Even though K is moderately available in the RUG zones, cultivation of crops will exhaust K in the soil. The quantity of K utilized by crops cultivated in urban and transitional zones is much greater than that utilized by crops cultivated in rural areas [33]. Increased OC and its rapid mineralization could enhance soil microbial populations in rural zones, as suggested by Groffman et al. [34]. Conversely, urban zones exhibit a greater proportion of passive carbon pools due to a faster carbon turnover rate, resulting in lower soil MBC. In urban environments, factors such as trampling and elevated levels of heavy metals can lead to a decline in soil organisms, thereby reducing nitrification and mineralization processes and ultimately affecting MBN levels in urban soil [35]. Anthropogenic activities and the presence of organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) and inorganic pollutants such as lead (Pb) are known to decrease soil microbial populations, as reflected in dehydrogenase activity [36].

4.2 Assessment of the SQI through PCA of Diverse RUG Zones

Soil urease activity is a valuable index of soil quality due to its role in regulating the N supply to plants after urea fertilization [37]. It effectively discriminates between various soil management practices and can provide information integrating environmental factors and N cycling, making it a useful tool for assessing soil fertility [38]. The MBC is a sensitive indicator of changes in pollutant toxicity, climate, and crop rotation due to its rapid turnover. Soil quality integrates soil physico-chemical properties and responds to anthropogenic activities, making it a suitable biological indicator of soil quality [39]. Mn is an essential micronutrient for plant growth and development, as well as for soil quality. It influences microbial activity, soil physicochemical properties, and nutrient availability [40].

Similarly, Tejashvini et al. [5] noted that a reduced salt content and higher organic matter content favored high SQIs in rural soils. The elevated SQI in rural areas might be attributed to factors such as high SOC content, nearly neutral soil pH, and robust soil biological properties such as MBC, MBC, dehydrogenase, and urease [41]. Mn influences various microbial activities, soil physicochemical properties, and nutrient availability [40]. Urbanization activities, industrialization, intensive farming activities, acidification, imbalanced fertilizer use, and soil erosion may be attributed to moderate soil quality in urban and peri-urban zones [42,43].

5. CONCLUSION

The study revealed that soil quality is significantly influenced by RUG zones. Geographically, the rural zones (NR and SR) exhibited the highest SQIs, benefiting from high SOC and nearly neutral soil pH. The peri-urban zones (NP and SP) had moderate SQIs, while the urban zones (NU and SU) had the lowest SQIs, with industrialization and heavy metal accumulation affecting soil quality. MBC, SOC, N, Mn, and urease are the soil quality parameters for the different RUG zones derived from the MDS. These findings highlight the need for efficient land use and management practices to improve soil quality across different regions and cropping systems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENTS

With a deep sense of pride and gratitude, I am thankful to the University of Agricultural Sciences, Bangalore, India, for providing permission and facilities to conduct this study and support from the Indian Council of Agricultural Research, New Delhi, India. I am also grateful to Mr. Shabarish for help in collecting the soil samples, which was instrumental in the completion of my research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sathish K, AS D. Composition of soil mesofauna in changing cropping systems due to urbanization in Bengaluru, India. Environ Monit Assess. 2024;196:335. Available:https://doi.org/10.1007/s10661-024-12452-1
2. Steinhübel L, von Cramon-Taubadel S. Somewhere in between towns, markets and jobs–agricultural intensifcation in the rural–urban interface. J Dev Stud. 2021;57:669–694. DOI:10.1080/00220388.2020.1806244
3. Bhagawat RL, Zhang F. Dongjie, K. Ripu Z, Yongguang. Monitoring urban growth and the Nepal earthquake 2015 for sustainability of Kathmandu Valley, Nepal. Land. 2017;6(2):42. DOI:10.3390/land6020042.
4. Seto KCS, Parnell T, Elmqvist. A global outlook on urbanization. In Urbanization, biodiversity and ecosystem services: Challenges and opportunities., ed. T, Elmqvist M, Fragkias J, Goodness B, Güneralp PJ, Marcotullio RI, McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, and C. Wilkinson, et al. 1–12. A Global Assessment; 2013. DOI:10.1007/978-94-007-.

5. Ashwathappa Tejashvini, Chickadibburahalli Thimmappa Subbarayappa, Venkataramanappa Ramamurthy & Ramasamy Srinivasan Urbanization Impact on Soil Quality Assessment in Semi-Arid Region: Bangalore Metropolitan City, India, Communications in Soil Science and Plant Analysis. 2023;54:22:3122-3135. DOI: 10.1080/00103624.2023.2256792
6. Li H, Liao X, Zhu H, Wei X, Shao M. Soil physical and hydraulic properties under different land uses in the black soil region of Northeast China. Can. J. Soil Sci. 2019;99:406–419. DOI: 10.1139/cjss-2019-0039
7. Liu D, Huang Y, An S, Sun H, Bhople P, Chen Z. Soil physicochemical and microbial characteristics of contrasting land-use types along soil depth gradients. Catena. 2018;162:345–353. DOI: 10.1016/j.catena.2017.10.028
8. Qi Y, Darilek JL, Huang B, Zhao Y, Sun W, Gu Z. Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. Geoderma. 2009;149:325–334. DOI: 10.1016/j.geoderma.2008.12.015
9. Uthappa AR, Devakumar AS, Das B, Mahajan GR, Chavan SB, Jinger D, Jha PK, Kumar P, Kokila A, Krishnamurthy R, Mounesh NV, Dhanush C, Ali I, Eldin SM, Al-Ashkar I, Elshikh MS and Fahad S. Comparative analysis of soil quality indexing techniques for various tree based land use systems in semiarid India. Front. For. Glob. Change. 2024;6:1322660. DOI: 10.3389/ffgc.2023.1322660
10. Bel-Lahbib S, Namr KI, Rerhou B, Mosseddaq F, Bourhrami BE, Moughli L. Assessment of soil quality by modeling soil quality index and mapping soil parameters using IDW interpolation in Moroccan semiarid. Modeling Earth Systems and Environment. 2023;9(4):4135–4153. Available:https://doi.org/10.1007/s40808-023-01718-1.
11. Karlen DL, Parkin TB, Eash NS. Use of soil quality indicators to evaluate conservation reserve program sites in Iowa in Methods for assessing soil quality. eds. J. Doran and A. J. Jones (Madison, WI: SSSA). 1997;345–355. DOI:10.2136/sssaspecpub49.c21.
12. Raiesi F. A minimum data set and soil quality index to quantify the effect of land use conversion on soil quality and degradation in native rangelands of upland arid and semiarid regions. Ecol. Indic. 2017;75:307–320. DOI: 10.1016/j.ecolind.2016.12.049
13. Jackson ML. Soil chemical analysis: Advanced course. UW-Madison Libraries Parallel Press; 2005.
14. Walkley A, In addition, Black IA. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1938;37:29-37. DOI:10.1097/00010694-193401000-00003.
15. Subbiah BV, In addition, Asija GL. A rapid procedure for estimation of available N in soil. Curr. Sci. 1956;25:259-260.
16. Bray RH, Kurtz LT. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 1945;59:39–45. DOI:10.1097/00010694-194501000-00006
17. Piper CS. Soil and Plant Analysis. Hans Publishers, Bombay; 1966.
18. Black CA. Methods of Soil Analysis: Part I Physical and mineralogical properties. American Soc. Agron., Madison, Wisconsin, USA; 1965.
19. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 1987;19:703–707.
20. Brookes PC, Kragt JF, Powlson DS, Jenkinson DS. Chloroform fumigation and the release of soil nitrogen: the efects of fumigation time and temperature. Soil Biol Biochem. 1985;17:831–835. DOI:10.1016/0038-0717(85)90143-9
21. Casida LE, Klein DA. In addition, Santoto T. Soil dehydrogenase activity. Soil Sci. 1964;98:371-376. DOI:10.1097/00010694-196412000-00004
22. Kandeler E, Gerber H. Short-term assay of soil urease activity using colorimetric determination of ammonium. Biol. Fertil. Soils. 1988;6:68–72. DOI:10.1007/BF00257924.
23. Andrews SS, Karlen DL, Mitchell JP. A comparison of soil quality indexing methods for vegetable production systems in northern California. Agric. Ecosyst. Environ. 2002;90:25–45. DOI: 10.1016/S0167-8809(01)00174-8
24. Vasu DSK, Singh SK, Ray VP, Duraisami PP, Tiwary AM, Nimkar SG, Nimkar SG, Anantwar. The soil quality index (SQI) is a tool for evaluating crop productivity in the

semiarid Deccan Plateau, India. Geoderma. 2016;282:70–79. DOI:10.1016/j.geoderma.2016.07.010.

25. Li XH, Li L, Yang Y, Ren. Assessment of soil quality of croplands in the corn belt of Northwest China. Sustainability. 2018; 10 (1):248, DOI:10.3390/su10010248.
26. Pouyat RV, Szlavecz K, Yesilonis ID, Groffman PM, In addition, Schwarz K. Chemical, physical, and biological characteristics of urban soils. J. Agric. Urban Entomol. 2010;55:119–152.
27. Acosta-Martinez V. In addition, Tabatabai MA. Enzyme activities in a limed agricultural soil. Biol. Fertil. Soils. 2000; 31:85–91. DOI:10.1007/s003740050628.
28. Sakandari, Mohammad Nazim. Influence of Urbanization on Agrobiodiversity: A Study in Bangalore Rural Urban Conglomerate. Ph.D. Thesis, Uni. Agric. Sci., Bangalore. 2014;180.
29. Jim CY. Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosyst. 1998; 2:171–181. DOI:10.1023/A:1009585700191.
30. Hassink J. In addition, Whitmore AP. A model of the physical protection of organic matter in soils. Soil Sci. Soc. Am. J. 1997; 61:131–139. DOI:10.2136/sssaj1997.03615995006100010020x.
31. Baxter JW, Pickett STA, Dighton J. In addition, Carreiro MM. Nitrogen and phosphorus availability in oak forest stands exposed to contrasting anthropogenic impacts. Soil Biol. Biochem. 2002;34:623–633. DOI:10.1016/S0038-0717(01)00224-3.
32. Zhang K, Xu XN. In addition, Wang Q. Characteristics of N mineralization in urban soils of Hefei, East China. Pedosphere. 2010;20:236–244. DOI:10.1016/S1002-0160(10)60011-2.
33. Khan MA, Khan S, Khan A, Alam M. Soil contamination with cadmium, consequences and remediation using organic amendments. Sci Total Environ. 2017;601–602(1):1591-1605. DOI:10.1016/j.scitotenv.2017.06.030.
34. Groffman PM, Pouyat RV, Mcdonnell MJ, Pickett STA, Zipperer WC. Carbon pools and trace gas fluxed in urban forest soils. Soil Biol. Biochem; 1995.
35. White CS. In addition, Mcdonnell MJ. Nitrogen cycling processes and soil characteristics in an urban versus rural forest. Biogeochemistry. 1988;5:243–262: 147–158. DOI:10.1007/BF02180230.
36. Naylo A, Pereira SIA, Benidire L, El-Khalil H, Castro PM, Ouvrard S, Schwartz C. In addition, Boularbah A. Trace and major element contents, microbial communities, and enzymatic activities of urban soils of Marrakech city along an anthropization gradient. j. soil sediment. 2019;19(5): 2153-2165. DOI:10.1007/s11368-018-2221-y.
37. Piotrowska-Dlugosz A, Charzynski P. The impact of the soil sealing degree on microbial biomass, enzymatic activity, and physicochemical properties in the ekranic technosols of toruń (poland). Journal of Soils and Sediments. 2015;15: 47-59. DOI:10.1007/s11368-014-0963-8.
38. Adetunji AT, Lewu FB, Mulidzi R, Ncube B. (The biological activities of β-glucosidase, phosphatase and urease as soil quality indicators: a review. Journal of soil science and plant nutrition. 2017;17(3): 794-807, DOI:10.4067/S0718-95162017000300018.
39. Rice CW, Moorman TB, Beare M. Role of microbial biomass carbon and nitrogen in soil quality. Methods for assessing soil quality. 1997;49:203-215. DOI:10.2136/sssaspecpub49.c12.
40. Dewangan SK, Shrivastava SK, Kehri D, Minj A, Yadav V. This Review discusses the study of the impact of micronutrients on soil physicochemical properties and environmental sustainability. EPRA International Journal of Agriculture and Rural Economic Research (ARER). 2023; 11(6):6-9.
41. Kuntoji A, Subbarayappa CT. Assessment of Soil quality in Rural and Peri-urban Areas of Southern Transect of Bengaluru by using Principal Component Analysis. Indian Journal of Ecology. 2022;49 (6): 2076-2081.
42. Bilgili F, Koçak E, Bulut Ü, Kuloğlu A. The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. Energy. 2017;133:242-256. DOI:10.1016/j.energy.2017.05.121.

43. Wu J, Joergensen RG, Pommerening B, Chaussod R, Brookes PC. Measurement of microbial biomass C by fumigation extraction – an automated procedure. Soil Biol Biochem. 1990; 22:1167–1169.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/122782