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Studies on soil physico-chemical and biological properties and evaluation of nutrient index for soil fertility along rural-urban interface of southern transect of Bengaluru

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Abstract

The expansion of urbanization and industrialization has an adverse effect on the physical, chemical, and biological properties of soils with this our objective was to study the soil quality and evaluation of nutrient index for soil properties along rural-urban interface of southern transect of Bengaluru. The results of the analysis of variance with unequal number of observations showed that rural soils were recorded significantly higher mean values of SOC (0.70%), N (323.01 kg ha^{-1}), P_2O_5 (28.98 kg ha^{-1}), K_2O (246.16 kg ha^{-1}), S (19.32 kg ha^{-1}), Zn (0.73 ppm), B (0.84 ppm) and DHA activity (14.59 µg TPF g^{-1} soil 24 h^{-1}) whereas, urban soils were characterized by higher mean values of soil pH (7.93), EC (1.33 dS m^{-1}), exchangeable Ca (12.03 c mol (p^{+}) kg^{-1}) and Mg (7.70 c mol (p^{+}) kg^{-1}) and heavy metals such as Cd (0.088 ppm), Cr (0.086 ppm), Pb (0.065 ppm) and Ni (0.056 ppm).The results of nutrient index revealed that available nitrogen (1.61 and 1.42) and zinc (1.65 and 1.57) were belongs to low category of nutrient index in rural and peri-urban, respectively. Urban soils were characterized by low nutrient index category *w.r.t.* SOC (1.44), available N (1.25), P_2O_5 (1.52), K_2O (1.50), S (1.56), Fe (1.50), Mn (1.40), Zn (1.25) and B (1.42). Conclusively, rural soils were recorded higher available nutrients and microbial activity, followed by peri-urban and lowest were recorded in urban soils, this clearly suggests that the process of urbanization has adversely affected the soil quality along rural-urban interface.

Keywords: Soil Physcio-chemical, biological, rural-urban interface, nutrient index, soil fertility map, southern transect of Bengaluru

Introduction

Environmental degradation is often caused by urbanization in developing countries and harms human health. Due to urbanization, the soil quality is degrading year by year in the surrounding area by which most of the farmers are facing problems such as the accumulation of heavy metals and pollutants in the soils as well as in the drinking water, acidification or alkalisation, salinity and change of land use, finally, in turn affect the levels of production and productivity of crops (Vasu *et al*., 2016) [41]. Usually, in rural soils farmers were growing traditional crops or agriculture crops with minimum input to get sustainable yield. The process of urbanization led to a 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 the long run which leading to soil acidity and imbalance of nutrients and the further drastic reduction in the productivity of crops and soils become unsuitable for crop production. Soil quality reflects the capacity of the soil to sustain productivity of plant and animal, maintain or enhance quality of water and air, and promote plant and animal health (Andrews *et al*., 2004) [2]. Soil quality is core to sustained fertility and productivity (Pulleman *et al*, 2000) [30]. Urban soils get altered by anthropogenic activities such as compaction, construction, mixing, land filling and degradation. Topsoil usually gets filled up with stones, construction rubble, bricks, and other building materials, contributing to poor soil fertility (Jin *et al*., 2011) [22]. Disturbance in soil texture, increased in BD and decrease in soil moisture content as major factors responsible for depletion in soil microbial activity in urban soils, ultimately the process of urbanization adversely effected soil microbial activity by altering natural soil characteristics (Pradeep *et al*., 2018) [31].

To the best of our knowledge, this study is the first of its kind to systematically assess the effects urbanization, intensified use of mineral fertilizers, irrigation, and cropping system on the soil fertility status along rural-urban gradient in India. Thereby Bengaluru is an example for many other Indian megacities where urbanization encroaches on traditional land-use systems and their ecosystem services ranging from food provision to C storage and water retention. However, achieving a balance between agricultural practice and conservation of natural resources is a necessary goal for the development of sustainable agricultural systems. Understanding the effect of gradients on soil properties is necessary for the management of the soils around urban areas. In this context, the present study was approached to investigate the effect of urbanization on soil quality along rural-urban interface of southern transect of Bengaluru.

Material and Methods

Bengaluru district is divided into two transects (towards north and south from the centre of the city). The northern transect (N-transect) is a rectangular strip of 5 km width and 50 km length, the lower part of this transect cuts into urban Bengaluru and the upper part contain rural villages. The Southern transect (S-transect) is a polygon covering a total area of 300 km^2.The red area corresponds to the districts under Bengaluru's administrative authorities. The Outer Ring Road is shown in yellow. The blue contours indicate the Northern and Southern research transects; the star marks the reference point (Vidhana Soudha) in the city centre.

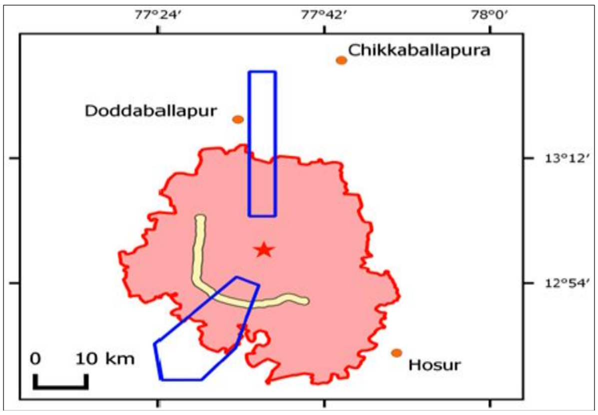

Fig 1: Bengaluru and its rural–urban interface

Each transect was further divided into rural, peri-urban, and urban areas based on the simplified Survey Stratification Index (SSI) by Elen Hofman *et a1*. 2015. The space between rural and urban areas has been described as the "peri-urban or rural-urban fringe" (Pryor 1968 and Simon, 2008) [33], the "peri-urban interface" (Adell, 1999) [1] or as the "rural-urban continuum" (Desakota study team. 2008) [2], the "rural–urban interface" (Elen Hofman *et a1*. 2015).

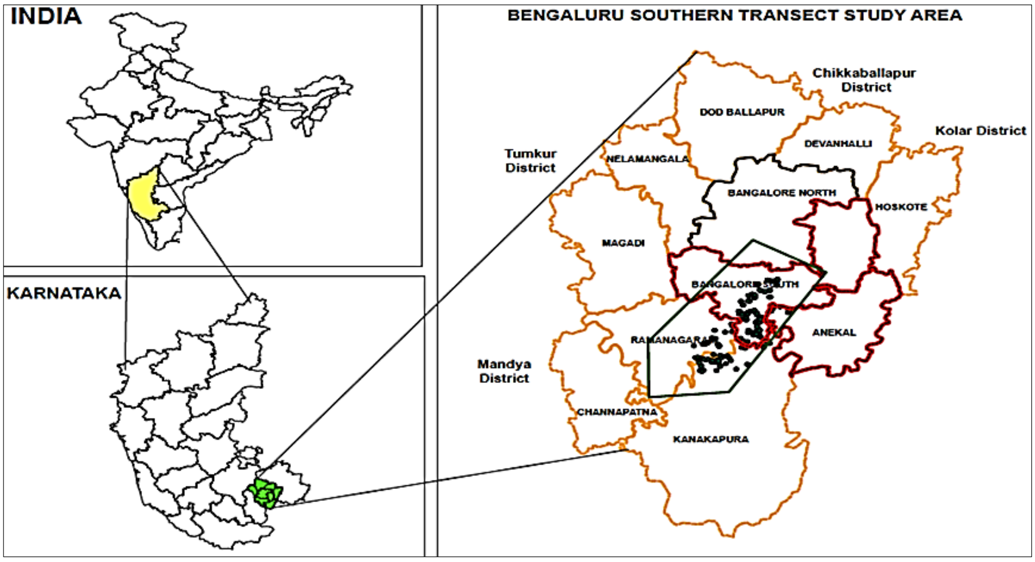

Fig 2: Base map showing present study area (Southern transect of Bengaluru)

The level of urbanization was characterized based on *per cent* build up area (buildings, roads, and asphalt-covered paths) and distance to the city centre (Vidhana Soudha). Village stratification was done on the basis of SSI stratum as mentioned in Table 1. The twenty-five villages were selected in each rural and peri-urban of southern transect of Bengaluru, whereas twelve villages were selected in urban. Geo-referenced surface soil samples (0–15 cm depth) were collected from each village of rural, peri-urban and urban, in such a way that one sample from each major land use system (Agriculture, Horticulture, Mulberry, and Plantation) in rural and peri-urban respectively. Since in urban areas we couldn't find any land use system so, soil samples were collected beside the road, near concrete buildings, barren land, and home gardens. This paper mainly concentrates on the soil properties affected by different gradients.

Table 1: Village stratification in the Southern transect of Bengaluru

SSI Stratum	Region
1	Urban
2	
3	Peri-urban
4	
5	Rural
6	

Soil samples thus collected were air-dried in shade, powdered with a wooden mallet, and passed through 2 mm sieve and analysed for various physical, chemical and biological properties of soil by adopting standard following procedures as given in Table 2.

Table 2: Methods and References employed for analysis of soil samples

Parameters	Methods	References
Physical analysis		
Particle analysis	International Pipette method	Piper, 1966 [29]
Chemical analysis		
pH (1: 2.5)	Potentiometry	Jackson, 1973 [18]
EC (dS m^{-1})	Conductometry	Jackson, 1973 [18]
Organic Carbon (%)	Wet oxidation	Walkley and Black, 1934 [5]
Avail. N (kg ha^{-1})	Alkaline potassium permanganate	Subbiah and Asija, 1956 [39]
Avail. P_2O_5 (kg ha^{-1})	Bray's extraction, Colorimetry	Jackson, 1973 [18]
Avail. K_2O (kg ha^{-1})	Ammonium acetate extraction Flame photometry	Jackson, 1973 [18]
Exch. Ca and Mg [c mol (p^+) kg^{-1}]	Ammonium acetate extraction, Versenate titration	Jackson, 1973 [18]
Available S (mg kg^{-1})	$CaCl_2$ extractant method, Turbidometry	Black, 1965 [5]
DTPA extractable Fe, Mn, Zn and Cu (mg kg^{-1})	Atomic absorption spectrophotometry	Lindsay and Norvell, 1978 [25]
DTPA extractable Pb, Cd, Cr and Ni (mg kg^{-1})	Atomic absorption spectrophotometry	Lindsay and Norvell, 1978 [25]
Biological analysis		
Dehydrogenase (µg TPF g^{-1} soil h^{-1})	2-3-5-triphenyl tetrazolium chloride reduction technique	Casida *et al*., 1964 [7]

Statistical analysis and nutrient index (NI)

The statistical analyses were performed using the software SPSS 16 version. Analysis of variance with unequal number observations and Duncan multiple range test (DMRT) were analyzed to determine the statistical significance between samples along the gradient. Nutrient Index was enumerated for soil samples of rural-urban gradient using the following equation (Ramamoorty and Bajaj, 1969) [34].

$$\text{Nutrient Index} = [(\text{Nl} \times 1) + (\text{Nm} \times 2) + (\text{Nh} \times 3)] / \text{Nt}$$

Where

Nt: Total number of samples analyzed for a nutrient in the given area

Nl: Number of samples falling in the low category of nutrient status

Nm: Number of samples falling in the medium category of nutrient status and

Nh: Number of samples falling in the high category of nutrient status

Further, on the basis of NI, soil fertility level in respect of different nutrients was categorized as low (<1.67), medium (1.67-2.33) and high (>2.33).

Geostatistical analysis and preparation of soil fertility maps

The collection of soil samples by using the Global Positioning System (GPS) is very important for preparing the GPS and GIS-based thematic soil fertility maps (Mishra *et al*., 2013) [28]. A dbf file consisting of data for X and Y co-ordinates in respect of sampling site location was created. A shape file (Vector data) showing the outline of southern transect was created in ArcGIS 10.4. The dbf was opened in the project window and X and Y co-ordinates were selected in respective X and Y-fields. The Z field was used for different nutrients. Then map was reclassified based on ratings of the respective nutrients.

Result and Discussion

Physical, chemical and biological soil properties as affected by gradients are presented in Table 4.

Soil physical attributes

Soil texture (except silt) was significantly varied along the gradient. The higher mean value of sand was recorded in urban (59.59%), followed by peri-urban (55.03%) and the lowest was recorded in rural soils (53.57%). *Per cent* clay was found high in rural soils (30.47%), followed by peri-urban (28.19%) and the lowest was found in urban gradient (22.72%). The high content of sand in urban soils may be attributed to the reason that soil samples were collected at nearby construction sites and barren land. Pradeep *et al*., 2018 [31] reported that the clay content was high in the rural soils than that of sub-urban and urban soils. Clay particles interact with soil organic matter to form aggregates that protect the organic matter from decomposition (Hassink and Whitmore, 1997) [15, 16]. Soils with higher clay contents tend to have greater organic matter (Hassink *et al*, 1993; Jenkinson, 1988) [15, 16], which is crucial in determining the microbial biomass, microbial activity and composition of microbial community (McCulley and Burke, 2004) [27].

Soil chemical attributes

Soil pH, EC and OC

The measure of soil pH is an important parameter that helps in the identification of chemical nature of the soil (Shalini *et al*., 2003) [35] as it measures hydrogen ion concentration in the soil to indicate its acidic and alkaline nature of the soil. Soil pH was varied along rural-urban interface of Bengaluru. The soil pH found to be more acidic in the peri-urban areas (6.01), whereas rural soils found near neutral (6.81) in their reaction. Indiscriminate application of acid forming nitrogenous fertilizers *viz*., urea, ammonium chloride, ammonium sulphate for the commercial crops which resulted in more acidic soils in peri-urban areas than rural areas. Urban soils were characterized by alkaline pH (7.93) and this alkaline pH might be due to the release of carbonates from concrete materials (Bricks). Jim (1998a) [20, 21] reported that urban roadside soil in Hong Kong was alkaline than natural soil this might be due to the release of carbonate from the calcareous construction waste to increase in pH of the soil. Similarly, Stephen *et al*., 2018 [38] reported that soil pH in the long-term urban soils of Kumasi was significantly higher, compared to the short-term urban soils. Both, long-term and short-term urban soils, had higher pH (mean pH>7) compared to the rural arable soils and the forest soils. Shifting soil pH from acid to neutral, or even slightly alkaline, is a typical consequence of urbanization, usually attributed to deposition of lime and cement dust from building construction (Gerasimova *et al*., 2003; Prokofeva *et al*., 2017) [14]. Conductivity, as the measure of current carrying capacity, gives a clear idea of the soluble salts present in the soil. It indicates the salinity status of soil. The lesser the EC value, low will be the salinity value of soil and vice versa. The electrical conductivity of the soils along rural-urban interface followed same trend as that of soil pH. Electrical conductivity of peri-urban areas found least (0.59 dS m^{-1}) due to acidic soil pH. Urban soils were recorded significantly higher soluble salts (1.70 dS m^{-1}). 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 (Debi *et al.*,2019) [9].

The importance of the organic matter in the soil is implied in the definition of soil, which recognizes fertility status of the soil, as a unique feature distinguishing soil from the parent rock / other non-fertile soils. It increases the soil fertility / nutrient status and controls erosion by wind and water, besides it plays a vital role in the improvement of soil structure, moisture content and nutrient status of the soil. Organic carbon content which is an indicator of soil quality varied significantly along rural-urban interface of southern transect of Bengaluru. Organic carbon content found to be significantly higher in rural areas (0.70%) than peri-urban (0.60%) and urban areas (0.46%). The higher organic carbon content in the rural areas may be attributed to the cultivation of non-exhaustive crops, availability and frequent use organic manures like FYM, practices like crop rotation and green manuring whereas, non-availability of organic manures in the vicinity of peri-urban areas, and due to multiple cropping systems might have resulted in low organic carbon content in soil. Similarly, Pradeep *et al.*, 2018 [31] observed a significant variation in OC along the gradient. OC was high in rural soils than that of the sub-urban and urban soils. Similar results were reported by Jim (1998a, 1998b) [20, 21] and Chen *et al.* (2013) [8].

Table 3: Mean values of selected soil Physcio-chemical and biological properties along rural and urban gradient

Soil properties	Rural	Peri-urban	Urban	S.E.m. ±	CD (*p*=0.05)
Sand (%)	53.57^{b}	55.03^{b}	59.59^{a}	1.27	3.53
Silt (%)	15.27^{b}	16.31^{ab}	16.71^{a}	0.84	NS
Clay (%)	30.47^{a}	28.19^{b}	22.72^{c}	1.21	3.36
Soil pH	6.81^{b}	6.01^{c}	7.93^{a}	0.23	0.64
EC (dS m^{-1})	0.65^{b}	0.59^{b}	1.70^{a}	0.15	0.43
OC (%)	0.70^{a}	0.60^{b}	0.46^{c}	0.05	0.15
N (kg ha^{-1})	323.01^{a}	285.08^{b}	244.32^{c}	16.26	45.30
P_2O_5 (kg ha^{-1})	28.98^{a}	25.43^{b}	20.72^{b}	1.82	5.07
K_2O (kg ha^{-1})	246.16^{a}	196.65^{b}	181.57^{b}	13.68	38.10
Ca (c mol (p^{+}) kg^{-1})	9.67^{b}	8.83^{b}	12.03^{a}	0.76	2.11
Mg (c mol (p^{+}) kg^{-1})	7.21^{a}	6.84^{a}	7.70^{a}	0.56	NS
S (kg ha^{-1})	19.32^{a}	17.52^{a}	13.05^{b}	1.35	3.76
Fe (mg kg^{-1})	9.89^{b}	13.19^{a}	5.52^{c}	0.78	2.18
Mn (mg kg^{-1})	7.58^{a}	8.23^{a}	4.04^{b}	0.49	1.36
Cu (mg kg^{-1})	0.61^{a}	0.59^{a}	0.54^{a}	0.04	NS
Zn (mg kg^{-1})	0.73^{a}	0.63^{a}	0.45^{b}	0.07	0.19
B (mg kg^{-1})	0.84^{a}	0.64^{b}	0.50^{c}	0.05	0.15
Cd (mg kg^{-1})	0.031^{b}	0.039^{b}	0.088^{a}	0.01	0.04
Cr (mg kg^{-1})	0.037^{b}	0.049^{b}	0.086^{a}	0.01	0.04
Pb (mg kg^{-1})	0.020^{b}	0.033^{b}	0.065^{a}	0.01	0.03
Ni (mg kg^{-1})	0.029^{b}	0.043^{ab}	0.056^{a}	0.01	0.03
DHA (µg TPF g^{-1} soil 24 h^{-1})	14.59^{a}	12.36^{b}	10.02^{c}	1.32	3.68

Available N, P_2O_5 and K_2O

Nitrogen is the most often a limiting nutrient for plant growth. Available nitrogen content varied significantly along rural-urban interface of southern transect of Bengaluru. This variation in the availability of nitrogen follows the same trend as that of organic carbon. Available nitrogen content recorded significantly higher in rural areas (323.01 kg ha^{-1}) than peri-urban (285.08 kg ha^{-1}) and urban areas (244.32 kg ha^{-1}). Phosphorus is the second most important macronutrient available in the biological systems, which constitutes more than *1 per cent* of the dry organic weight. It is also the second most limiting factor often affecting plant growth, which exists in the soil in both organic and inorganic forms. Available phosphorus content varied significantly along rural-urban interface of southern transect of Bengaluru. This variation in the availability of phosphorus follows the same trend as that of organic carbon and available nitrogen. Available phosphorus content found to be significantly higher in rural areas (28.98 kg ha^{-1}) than peri-urban (25.43 kg ha^{-1}) and urban areas (20.72 kg ha^{-1}). Potassium (K) is the third most required element by the plants, which plays a key role in water balance in plants or regulation of osmosis (Singh and Tripathi, 1993) [35, 37, 41]. Available potassium content varied significantly along rural-urban interface of southern transect of Bengaluru. Available potassium content recorded significantly higher in rural areas (246.16 kg ha^{-1}) than peri-urban (196.65 kg ha^{-1}) and urban areas (181.57 kg ha^{-1}). Though application of high value commercial fertilizers is restricted in rural areas, availability of major nutrients like nitrogen, phosphorus and potassium is high in rural areas than peri-urban areas. The agriculture in the rural areas is mostly under rainfed and crops under cultivation are conventional agriculture crops. The practice of multiple cropping is very rare in rural areas, which is more popular in peri-urban areas for higher demand of vegetables, fruits and flowers which make soil exhaustive. In addition to increased removal of nutrients by crops, faster rate of mineralisation under irrigated condition lead to lower availability of nutrients to subsequent crop. Pradeep *et al.*, 2018 [31] reported high concentrations of macronutrients (N, P, K) in rural soils than semi-urban and urban soils. High soil pH could have affected the nitrogen mineralization and nitrification processes in urban soil (Baxter *et al.*, 2002) [3], resulting in the depletion of nitrogen content in urban soil to that of the sub-urban and rural soils (Jim, 1998a; Zhang *et al.*, 2010) [20, 21]. Similar results were reported that high soil pH as observed in the urban arable soils of Kumasi may induce phosphorus and micronutrient deficiency (Jim, 1998a) [20, 21]. Jim (1998a) and Baxter *et al.* (2002) [3, 20, 21] suggested that the lower concentration of available P in urban soil is likely a result of the reduced organic inputs. Bennett (2003) [4] reported low concentration of available P in urban land surrounding agricultural land. Carbonates that are abundantly available in the urban region bind with soil P further limit its availability (Hong *et al*., 2001) [44].

Exchangeable Ca, Mg and available sulphur

Exchangeable calcium was varied significantly along rural-urban interface of southern transect of Bengaluru. Exchangeable calcium was recorded significantly higher in urban areas (12.03 c mol (p^+) kg^{-1} followed by rural areas (9.67 c mol (p^+) kg^{-1}) and lowest was recorded in peri-urban (8.83 c mol (p^+) kg^{-1}). Exchangeable magnesium did not vary significantly along rural-urban interface of Bengaluru. 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 calcium and magnesium content found less in these areas. Sulphur being a soil conditioner helps reduce the sodium content of soils. Available sulphur content varied significantly along rural-urban interface of Bengaluru. Available sulphur content found to be significantly higher in rural areas (19.32 kg ha^{-1}) than peri-urban (17.52 kg ha^{-1}) and urban areas (13.05 kg ha^{-1}). Higher availability of sulphur in rural areas is mainly attributed to higher soil organic matter content than in peri-urban and urban areas.

Soil micronutrients (Fe, Mn, Cu, Zn and B)

Iron (Fe) and manganese (Mn) plays important role in plant nutrition and are highly pH dependant. Hence the availability of iron and manganese follows the same trend as that soil reaction along rural-urban interface of southern transect of Bengaluru. Iron (Fe) and manganese (Mn) varied significantly along urbanisation gradient. Soils in the peri-urban areas recorded significantly higher available Fe and Mn content (13.19 and 8.23 ppm, respectively) as compared to rural (9.89 and 7.58 ppm, respectively) and urban areas (5.52 and 4.04 ppm, respectively). Zinc is a growth promoting substance that controls the development of the shoot and the most commonly deficient micronutrient in agriculture today. Zinc deficiency can limit yields of almost all crops in agriculture, presently which is deficient in 48.1 *per cent* of Indian soils. Available zinc content was recorded significantly higher in rural areas (0.73 ppm) than peri-urban (0.63 ppm) and urban areas (0.45 ppm). Similarly, available boron content found to be significantly higher in rural areas (0.84 ppm) than peri-urban (0.64 ppm) and urban areas (0.50 ppm). Higher availability of zinc and boron in rural areas than peri-urban and 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 urban areas. Copper (Cu) being the least affected micronutrient by agricultural practices abundantly available in Indian soils. Copper availability did not vary significantly along rural-urban interface of Bengaluru. However, rural soils recorded higher available copper content than that of urban and peri-urban areas.

Heavy metals (Cd, Cr, Pb and Ni)

The contents of heavy metals were significantly affected by the gradient. The urban soils were recorded significantly higher mean values of Cd (0.088), Cr (0.086), Pb (0.065) and Ni (0.054). The higher level of heavy metals in urban soils might be due to industrialization and urbanization activities resulted in the accumulation of heavy metals in the urban soils. The soil samples obtained from nearby industrial areas were tested for heavy metals by Krishna and Govil (2005) [23] and results showed that the soils are enriched with Cu, Cr, Co, Ni, and Zn. Similarly, White and Mcdonnell (1988) [43] observed that trampling and high concentration of heavy metals in urban areas. Most of the heavy metal sources in urban landscapes have been associated with roadside environments (Van Bohemen and Janssen van de Laak, 2003; Zhang *et al*., 2006) [40]. Urban soils in cities are well known to exhibit poor soil health and contain high concentrations of heavy metals, including lead (Pb), mercury (Mg), copper (Cu) and arsenic (As) among others (Italy (Manta *et al*. 2002) [26]; Sweden (Linde *et al*. 2001) [24]; China (Wei and Yang 2010; Zhao *et al*. 2014) [42, 44, 46]; United States (Cannon and Horton 2009) [6].

Soil biological properties

Dehydrogenase

Soil is an ecosystem capable of producing the resources necessary for the development of living organisms. Soil microorganisms (bacteria and fungi) are responsible for biomass decomposition, biogenic element circulation, which makes nutrients available to plants, biodegradation of impurities, and maintenance of soil structure. The presence of microorganisms in soil depends on their chemical composition, moisture, pH, and structure. Human activity has an indispensable influence on the formation of ecosystems. Dehydrogenase activity as an indicator of microbial activity in soils varied significantly along rural-urban interface of southern transect of Bengaluru. Dehydrogenase activity was recorded significantly higher in rural soils (14.59 µg TPF g^{-1} soil 24 h^{-1}) than peri-urban (12.36 µg TPF g^{-1} soil 24 h^{-1}) and urban areas (10.02 µg TPF g^{-1} soil 24 h^{-1}). Microbes decompose soil organic matter releasing carbon dioxide and plant available nutrients.

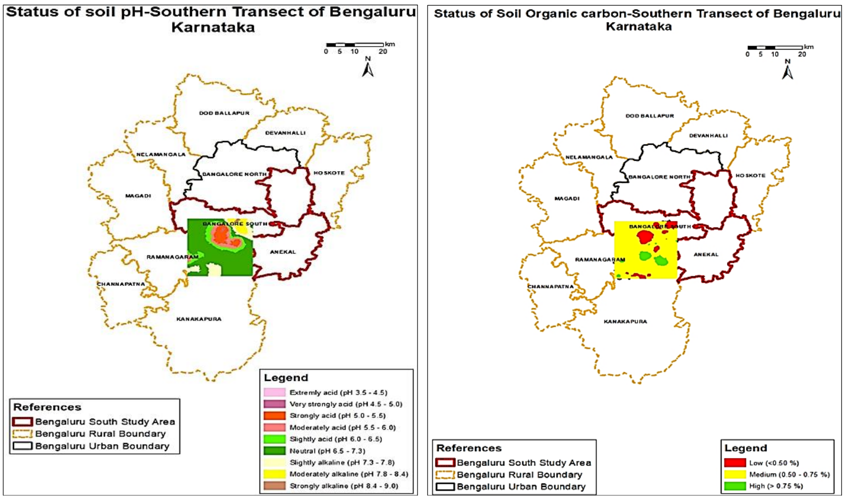

Fig 3: Status of soil pH and OC along rural-urban interface of Bengaluru

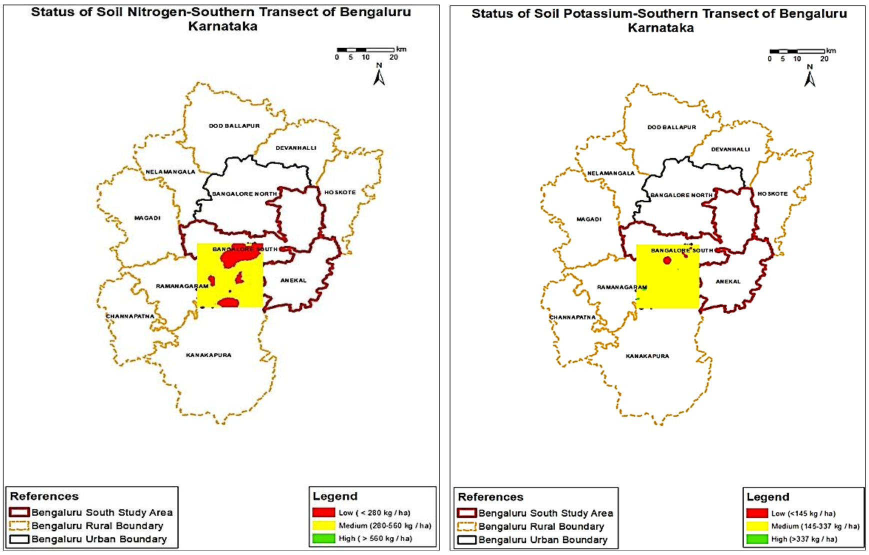

Fig 4: Status of available Nitrogen and potassium (K_2O) along rural-urban interface of Bengaluru

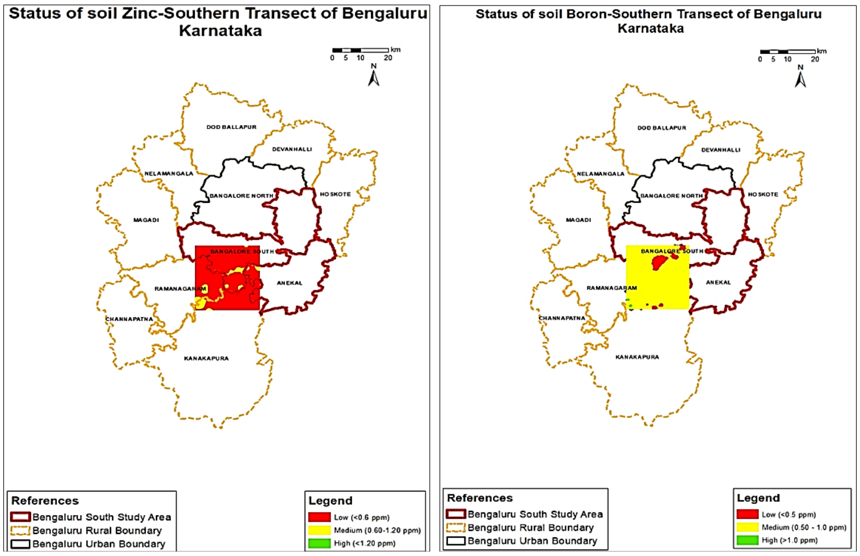

Fig 5: Status of Zinc and Boron along rural-urban interface of Bengaluru

Higher organic carbon content and judicious use of inorganic commercial fertilizers resulted in higher dehydrogenase activity in the rural soils. Similarly, White and Mcdonnell (1988) [43] observed that trampling and high concentration of heavy metals in the urban areas reduced the numbers and diversity of soil microbes and invertebrates. Urban soils are subject to strong anthropogenic influences, such as mechanical disturbance, soil sealing, and contamination. These factors have an impact on urban soil functions and most importantly on soil microbial properties (Doran, 2002; Dobrovolsky and Nikitin, 2012) [10, 11].

Nutrient index of rural-urban interface

The soil nutrient indices are obtained by classification of soils into low, medium and high categories with respect to organic carbon, available macronutrients (N, P_2O_5 and K_2O), secondary nutrient (S) and micronutrients (Fe, Mn, Cu, Zn. B). Nutrient index values of different soil properties of rural-urban interface were presented in Table 2, 3 and 4. The results of nutrient index showed that available nitrogen and zinc were belonged to low nutrient index in both rural (1.61 and 1.42%, respectively) and peri-urban areas (1.65 and 1.57%, respectively). The nutrient index ratings for SOC, P_2O_5, K_2O, Mn, Cu and B were found to be medium category in both rural and peri-urban gradients as mentioned in Table 2 and 3. Urban soils were characterized by low nutrient index for the soil properties such as SOC (1.44), N (1.25), P_2O_5 (1.52), K_2O (1.50), S (1.56), Fe (1.50), Mn (1.40), Zn (1.25) and B (1.52). This clearly indicates that there is much variation in the soil fertility along rural-urban gradient. Soil fertility status of rural-urban interface followed the order: Rural > Per-urban > Urban. High soil fertility in the case of rural soils may be attributed to judicious use of chemical fertilizers and the application of organic manures contributed organic matter to soils, which helps in the improvement of soil physcio-chemical and biological properties of soil.

Table 4: Nutrient index values of different soil properties of rural gradients of southern transect of Bengaluru

Rural						
Parameters	**Status**			**Nutrient index**		
	Low	**Medium**	**High**	**Value**	**Range**	**Remarks**
OC	38	17	45	2.07	1.67-2.33	Medium

N	40	59	1	1.61	1.67-2.33	Low
P	32	68	0	1.68	1.67-2.33	Medium
K	6	90	4	1.98	1.67-2.33	Medium
S	6	45	49	2.43	1.67-2.33	High
Fe	10	39	51	2.41	1.67-2.33	High
Mn	8	54	38	2.30	1.67-2.33	Medium
Cu	14	65	21	2.07	1.67-2.33	Medium
Zn	54	27	19	1.65	1.67-2.33	Low
B	9	75	16	2.07	1.67-2.33	Medium

Table 5: Nutrient index values of different soil properties of peri-urban gradients of southern transect of Bengaluru

Peri-urban						
Parameters	**Status**			**Nutrient index**		
	Low	**Medium**	**High**	**Value**	**Range**	**Remarks**
OC	57	13	30	1.73	1.67-2.33	Medium
N	58	42	0	1.42	1.67-2.33	Low
P	32	68	0	1.68	1.67-2.33	Medium
K	17	78	05	1.88	1.67-2.33	Medium
S	29	19	42	1.93	1.67-2.33	Medium
Fe	4	21	75	2.71	1.67-2.33	High
Mn	1	39	60	2.59	1.67-2.33	High
Cu	27	60	13	1.86	1.67-2.33	Medium
Zn	58	27	15	1.57	1.67-2.33	Low
B	33	65	2	1.69	1.67-2.33	Medium

Table 6: Nutrient index values of different soil properties of urban gradients of southern transect of Bengaluru

Urban						
Parameters	**Status**			**Nutrient index**		
	Low	**Medium**	**High**	**Value**	**Range**	**Remarks**
OC	29	17	2	1.44	1.67-2.33	Low
N	36	12	0	1.25	1.67-2.33	Low
P	24	23	1	1.52	1.67-2.33	Low
K	27	18	3	1.50	1.67-2.33	Low
S	29	11	8	1.56	1.67-2.33	Low
Fe	32	8	8	1.50	1.67-2.33	Low
Mn	33	11	4	1.40	1.67-2.33	Low
Cu	15	26	7	1.83	1.67-2.33	Medium
Zn	38	8	2	1.25	1.67-2.33	Low
B	30	16	2	1.42	1.67-2.33	Low

Soil fertility map

The fertility map indicates the soil fertility status with regard to soil pH, organic carbon, available nitrogen, available potassium and micronutrients (Zn and B) are presented in Fig. 3,4, and 5. Indices obtained can be depicted in an outline map of the study area with the help of a square with different colours for individual soil characteristics. The region inside the orange boundary represents the rural area, while the region inside black boundary represents the urban area. The study area of southern transect of Bengaluru is represented with red boundary. Based on the nutrient index criteria the soil fertility of southern transact can be categorized into low, medium and high with respect to available organic carbon, nitrogen, potassium, zinc and boron concentrations inside the square. Red colour is usually used to indicate low index, yellow for medium and green for high index. Soil pH ranged from 4.23 to 8.76, where pink colour represented extremely acidic, violet for very strongly acidic, red for strongly acidic, light red colour for moderately acidic, green for slightly acidic, dark green for neutral, light yellow for slightly alkaline, yellow for moderately alkaline and brown for strongly alkaline. Soil fertility maps clearly indicates that available nitrogen and zinc were found most deficient nutrients along rural –urban interface of southern transect of Bengaluru.

Conclusion

It was evident from the results that the process of urbanisation had adversely affected soil properties along rural-urban interface. Soil fertility status of rural-urban interface followed the order: Rural > Per-urban > Urban. Nitrogen and zinc were the most deficit nutrients along the gradients. In order to improve soil fertility status, appropriate measures need to be taken to correct these deficiencies such as the incorporation of organic manures, conservation agriculture, Judicious use of chemical fertiliser and soil erosion control measures.

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