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Soil characteristics in an exhumed cemetery land in Central Singapore

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Abstract Soils in urban landscape act as a component for various ecological functions. For sustainable urban greenery and effective management of urban ecosystems, evaluation of soil quality is of paramount importance. A study was undertaken to assess the existing soil quality and determine spatial soil variability of an exhumed cemetery land in central Singapore, so that systematic and sustainable soil management practices could be implemented for its conversion into an urban park. A stratified sampling method was followed to collect the soil samples from three depths: 0–30, 30–50, and 50–100 cm. An integrated soil quality index (SQI) approach was undertaken to monitor the changes in soil properties. The visual assessment showed the uniformity of horizon distribution of the soil profiles across the park and the soils had acidic pH ($\bar{x}$ 5.2) and moderately high bulk density ($\bar{x}$ 1.6 g cm^{-3}). Considering the soil depths, top layer had higher organic carbon content ($\bar{x}$ 1.03%) and it was significantly lower in deeper layers ($\bar{x}$ 0.71%). Detailed soil analysis results indicated that the soils of the proposed park area were in low fertility status, devoid of macro nutrients (available nitrogen: $\bar{x}$ 486.1, phosphorus: $\bar{x}$ 8.5 and potassium: $\bar{x}$ 9.2 mg kg^{-1}) and high in iron content ($\bar{x}$ 114.8 mg kg^{-1}), and can be classified as "Ferric Acrisol" (FAO WRB) or "Ultisol" (USDA). The SQI map of total soil (0–100 cm) was different from surface soil, indicating impact of human activities on overall changes in soil quality distribution.

Keywords Urban soil · Urban park · Ecosystem services · Soil quality index

Introduction

In the pursuit of healthy, livable, and sustainable cities, urban greenery plays an essential role, and therefore, it is imperative to improve and optimize the existing green space facilities. It has already been reported that greenery has positive influence on urban environment (Haq 2011; Unal et al. 2016) like mitigation of urban heat island effect, as protection of noise pollution (Ow and Ghosh 2017), and also benefits on improvement of public health (Ruth et al. 2015). Green alternatives such as community parks, roof gardens, and roadside greenery are becoming more important within urban settings for sustainable urban environment (Thwaites et al. 2005). Even small urban green spaces may have substantial restorative value (Kaplan et al. 1998). However,

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with increasing urbanization, most cities face problems of urban sprawl, loss of natural vegetation and open space and thereby facing challenges to maintain adequate amount of green spaces for city-dwellers.

Soils in urban areas are characterized by a high degree of variability due to the interplay of physical, chemical, biological, and anthropogenic processes that operate with different intensities and at different scales (Goovaerts 1998). Each soil type has a unique set of physical, chemical, and mineralogical characteristics and besides spatial variability, urban soils represent a great deal of complexity. The anthropogenic activities may not cause drastic changes in soil morphology but may modify their properties which are significant for soil management. As conversion of land-use system cause abrupt changes in the soil properties, historical land-use patterns and geographic understanding of land-use change in urban areas are important aspects which need to be considered before predictions of alternative landscape (Vrscaj et al. 2008). On the other hand, during the development of new green space or conversion of old land to new uses, detailed soil assessments can provide a more meaningful approach to monitor soil quality changes, identify constraints, and thereby devise the target management practices or remediation strategies (Schindelbeck et al. 2008). The information assembled in the soil survey studies can be utilized to predict the potentials and limitations of the soils' behavior under different uses (Ghosh et al. 2015).

Urban soils provide a wide range of ecosystem services and crucial for sustainable environmental management. However, their contributions remain insufficiently recognized in urban planning management framework (Blanchart et al. 2018). Singapore is a city state dedicated to ensure improving the livability and adopt initiatives to provide green habitats and protection of green spaces (Ghosh et al. 2016b). So far, urban soils have received little research attention and very few studies have conducted characterizing Singapore soils and this paucity of data inhibiting the impact of urbanization and land-use change on soil quality (Ghosh et al. 2016a). There is a need to initiate studies on Singapore soils including areas where there are possibilities of establishment of new urban green spaces.

The geology of Singapore consists of four major formations: (i) igneous rocks consisting of the Bukit Timah granite and the Gombak norite, occupying the north and central-north region; (ii) sedimentary rocks of the Jurong formation, occupying the west and southwest region; (iii) quaternary deposit of the old alluvium in the eastern region; and (iv) recent alluvial deposits of the Kallang formation, distributed throughout the island (Leong et al. 2002; Ghosh et al. 2016a). The present study was conducted in an exhumed cemetery area in central Singapore. This area has been proposed to be converted as an urban park. As per the generalized geological map of Singapore, the geology of the study site is old alluvium (Pitts 1984). Cemetery soils are characterized by variable morphological features and may differ in their properties depending on the age of the cemetery and previous land use (Charzyński et al. 2010). A comprehensive evaluation of soil attributes was attempted to assess the existing soil. The principal objectives of the study were to (1) characterize the soil type and qualitative evaluation of the soils and (2) determine the spatial soil variability using geostatistics in order to devise future soil management strategies for the proposed urban park. In this context, comparison through a synthetic integrated soil index approach was undertaken to monitor changes in soils as well as to assess soil ecosystem services (Granatstein and Bezdicek 1992). Thus, a soil quality index (SQI) was prepared, and single significant value to each soil was assigned as per their combined qualitative parameters (Velasquez et al. 2007).

Materials and methods

Site information and sample collection

The study was conducted in Bidadari estate, which is located in the central region of Singapore (Fig. 1). The estate occupies approximately 93 ha of land and yield a mix of public housing and green spaces. In the early years, it was known as the Bidadari cemetery, which was opened in 1908. Eventually, the cemetery was closed in 1972 and was exhumed in early 2000s. The site was opened for temporary park space since 2006 and will be designed as a regional urban park of this newly developing estate.

The sampling plan was designed with the emphasis on practicality, in keeping with the expenditures of time and funds available and at the same time considering consistent methodologies within the wide area to be sampled. Therefore, a stratified random sampling approach was followed for collection

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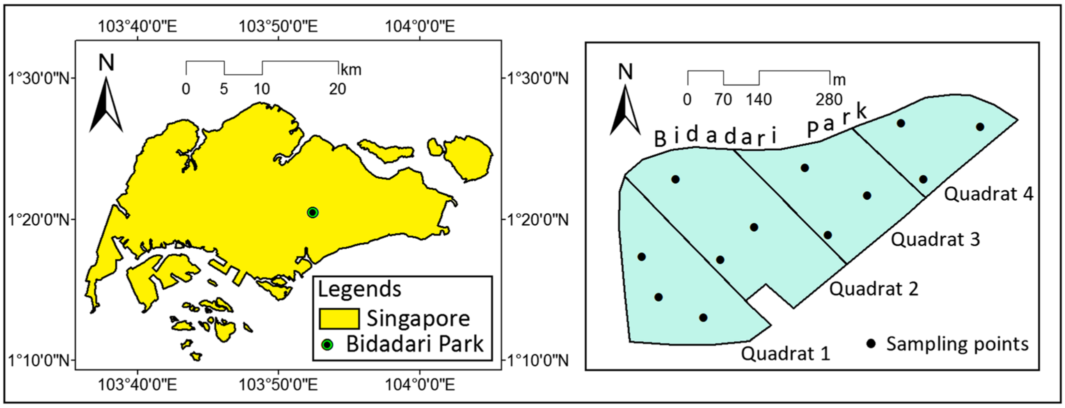

Fig. 1 Bidadari park in Singapore and soil sampling locations in the park

of soil samples from the study area. Firstly, the area was divided into four quadrats (A, B, C, and D) to isolate standard unit of area for study and then three unbiased random sampling locations were selected within each quadrat (Fig. 1). In each sampling location, 1 m deep soil pit was excavated. Profile morphology and selected physical properties were measured in the field following standard soil survey methods (Hodgson 1974). Composite soil samples were collected from the walls of the pits from three different depths—0–30 cm, 30–50 cm, and 50–100 cm. Undisturbed core samples were also collected from each depth for in situ bulk density determination.

Soil analysis

The samples were air dried and passed through a 2-mm sieve and analyzed for selected soil quality (physical and chemical) parameters. The methods of physical and chemical analyses are summarized in Table 1. A preliminary soil classification was done using all observable (texture, soil color) and easily measurable properties (pH, bulk density) and features of the soil (Fig. 2). The final classification was made after the full analysis of the samples. US Department of Agriculture (USDA) soil taxonomy system and Food and Agriculture Organization of the United Nations World Reference Base (FAO WRB) for soil resources, which are the international soil classification system for naming soils, were followed to describe soil classification of the study site (USDA 1999; WRB 2014). A vegetation survey was also conducted to assess the current plant population in the study site.

Computation of soil quality index (SQI) and spatial analysis

Results were analyzed in R 2.5.0 (R Development Core Team 2006) using analysis of variance (ANOVA) with sampling location, depth, and soil properties as factors, and *P* values ≤ 0.05 were considered significant. Variances were checked by plotting residual versus fitted values to confirm the homogeneity of the data. All data were tested for normality and no transformations were necessary. Means

Table 1 Field and laboratory methods for soil analysis

Soil parameter	Method
Physical	
Profile description	Soil survey method (Hodgson 1974)
Soil colour	Munsell standard colour chart
Soil texture	Hydrometer (Gee and Bauder 1986)
Chemical	
pH	1:2.5 w/w soil-water
Electrical conductivity (EC)	Sparks et al. 1996
Cation exchange capacity (CEC)	Ammonium acetate saturation (van Reeuwijk 1993)
Organic carbon (OC)	Walkley and Black 1934
Total nitrogen (N)	Kjeldahl method (Bremner and Mulvaney 1982)
Extractable phosphorus (P)	Watanabe and Olsen 1965
Extractable potassium (K), calcium (Ca), magnesium (Mg)	Sparks et al. 1996
Extractable iron (Fe)	Mehlich 1984

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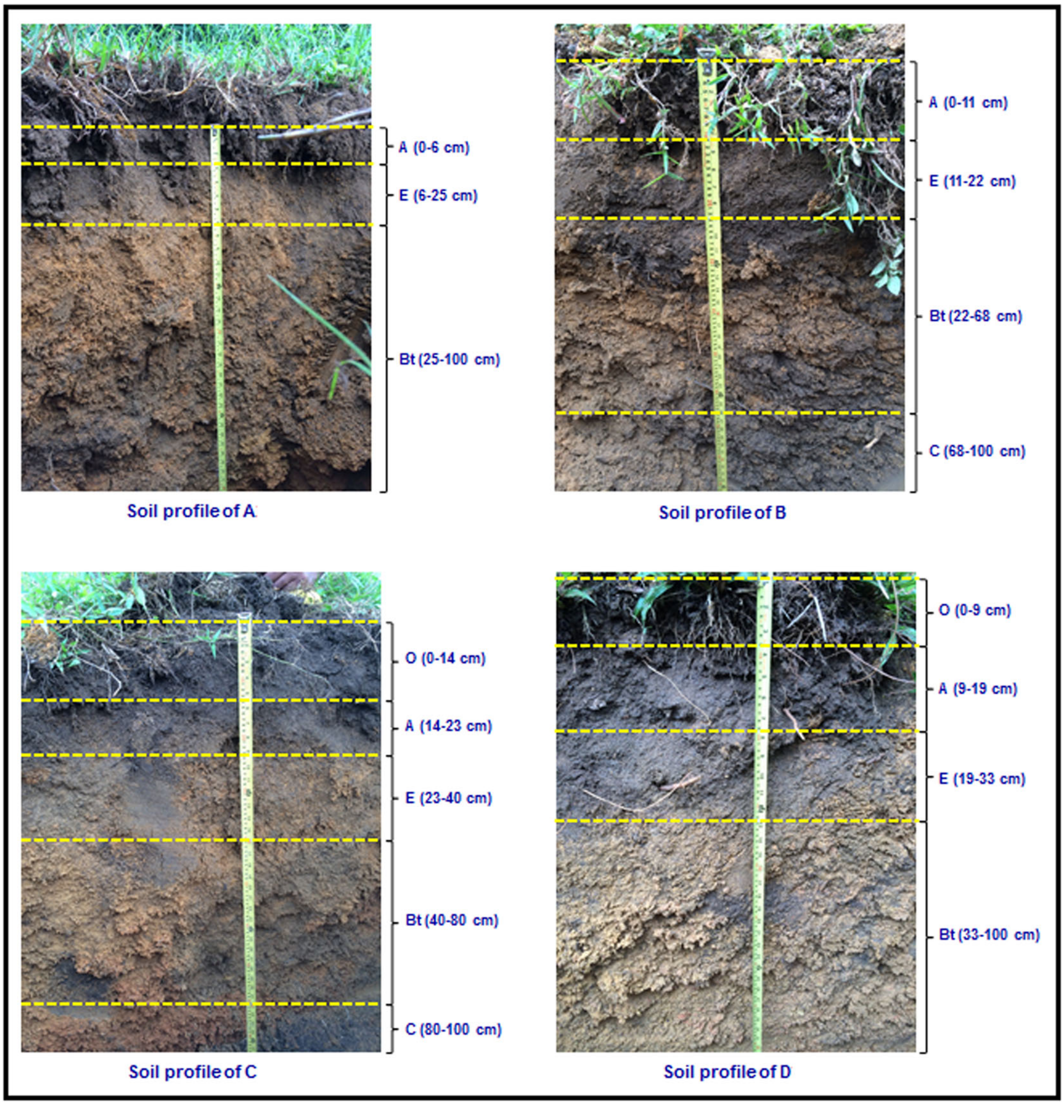

Fig. 2 Soil profile distribution in different parts of Bidadari park

for significant treatment effects were separated based on least significant difference (LSD) values.

The SQI of the study site was developed following Andrews et al. (2002): choosing appropriate soil parameters/indicators to develop a minimum dataset (MDS), transforming of indicator scores, and combining the indicator scores into index. To develop MDS, only the representative soil parameters were selected using principal component analysis (PCA) (Velasquez et al. 2007). In PCA, indicators (variables) with high eigenvalues were selected as higher factor loadings represent better system attributes (Table 4). After this selection, indicator transformation was done through linear scoring to convert the score range of the indicators within 0–1 (Andrews et al. 2002). To develop a weighted additive index, the particular principal components (PCs) were identified having the highest absolute coefficients of each of the indicator variables as per Eq. 1:

$$\mathrm{SQI} = \sum_{i=1}^{7} \mathrm{W_i} \times \mathrm{S_i} \tag{1}$$

where S denotes score of PCA selected soil parameters/indicators and W is corresponding weights of the parameters as the ratio of variation explained by each PC to the total percentage of variation explained by all PCs.

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Their corresponding weights were calculated as the ratio of variation explained by each PC to the total percentage of variation explained by all PCs.

The spatial variability of SQI was estimated using ordinary kriging algorithm. Based on the weighted linear combination of SQI values of the known sampling points, it interpolated the SQI values of the un-sampled location in the neighborhood area (Santra et al. 2017). The Geostatistical Analyst tool of ArcGIS 10.1 (ESRI Inc., USA) was used for this purpose.

Results and discussion

Physicochemical characterization of soils and qualitative evaluation of soil types

Soil properties are not only interrelated with each other but also with other soil components, and therefore, it is extremely important to understand the influence of soil properties on various soil processes and their contributions to ecosystem services (Dominati et al. 2010). These processes are affected by both natural and anthropogenic drivers. In Singapore, old alluvium soils are distributed over 7200 ha (approximately 15% of the geographical area). These soils are formed due to rapid deposition of weathered materials from slopes of granite and metamorphic rocks from Malaysia and as a result of that, the soils consist of many layers and the layer properties are highly variable (Gupta et al. 1987). Soil classification is generally based on horizon properties that can be observable and measured in the field and in laboratory. The preliminary field assessment of the soil pits showed the uniformity of horizon distributions of soil profile throughout the study region, but distinct characteristics for each soil layer were observed. The A, E, and Bt horizons dominated the upper 100 cm soil depth with thicknesses of 5–11 cm, 7–21 cm, and 34–88 cm, respectively (Fig. 2). Few soil profile showed presence of surface O horizon (5–14 cm) as well as subsurface C horizon (after Bt). The profile distribution was similar as observed by Rahman (1991) for soils formed on old alluvium. It was also reported that Singapore soils formed on old alluvium were difficult to classify as these soils were mostly developed over coarse-grained parent materials and had variable drainage characteristics that might give rise to different soil thicknesses; he termed these soils as Harimau and Tampoi soil series.

Initial soil analysis showed that across Bidadari park, soil pH ranged from 4.8–5.7 ($\bar{x}$ 5.2) (Table 2). Considering the depth, soils were more acidic ($\bar{x}$ 5.0) at lower depth (50–100 cm) than the soils of 0–30 and 30–50 cm ($\bar{x}$ 5.3) (Table 2). The dominant soil color was either strong brown (7.5YR 5/6) or yellowish brown (10YR 5/6) (Table 2), which was similar for old alluvium soils as reported by Tenando (2003). Soil texture of the study sites were sandy clay loam with 71% sand, 4% silt, and 25% clay at 0–30 cm; 70% sand, 3% silt, and 27% clay at 30–50 cm; and 65% sand, 3% silt, and 32% clay at 50–100 cm soil depths. The particle distribution was similar with the textural analysis for Harimau and Tampoi soil series done by Trinh and Chui (2013). Earlier researches revealed that soils in old alluvium contain 15–30% silt and clay, which generally decrease with depth (Chiam et al. 2003). Further, most of these soils are heavily leached and have a very low cation exchange capacity (CEC) (Rahman 1991). Similarly, we observed an average clay concentration of 28% with gradual decrease in finer silt concentration with depth in these soils. The soil CEC was very low (4.3 cmol kg^{-1}) (Table 2), which was indication of decrease in the degree of weathering. Analysis of the soil salinity further indicated a high level of soil EC ($\bar{x}$ 13.5 dS m^{-1}) with highest salinity in the D quadrats (Table 2). The average bulk density (0–100 cm) of the soils of study site was 1.6 g/cm^3, which was similar as observed by other researchers on similar soils (Wells 1977; Wells and Leamy 1980; Chia 1977). Critical physical observation of soil profiles showed the presence of “argillic horizon” (illuvial sub-surface horizon) in the soils of the Bidadari park area. On the other hand, comprehensive vegetation survey showed the dominance of *Imperata cylindrica* (Lalang) throughout the area which was supported by earlier studies (Lau 1979; Rahman 1991). Lalang grasses are commonly found in tropical humid climate and in a large variety of habitats, particularly in areas affected by human use (Brook 1989).

With preliminary assessments of soil horizon distribution and initial soil tests, it can be affirmed that the soils of Bidadari park area have uniform soil profile distribution with varying layer characteristics. Therefore, according to Singapore soil map (Pitts 1984), these soils can be classified as Harimau-Tampoi soil series and according to soil taxonomy the soil order is “Acrisol” (WRB) or “Ultisol” (USDA). Further in-detailed soil analysis would enable us to confirm the soil classification and evaluate their fertility status.

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Evaluation of soil quality

In order to ensure effective management of urban ecosystem, evaluation of soil quality is vital to understand soil's capacity to perform its environmental function. We have assessed soil quality of the study sites across 0–100 cm depth using multiple soil parameters (Tables 2 and 3). Results showed that the soils of Bidadari park had low pH which significantly decreased with depth and moderately high bulk density (Table 2). The acidic nature of these soils might be due to the parent materials that were high in silica and high levels of sand with low buffering capacity (Table 2); moreover, the high rainfall environment of Singapore promotes the leaching of bases. Chia (1977) observed similar soil pH values on Singapore old alluvium soils. Higher bulk densities were noted in soils developed over the old alluvium (Rahman 1991). Aside from their coarse texture (Table 2), these soils might have been subjected to compaction in the past, giving rise to higher bulk densities. The very low CEC of these soils, which is a common characteristic of Harimau-Tampoi soil series, reflected the presence of iron oxides, quartz etc. However, CEC values also depend on the underlying geology and resultant formation.

Quantitative estimation revealed low organic carbon status ($\bar{x}$ 0.82) of the soils of Bidadari park (Table 3), which was might be because of higher decomposition rate of organic matter in the tropics (Deb et al. 2016). The organic carbon content was higher in the top layer

Table 2 General characteristics of Bidadari soil profile

Quadrats of the park	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Color		pH	EC[a] (dS m^{-1})	CEC[b] (cmol kg^{-1})	Bulk density (g cm^{-3})
A	0–30	71.0a	3.7a	25.3b	Sandy Clay Loam	7.5YR 5/6	Strong brown	5.75a	13.50a	4.20a	1.43b
	30–50	71.0a	2.3c	26.7b	Sandy Clay Loam	7.5YR 5/6	Strong brown	5.11b	12.82a	4.20a	1.45b
	50–100	66.4b	2.9b	30.7a	Sandy Clay Loam	7.5YR 5/6	Strong brown	4.93c	13.20a	3.87b	1.64a
		*	**	*				**	n.s.	*	*
B	0–30	71.5a	3.5a	25.0b	Sandy Clay Loam	10YR 5/6	Yellowish brown	5.46a	12.65a	5.67a	2.05b
	30–50	71.6a	2.4b	26.0ab	Sandy Clay Loam	7.5YR 5/6	Strong brown	5.28ab	11.65b	3.20c	2.19a
	50–100	68.2a	2.5b	29.3a	Sandy Clay Loam	10YR 5/6	Yellowish brown	4.95b	11.71b	4.27b	2.02b
		n.s.	*	*				*	*	**	*
C	0–30	71.6a	5.0a	23.4b	Sandy Clay Loam	10YR 5/6	Yellowish brown	5.26ab	11.86a	3.57b	1.54a
	30–50	72.9a	4.3ab	22.8b	Sandy Clay Loam	7.5YR 5/6	Strong brown	5.44a	10.36b	3.40b	1.52a
	50–100	64.3b	3.6b	32.1a	Sandy Clay Loam	7.5YR 5/6	Strong brown	5.14b	11.91a	4.40a	1.58a
		*	*	*				*	*	*	n.s.
D	0–30	70.7a	3.0b	26.3c	Sandy Clay Loam	10YR 5/6	Yellowish brown	5.59a	15.83c	5.07a	1.29a
	30–50	64.9ab	4.3a	30.8b	Sandy Clay Loam	7.5YR 7/8	Reddish yellow	5.52a	17.26b	4.33b	1.32a
	50–100	61.6b	4.3a	34.1a	Sandy Clay Loam	7.5YR 7/8	Reddish yellow	4.82b	19.06a	5.20a	1.35a
		*	*	*				*	**	*	n.s.

For every soil parameter, different lowercase letters are significantly different at the 5% level as per the standard error of mean

n.s. not significant according to F-value of ANOVA

** ≤ 0.01; * ≤ 0.05

[a] Eletrical conductivity

[b] Cation exchange capacity

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Table 3 Qualitative parameters of Bidadari soil profile

Quadrats of the park	Depth (cm)	Organic carbon (%)	Available soil nutrients					
			N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Fe (mg kg^{-1})
A	0–30	0.77a	466.7b	12.8a	16.2a	217.3b	48.8a	87.0b
	30–50	0.70a	373.3c	8.7b	11.9b	224.7b	53.0a	80.5b
	50–100	0.77a	513.3a	12.1a	10.1c	317.3a	55.2a	109.9a
		n.s.	**	*	*	**	n.s.	*
B	0–30	1.13a	560.0a	14.7	5.6a	295.7a	50.5a	115.0a
	30–50	0.67b	513.3ab	8.2	5.3a	230.3b	47.5a	92.8b
	50–100	0.70b	466.7b	13.5	5.7a	204.0c	45.8a	61.1c
		**	*	*	n.s.	**	n.s.	**
C	0–30	0.87a	466.7a	9.7	10.7a	202.3a	46.8a	139.8a
	30–50	0.47c	420.0ab	11.8	8.6b	207.7a	52.4a	139.8a
	50–100	0.63b	373.3b	3.2	8.7b	211.7a	50.3a	85.9b
		*	*	**	*	n.s.	n.s.	**
D	0–30	1.37a	746.7a	3.4	10.3a	306.3a	62.9a	227.3a
	30–50	0.93b	513.3b	2.0	9.1b	310.3a	57.6a	155.7b
	50–100	0.87b	420.0c	1.5	8.7b	244.0b	52.9a	82.3c
		**	**	*	*	**	n.s.	**

For every soil parameter, different lowercase letters are significantly different at the 5% level as per the standard error of mean

n.s. not significant according to F-value of ANOVA

$** \leq 0.01$; $* \leq 0.05$

(0–30 cm) ($\bar{x}$ 1.03%) and decreased in deeper layers ($\bar{x}$ 0.69 and 0.74% at 30–50 and 50–100 cm) (Table 3). This is possibly due to higher organic input in the surface soil from leaf-litter fall from the vegetation (Deb et al. 2019). The chemical characteristics of the soils are shown in Table 3, which indicated that the soils of Bidadari park were attributed to the low nutrient levels. The available N content of the top soil (0–30 cm) was very low ($\bar{x}$ 560 mg kg^{-1}) and was further decreased in the subsoil layers (Table 3). Results also indicated smaller concentrations of available P ($\bar{x}$ 10.2 mg kg^{-1}) and K ($\bar{x}$ 10.7) in the surface soils with a declining trend of these nutrients with soil depth (Table 3). However, the nutrient values were comparable with the previous studies on Singapore old alluvium soils (Harimau-Tampoi soil series) (Wells 1977; Wells and Leamy 1980). As observed, soils of the study area were with high red and yellow hues, which visually confirm presence of high amount of Fe (Table 2). To confirm presence of Fe, the soil samples were further analyzed for Fe concentrations. Results indicated that the Fe content was significantly high ($\bar{x}$ 114.8 mg kg^{-1}), and the concentration was even more in top soil (0–30 cm) ($\bar{x}$ 142.3 mg kg^{-1}) (Table 3). This higher Fe content of old alluvium soils were reported in earlier studies (Rahman 1991), and this was due to presence of hematite minerals (Torrent et al. 1983). This high soil Fe status might result in Fe-phosphate formation and subsequent low available soil *P* values ($\bar{x}$ 8.47 mg kg^{-1}), which is also indicative of the anthropogenic activity at the specific site (Brzezinski et al. 1983). High amounts of tropical rainfall combined with hot and humid climatic conditions in Singapore favor weathering of the bedrock to a considerable depth and to a varying degree (Rahardjo et al. 2004). This would facilitate higher decomposition of soil organic matter and increase leaching of nutrients. The low C/N ratio (12:1 for 0–100 cm) of the soils indicated the higher decomposition of soil organic matter leaving the soils lower in nutrient status. The high degree of weathering was reflected by a dominance of 1:1 layer lattice clays and oxyhydroxides of iron (USDA 1999). The chemical process (pedogenesis) undergone by these soils rendered them nutritionally very poor. The earlier geological analysis of Singapore soils inferred that the soils of Bidadari park were developed over mixed lithologies

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of undifferentiated granite and old alluvium. Therefore, from the horizon distribution and detailed soil analysis, we can surmise that these soils can broadly be classified as

Soil order—Ferric Acrisol (FAO WRB) or Ultisol (USDA)
Suborder—Udults and Great Group–Paleudults
Soil series—Harimau-Tampoi (soil map of Singapore)

Synthesis of SQI is important to monitor changes, to understand the heterogeneity, and to quantify contribution of soils in overall ecosystem services. It can act as decision tool, which is able to merge range of information (Karlen and Stott 1994). Fourteen soil parameters such as sand %; silt %; clay %; soil pH; EC; CEC; available N, P, K, Ca, Mg, Fe, soil organic carbon; and C/N ratio were considered for preparing a SQI. Within these parameters, only seven parameters (N, Fe, Ca, Mg, K, OC, and EC) were selected in PCA following their highest absolute coefficient of eigenvectors and high factor loadings to represent best system attributes (Table 4). The proportion of these parameters was then used to calculate the weighted additive index as indicated by Table 5. As per the SQI score, surface soils (0–30 cm) of D quadrat of the Bidadari park area were qualitatively better compared to other parts (Fig. 3), while soils of B quadrat received highest score across total soil depth (0–100 cm). Soils of A and C quadrat scored lowest in SQI for surface soils (0–30 cm) and total soil depth (0–100 cm) respectively (Fig. 3). The variability of urban soils depends on the soil forming factors such as parent material, climate, topography, organisms, and time along with anthropogenic influences and altered resources (Pickett and Cadenasso 2009). This exhumed cemetery land had undergone intense human activities in the past that resulted in morphological changes, humus accumulation, and alteration of soil physical and chemical properties (Sobocka 2003). Consequently, soil characteristics were spatiotemporally heterogeneous within the land and variations in soil properties occur in both horizontal and vertical directions, even though land management was uniform over the next few decades after exhumation (Patzold et al. 2008).

Table 4 Selection of parameters for soil quality index using principal component analysis (PCA)

Eigenvectors							
	*PC1	PC2	PC3	PC4	PC5	PC6	PC7
Sand	0.000400	0.000195	0.012616	0.090739	0.378921	0.202276	0.415642
Slit	0.003184	0.001846	0.003143	0.001985	0.064599	0.031864	0.130900
Clay	0.000231	0.000446	0.009823	0.123600	0.495987	0.139840	0.452363
pH	0.000891	0.000821	0.002633	0.019847	0.005064	0.037633	0.009880
EC	0.006802	0.002871	0.009615	**0.115640**	0.049990	0.068516	0.086466
CEC	0.005141	0.003682	0.006462	0.033983	0.076267	0.020637	0.095504
N	**0.788353**	0.481414	0.381985	0.001082	0.005309	0.020462	0.003869
P	0.006491	0.021735	0.031526	0.532554	0.590592	0.130406	0.513912
K	0.009910	0.025461	0.003432	0.183750	0.049999	**0.792425**	0.469434
Ca	0.329689	**0.851688**	0.394092	0.088064	0.033235	0.024156	0.020891
Mg	0.027986	0.082052	0.044424	**0.787219**	0.490247	0.152139	0.061531
Fe	0.518403	0.186950	**0.833881**	0.017014	0.003949	0.008590	0.021681
OC	0.007340	0.006083	0.005582	0.070780	0.047386	**0.294679**	0.157128
C/N ratio	0.001055	0.001458	0.001928	0.106849	0.053547	0.419494	0.273696

*Principal component

[values of coloured cells indicate selected parameters in PCA to calculate weighted additive index. The cells carrying PC with highest absolute coefficients of each of the indicator variables are red coloured. The bold values therein are used to calculate corresponding weights as the ratio of variation explained by each PC to the total percentage of variation explained by all PCs]

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Table 5 Proportion of the indicator parameters for weighted additive soil quality index

Indicator parameters	PC[a]	Proportion
EC	4	0.0028
N	1	0.5300
K	6	0.0003
Ca	2	0.3200
Mg	4	0.0028
Fe	3	0.1400
OC	6	0.0003

[a] Principal component

This erratic heterogeneity of soil properties throughout the study area indicated the necessity to map the spatial distribution of SQI in order to devise and improve the site-specific landscape management strategies of the Bidadari park. Conventional soil sampling and laboratory analysis are combined with geostatistics, including semivariogram analysis normally performed to visualize the spatial variations of the entire field (Behrens and Scholten 2006; Heuvelink et al. 2016). However, this study was not aimed to focus primarily on digital soil mapping, but on quantitative detection of spatial soil heterogeneity. Two distribution maps were produced using the SQI values of each of the three sampling locations of each quadrats for surface soils (0–30 cm) (Fig. 4) and for total soil depth (0–100 cm). Ordinary kriging interpolation method was used for these SQI maps with prediction output surface. The geostatistics in relation to these two maps have been described in Table 6. Exponential model was selected to describe the mapping as there were low correlations in the values of neighboring quadrats of the study area. The nugget/sill ratio (0.365 for surface soil and 0.337 for total soil) indicated a moderate spatial dependence of the data (Chakraborty et al. 2017).

The spatial distribution of SQI in the Bidadari park area is depicted in Fig. 4 which divided the whole area into SQI classes as per value ranges. Results showed that SQI heterogeneity was higher in surface soils (SQI range < 0.6 to > 0.7) compared to subsoil layers (SQI range < 0.7 to > 0.7). In surface soil, highest SQI (> 0.7) was observed in quadrat 4 while quadrat 1 was associated with lowest SQI (< 0.6). The trend was completely similar to the soil quality score as found in the box-plots of Fig. 3. However, the SQI map of total soil was different from surface soil, indicating a total change in soil quality distribution with change in soil depth. This was possibly due to the nature of urban soil where continuous anthropogenic activity resulted in abrupt changes in soil properties (Vasenev et al. 2013; Greinert 2015).

Soil provides a wide diversity of ecosystem services, and there is a need to recognize soil's contribution while developing management framework for quantifying ecosystem services. It is also useful to distinguish between "inherent" soil properties that are derived from underlying geology and soil formation processes and "manageable" soil properties that respond to soil management (Dominati et al. 2010). The inherent soil

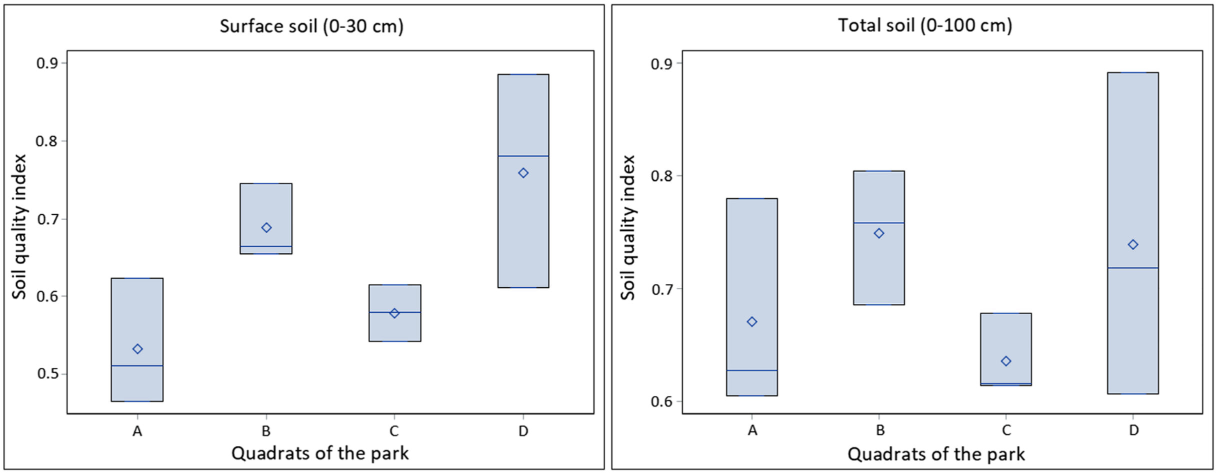

Fig. 3 Soil quality index scores for soils of the Bidadari park area

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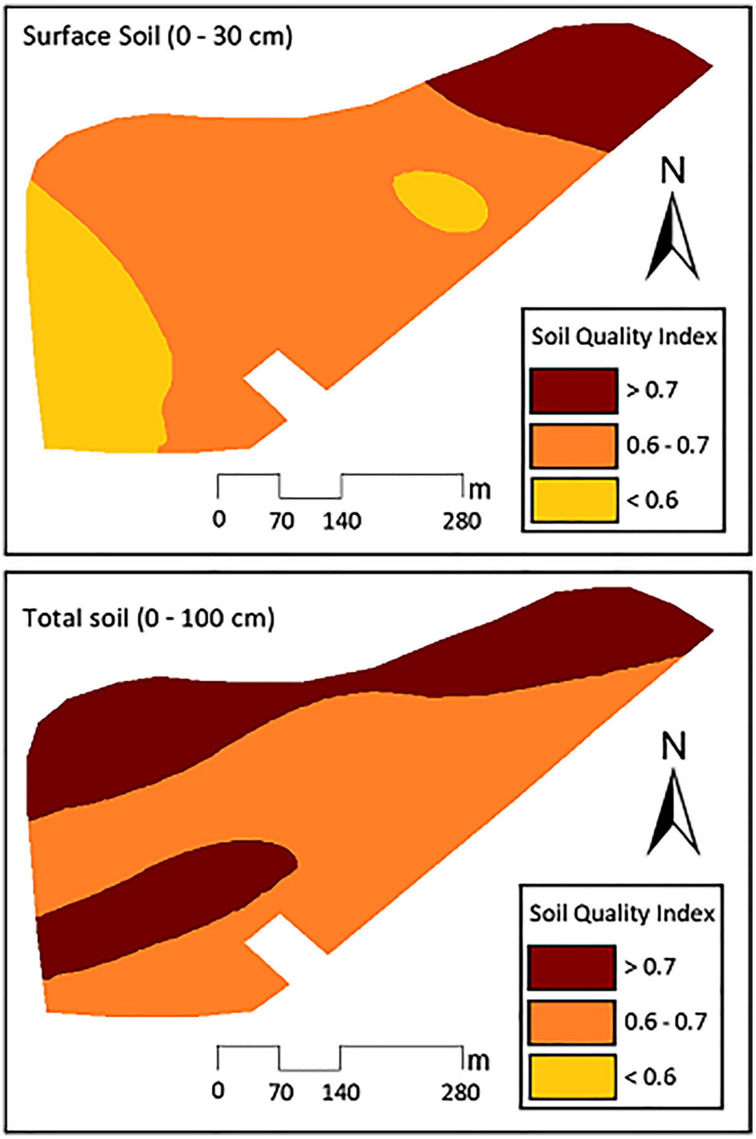
Fig. 4 Spatial distribution of soil quality index in Bidadari park area



properties which include depth, texture, and CEC are difficult to change without significant modification of the soil environment, whereas the other manageable soil properties are of more practical importance since there are provisions to optimize them. The comprehensive field and laboratory tests helped to identify the specific problems, and the map provided a more complete picture to characterize the entire area, enable us to understand the sustainable productive capacity of the study area, so that proper management practices can be adopted for future landscape planting projects in the proposed parkland (Jim 1998).

Table 6 Ordinary kriging semi-variogram model parameters for soil quality index

	Model	Anisotropy	Nugget	Sill	Nugget/ sill	RMSE[a]
Surface soil	Exponential	Yes	0.0035	0.0096	0.365	0.1047
Total soil	Exponential	Yes	0.0028	0.0083	0.337	0.1025

[a] Root mean square error

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Conclusions

Restoration, maintenance, and sustainable management of urban greenery are imperative to maximize their benefits to the ecosystem services. There is a need to integrate soils in ecosystem management framework to tackle major environmental issues. It is, therefore, essential to develop better understanding of soil variability and optimize management approaches that enhance soil ecosystem services. The study revealed the spatial heterogeneity of soil properties of a proposed urban park and consequently soil quality maps were developed, which would be helpful to establish site-specific management strategies and effective policies for urban park management. Development of a single index, which represents multiple soil parameters and subsequent mapping of that index, can serve as a tool to understand the soil and its diversity over a large urban area.

Soils of Bidadari park were low in fertility status, devoid of macronutrients, low in organic matter, and high in iron content. Soil composition (high sand and gravel content) and high leaching were responsible of low CEC and low base saturation, which would not allow retaining of nutrients. Further, the proposed transformation of this exhumed cemetery site to an urban park would result in some specific morphological and chemical changes. Future research will need to establish such changes through long-term monitoring of soil quality. Balanced fertilization along with addition of soil organic matter can be a possible way to improve soil quality and prevent long-term deficiencies and enhance the soil's resilience. The recycling of organic soils will facilitate enhanced natural symbiotic relationships. GIS-based approach will assist to evaluate the potential as well as allow better implementation of the nature-based solutions in the urban park relating the vegetation condition to variability in soil properties and land-use history resulted from increased anthropogenic activities.

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