



Assessment of Soil Quality Index in the Southern Coastal Sandy Soils of Kerala, India

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Authors' contributions

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

Article Information

DOI: 10.9734/IJECC/2023/v13i81980

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/100863>

Original Research Article

Received: 17/03/2023

Accepted: 26/05/2023

Published: 30/05/2023

ABSTRACT

Context: The Indian state of Kerala has a long coastline of 589.50 km all along its western border, which has a great potential in biomass production. The agro-ecological unit 1 (AEU 1) in Kerala represents the southern coastal plains, with typical sandy soils. The major constraints of these coastal sandy soil with regard to agriculture are: low organic matter and clay content, as well as their poor water holding capacity, resulting in limited ability to hold nutrients.

Aims: A study was carried out to evaluate the physico-chemical parameters and quality of the soils of coastal sandy soils in AEU 1.

Methods: Fifty geo-referenced composite soil samples were taken from different locations of AEU-1 in Thiruvananthapuram district, and were characterised for physical, chemical and biological

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attributes. Principal component analysis (PCA) was carried out for the analysed soil properties which resulted in 6 principal components (PCs) and a minimum data set (MDS) was obtained using the selected indicators i.e., texture (clay %), water holding capacity, bulk density, soil pH, organic carbon, available nutrients such as potassium, sulphur, zinc, manganese and boron. The soil indicators were changed to unit-less scores after the development of MDS, and were assigned with appropriate weights based on existing soil conditions and soil nutrient content.

Key Results: Value of SQI recorted the highest in Kadakkavoor and the lowest in Anchuthengu. Further, the locations were classified into three groups namely poor, medium, and good, based on the relative soil quality index (RSQI). Less than 50% of RSQI is considered poor, from 50% to 70% is medium, while more than 70% is considered good. From the study, majority of the land area (60% of samples) in AEU 1 of Thiruvananthapuram district were observed to have a medium level of relative soil quality index.

Keywords: AEU 1; coastal sandy soils; minimum dataset; soil quality; relative soil quality index.

1. INTRODUCTION

The coastal zone serves as a transition area from terrestrial to marine influences and vice versa. Total coast line of the world is 3,56,000 km and the coastal region covers more than 10% of the earth's surface. According to Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC) [1], low-lying areas and coastal systems are predicted to be more at risk as they are particularly exposed to a variety of climate-related hazards. The uncertain impacts of the climate change will have negative effects on crop production in the area.

Kerala, a south-western coastal state of India, has nearly 590 km of Arabian Sea shoreline distributed all along the western border and it constitutes 1.52% of entire geographical area of the state. Lying between northern latitudes of 8°18' and 12°48' and eastern longitudes of 74°52' and 77°22', Kerala has a humid tropical rainforest climate and width of state varies between 11 and 121 kilometres. In order to achieve food security and self-reliance in food production, the Government of Kerala is aiming at bringing maximum area under cultivation. Coastal soils have high potential to be used in biomass production.

Based on climatic variability, landforms and soil, the state Kerala has been delineated to 23 agro-ecological units (AEUs) by National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) based on the commission of Kerala State Planning Board. Of them, five are identified for special soil and hydrological conditions in the coastal zone of Kerala which includes diverse ecosystems requiring unique management strategies, and one among them is the Southern coastal plains.

The southern coastal plains, agro-ecological units (AEU 1) is delineated to represent nearly coastal lands where sand is of the dominant soil type, which is acidic, well drained with moderate salinity due to seawater intrusion. They are composed mainly of primary minerals, especially quartz (SiO₂), which is resistant to decomposition and contain little nutrients. One of the primary concerns with coastal sandy soil is that, it has a poor water holding capacity, poor content of clay minerals, organic matter, and nutrient retention [2]. As the coastal sandy soils fails to produce soil aggregates due to poor ability to bind particles, the soil has high leaching capacity, which causes majority of the nutrients to move downward through gravitational water. Also, soil's low CEC, buffering capacity and easily leached cations cause inadequate biological diversity [3,4].

Therefore, a sustainable management system for improving fertility and productivity of the coastal sandy plains needs to be developed. Plant nutrition needs to be looked into and location-and-crop specific management practices should be recommended. In this context, evaluating the soil quality is an essential step for improving soil production. Objectives of the study is assessment of soil quality of southern coastal sandy soils of AEU 1 of Thiruvananthapuram district, and to work out the soil quality index (SQI).

2. MATERIALS AND METHODS

2.1 Characterisation of Soil

During March 2022, composite geo-referenced surface soil samples using V-shaped sampling method at a depth of 0-20 cm and surface core samples were collected from coastal sandy areas

in Thiruvananthapuram district in AEU 1. A total of 50 composite surface samples along with 50 core samples were collected from the entire AEU-1 of Thiruvananthapuram

district (Fig. 1) and were evaluated for various physical, chemical and biological properties by following the standard analytical procedures.

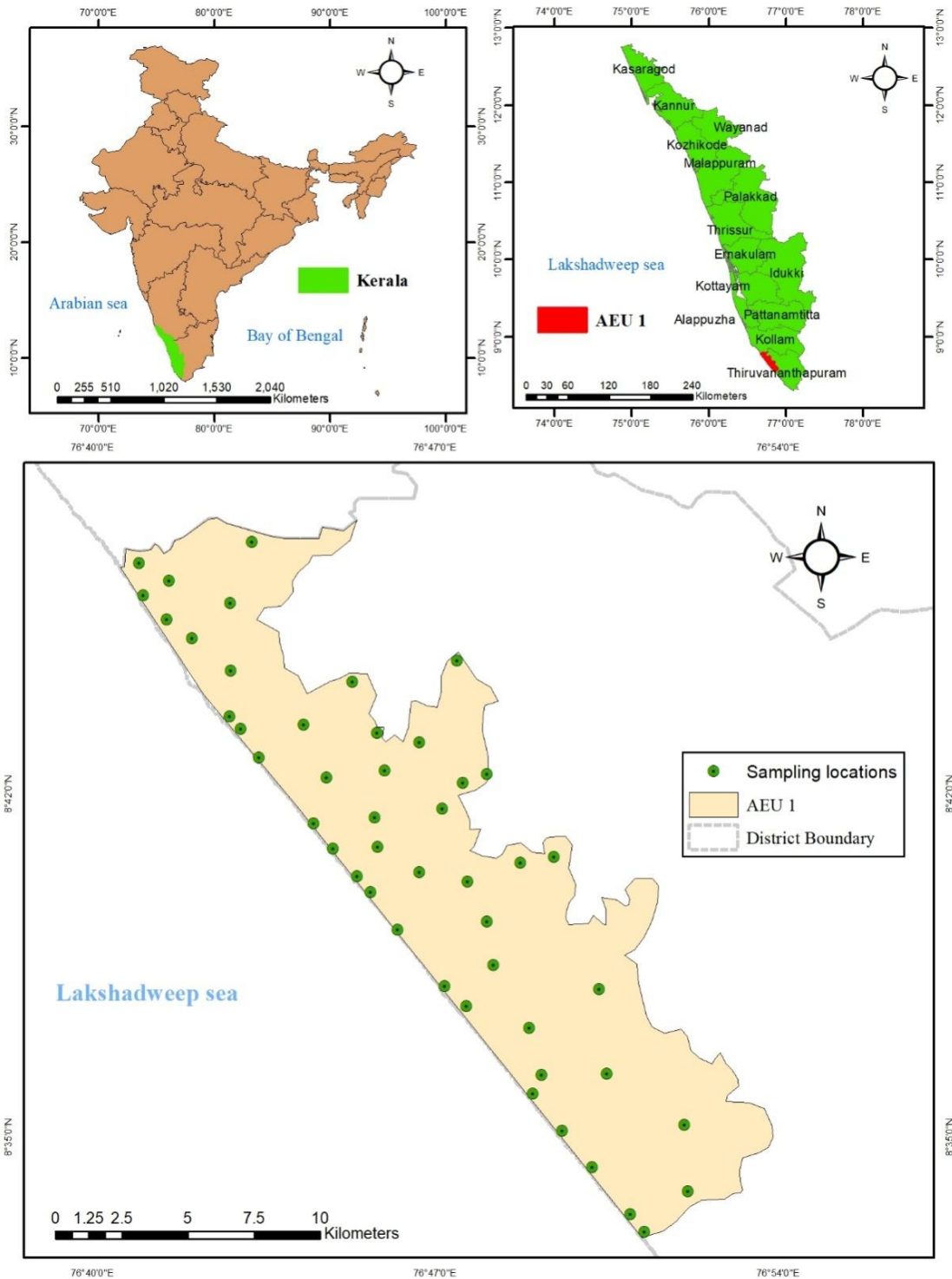


Fig. 1. Sampling locations of Southern Coastal Plains in AEU 1 of Thiruvananthapuram district

Soil texture analysis was done using Bouyoucous hydrometer method [5]. Bulk density [6] and maximum water holding capacity [7] were examined using undisturbed core samples. Particle density was determined by pycnometer method [8], while soil aggregate stability was done by Yoder's wet sieving method [9]. Soil pH and electrical conductivity were measured in 1:2.5 soil water suspension using a pH meter (Systronics, Digital pH meter 335) and EC meter (Systronics, Conductivity meter 304), respectively [10]. Soil CEC was determined by saturation with ammonium ions [11] and exchangeable acidity was by potassium chloride extraction method [12].

The wet oxidation method by Walkley and Black [13] was used to measure soil organic carbon content. Available nitrogen was examined by alkaline permanganate method [14], and available phosphorus was analysed using Bray No. 1 solution and determined using spectrophotometer (Systronics, VIS Double beam spectro 1203) [15]. Available potassium was analysed using flame photometer (Systronics, Flame photometer 130) after extraction with neutral normal ammonium acetate [10]. Determination of available calcium and magnesium were done by versenate titration method [16] and available sulphur was extracted using calcium chloride and estimated using spectrophotometer [17], while available boron was done by hot water extraction and spectrophotometry (Azomethane-H reagent method) [18]. Available micronutrients such as Fe, Cu, Zn and Mn were extracted using 0.1 N HCl and the concentrations were estimated using atomic absorption spectrophotometry (PerkinElmer, Atomic Absorption Spectrometer, PinAAcle 500) [19]. Available Na was detected by flame photometry, while Cl was done by Mohr method of argentometric titration against standard silver nitrate solution [20]. Biological analyses of dehydrogenase activity was determined by colorimetric estimation of TPF hydrolysed [21], while the chloroform fumigation-extraction method was employed for microbial biomass carbon estimation [22].

2.2 Setting up of a Minimum Data Set for Assessment of Soil Quality

Soil quality index was arrived mainly through three steps which includes (i) selection of the relevant indicators to form a minimum data set (MDS), (ii) scoring of indicators on the basis of performance in soil functions and (iii) combining

the scores of indicators and calculation of soil quality index [23].

A minimum data set (MDS) for soil properties was developed using principal component analysis (PCA) [24]. Since it is based on the assumption that the principal components (PCs) obtaining the higher values can best represent the system attributes, only the PCs with eigenvalues greater than 1 were examined. The contribution of each variable to the PC is indicated by the weight or factor loading it received. Only the highly weighted variables (within 10% of the highest factor loading) from each PCs were retained. When more than one variable is present in the PC, linear correlations among them are worked, and if the variables are seen to be highly correlated, the one with highest sum of correlation coefficient (absolute values) is chosen for MDS. Whereas, if the variables are not correlated (coefficient value < 0.60), each one of them is retained [25].

2.2.1 Statistical analysis

Principal component analysis (PCA) was carried out to understand better the complex interactions between the parameters and factors. Also PCA can be represented by generating biplots, which represent the original variables as vectors that summarise the correlations between the variables (Fig. 2). Length of the biplots indicates extent of correlation, while the angles shows its direction. The R-based web application GRAPES was used for principal component analysis [26]. Correlation analysis between various soil properties was also performed to identify any significant correlations.

2.3 Formulation of Soil Quality Index

The soil indicators were transformed into unit-less scores using non-linear scoring function after development of the MDS [23]. Three types of scoring curves have been used: 'more is better', 'less is better' and 'optimum' curve [27,28] and the soil parameters were divided into three groups – (i) more is better (e.g. organic carbon content, water stable aggregates, dehydrogenase activity, microbial biomass carbon), (ii) less is better (e.g. bulk density) and (iii) optimum (e.g. pH, soil moisture).

Soil quality index (SQI) was worked out using the weighted additive method [24] as:

$$SQI = \sum W_i \times S_i$$

Where, W_i and S_i are the weighted factor and scores respectively.

The change of soil quality was determined by computing the relative soil quality index (RSQI) [29] using the formulae:

$$RSQI = (SQI/SQIm) \times 100$$

Where, SQI is the computed soil quality index and SQIm is the theoretical maximum. Then each sampling location were rated based on the RSQI value as poor (RSQI < 50%), medium (RSQI 50 – 70%) and good (RSQI > 70%) [30].

2.3.1 Generation of maps using geographic information system

GIS based thematic maps were generated using IDW in ArcGIS 10.5.1 software [31] through interpolation. Mapping was done to illustrate the

sampling locations and soil quality index throughout the AEU-1 of Thiruvananthapuram district.

3. RESULTS AND DISCUSSION

3.1 Formulation of Minimum Data Set (MDS)

The minimum data set was produced using Principal Component Analysis (PCA). Six principal components (PCs) with eigenvalues greater than 1 were obtained from PCA and selected for the MDS. The PCs explained the variance in following percentages: 21.28, 13.66, 8.77, 7.96, 7.41 and 6.17 respectively (Table 1). The factor loading of a variable under particular PC gives the contribution of that variable to the PC.

Table 1. Result of principal component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.618	2.323	1.49	1.354	1.259	1.05
% variance	21.281	13.664	8.767	7.964	7.407	6.174
Cumulative variance	21.281	34.945	43.712	51.677	59.084	65.2
Eigenvectors						
pH	14.901	0.06	3.612	1.473	0.168	16.947
EC	4.52	0.929	1.164	8.416	0.132	0.113
B.D.	0.048	10.531	17.356	4.467	3.44	7.265
WHC	0.989	4.865	20.38	10.385	17.254	0.008
Clay %	0.038	1.554	10.115	30.733	1.448	7.572
OC	16.857	0.803	2.423	0.109	8.843	0.62
N	9.491	0.188	15.995	0.496	5.933	8.883
P	1.134	11.588	0.415	5.507	4.679	11.786
K	13.84	0.102	0.073	0.853	0.313	8.484
Ca	9.697	1.939	0.218	0.253	10.591	2.482
Mg	7.838	0.905	1.454	0.077	2.869	1.768
S	12.344	0.367	1.092	0.829	19.175	0.395
B	5.194	0.882	0.481	5.84	23.654	6.281
Fe	1.027	22.174	2.383	0.306	0.003	3.208
Cu	0.525	11.611	14.826	7.352	1.035	6.446
Mn	1.384	29.704	0.037	2.653	0.462	0.115
Zn	0.174	1.798	7.976	20.251	0.001	17.626

Table 2. Minimum data set (MDS) for the assessment of soil quality

PC1	PC2	PC3	PC4	PC5	PC6
Organic carbon	Available Mn	Water holding capacity	Clay %	Available B	Available Zn
pH		Bulk density		Available S	pH
Available K					

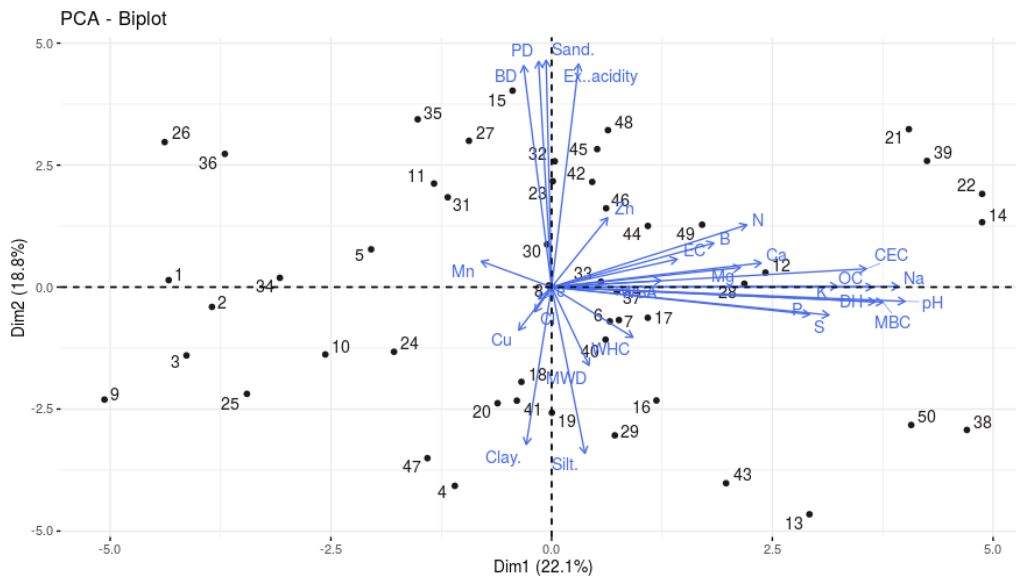


Fig. 2. Principal component analysis biplot with properties of coastal sandy soils of AEU 1, Thiruvananthapuram district

In PCA, arrows with narrow angles are strongly correlated, those with perpendicular angles are not, and those pointing opposite directions exhibit negative correlation. PCs 1 and 2 are denoted by Dim1 and Dim2, respectively

From PC1, organic carbon, soil pH and available K were considered having highest factor loading and each of them had a correlation coefficient < 0.60, so all three were selected for MDS, and from PC2, available Mn was selected. From PC3, water holding capacity and bulk density had the highest factor loading, while from PC4, clay% had the highest loading factor. From PC5, available B and S were selected for MDS. In PC6, available Zn and soil pH were selected. Out of the total six PCs, 10 attributes were selected for MDS (Table 2).

3.2 Formulation of Soil Quality Index (SQI)

3.2.1 Scoring of the parameters

In order to formulate the soil quality index, the parameters in MDS were assigned with appropriate weights based on existing soil conditions and soil nutrient content [32] and each class with proper score [30,33] with slight modifications based on soil fertility ratings for secondary and micronutrients in Kerala soil (Table 3).

In AEU 1, the following was the order in which soil properties contributed to the soil quality index: O.C % > pH = Available K > Clay % =

WHC = available S > bulk density = available Zn = available Mn = available B (Table 3). Each MDS parameter has different impact on soil quality. The order of contribution indicates how each MDS parameter influences the soil quality.

3.2.2 Computation of SQI and Relative soil quality index (RSQI)

Soil quality index (SQI) of the soil samples were computed by weighted additive method, and relative soil quality index (RSQI) of the samples were calculated to study the change in soil quality. The SQI of the soil samples ranged between 185 and 360, with a mean value of 266.9 (Table 4). Value of SQI was found to be maximum (360) in Kadakkavoor and minimum (185) in sample taken from Anchuthengu. RSQI of the samples in Southern coastal plains of AEU 1 ranged from 46 per cent to 90 per cent with a mean value of 66.73 percent (Table 4). Kadakkavoor was observed to have the highest RSQI (90 per cent) and sample from Anchuthengu was observed to have the lowest value (46 per cent). RSQI were then rated as poor (< 50 %), medium (50-70 %) and good (>70 %). 60 percent of the samples had medium soil quality index, followed by 36 percent good and 4 percent poor (Fig. 3).

Table 3. Scoring of the parameters for the computation of soil quality index

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Texture (clay %)	10	Loam	Clay loam / Sandy loam	Sand / Clay	Grit
WHC (%)	10	> 60	50 - 60	30 - 50	< 30
BD (Mg m ⁻³)	5	1.3 – 1.4	1.2-1.3 / 1.4-1.5	1.1-1.2 / 1.5-1.6	< 1.1 / > 1.6
pH	15	6.5 - 7.5	6-6.5 / 7.5-8	5.5-6 / 8-8.5	< 5.5 / > 8.5
O.C (%)	20	> 1	0.9 - 1	0.3 - 0.9	< 0.3
Available K (kg ha ⁻¹)	15	> 280	200 - 280	120 - 200	< 120
Available S (mg kg ⁻¹)	10	> 5.0	2.0 - 5.0	1.0 - 2.0	< 1.0
Available Zn (mg kg ⁻¹)	5	> 1.0	0.5 – 1.0	0.25 - 0.5	< 0.25
Available Mn (mg kg ⁻¹)	5	> 5.0	2.0 - 5.0	1.0 - 2.0	< 1.0
Available B (mg kg ⁻¹)	5	> 0.5	0.25 - 0.5	0.1 - 0.25	< 0.1

Table 4. SQI and RSQI of coastal sandy soils of AEU 1, Thiruvananthapuram district

Parameters→	Soil quality index		Relative soil quality index (%)	
	Range	Mean ± SD	Range	Mean ± SD
AEU 1	185 – 360	266.9 ± 37.69	46.25 – 90	66.73 ± 9.43

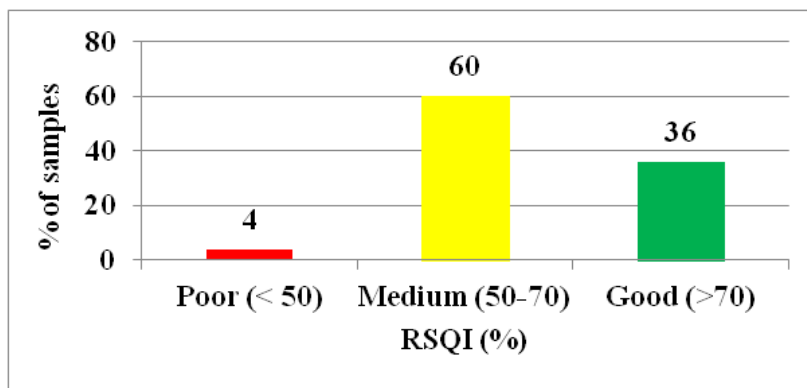


Fig. 3. Frequency distribution of relative soil quality index in the soils of AEU 1

3.2.3 Generation of maps using geographic information system

Using the GIS technique, geo-referenced thematic map of relative soil quality index of the southern coastal sandy soils of AEU 1 was created (IDW in ArcGIS) after the assessment of SQI. Spatial distribution of relative soil quality index in soils of AEU 1 is depicted in Fig. 4.

3.3 Correlation Analysis of the Data

Pearson’s Correlations were worked out for physical, chemical and biological parameters

among the analysed soil samples (Fig. 5) [34]. Positive correlations were found between the sand per cent, bulk density and particle density. Clay per cent was seen to be highly positively correlated with the per cent of WSA and WHC. Organic content in the soils was positively correlated with WSA and WHC, while sand per cent in the samples were negatively correlated with both WSA and WHC. Negative correlations were found between silt per cent and the bulk density and particle density.

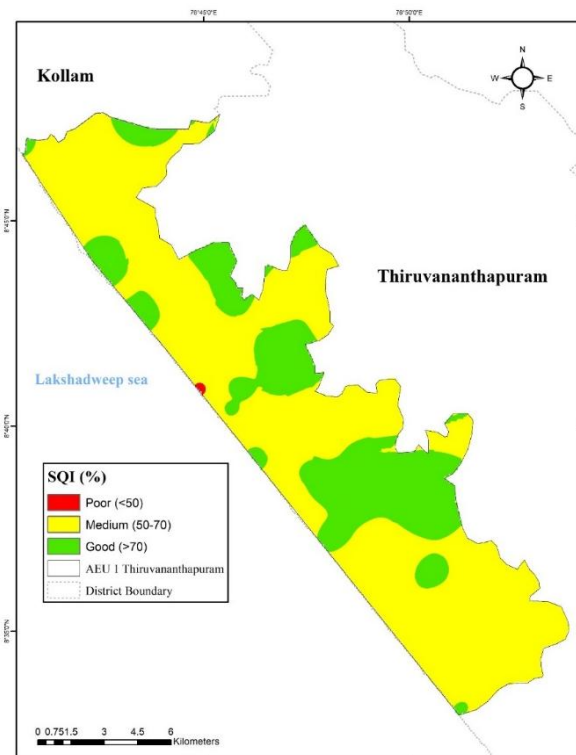


Fig. 4. Spatial variability of RSQI in AEU 1, Thiruvananthapuram district

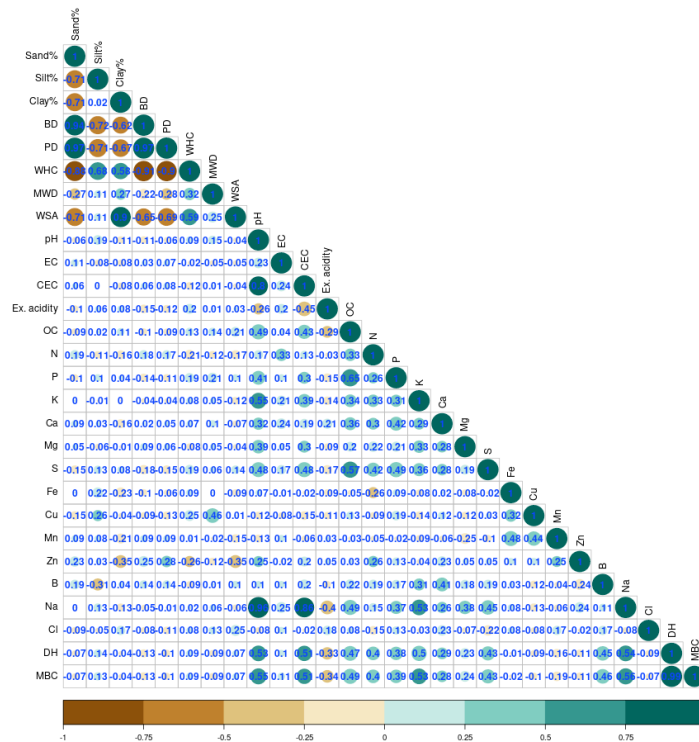


Fig. 5. Correlogram showing Pearson's correlations between the various properties of coastal sandy soils of AEU 1, Thiruvananthapuram district

Blue and brown represents positive and negative correlations, respectively. The size of circle indicate the strength of correlation (r) ($p \leq 0.5$)

In case of the chemical parameters, positive correlations were observed among OC and N, OC and Mg, OC and S, N and K, S and Fe, S and Mn, Fe and Mn, and CEC and K. Parameters like pH and Fe, and N and Cu were negatively correlated. The biological attributes such as dehydrogenase (DH) activity and microbial biomass carbon (MBC) were observed to be positively correlated with soil organic carbon content.

4. CONCLUSION

The results of soil quality analyses conducted in southern coastal sandy soils of AEU 1 in Thiruvananthapuram district can be considered as a base for further modifications and recommendations in the crop management practices to be followed in the area. More organic matter additions have to be encouraged in the cultivation practices so that the physical constraints of soil, along with chemical and biological constraints of the coastal sandy soil can be minimized. Despite the fact that majority of soils belong to medium soil quality class, due to the inherent drawbacks associated with the coastal sandy soils, it is still essential to use site and crop-specific management strategies as well as fertilizer application that is based on soil tests in order to grow crops profitably. It is mandatory to improve and maintain the soil health for sustainability of the environment.

ACKNOWLEDGEMENTS

The authors hereby acknowledge the research facilities and funding provided by Kerala Agricultural University.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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