Original Research Article

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

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 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 was found to be highest in Kadakkavoor and lowest in Anchuthengu. Further, the locations were classified into three groups namely poor, medium, and good, based on relative soil quality index (RSQI). Less than 50% of the RSQI is considered poor, from 50% to 70% is medium, while more than 70% is considered good, with 60% of samples in AEU 1 of Thiruvananthapuram district coming under 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 (SiO_2), 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. MATERIAL 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 0-15 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.

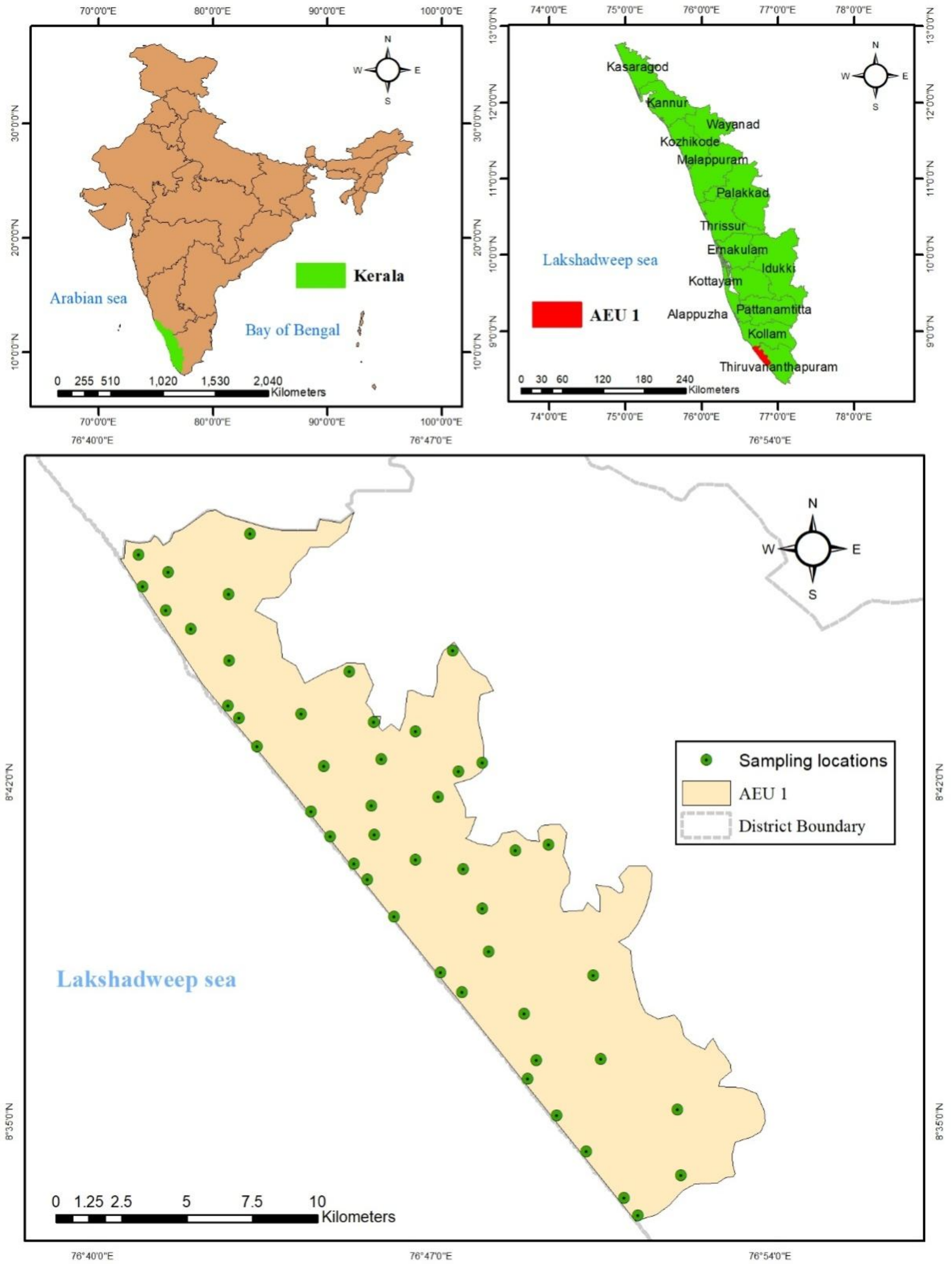

Fig. 1. Sampling locations of Southern Coastal Plains in AEU 1 of Thiruvananthapuram district

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 photometery, 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 it’s 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 (eg. organic carbon content, water stable aggregates, dehydrogenase activity, microbial biomass carbon), (ii) less is better (eg. bulk density) and (iii) optimum (eg. pH, soil moisture).

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

$SQI = \sum Wi \times Si$

where, Wi and Si 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 ArcGIS 10.5.1 software 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**

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).

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					

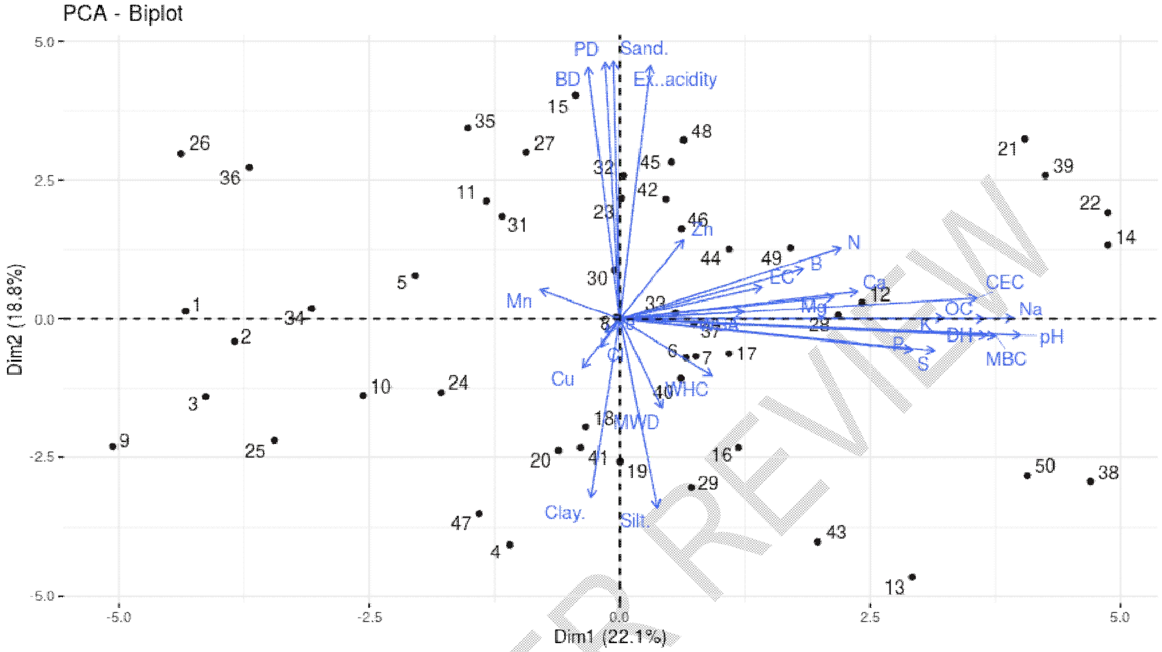

Fig. 2. Principal component analysis biplot with properties of coastal sandy soils of AEU 1, Thiruvananthapuram district. In PCA, arrows with narrow angles are strongly correlated, those with perpendicular angles are not, and those pointing opposite directions exhibit negative correlation. PCs 1 and 2 are denoted by Dim1 and Dim2, respectively.

3.2 Formulation of Soil Quality Index (SQI)

3.2.1 Scoring of the parameters

Inorder to formulate the soil quality index, the parameters in MDS were assigned with appropriate weights based on existing soil conditions and soil nutrient content [31] and each class with proper score [30,32] with slight modifications based on soil fertility ratings for secondary and micronutrients in Kerala soil (Table 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

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 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

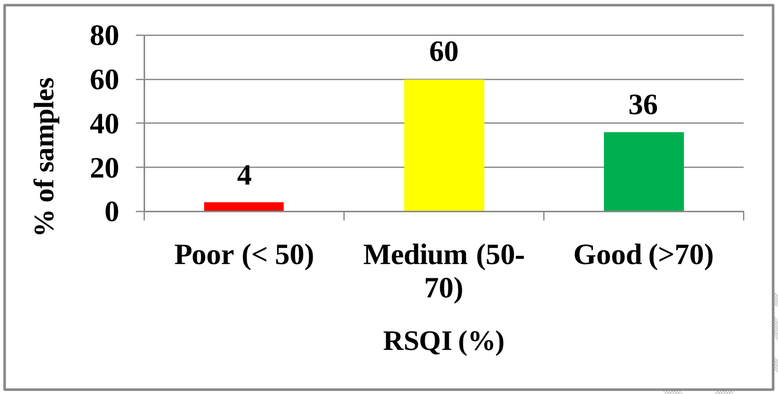

Fig. 3. Frequency distribution of relative soil quality index in the soils of AEU 1

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 (ArcGIS) after the assessment of SQI. Spatial distribution of relative soil quality index in soils of AEU 1 is depicted in Fig.4.

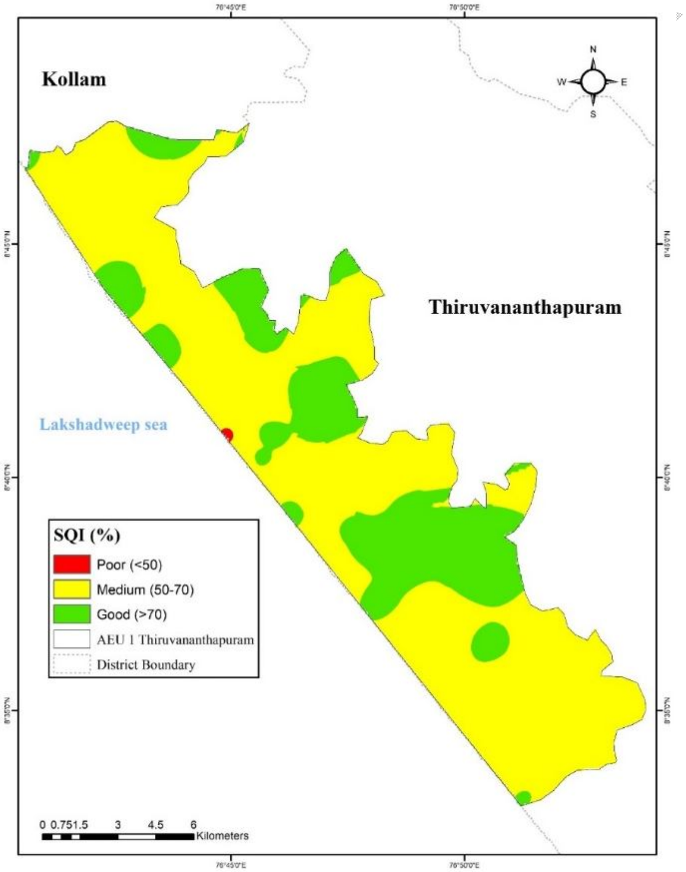

Fig. 4. Spatial variability of RSQI in AEU 1, Thiruvananthapuram district

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) [33]. 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.

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.

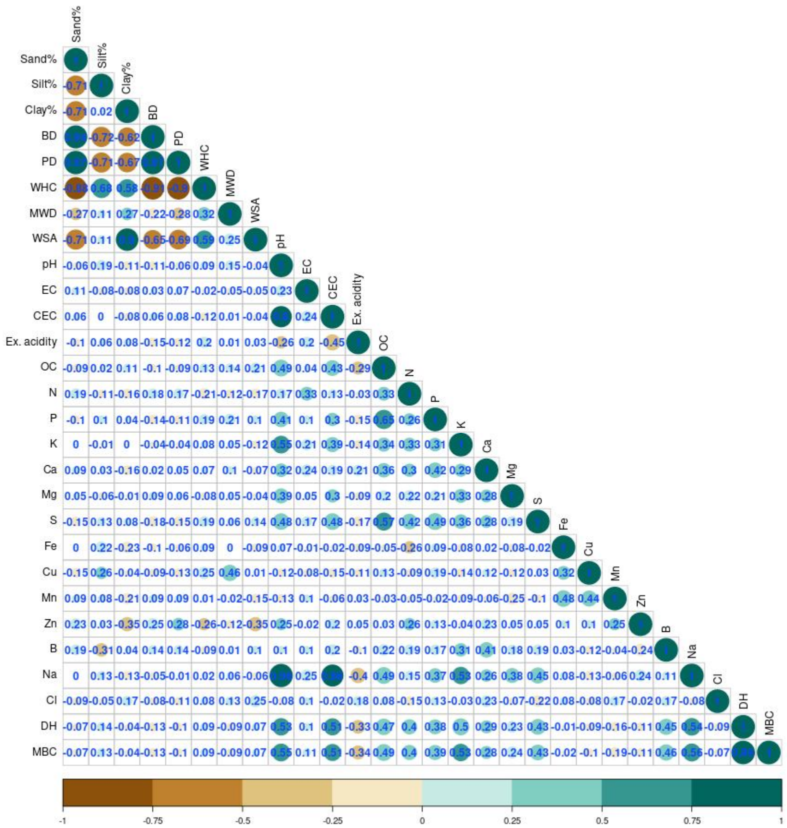

Fig. 5. Correlogram showing Pearson's correlations between the various properties of coastal sandy soils of AEU 1, Thiruvananthapuram district. Blue and brown represents positive and negative correlations, respectively. The size of circle indicate the strength of correlation (r) ($p \leq 0.5$).

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.

REFERENCES

1. Parry ML, Canziani O, Palutikof J, Van der Linden P, Hanson C, editors. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC. Cambridge University Press: Cambridge, UK; 2007.

2. Ismail SM, Ozawa K. Improvement of crop yield, soil moisture distribution and water use efficiency in sandy soils by clay application. Appl. Clay Sci. 2007; 37(1-2):81-89. doi: 10.1016/j.clay.2006.12.005

3. Havlin JL, Beaton JD, Tisdale SL, Nelson WL. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 7th ed. Pearson Educational Inc.: New Jersey; 2005.

4. Hoang TTH. Soil characteristics, cropping patterns, and use of organic resources in the coastal sandy area of Thua Thien Hue province, Central Vietnam. PhD Thesis. Université catholique de Louvain, Louvain-la-Neuve, Belgium; 2008.

5. Bouyoucos GJ. Directions for making mechanical analyses of soils by the hydrometer method. Soil Sci. 1936; 43(3):225-230.

6. Blake GR. Bulk density. In: Black CA. Methods of soil analysis part 1, physical and mineralogical properties, including statistics of measurement and sampling. Soil Science Society of America; 1965.

7. Dakshinamurthi C, Gupta RP. Practicals in Soil Science. I.A.R.I: New Delhi; 1968.

8.Vadyunina AF, Korchagina ZA. Methods of Studying Soil Physical Properties. Agropromizdat: Moscow; 1986.

9. Yoder RE. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Agron. J. 1936; 28(5): 337-351.

10. Jackson ML. Soil Chemical Analysis. Prentice Hall of India Ltd.: New Delhi; 1973.

11. Amma MK. Plant and Soil Analysis. Rubber Research Institute: Rubber Board, Kottayam, Kerala, India; 1989.

12. Sarma VA, Krishnan P, Budihal SL. Laboratory methods. NBSS pub. 14. Technical bulletin, National Bureau of Soil Survey and Land Use Planning: Nagpur. 1987; 49.

13. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934; 37(1):29-38.

14. Subbiah BV. A rapid procedure for the determination of available nitrogen in soils. Curr Sci. 1956; 25:259-260.

15. Bray RH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 1945; 59(1): 39-46.

16. Hesse PR. A Textbook of Soil Chemical Analysis. John Murray Publishers Ltd.: London; 1971.

17. Massoumi A, Cornfield AH. A rapid method for determining sulphate in water extracts of soils. Analyst. 1963; 88(1045): 321-322. doi: 10.1039/AN9638800321

18. Gupta UC. Effects of boron and limestone on cereal yields and on B and N concentration of plant tissue. Plant Soil. 1977; 47:283-287.

19. Sims JT, Johnson GV. Micronutrient soil tests. *Micronutr. Agric*. 1991; 4:427-476. https://doi.org/10.2136/sssabookser4.2ed.c12

20. Doughty HW. Mohr's method for the determination of silver and halogens in other than neutral solutions. *J. Am. Chem. Soc*. 1924; 46(12): 2707-2709. https://doi.org/10.1021/ja01677a014

21. Casida Jr LE. Microbial metabolic activity in soil as measured by dehydrogenase determinations. Appl. Environ. Microbiol. 1977; 34(6): 630-636. doi: 10.1128/aem.34.6.630-636.1977.

22. Jenkinson DS, Ladd JN. Microbial biomass in soil. Measurement and turn over. In: Paul EA, Ladd JN, editors. Soil Biochemistry 5. Marcel Dekker Inc.: New York; 1981.

23. Andrews SS, Mitchell JP, Mancinelli R, Karlen DL, Hartz TK, Horwath WR, Pettygrove GS, Scow KM, Munk DS. On-farm assessment of soil quality in California's Central Valley. Agron. J. 2002; 94(1): 12-23. https://doi.org/10.2134/agronj2002.1200

24. Doran JW, Parkin TB. Defining and assessing soil quality. Defining Soil Qual. Sustain. Environ. 1994; 35: 1-21. https://doi.org/10.2136/sssaspecpub35.c1

25. Andrews SS, Caroll CR. Designing a soil quality assessment tool for sustainable agroecosystem management. Ecol. Appl. 2001; 11(6):1573-1585. https://doi.org/10.1890/1051-0761(2001)011[1573:DASQAT]2.0.CO;2

26. Gopinath PP, Parsad R, Joseph B, Adarsh VS. GRAPES: General R-shiny Based Analysis Platform Empowered by Statistics. 2020. Accessed 14 February 2023. Available: https://www.kaugrapes.com/home

27. Bastida F, Moreno JL, Hernandez T, Garcia C. Microbiological degradation index of soils in a semiarid climate. Soil Biol. Biochem. 2006; 38(12): 3463-3473. https://doi.org/10.1016/j.soilbio.2006.06.001

28. 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. https://doi.org/10.1016/j.ecolind.2016.12.049

29. Karlen DL, Stott DE. A framework for evaluating physical and chemical indicators of soil quality. Defining Soil Qual. Sustain. Environ. 1994; 35:53-72.doi:10.2136/sssaspecpub35.c4

30. Kundu S, Coumar MV, Saha JK, Rajendiran S, Hati KM, Biswas AK, Reddy KS, Rao AS. Assessing soil health of vertisol of AESR 10.1 using selected physical, chemical and biological attributes of soils. *J. Indian Soc. Soil Sci.* 2012; 60(4): 281-287.

31. Singh AK, Mazumdar SP, Saha AR, Kundu DK. Soil quality changes resulting from long-term fertilizer application under intensive cropping system in alluvial soils. Commun. Soil Sci. Plant Anal. 2017; 48(13):1503-1510. https://doi.org/10.1080/00103624.2017.1373790

32. Mukherjee A, Lal R. Comparison of soil quality index using three methods. PloS one 2014; 9(8): e105981. doi: 10.1371/journal.pone.0105981

33. Pearson ES. The test of significance for the correlation coefficient. . J. Am. Statistical Assoc. 1931; 26(174):128-134.