Original Research Article

Assessment of Soil Quality and Nutrient index in Agroecological Unit 7 of Kerala and Mapping using GIS

ABSTRACT

Aims: Soil quality assessment is valuable for agricultural production. In this study, 150 soil samples at two soil depths were collected from Kaipad land (Agroecological unit 7) of Kerala to assess the quality and nutrient index.

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Study design: Survey, collection of sample and principal component analysis.

Place and Duration of Study: Department of Soil Science and Agricultural Chemistry, between 2020 and 2021.

Methodology: Soils were analyzed for physical, chemical and biological indicators for evaluating soil quality, fertility and thematic maps were prepared using geographical information system (GIS). Principal component analysis (PCA) was carried out with ~~thirteen~~ 13 soil parameters to compute the soil quality index which resulted in 6 principal components and a minimum data set (MDS) of nine parameters (pH, EC, organic carbon, available N, Mg, K, B, P and Zn) with eigen values greater than 1.

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Results: The results revealed that the Kaipad soils (AEU 9) are sandy clay loam in texture, extreme to strong acid condition (pH 3.5- 5.0), high in organic carbon, low in available N and K, medium in available P, deficient in available Ca, Mg and B. Majority (88%) of the soils are rated medium in soil quality. Relative soil quality index ranged between 47.5 and 76.3 per cent in the Kaipad soils with a mean of 61.0 per cent.

Conclusion: The soils of Kaipad (AEU 7) under different agricultural land uses experiences various constraints to crop production like extremely acidic pH, high EC, nutrient deficiencies of N, K, Ca, Mg, B and toxicities of Fe and Al. Examining relationships of parameters, and analyzing principal components indicated that nine parameters have significantly contributed to the SQI. Soil pH, EC, organic carbon, nutrients N, Mg, K, P, Zn and B are the important key indicators of soil quality. The soil quality can be enhanced by managing the soil pH through regular liming, addition of organic amendments and application of N, P, K, Ca, Mg, Zn and B containing fertilizers.

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Keywords: Kaipad; hydromorphic soils; acid saline soil; soil quality index; GIS mapping

1. INTRODUCTION

Soil quality, like air or water quality, has an impact on the environment's health and agriculture production. Soil quality is the ability of soil to provide nutrients to plants, maintain and improve water and air within the soil, and support human needs [1]. Unfortunately, soil quality is rapidly decreasing in many regions around the world. There are many reasons leading to soil quality deterioration, including changes in land use types from forest to arable land [2]and the consequences from intensive land use [3]. The capacity of soil to support plant growth could be measured and used for assessing sustainability of resources by assessment of soil quality.

Soil quality assessment includes a variety of sensitive physical, chemical, and biological characteristics that represent the soil's current functioning status. Soil quality evaluation gives an opportunity to redesign land and soil management systems for improved agricultural productivity by providing a framework for assessing the sustainability of various land use regimes. The technologies such as remote sensing (RS), geographic information systems (GIS) and global positioning systems aid in the collection of data on agricultural operations, such as land - use/land - cover, weather conditions, soil conditions and other factors that are critical for site characterization and help in determining soil quality and land suitability for farming [4]. Arriving at proper soil quality index (SQI) and nutrient index (NI) can help to determine the degraded soil properties and help in proper interpretation of soil resources for growing crops, apart from developing fertilizer recommendations [5].

The hydromorphic acid saline soils are common in Kerala and are found near thecoastal tracts of the state in the districts of Ernakulam, Alleppey, Thrissur and Kannur [6]. Kaipad ecosystem which belongs to agroecological unit (AEU) 7 occurring along the coast of Kozhikode, Kannur and Kasargod districts as isolated stretches of water-logged lands is one among these soils in Kerala. The climate of Kaipad is tropical humid monsoon type and these low lands often lie below sea level without any protection against sea water inundation there by the soils become acid saline [7]. These soils are developed from alluvial and marine sediments containing sulphur bearing minerals. The soils developed from these sediments are very deep, acidic and saline, often underlain by potential acid sulphate soils.

This unique ecosystem has a great potential to contribute to food, nutritional, livelihood and water security, bio-diversity and environmental protection. The deterioration of soil quality is a threat to this ecosystem and the farming practices. Soil quality studies have not been carried out for this area. Therefore, the present investigation was made asses the quality and nutrient index of Kaipad soils and to map their spatial variation for planning and development activities.

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2. MATERIAL AND METHODS

Study area

A study was conducted in the Kaipad lands (AEU-7) of Kannur, Kasargod and Kozhikode districts of Kerala to assess the soil quality indicators, to compute soil quality index (SQI), nutrient index (NI) and to generate thematic maps using GIS. The study area lies between 11.25° and 12.5° N latitude, 75.77° and 75.0° E longitude. Kaipad lands are distributed in Quilandy municipality of Kozhikode district, Kalliassery block of Kannur district and Neeleswaram block of Kasargod district, covering a total area of 24,209 ha spreading over 16 panchayaths [7]. This region experiences tropical humid monsoon type of climate with a mean annual temperature of 27.3°C and rain fall 3254 mm [8].

Survey and collection of soil sample

A survey was conducted in the study area to identify locations for the collection of soil samples. Georeferenced surface (0-15 cm depth) and sub surface (15-30 cm depth) soil samples were collected from 120 sites (Fig.1) from different agricultural land use systems viz. rice, rice– shrimp, mangrove, coconut and fallow. Kaipad land (AEU 7) belongs to the soil order fine, mixed, iso hyperthermic, Typic or Aquic Ustifluvents including the soil series Narikott, Ezhome, Nileswaram, Hosdurg, Thekkila, Elathur and Chelapram [9]. With the help of GPS, geographical coordinates of each sample site are recorded and used for GIS mapping. The soil samples were shade dried, powdered with wooden pestle and mortar, sieved through a 2mm sieve and stored for analysis.

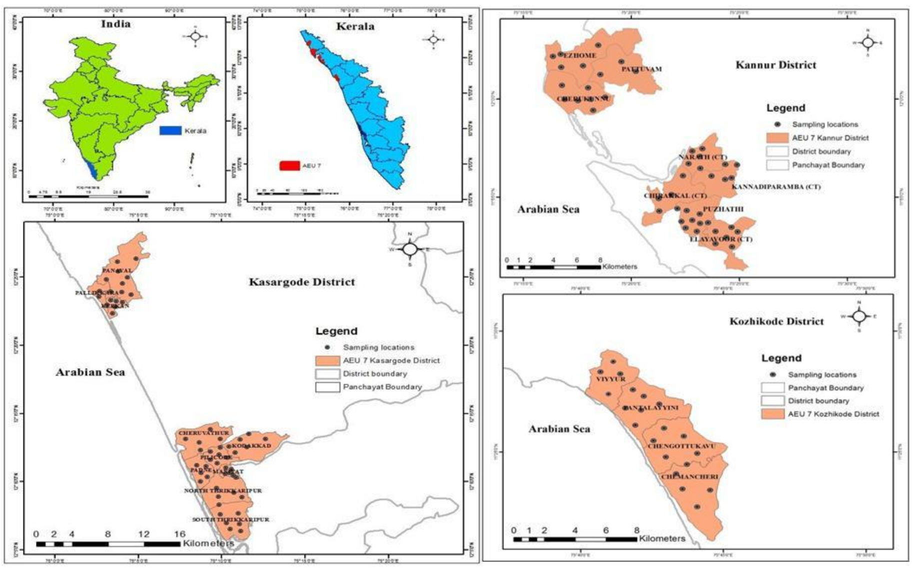

Fig. 1. Location map of study area and soil sampling sites in Kaipad (AEU 7)

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Characterization of soil

Soil samples collected from Kaipad area (AEU 7) were characterized for physical, chemical and biological indicators of soil quality using standard procedures. Bulk density and maximum water holding capacity were analysed by core method, pH and EC (soil - water ratio of 1:2.5) using pH and EC meter respectively, organic carbon by wet oxidation method, available nitrogen by alkaline permanganate method, available phosphorus by colorimetric method , available potassium by neutral normal ammonium acetate extraction followed by flame photometry method, available calcium and magnesium by versanate titration method , available boron by azomethane H reagent method, available sulphur by $CaCl_2$ extraction followed by spectroscopy and available zinc by atomic absorption spectroscopy.

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Principal component analysis to assess soil quality

To assess soil quality index (SQI), 13 soil parameters were considered and tested for significance based on the PC analysis as described by [10]. using SPSS software. The PCs which had eigen values of more than one [11] and explained more than 5% variation in data and only highly weighted factors having absolute loading values of more than 0.60 were considered for minimum data set (MDS). The variables qualified under these series of steps were termed as 'key indicators' and considered for deriving SQI after suitable transformation and scoring.

All observations of each identified key MDS indicators were transformed using linear scoring technique. To assign scores, indicators were arranged in the order depending on whether a higher value was considered "good" or "bad" in terms of soil function.

After transformation using linear scoring, MDS indicators for each observation were weighted using PC analysis results. Each PC explained certain amount of variation (%) in the total data set. This variation when divided by total variation explained by all PCs with eigen vectors more than 1, gave weighted factors for indicators chosen under given PC. After performing these steps, to obtain SQI, weighted MDS indicator scores for each observation were summed up using the function.

$$SQI = \sum_{i=1}^{n} (W_i \times S_i)$$

In this relation, S_i is the score for the subscripted variable and W_i is the weighing factor obtained from PC analysis. The assumption is that, higher index scores indicated better soil quality or greater performance of soil function. For better understanding and relative comparison, SQI values were reduced to a scale of 0-1 by dividing SQI values with highest SQI value. The numerical values thus obtained, reflect the relative performance of soils, and hence were termed as 'Relative soil quality index' (RSQI). Mean scoring values of MDS were then expressed in percentage to explain their respective contribution to the SQI. RSQI of each sampling location was classified as poor (RSQI < 50%), medium (RSQI 50% - 70%) and good (RSQI > 70%) [12]. Nutrient indices were calculated for soil organic carbon, available nitrogen, available phosphorus and available potassium to evaluate soil fertility using the equation given by [13]. Based on nutrient index ratings given by [14] soils of the study area were classified as high (>2.33), medium (1.67-2.33) and low (<1.67).

Generation of maps using Geographic Information System

GIS-based thematic maps for soil quality and nutrient index were created through interpolation, using ArcGIS 10.5 software following Inverse Distance Weighting (IDW) method, a spatial analyst tool in ArcGIS software. This method assumes that as the distance from the sample point increases, the influence of the value of the variable being mapped decreases [15]. A weighting value and values at defined points are used to determine the values at unknown sites. The distance between the known and unknown sites, as well as the total number of sampling points, are used to calculate weights [16].

The soil analysis data was loaded into MS Excel, converted to a CSV (Comma delimited) file, then imported into the ArcGIS mapping software. The mapping software also imported a shape file containing the boundaries of sampled area. From the spatial analyst tool, IDW was chosen. In the IDW dialogue box, longitude, latitude, and soil attribute values were selected as x, y, and z, respectively, and the processing extent was set to the boundaries of the sampled area. The data was interpolated once the number of sampling points was entered. The resultant map for each parameter was manually categorized using conventional ratings, with distinct colours assigned to each class.

3. RESULTS AND DISCUSSION

The efficiency of soils to supply nutrients for crop growth, apart from maintenance of soil physical conditions to optimize yield is one of the important components of soil fertility or quality that would determine the productivity of agricultural system. Hence, the results of physical, chemical and biological indicators of soil quality based on samples taken from Kaipad land (AEU 7) are described, SQI and NI are computed and GIS maps are prepared.

Assessment of Soil quality indicators

Bulk density of the soils of AEU 7 varied from 1.05 Mg m^{-3} to 1.16 Mg m^{-3} in suface (0-15 cm) and increased with depth 1.20 to 1.31 in subsurface (15-30 cm). Bulk density is a dynamic property of a soil that varies with organic matter content in soils, soil texture, constituent minerals and porosity [17]. Lower bulk density observed in the surface soil than subsurface is due to the presence of higher amount of organic matter in the top layer. The maximum water holding capacity ranged from 22.0 to 70.0 and 33.8 to 76.4 per cent in surface and subsurface soils respectively (Table 1). Higher soil organic carbon and clay content improved the water holding capacity of soil due to improved soil structure resulting in better porosity [18].

The pH ranged between 3.80 and 6.64 in the surface soil of AEU 7 with a mean of 4.84. An increase in the pH of 4.4 to 6.9 (mean value of 5.12) was observed in the sub surface soil. Majority of samples (45.20 per cent) showed extremely acid pH (3.5-4.5) followed by 23.0 percent very strongly acid pH (4.5-5.0). [19] reported that the presence of pyrites in the soils of low lying areas which undergo oxidation and produce sulphuric acid which increases acidity. Moreover, a low level of calcium and magnesium in the soils also contributes to the lower soil pH. Moderately acid,slightly acid and neutral pH was observed in some areas which may be due to lime shell depositions as a result of sea water intrusion. Electrical conductivity a measure of salt concentration in soil varied between 1.40 and 8.52 with a mean of 5.65 dS m^{-1} in the surface soil, while it ranged between 0.04 and 5.00 dS m^{-1} with a mean of 1.46 dS m^{-1} in the subsurface soil (Table 1). The higher EC values (>2 dS m^{-1}) observed may be attributed to the accumulation of salts due to the intrusion of sea water in low lying areas. The lower EC values obtained can be attributed to the washing away of salts during rains.

The organic carbon content varied from 0.39 to 3.68 per cent in the surface soil and it decreased in subsurface (0.31 to 3.13 per cent) (Table 1). Majority of samples (57.10 per cent) were high (>1.5 per cent) in organic carbon followed by 42.1 per cent in the medium range (0.50-1.50 per cent) which is in line with the previous observations [20]. The continuous addition of organic matter through crop residues, rice residues (stubbles and roots), the remnants of rice shrimp cultivation practiced in Kaipad during high saline regime and presence of diverse flora and fauna contribute to high organic carbon status.

The available N content in soil varied from 87.8 to 351 kg ha^{-1} and 75.4 to 326 kg ha^{-1} in the surface and subsurface layer respectively (Table 1). It was found to be low (< 280 kg ha^{-1}) for 94.4 per cent of samples which can be due to the low mineralization of organic matter in the extremely acidic environment. The available phosphorus content varied between 4.20 and 149 kg ha^{-1} in top soil and the availability increased with depth. The available P content of 27.1 to 170.1 kg ha^{-1} was noticed in the 15-30 cm depth of soil (Table 1). It was rated medium (10-24 kg ha^{-1}) for 41.30 per cent of the samples analysed, followed by high for 32.5 per cent and low for 26.2 per cent samples. The variation in P availability might be due to buildup of phosphorus in soil from high levels of phosphorus fertilization and through deposition of phosphates from the sea water. Deficient levels of phosphorus (<10 kg ha^{-1}) is attributed to the increased soil acidity which adversely affects phosphorus availability. The available K content varied between 33.6 and 526 kg ha-1 in 0-15 cm depth of soil and 77 to 374 kg ha-1 in 15-30 cm depth of soil (Table 1). The 46.0 per cent of the samples tested were low (< 115 kg ha^{-1}) in available K closely followed by 42.9 per cent samples in the medium range (115 to 275 kg ha^{-1}). Potassium being a mobile element is easily leached from the soil there by reducing the levels of plant available potassium in soil.

The soils of Kaipad was deficient in exchangeable calcium (Ca) and magnesium (Mg) with mean of 283 and 35.8 mg kg^{-1} in the top 15-30 cm layer (Table 1). In the subsurface layer the concentration of Ca and Mg increased 315 and 97.4 mg kg^{-1} respectively. The 61 per cent of samples tested were deficient in plant available calcium (< 300 mg kg^{-1}) and all the samples were deficient in plant available magnesium (<120 mg kg^{-1}). The basic cations like calcium and magnesium will be leached from soils in rain water. Magnesium was lower than Calcium because of higher mobility. These results are in conformity with the findings of [21]. [22] reported that calcium and magnesium are not dominant in the exchange complex soils of Kaipad. The available S content varied between 11.2 and 248 mg kg^{-1} in the surface soil, 15.6 and 326 mg kg^{-1} in the subsurface and was found to be sufficient. The presence of sulphur containing minerals like pyrite and jarosite might have contributed to the higher levels of available sulphur in soil.

The available zinc content varied between 4.60 and 25.9 mg kg^{-1} in the 0-15cm depth and it decreased in 15-30 cm depth (1.1-9.0 mg kg^{-1}). The Zn concentrations was found to be sufficient for all the samples. The higher content of Zn can be attributed to the extremely acidic nature of the soils. Available boron content varied between 0.06 and 1.39 mg kg^{-}with a mean of 0.56 mg kg^{-1} in the top 0-15 cm depth of soil and was found to be decreased in the lower 15-30 cm depth (0.05-0.33 mg kg^{-1} with a mean value of 0.22 mg kg^{-1}) (Table 1). Available B was deficient for 53.2 per cent and sufficient for 46.8 per cent of samples. Boron is highly mobile in soil and hence easily leached from soil and caused deficiency [23].

Table1. Soil quality parameters of Kaipad land (AEU 7)

Soil properties	Soil depth (cm)	Maximum	Minimum	Mean	SD
Bulk density (Mg m^{-3})	0-15	1.05	1.16	1.12	0.036
	15-30	1.20	1.31	1.28	0.042
Maximum WHC* (%)	0-15	22.00	70.00	34.80	10.80
	15-30	33.8	76.40	48.60	12.30
~~Ph~~pH	0-15	3.80	6.64	4.84	0.68
	15-30	4.40	6.90	5.12	0.76
EC (dS m^{-1})	0-15	1.40	8.52	5.65	1.22
	15-30	0.04	5.00	1.46	0.89
Organic carbon (%)	0-15	0.39	3.68	1.77	0.78
	15-30	0.31	2.13	1.40	0.48
Available nitrogen (kg ha^{-1})	0-15	87.80	351.00	187.00	57.60
	15-30	75.40	326.00	156.00	34.80
Available phosphorus (kg ha^{-1})	0-15	4.20	149.00	31.40	39.00
	15-30	27.10	170.10	76.40	25.30
Available potassium (kg ha^{-1})	0-15	33.60	526.00	150.00	106.00
	15-30	77.00	374.00	182.00	86.50
Available calcium (mg kg^{-1})	0-15	100.00	475.00	283.00	67.80
	15-30	90.00	560.00	315.00	74.50
Available magnesium (mg kg^{-1})	0-15	21.30	43.60	35.80	5.32
	15-30	78.00	132.00	97.40	6.78
Available sulphur (mg kg^{-1})	0-15	11.20	248.00	69.90	46.90
	15-30	15.60	326.00	81.50	23.90

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Available zinc (mg kg^{-1})	0-15	4.60	25.9.00	14.30	5.74
	15-30	1.10	9.00	5.28	0.82
Available boron (mg kg^{-1})	0-15	0.06	1.39	0.56	0.38
	15-30	0.05	0.33	0.22	0.02

**WHC- water holding capacity*

Soil quality index

A weighted soil quality index was developed based on a minimum data set of parameters obtained by principal component analysis. A minimum data set was obtained after analyzing thirteen soil parameters using principal component analysis. The parameters used in PCA were bulk density, maximum water holding capacity, pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Zn and B. The PCA gave six principal components with eigen value greater than 1, which were selected to develop MDS (Table2). These six principle components showed a variance of 12.8 per cent, 10.8 per cent, 10.0 per cent, 9.56 per cent, 8.54 per cent and 8.24 per cent respectively (Fig. 2).

Table 2. Principal component analysis (PCA) of soil quality parameters of AEU 7

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	1.668	1.406	1.306	1.242	1.111	1.071
% variance	12.833	10.816	10.043	9.555	8.547	8.241
Cumulative variance	12.833	23.649	33.692	43.247	51.793	60.035
Eigen vectors	**Loading of variables on PCs**					
EC (dSm^{-1})	-0.454*	-0.061	-0.326	-0.166	-0.091	-0.028
pH	-0.434*	-0.181	0.177	0.144	-0.21	-0.343
OC (%)	-0.439*	0.249	0.385	-0.006	-0.107	0.303
N (kg ha^{-1})	-0.253	0.505*	-0.094	-0.011	-0.006	-0.222
P (kg ha^{-1})	0.247	-0.155	0.107	-0.485*	-0.286	0.274
K (kg ha^{-1})	-0.322	-0.024	0.430*	-0.309	0.191	0.15
S (mg kg^{-1})	0.215	0.292	0.314	-0.006	-0.446	-0.234
Ca (mg kg^{-1})	0.309	0.375	0.147	-0.344	-0.056	-0.165
Mg (mg kg^{-1})	0.01	0.321	-0.397*	0.226	-0.211	-0.061
Zn (mg kg^{-1})	-0.05	0.014	-0.133	0.211	-0.570*	0.599*
B (mg kg^{-1})	0.189	-0.072	0.229	0.477*	0.287	0.233
Bulk density (Mg m^{-3})	-0.033	-0.418	-0.235	-0.305	-0.17	-0.144
Water holding capacity (%)	-0.059	0.335	-0.326	-0.293	0.369	0.351

*Parameters selected for MDS

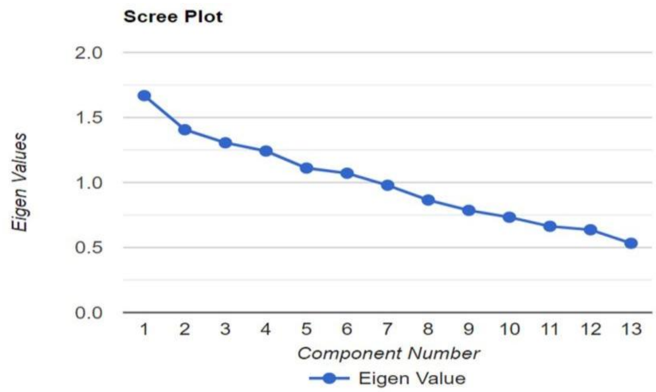

Fig. 2 Scree plot of principal component analysis

In the first principal component (PC), pH, electrical conductivity and organic carbon had the highest factor loading. The highly weighted variable retained in the second PC was available N. Available Mg and K were the variables retained in the third PC. In the fourth principal component, available P and available B were retained. In the fifth and sixth principal components available Zn was the parameter retained (Table 3).

Table 3. Minimum data set (MDS) for the assessment of soil quality in AEU 7

PC1	PC2	PC3	PC4	PC5	PC6
pH	Available N	Available Mg	Available B	Available Zn	Available Zn
Electrical conductivity		Available K	Available P		
Organic Carbon					

The soil quality index and relative soil quality index values ranged between 190 and

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305, 47.5 and 76.3 per cent respectively in the soils of AEU 7 with a mean of 242 for SQI and 61.0 per cent for RSQI (Table 4) . Figure 3 indicated that the soil quality was medium for majority of samples (88.2 per cent) which is attributed to the inherent properties of soil such as acidity, organic carbon content, available nutrient status, type of vegetation and micro climate as reported by [24]. The spatial variabilty of soil quality index is presented in Fig. 4

Table 4. Soil quality index (SQI) and relative SQI (RSQI) of soils of AEU 7

District	Location	SQI		RSQI (%)	
		Range	Mean ± SD	Range	Mean ± SD
Kozhikode	Chemancheri	225-265	240 ± 13.4	56.3 - 66.3	60.0 ± 3.35
	Chengottukavu	240-265	253 ± 9.70	60.0 - 66.3	63.3 ± 2.44
	Panthalayini	200-220	213 ± 7.60	50.0 - 55.0	53.3 ± 1.90
	Viyyur	235-260	242 ± 10.4	58.8 - 65.0	60.5 ± 2.59
Kannur	Cherukunnu	205-300	255 ± 33.4	51.3 - 75.0	63.8 ± 8.35
	Chirakkal	205-290	270 ± 36.9	51.3 - 72.5	67.5 ± 9.23
	Elayavoor	215-280	253 ± 26.6	53.8 -70.0	63.2 ± 6.65
	Ezhome	195-250	226 ± 23.3	48.8 - 62.5	56.5 ± 5.82
	Kannadiparamb	215-275	237 ± 25.1	53.8 - 68.6	59.3 ± 6.29
	Narath	210-305	242 ± 35.0	52.5 - 76.3	60.4 ± 8.76
	Pattuvam	215-280	255 ± 29.7	53.8 - 70.0	63.8 ± 7.43
	Puzhathi	235-270	256 ± 14.6	58.8 - 67.5	64.0 ± 3.66
Kasargod	Cheruvathur	190-255	216 ± 23.1	47.5 - 63.8	54.0 ± 5.78
	Keekan	200-235	222 ± 14.8	50.0 - 58.8	55.5 ± 3.71
	Kodakkad	215-245	236 ± 13.9	53.8 - 61.3	59.0 ± 3.48
	Maniyat	220-305	228 ± 11.7	55.0 - 76.3	56.9 ± 2.93
	Padne	230-295	255 ± 30.8	57.5 - 73.8	63.8 ± 7.71
	Pallikkara	215-275	258 ± 21.4	53.8 - 68.8	64.6 ± 5.34
	Panayal	200-255	245 ± 23.0	50.0 - 63.75	61.3 ± 5.76
	Pilicode	245-285	223 ± 18.1	61.3 - 71.3	55.6 ± 4.52
	Thrikkaripur North	220-250	261 ± 19.8	55.0 - 62.5	65.3 ± 4.95
	Thrikkaripur South	225-265	216 ± 23.1	56.3 - 66.3	59.6 ± 2.58
AEU 7		190-305	242 ± 25.8	47.5 - 76.3	61.0 ± 6.50

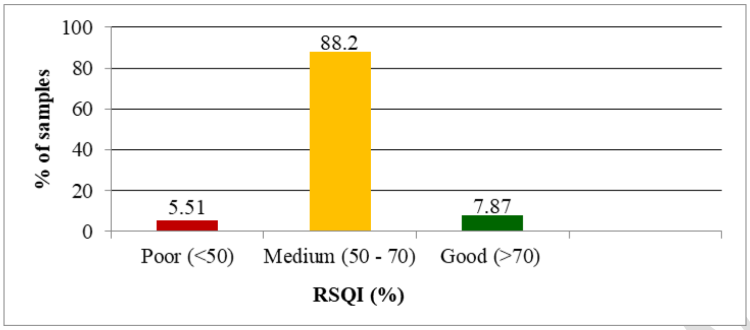

Fig. 3. Frequency distribution of relative soil quality index in the soils of AEU 7

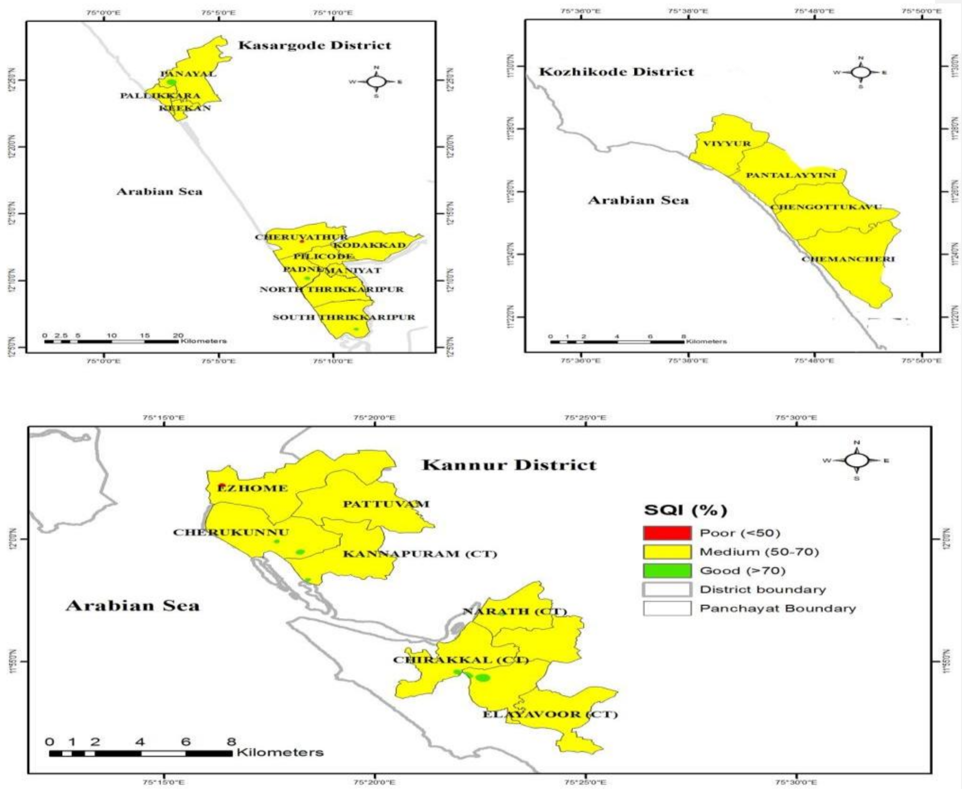

Fig. 4. Spatial variability of SQI in AEU 7

Nutrient Index

Nutrient index value for organic carbon ranged from 2.0 to 3.0 which was found to be high for most of the area. Nutrient index for available nitrogen varied between 1.0 and 1.6, available phosphorus between 1.0 and 2.8 and available potassium between 1.0 and 2.4 (Table 5). Nutrient indices (NI) were high for organic carbon (> 2.33), low for available N (< 1.67), medium for available P (1.67 – 2.33) and low for available K (< 1.67) in AEU 7. This was in accordance with the organic carbon and available primary nutrient status in the study area. High NI for organic carbon can be attributed to the accumulation of organic matter and clay in soil [25]. Low NI for nitrogen can be attributed to the losses of nitrogen that has occurred and also the low mineralization of organic matter in highly acidic soil which requires replenishment for sustaining soil productivity [26]. Medium NI for phosphorus might be due to the buildup of P due to P fertilization and low NI for potassium may be due to the reason that potassium being a highly mobile element it may be easily leached from soil. The spatial variability of nutrient indices of organic carbon, available phosphorus and potassium are depicted in Fig. 5 to 7.

Table 5. Nutrient indices of organic carbon and available primary nutrients in AEU 7

District	Locations	Nutrient index			
		Organic carbon	Nitrogen	Phosphorus	Potassium
Kozhikode	Chemancheri	2.80	1.00	2.60	1.20
	Chengottukavu	3.00	1.00	2.80	1.80
	Panthalayini	2.80	1.00	1.00	1.00
	Viyyur	3.00	1.60	2.00	1.60
Kannur	Cherukunnu	2.55	1.18	2.27	1.73
	Chirakkal	2.00	1.00	2.40	2.20
	Elayavoor	2.14	1.29	1.86	2.43
	Ezhome	3.00	1.00	1.60	2.40
	Kannadiparamb	2.40	1.00	2.00	1.40
	Narath	2.50	1.00	2.17	1.50
	Pattuvam	2.75	1.00	2.00	1.00
	Puzhathi	2.50	1.00	2.33	1.40
Kasargod	Cheruvathur	2.00	1.00	2.00	1.17
	Keekan	2.40	1.00	1.80	1.40
	Kodakkad	3.00	1.00	1.50	2.00
	Maniyat	2.83	1.00	2.00	1.33
	Padne	2.40	1.00	2.60	1.00
	Pallikkara	2.00	1.00	2.25	1.83
	Panayal	2.50	1.00	2.00	2.00
	Pilicode	2.67	1.00	1.67	1.33
	Thrikkaripur North	3.00	1.00	2.80	1.40
	Thrikkaripur South	2.67	1.00	1.67	1.50

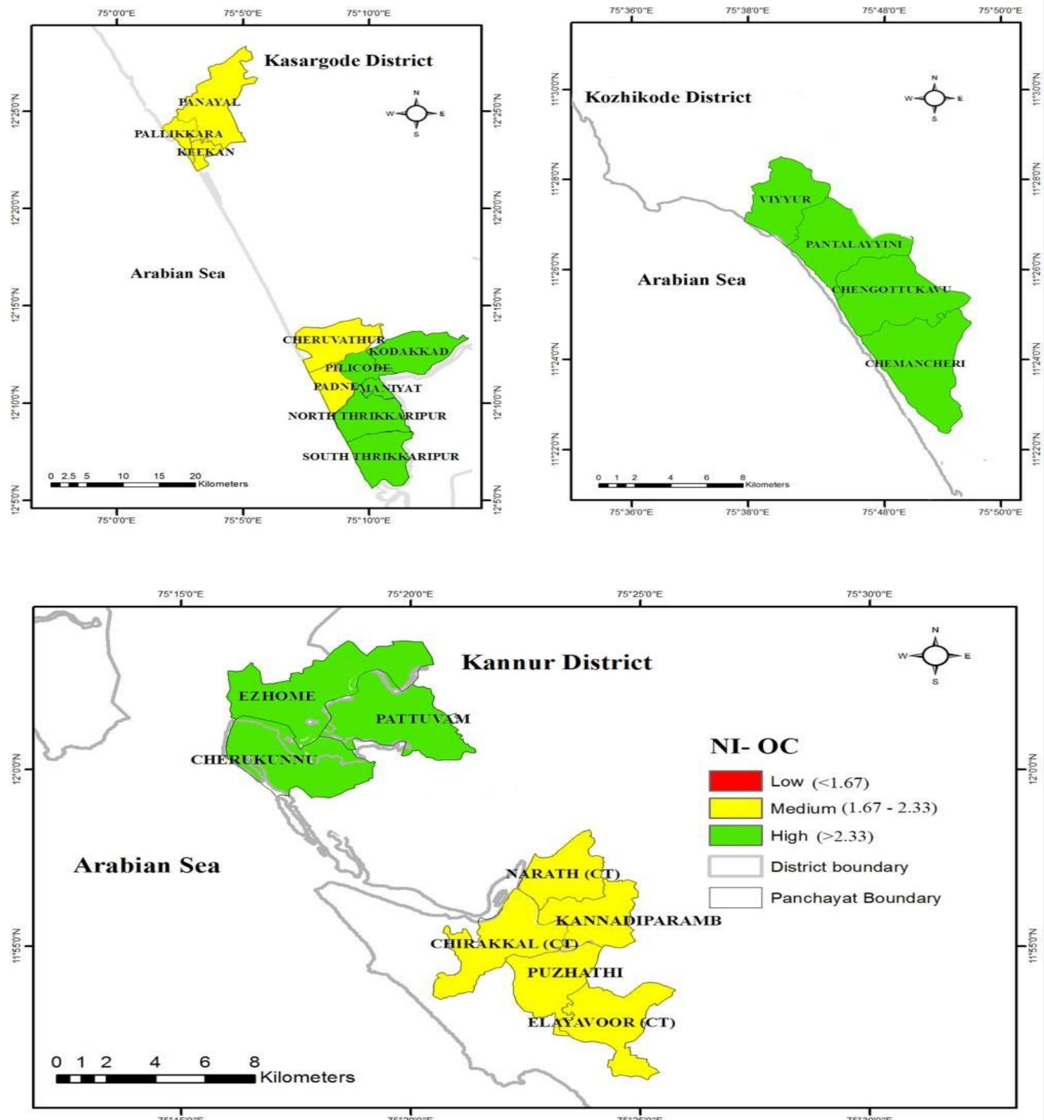

Fig. 5 Spatial variability of NI of organic carbon in AEU 7

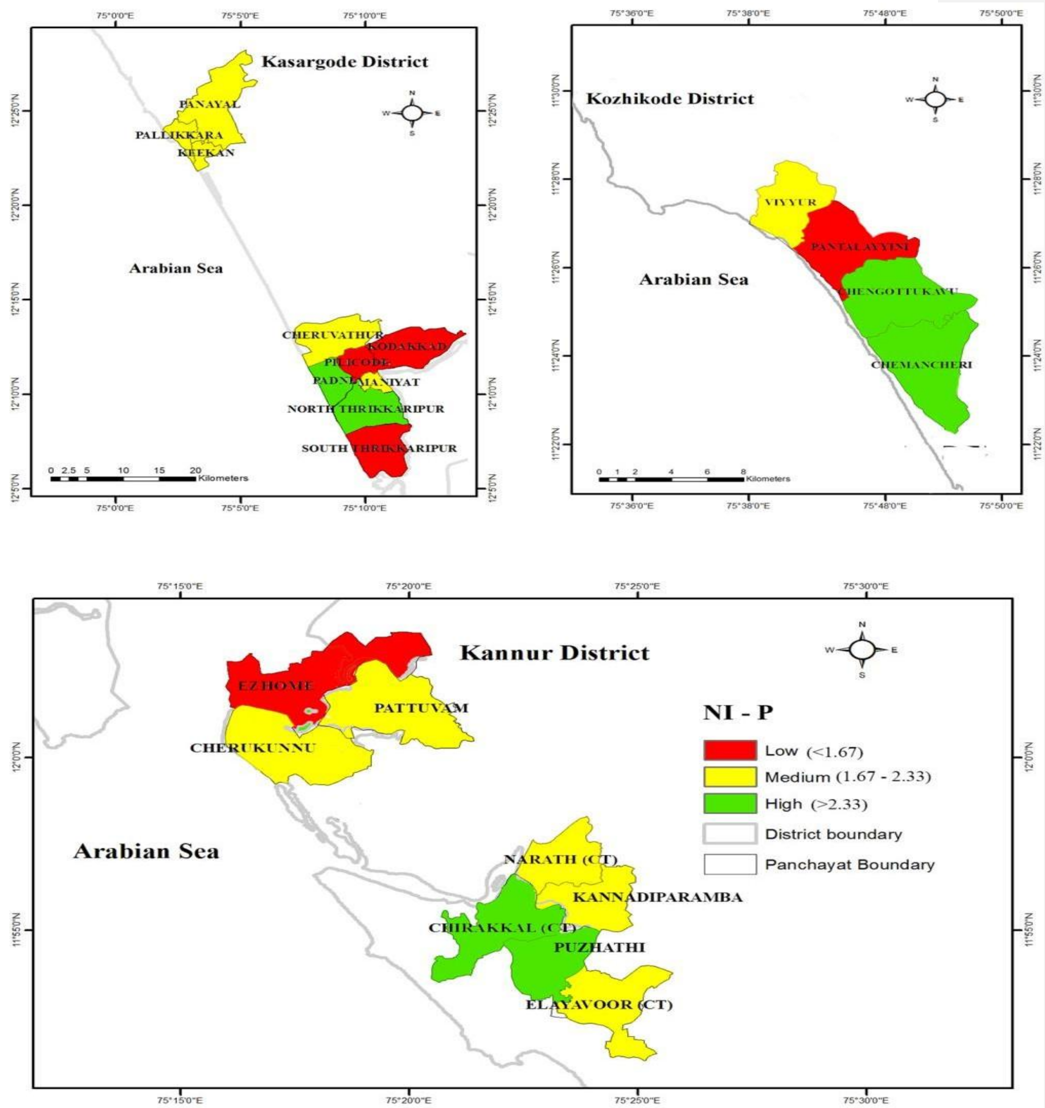

Fig. 6 Spatial variability of NI of available P in AEU 7

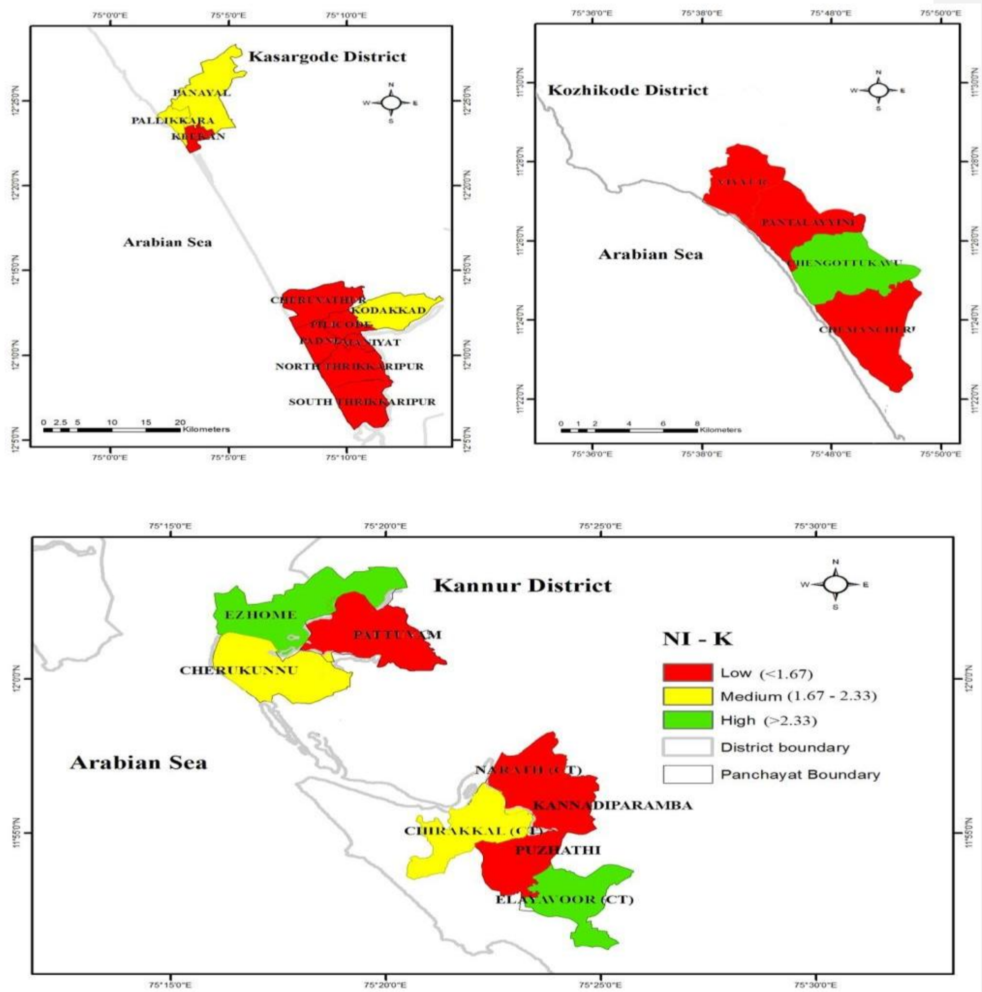

Fig. 7 Spatial variability of NI of available K in AEU 7

4. CONCLUSION

The soils of Kaipad (AEU 7) under different agricultural land uses experiences various constraints to crop production like extremely acidic pH, high EC, nutrient deficiencies of N, K, Ca, Mg, B and toxicities of Fe and Al. Examining relationships of parameters, and analyzing principal components indicated that nine parameters have significantly contributed to the SQI. Soil pH, EC, organic carbon, nutrients N, Mg, K, P, Zn and B are the important key indicators of soil quality. The soil quality can be enhanced by managing the soil pH through regular liming, addition of organic amendments and application of N, P, K, Ca, Mg, Zn and B containing fertilizers.

Comment [sm10]: This section shoud rewrite based on your research question and aims.

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Comment [sm11]: The references are very old, and you should use new citations in regard to your research. Some recent studies or papers can enhance your work. I propose adding them.

Almost you should add to introduction

- 10.1016/j.catena.2023.107392
- 10.1016/j.compag.2023.107821
- 10.1016/j.compag.2022.106978
- 10.1016/j.measurement.2022.111706

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