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Soil quality assessment and GIS based mapping in post-flood soils of *kole* wetlands of Kerala

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Abstract
Kerala state experienced a devastating flood in 2018, causing significant damage to the agricultural sector. Great damage resulted in the soil environment of *kole* lands (AEU 6). The georeferenced soil samples collected from post-flood soils of *kole* lands were analysed for different physical, chemical, and biological quality indicators. A minimum data set was formulated using principal component analysis (PCA), and the weighted additive method found the soil quality index. Among the 24 parameters studied, nine parameters, *viz*., particle density, porosity, exchangeable acidity, available Ca, S, N, Fe, Zn, and B, formed the minimum data set for soil quality index assessment and it varied from 0.28 to 0.78. The relative soil quality index varied from 25.93 to 72.22 per cent. The organic carbon had been shifted towards medium to high from low to medium after the flood. The high content of available phosphorus before flood had changed to medium to high after flood. Among the secondary nutrients, deficiency of available magnesium was severe in *kole* lands. Available boron was deficient in all the soil samples. Thematic maps were prepared using ArcGIS package to provide ready information about soil fertility status, which could serve as a decision making tool for cultivation of rice.

Keywords: Flood, *Kole* land, Minimum data set, Soil quality, Wetlands.

Introduction

Soil is a non-renewable resource that acts as a medium for plant growth. It acts as a habitat for various microorganisms, helps in nutrient cycling, and supports plant growth; hence considered an ecosystem service provider on the earth. Soil differs widely in its properties due to variations in climate and geology over time and space. Any change in one of its properties can significantly affect its fertility since the soil is a complex entity. Most of the soils in the world are being exposed to unprecedented weather events, which adversely affect-their various properties and may lead to deterioration in its quality.

Soil quality has been defined as the capacity of a specific kind of soil to function within the ecosystem and land-use boundaries, sustain biological productivity, maintain environmental quality, and sustain plant, animal, and human health (Doran and Parkin, 1994). Soil quality is widely used to identify the status and use the potential of soil. It is used to assess various production systems of agriculture and horticulture all around the world (Armenise et al., 2013). According to Seybold et al. (1999), soil quality is a combination of inherent and dynamic soil quality. The dynamic soil quality might change with a change in soil management, whereas inherent soil quality shows not much change over time (Larsen and Pierce, 1994)

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Kerala state receives very high rainfall during the monsoon season. In August 2018, the state received a terrific rainfall of nearly 2346.6 mm against the normal value of 1649.5 mm, causing much havoc to the entire Kerala except the Kasargod district. Vishnu et al. (2019) found that 36 per cent excess rainfall occurred during this period leading to floods and landslide events. The soils of Kerala, exposed to this devastating flood experienced significant damage to the soil environment in different ways. Besides heavy agricultural losses, soil fertility and productivity have been disturbed, exposed soils were eroded, and various debris accumulated on farm fields. Soil compaction occurred due to sedimentation, and soluble nutrients from surface soil were leached out. The physical, chemical, and biological properties of soil were highly altered, and this demanded a site-specific investigation in the flood-affected areas of *kole* lands to put forward post flood management strategies.

Kole lands, a part of Vembanad *kole*, is one of the major wetland systems on India's south-west coast. Since 2002, these wetlands have been assigned as a Ramsar site. Under the classification of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP, 2012), *kole* lands come under agro-ecological unit 6 (AEU 6) in taxonomic order - Inceptisols, having an area of 13,632 ha. The word *kole* in Malayalam indicates bumper yield or high returns from crops, and these *kole* lands form one of the rice granaries of Kerala. These lowlying tracts, located 0.5 to 1m below mean sea level, situates between 10° 20' to 10° 40' N and 75° 58' to 76° 11' E and are mainly divided as Thrissur *kole* and Ponnani *kole*. Thrissur *kole* is geographically distributed mainly in Anthikkad, Puzhakkal, Irinjalakkuda, Mullassery, and Cherpu block panchayats of Thrissur district, and Ponnani *kole* is mainly in Perumpadappu and Ponnani block panchayats of Malappuram district. Rice is the major crop grown under this unique wetland system. The soils are hydromorphic acid clays with ultra-acidic condition. Soils are deep with surface soils having silty clay to clay texture, and sub-soils are clayey with highly decomposed organic debris causing ultra-acidic condition.

The flood inundation adversely affected the *kole* lands of Thrissur and Malappuram districts. A detailed study on soil quality of post flood soils of these areas in AEU 6 will help to develop management strategies for enhanced productivity of crops under post-flood situation.

Materials and Methods

Weather data collection

A decade data (2007-2018) of maximum temperature, minimum temperature and rainfall (Table 1) were collected from the Department of Agricultural Meteorology, Vellanikkara, Thrissur,

Table 1. Comparison of rainfall of 2008-2017 with 2018

Month	Average rainfall (2008-2017)	Rainfall during 2018	Deviation in rainfall	Average no. of rainy days (2008-2017)	No. of rainy days during 2018	Deviation in no. of rainy days
	(mm)			(days)		
January	2.38	0	-2.4	0	0	0
February	20.3	5.2	-15.1	1	1	0
March	37.03	33.2	-3.8	2	2	0
April	76.28	28.9	-47.4	4	2	-2
May	177.05	483.6	+306.6	7	14	7
June	666.95	730.0	+63.1	24	23	-1
July	590.44	793.2	+202.8	24	22	-2
August	418.57	928.0	+509.4	18	21	3
September	284.52	29.0	-255.5	14	1	-13
October	257.27	393.0	+135.7	11	13	2
November	116.24	66.6	-49.6	6	5	-1
December	25.48	0.0	-25.5	1	0	-1

Kerala Agricultural University (KAU). The details about the rainy days in 2018 and its deviation from the average number of rainy days from 2007-2018 were calculated, and showed an increase in the number of rainy days in August 2018. The data revealed a continuous increase in the amount of rainfall received from May 2018 to August 2018, though a slight deviation in the number of rainy days was observed during the period. The minimum and maximum temperatures were also less from June 2018 to August 2018 (Figure 1.).

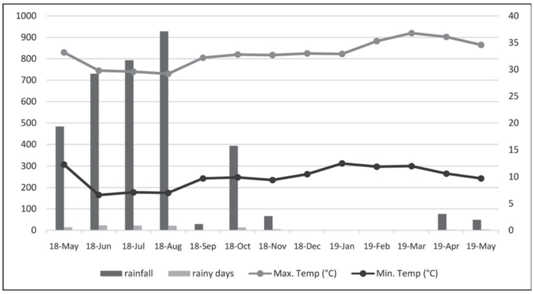

Figure 1. Weather parameters of 2018 May to 2019 May

Survey and sample collection

The study was conducted in 2019, and a survey was carried out in the summer months. The GPS referenced surface (0 - 20 cm) composite soil samples were collected from flood-affected areas of *kole* lands in Thrissur and Malappuram districts (Figure 2.). A total of hundred soil samples were collected from Mullassery, Cherpu, Anthikkad, Irinjalakkuda, Puzhakkal, Perumpadappu, and Ponnani block panchayats. The soil samples were analysed as wet samples without drying, and the moisture content of the soil was measured gravimetrically for moisture correction.

Characterization of soil samples

The physical, chemical, and biological properties of soil were analysed. The physical properties like

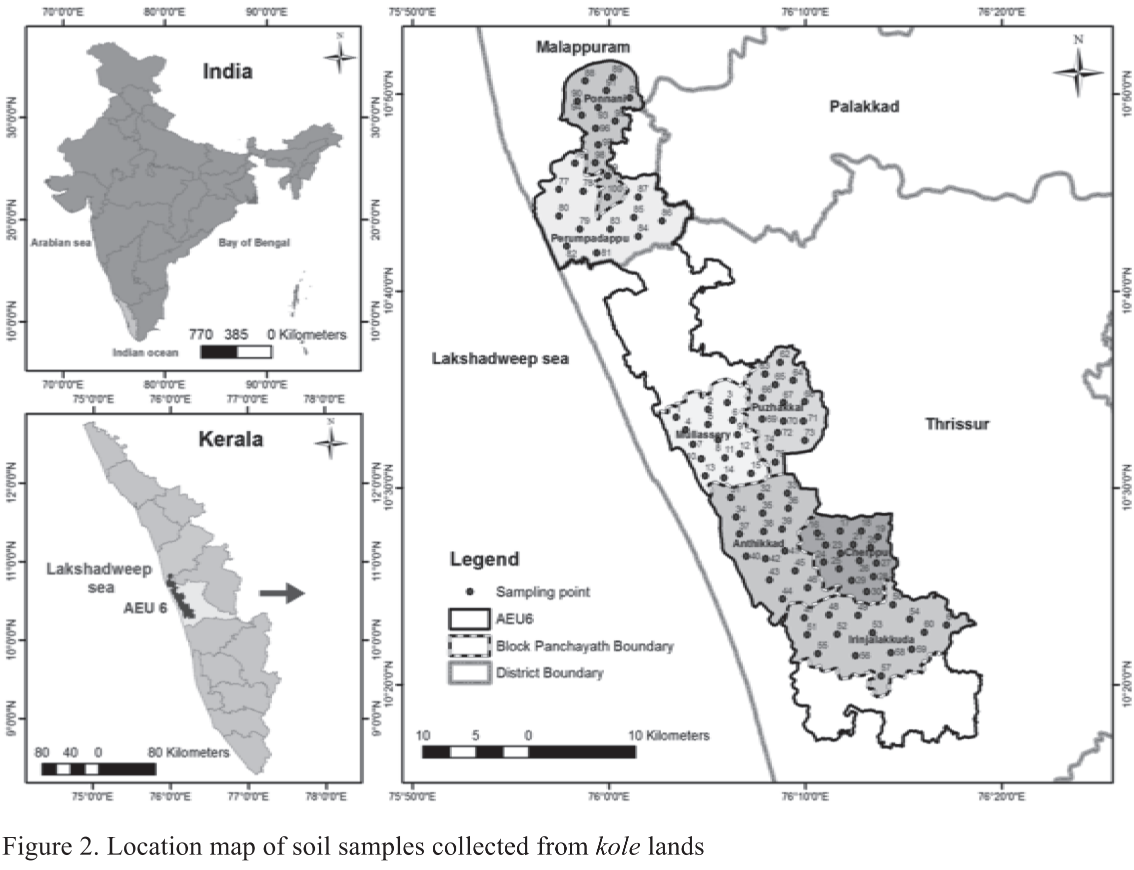

Figure 2. Location map of soil samples collected from *kole* lands

bulk density, particle density, and maximum water holding capacity were analysed by Keen Raczkowski (KR) box method (Keen and Raczkowski, 1921). Porosity was calculated using the relationship between bulk density and particle density. Soil moisture content was analysed by gravimetric method, whereas mean weight diameter by Yoder's wet sieving method (Yoder, 1936). Soil pH and electrical conductivity (EC) were measured with 1:2 soil:water ratio and organic carbon by wet oxidation method (Walkley and Black, 1934). Exchangeable acidity was found using extracted 1M KCl (McLean, 1965). Available N was analysed by alkaline permanganate (Subbiah and Asija, 1956) and available P by Bray No.1 method (Bray and Kurtz, 1945). Available K, Ca, and Mg were analysed using 1N ammonium acetate method (Jackson, 1958). Available S and micronutrients (Fe, Mn, Zn, and Cu) were extracted using 0.15 % $CaCl_2$ (Tabatabai, 1996) and 0.1M HCl (Sims and Johnson, 1991), respectively. Hot water extraction (Gupta, 1972) was followed for available B estimation whereas 0.1M $BaCl_2$ (Hendershot and Duquette, 1986) was used for assessing effective cation exchange capacity of soil. Dehydrogenase activity in the soil was estimated based on the rate of reduction of 2,3,5 triphenyltetrazolium chloride (Klein et al., 1971). The chloroform fumigation and extraction method determined soil microbial biomass carbon (MBC) (Jenkinson and Powlson, 1976).

Soil quality evaluation

Evaluation of soil quality was carried out by the method proposed by Andrews et al. (2002). A minimum dataset (MDS) was selected by principal component analysis of soil quality indicators using the SPSS version 16 statistical package.

Principal components (PC) with eigen values greater than one was selected for MDS. Only the highly weighted variables were retained from each PC for MDS. If more than one variable was retained within a principal component, their linear correlations were checked to determine whether the variables could be considered redundant and, therefore, eliminated from the MDS. Among well-correlated variables within a principal component, the variable with the highest loading factor was chosen for the MDS. If the highly weighted variables were not correlated and their correlation coefficients were less than 0.60, then each was considered an important indicator and was retained in the MDS. The selected variables in each MDS were categorized into three groups *viz*., more is better, less is better, optimum,based on the performance on soil functions. Subsequently, the indicators were scored by non-linear scoring method, and the following equation was used for non-linear scoring.

$$S_{NL} = a/\left(1 + \left(\frac{X}{Xm}\right)^{b}\right)$$

Where S_{NL} is the non-linear score, '*a*' is the maximum score 1, *X* is the value of soil indicator, X_m is the mean value of each indicator and *b* is the slope of curve. Slope of the curve is set as negative 2.5 for more is better and as positive for less is better with a value of 2.5 (Raiesi, 2017).

The weightage of each principal component was calculated using the variance obtained from the principal component analysis. Weight of each PCs were determined by dividing the percent variance of each PC with the cumulative variance explained by all PCs having eigen vectors greater than one. The SQI was calculated by aggregating the product of score of each indicator with its weightage factor. The SQI of different sites of *kole* lands was calculated using the formula

$SQI = \sum_{i=1}^{n} wi \times si$ where,

si- score of subscripted variables and *wi*- weighing factor derived from PCA

Relative soil quality index is the ratio of soil quality index of a given site to the maximum theoretical value of soil quality index (SQIm) for the same site (Karlen and Stott, 1994) and given in percentage, was also calculated. Thus,

$$RSQI = \frac{SQI}{SQIm} \times 100$$

According to the values of RSQI, soils were classified into poor, medium, and good as shown below,

Sl No.	Range of RSQI	Soil quality class
1	<50%	Poor
2	50-70%	Medium
3	>70%	Good

Results and Discussion

Soil parameters

The results showed that the soils of *kole* lands were low in bulk density and high in porosity while particle density varied from 2.05 to 2.67 Mg m^{-3} (Table 2). The low bulk density might be due to the presence of high organic matter content in *kole* lands, ranging from 2.07 to 4.16 per cent (Johnkutty and Venugopal, 1993). The variation in particle density from 2.05 to 2.67 Mg m^{-3} might be due to its mineral composition, textural difference, ormixing with organic matter (Ruhlmann et al., 2006; Rajalekshmi, 2018). There was also a significant correlation between bulk density and porosity. Ninety eight per cent of soils have high porosity. Kay and Bygaart (2002) observed positive effect of organic matter on soil porosity and reported that organic matter would stabilize soil pores and increase its persistence under any environmental or anthropogenic stresses. Maximum water holding capacity (MWC) and soil moisture content of the soil samples ranged from 28.44 to 73.49 percent and from 12.00 to 41.30 per cent, respectively. It was found that 69 per cent of soil samples had greater than 25 per cent moisture content in soil, and this might be due to the high organic matter content and clayey texture of soil (Wu et al., 2013).

Table 2. Characterization of soil parameters in AEU 6

Characters	Min.	Max.	Mean	SD
Bulk density (Mg m^{-3})	0.53	1.34	0.91	0.18
Particle density (Mg m^{-3})	2.05	2.67	2.43	0.19
Porosity (%)	44.34	78.21	61.93	6.76
MWC (%)	18.11	73.49	58.68	23.82
Moisture content (%)	12.00	41.60	30.32	8.37
MWD (mm)	0.70	6.95	3.02	0.94
pH	3.51	5.35	4.92	0.72
EC (dSm^{-1})	0.01	0.38	0.11	0.12
Organic carbon (%)	0.28	3.47	1.11	0.54
EA (cmol (+) kg^{-1})	0.05	2.20	0.99	0.54
Available N (kg ha^{-1})	92.13	1113.62	704.59	210.38
Available P (kg ha^{-1})	2.17	101.39	17.81	14.59
Available K (kg ha^{-1})	30.42	684.03	196.04	137.78
Available Ca (mg kg^{-1})	5.29	1600.92	400.97	234.44
Available Mg (mg kg^{-1})	3.61	374.46	103.41	103.34
Available S (mg kg^{-1})	4.46	53.15	21.20	20.44
Available Fe (mg kg^{-1})	15.06	3851.06	660.72	1026.92
Available Mn (mg kg^{-1})	3.20	73.76	19.26	16.05
Available Zn (mg kg^{-1})	1.02	9.93	2.66	1.96
Available Cu (mg kg^{-1})	0.44	14.77	2.99	2.09
Available B (mg kg^{-1})	0.01	0.27	0.08	0.05
ECEC (cmol (+) kg^{-1})	0.62	9.00	3.82	1.18
DHA (µg TPF g^{-1} 24 hr^{-1})	65.54	1909.59	594.68	402.43
MBC (µg g^{-1} soil)	6.47	383.26	158.58	95.06

* MWC = Maximum water holding capacity, MWD = Mean weight diameter, EC = Electrical conductivity, EA = Exchangeable acidity, ECEC = Effective cation exchange capacity, DHA = Dehydrogenase activity, MBC = Microbial biomass carbon

The soils were acidic in reaction, and the exchangeable acidity varied from 0.05 to 2.07 cmol (+) kg^{-1}. This conforms with the findings of Johnkutty and Venugopal (1993). They reported that soil in *kole* area was generally acidic with a pH ranging from 2.6 to 5.5. The extreme acidity of these soils was due to the presence of an organic peat layer in the subsurface. All the soil samples collected from *kole* lands have an electrical conductivity of less than 1 dSm^{-1}. It might be due to loss of soluble salts during flooding, variation in soil mineralogy, and high soil moisture present in soil (Brevik, 2006). The organic carbon was shifted towards medium to high level from low to medium after the flood. Seventy seven per cent of samples collected from *kole* lands showed high content of available nitrogen, and the maximum mean value was found in Irinjalakkuda block panchayat (811.0 kg ha^{-1}). The high content of nitrogen in *kole* lands might be due to the occurrence of high organic matter. After the flood, available phosphorus was medium in 49 per cent of soil samples. Available potassium was found in the range of low to medium. Soil fertility status of *kole* lands after the flood was compared with previous data available for the area (Table 3). This revealed that there is no difference in pH after the flood occurrence. The phosphorus content changed from high status before flood to medium

Table 3. Fertility status of *kole* lands before the flood occurrence in 2018

Soil parameter	Fertility status*
Organic carbon	Low to medium
Available P	High
Available K	Low to medium
Available Mg	Deficient
Available S	Adequate
Available Zn	Adequate
Available B	Deficient

*Project: Soil based plant nutrient management plan for agro-ecosystems of Kerala (2017) (Venugopal et al., 2018)

status after flood and this might be due to fixation of P as iron and aluminium phosphate in acid soil higher immobilisation of P in organic soils. There is no change in potassium status before and after the flood. Similar findings were reported by Mbene et al. (2017).

Among the secondary nutrients, available calcium was found sufficient in 63 per cent of soil samples, while deficiency of available magnesium was observed in *kole* lands, and available sulphur was found sufficient in 86 per cent of soil samples. Available Mg and B deficiency might be due to the low pH in soil. The micronutrients like available Fe, Mn and Zn were high in AEU 6. Comparing to the data presented by Venugopal et al. (2018), status of Zn and B are not much changed. Available copper was found sufficient in 85 per cent of soil samples, whereas available boron was found deficient in all the soil samples. Available Fe, Mn, and Cu content increased due to reducing conditions in paddy field. Effective cation exchange capacity of soil in AEU 6 varied from 0.62 to 7.03 cmol (+) kg^{-1}. In the biological attributes, *kole* lands showed high dehydrogenase activity while microbial biomass carbon was found medium in 58 per cent of soil samples. Dehydrogenase activity increased whereas microbial biomass carbon decreased due to anaerobic condition (George et al., 2017).

Principal component analysis

The analysis of variables by principal component analysis resulted in eight principal components (PCs), and only the highly weighted variables, factors loading within 10 per cent of the absolute values of the highest factor loading, were retained from each PC for the MDS. Thus, the variables *viz*., available Ca, available S, available N, porosity, exchangeable acidity, available Fe, available Zn, particle density, and available B were selected for MDS.

Scoring of MDS indicators

More is better function was used for attributes like available calcium, available sulphur, available nitrogen, available zinc and available boron since they influence soil quality in a positive manner. Less is better function was used for variables like available iron and exchangeable acidity. Since available iron was ata toxic level in most of the soil samples, less is better function was used. Particle density and porosity are grouped under optimum function.

Soil quality

SQI in different block panchayats of AEU 6 was compared using one way ANOVA with DMRT. The SQI values varied from 0.28 to 0.78. The highest mean (0.64) was recorded in Mullassery block panchayat, and the lowest (0.39) was in Cherpu block panchayat (Figure 3.). SQI was found significant at both 1 per cent and 5 per cent level of significance. The soils of Mullassery block panchayats showed significantly superior soil quality compared to all other blocks.

The spatial distribution of available N, P, K and relative soil quality were depicted using GIS (Figure

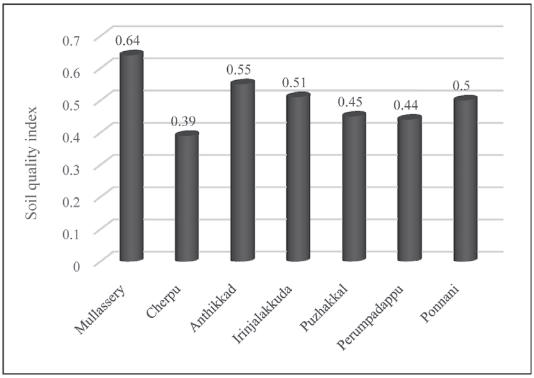

Figure 3. Average soil quality index in block panchayats

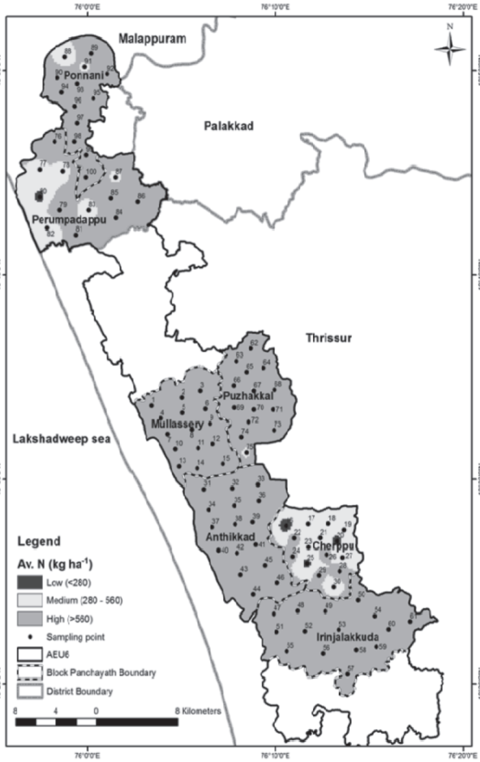

Figure 4. Spatial distribution of available N in AEU 6

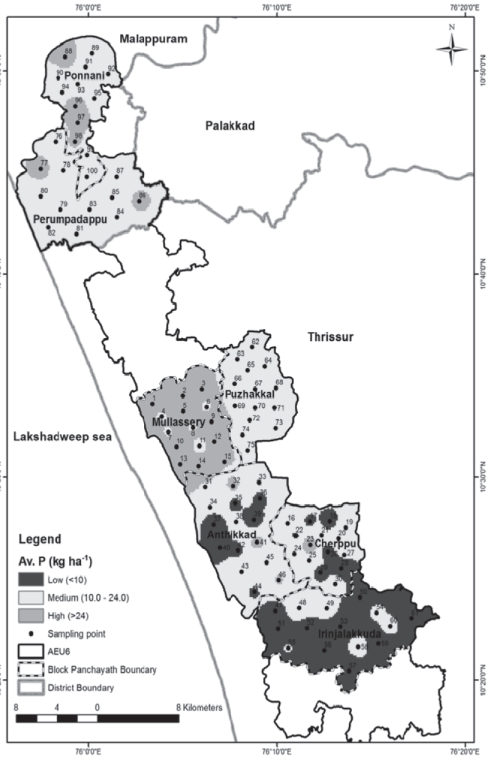

Figure 5. Spatial distribution of available P in AEU 6

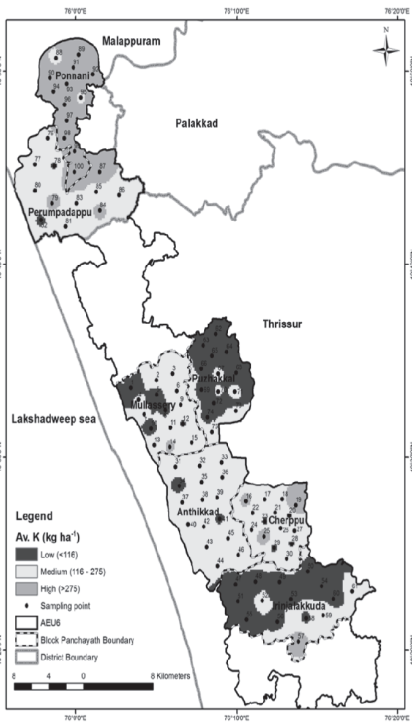

Figure 6. Spatial distribution of available K in AEU 6

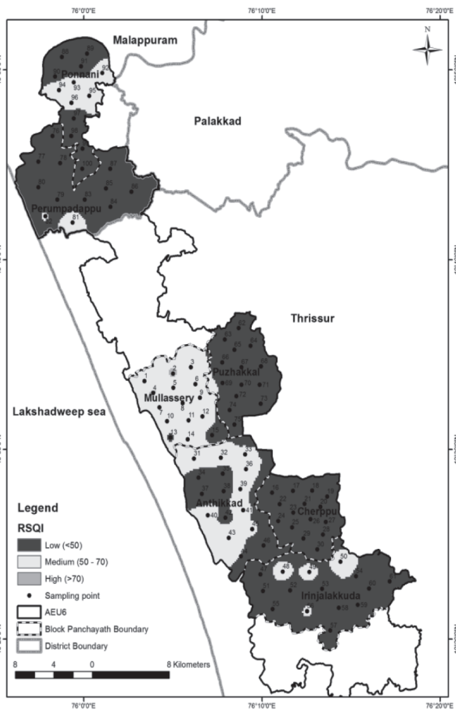

Figure 7. Spatial distribution of RSQI in AEU 6

4 to 7.). Sixty three per cent of soil collected from AEU 6 (*Kole* lands) was poor in soil quality. Since there was no standard rating for SQI, RSQI was used to interpret the soil quality index of soil. RSQI varied from 25.93 per cent to 72.22 per cent with a mean of 46.70 per cent.

Cherpu, Puzhakkal, and Perumpadappu block panchayat were low in soil quality (Figure 3.). The poor soil quality might be due to the drastic variation of minimum data set components (porosity, particle density, exchangeable acidity, available Ca, S, N, and Zn) from the optimum range. Further the toxicity of available Fe and deficiency of available B also contributed to the poor soil quality index. Mullassery, Anthikkad, Irinjalakkuda, and Ponnani block panchayat were medium in soil quality (Figure 3.). This might be due to high availability of nutrients like N, Ca, Zn and low Fe and S toxicity. Thus, post flood study in *kole* lands revealed that drastic changes in the soil environment had occurred, with a greater number of soil samples from block panchayats falling in both low and medium soil quality.

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