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Post Flood Changes in Soil Quality of AEU 13 in Palakkad District of Kerala

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Abstract
Soil quality of the parts of Palakkad district coming under Agro Ecological Unit (AEU) 13 located within Agro Ecological Zone 5 was assessed after the flood, 2018. Hundred and one soil samples were collected from the flood/landslide affected locations after detailed survey of the study area. A total of 22 soil parameters (physical, chemical and biological parameters) were analyzed for each sample. Principal component analysis (PCA) of the test results provided a minimum data set (MDS) using which the soil quality index (SQI) was elucidated for different panchayats belonging to AEU 13 in the study area. The test results were compared with the pre flood data for a better understanding of the changes occurred after flood. There was a significant increase of organic C, available P and S and a decrease of available Ca, Mg, B, soil pH and EC after flood. Overall relative soil quality index (RSQI) after the floods was poor in the area. So this study expounds the complete information regarding soil quality of the preferred area after flood which reiterates the need for adopting appropriate soil health management strategies to boost up the agricultural production of the area.

Key words: Agro Ecological Unit (AEU), Minimum data set (MDS), Principal component analysis (PCA), Soil quality index (SQI) and Relative soil quality index (RSQI).

Introduction

Soil quality is the capacity of the soil to function within its ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. It primarily depends on its dynamic properties which significantly change under environmental disturbances. The flood of August 2018 witnessed by Kerala not only caused havoc to life and properties but also triggered alarming changes in soil quality. Two types of flood damages were noticed throughout the state either due to river overflow and water logging or by caustic landslides. AEU 13 (northern foot hills) is one of the major flood affected area of the state. The area under AEU 13 in Palakkad district includes ten panchayats coming under Mannarkkad and Sreekrishnapuram blocks. Undulating to rolling topography is the characteristic feature of this AEU making it prone to both river overflow and landslides in the study area.

Floods have significant and varied impacts on soil. They can result in the deposition of sand and debris, erosion of agricultural soils, the loss of beneficial fungi crucial for nutrient mobilization, and nutrient imbalances. Fertile topsoil is vital for plant growth, and flood-induced erosion can seriously affect plant health (Mahabaleshwara and Nagabhushan, 2014). Flooding can either increase or decrease nutrient availability in soil. The altered oxygen cycle during flooding can reduce soil quality, yet flood waters can also enrich the land by depositing organic materials, minerals and nutrients, making it more fertile (Ubuoh et al., 2016). However, soils with low

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cation exchange capacity (CEC) may experience nutrient leaching. The impact of floods and landslides on soil quality depends on the physiographic and terrestrial characteristics of the affected area.

Soil quality cannot be measured directly; it primarily describes the combination of chemical, physical and biological characteristics that enable soils to perform a wide range of ecological functions (Karlen et al., 1997). So these attributes are called soil quality indicators (Wander and Bollero, 1999). Based on the soil function and type and characteristics of the study area the quality indicators were selected and using Principle component analysis (PCA) the minimum data set (MDS) parameters were elucidated to compute soil quality index. There are three methods to compute the soil quality index; Simple additive SQI method, weighed additive method and a statistics-based model. Mukherjee and Lal (2014) compared the three SQI methods and suggested the third method as the best and easiest model with relatively less expensive procedure over time compared to the first and second models. Karlen and Stott (1994) put forward the relative soil quality index over SQI to get the clear picture of soil quality of an area.

Materials and methods

A. **Study area -** AEU 13 in Palakkad district is comprised of ten panchayats which covers an area of 483 km^2 area which is surrounded by hills such as Siruvani hill, Kalladikkode hill, Anangan hill and Attappadi hill. Massive landslides occurred in the valleys of Anangan and Kalladikkodan hills (Kottopadam, Kanjirappuzha and Karimba panchayat) during August 2018, resulted in the conversion of hectares of cropping area to barren lands. The main hands of Nila, Kanjirappuzha, Kunthippuzha, Nellippuzha etc. were the major rivers that put on a major role in the 2018 flood occurred in the area. Kanjirappuzha, Siruvani and Meenvallam dams also be present in AEU 13. The landscape has low hills and undulating to rolling topography. Laterite, alluvial and forest soils were found in the area. Soils were rich in organic matter, strongly acidic and dominated by low activity clays and sesqui-oxides and suffer from multi-nutrient deficiencies (mainly Mg and B) (Rajashekharan *e*t al., 2013). Coconut, arecanut and rubber were the main upland crops and rice, banana and vegetables were the crops grown mainly in low lands.

B. **Soil sampling, processing and analysis -** After a preliminary survey carried out in association with the respective Krishibhavans of Department of Agriculture, 101 composite soil samples (1 kg each) were taken and the GPS readings were also recorded. Apart from the soil samples from 15-20 cm depth, the undisturbed samples were collected using core sampler from each location. Clods were broken using wooden mallet and soil samples were passed through 2 mm sieve after drying under shade. A small portion is made to pass through 0.5 mm sieve for organic C estimation. The processed samples were analysed for physical, chemical and biological properties using standard procedures. Bulk density (BD), particle density (PD), porosity, soil moisture content and water holding capacity were the physical attributes analysed. Soil chemical attributes analyzed were soil pH, electrical conductivity (EC), exchangeable acidity, effective cation exchange capacity (ECEC), available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B. Organic carbon and dehydrogenase activity were also measured.

C. **Soil quality index (SQI) -** The entire results of 22 parameters were subjected to correlation analysis in PCA using a statistical software OPSTAT and a minimum data set (MDS) with 8 attributes were developed. Available N, Ca, S, Zn, B, pH, BD and PD were the attributes which came in MDS. Nonlinear scoring function (Equation 1) was used to score each attribute and SQI was calculated using additive method (Equation 2) (Andrews, 2002). Relative soil quality index was computed from SQI to categorize the area according to soil quality.

$$SQI = \sum_{i=1}^{n} Wi \times Si \qquad (1)$$

Where, Si = score for the subscripted variable,
Wi = weighing factor derived from PCA

$$S_{NL} = a/1+(x/x_m)^b \qquad (2)$$

Where, S_{NL} = non linear score, a = 1 (maximum score), x = soil indicator value, x_m = mean value, b = slope of the equation (-2.5 for "more is better" and 2.5 for "less is better")

The calculated soil quality index was compared with a theoretical maximum soil quality index and expressed in percentage which is known as relative soil quality index (RSQI).

Results and discussion

A. **Soil attributes after flood -**The test results of 22 soil attributes are listed in Table 1 as descriptive statistics. The results showed high variation among samples with respect to different soil attributes except available B, exchangeable acidity and electrical conductivity.

a. **Soil physical attributes after flood -** High bulk density was observed in the study area with 54% percentage of samples coming under a category with values above 1.40 Mgm^{-3}. Bulk density is influenced by the amount of organic matter in soil, soil texture, mineral constitution and porosity. Sand deposition due to river overflow was prominent in the study area in AEU 13 and generally low to medium organic carbon content was noticed. Askin and Ozdemir (2003) studied the relationships and stated that bulk density increases with increase in sand content and decrease in organic matter content. Avnimelech et al. (2001) recorded a high BD of 1.776 Mg m^{-3} for flooded soil having very low organic carbon content (1mg g^{-1}). Regarding particle density, 75% of the samples had values greater than 2.40 Mg m^{-3} with an average of 2.51 Mgm^{-3}. The average PD of an inorganic soil was 2.65 Mg m^{-3} (Brady, 1984) where as PD for organic matter was reported to be 1.25 Mg m^{-3} (Hakanson and Jansson, 1983). So addition of lighter materials results a decrease in PD, while incorporation of minerals with

Table 1. Descriptive statistics of the soil properties analyzed after the flood, 2018 in AEU 13 in Palakkad District,Kerala

	Mean	Standard deviation	Standard error	Range
BD (Mg m^{-3})	01.39	0.15	0.12	01.11-01.69
PD (Mg m^{-3})	02.51	0.16	00.10	01.95-02.76
Porosity (%)	45.00	0.05	00.08	32.00-59.00
Moisture content (%)	19.79	7.55	1.70	02.48-43.72
MWHC (%)	38.02	8.78	1.42	09.47-57.80
OC (%)	00.86	0.37	0.39	0.33-01.78
pH	05.36	0.60	0.26	03.86-06.77
EC (dS m^{-1})	00.07	0.04	0.14	0.02-0.30
Available N (kg ha^{-1})	238.20	91.11	5.90	94.08-273.50
Available P (kg ha^{-1})	47.02	23.21	3.39	12.06-108.90
Available K (kg ha^{-1})	459.30	229.70	10.72	134.10-1079
Available Ca (mg kg^{-1})	439.40	196.40	9.37	106.10-957.40
Available Mg (mg kg^{-1})	114.90	61.84	05.77	16.62-360.20
Available S (mg kg^{-1})	43.10	13.90	2.12	11.53-82.10
Available Fe (mg kg^{-1})	59.71	33.82	4.38	12.95-146.50
Available Mn (mg kg^{-1})	58.14	39.01	5.12	08.35-187.80
Available Zn (mg kg^{-1})	5.02	4.19	1.87	01.40-38.98
Available Cu (mg kg^{-1})	3.99	01.62	0.81	01.31-08.15
Available B (mg kg^{-1})	0.23	0.10	0.22	00.09-00.92
DHA (ìg TPF g $soil^{-1}day^{-1}$)	129.00	92.30	8.13	14.28-462.60
ECEC (cmol kg^{-1})	8.37	01.55	0.54	05.65-14.10
EA (cmol kg^{-1})	0.15	0.14	0.37	0.02-0.67

high density results an increase in particle density (Avnimelech et al., 2001). This might be the reason for a low average PD of 2.49 Mg m-3detected in river overflow affected soils than land slide affected soils (2.62 Mg m^{-3}). Highest P.D. was observed in Karimba Panchayat which was subjected to landslide during flood, 2018. Porosity, moisture content and water holding capacity were in an optimum range.

b. **Soil chemical attributes after flood -** In case of primary nutrients, most of the samples (75%) were deficient in available N whereas none of the samples were deficient in available P and K. Mean available N in the area was 238.20 kg ha^{-1} which came under low category, but the mean values of available P and K were 47.20 kg ha^{-1} and 459.30 kg ha^{-1} respectively coming under high category. In case of available P, 67% of sample came under very high class and 2% under extremely high class. Many authors reported high available P after flood due to high affinity of P (as PO_4^{3-}) to soil clay (Harry et al., 2006). The trend of available K is also similar to available P; among the samples 47% was under very high class and 2% under extremely high class. The survey conducted in the area indicated that the high available K might be due to blind application of potassium fertilizers by farmers immediately after flood.

Regarding secondary nutrients, available Mg was deficient in 60% of samples with a mean of 114.90 mg kg^{-1} while mean available Ca was 439.40 mg kg^{-1} and 30% of samples were deficient. Available S was high in all samples and the average content in the area was 43.10 mg kg^{-1}. Soil acidity and leaching might be the reason for the reduction of secondary cationic nutrients. High S availability may be due to the imbalanced fertilizer application which included sulphur as secondary source or increased mineralization of S after flood.

All the cationic micronutrients were sufficient for entire samples but a wide range was observed. Available Fe ranged from 12.95 to 146.50 mg kg^{-1}, available Cu from 1.31 to 8.15 mg kg^{-1}, available Mn from 8.35 to 187.80 mg kg^{-1} and available Zn from 1.40 to 38.98 mg kg^{-1}. The flooded condition increases the dissolution of cementing agents like iron oxide and affects the complex formation leading to an increase in iron content. Available B was deficient in 99% of samples and average available B of the area was 0.23 mg kg^{-1}.

All the samples were acidic with pH ranging from 3.9 to 6.8, but with very low exchangeable acidity. Electrical conductivity was also low in the area and all the samples had an EC less than 1 dS m^{-1}. The mean ECEC of the studied area was 8.37 cmol kg^{-1} and it ranged from 5.67 to 14.09 cmol kg^{-1}. Eighty four percent of the samples had low ECEC (<10 cmol kg^{-1}).

c. Soil biological attributes after flood- The average organic carbon content of the studied soil samples were 0.859%, which came under the medium category. Organic carbon content ranged from 0.315% to 1.83% in which 37% of the soil samples were under low, 58% under medium and only 5 % under high category. Dehydrogenase activity of the surveyed area varied from 14.28 to 462.6 µg TPF g $soil^{-1}day^{-1}$ with a mean activity of 129.0 µg TPF g $soil^{-1}day^{-1}$. Nearly seventy percentage of the samples had DHA more than 75 ìg TPF g $soil^{-1}day^{-1}$.

B. Comparison of post flood analytical results with pre flood data

The soil attributes measured after flood were compared with the pre flood data wherever available (soil health card data of 2017-18 and data published by Kerala state planning board in 2013). For this comparison, secondary data from DSTL, Pattambi was collected which included the analytical results of samples collected prior to flood in 2017-18. Nutrient availability rating of soils were carried out according to Table 2. Compared to the pre flood data from DSTL, Pattambi, Organic C, available P, K and S increased after flood where as soil pH and EC showed slight reduction after flood.

Table 2. Fertility ratings of soils (Venugopal *et al*., 2018)

Soil attribute	Range	Rating
Soil pH	<3.5	Ultra acid
	3.5-4.5	Ex. Acid
	4.5-5.0	V, Strongly acid
	5.0-5.5	Strongly acid
	5.5-6.0	Moderately acid
	6.0-6.5	Slightly acid
	6.5-7.3	Neutral
	7.3-7.8	Slightly alkaline
	7.8-8.4	Moderately alkaline
	8.4-9.0	Strongly alkaline
	>9.0	V, Strongly alkaline
Organic carbon (%)	<0.4	Very low
	0.4-0.7	Low
	0.7-1.5	Medium
	1.5-2.5	High
	2.5-5.0	V. high
	>5.0	Ex. High
Available N (Kg ha^{-1})	<280	Low
	280-560	Medium
	>560	High
Available P (Kg ha^{-1})	<5	Very low
	5-10	Low
	10-25	Medium
	25-35	High
	35-100	V. high
	>100	Ex. High
Available K (Kg ha^{-1})	<75	Very low
	75-115	Low
	115-275	Medium
	275-400	High
	400-1000	V. high
	>1000	Ex. High
Available Ca (mg kg^{-1})	<150	Very low
	150-300	Low
	>300	Adequate
Available Mg (mg kg^{-1})	60	Very low
	60-120	Low
	>120	Adequate
Available S (mg kg^{-1})	<5	Low
	5-10	Medium
	11-25	Adequate
	>25	High
Available Fe (mg kg^{-1})	<5	Deficient
	>5	Adequate
Available Mn, Zn and Cu (mg kg^{-1})	<1	Deficient
	>1	Adequate
Available B (mg kg^{-1})	<0.5	Deficient
	0.5-2	Adequate

In the pre flood data there were no samples that came under very high or extremely high class of available P, but in post flood data 65% of samples had very high and 2 % had extremely high P content (fig. 1(a)). The analysis of the pre and post flood data of available K gave prominent information regarding the tremendous increase of available K in soil, because in pre flood condition the samples were under very low (12%), low (35%), medium (40%) or high (13%) category whereas after flood 47% of samples came under very high and 5% under extremely high categories (fig. 1(b)). Regarding available S, 95% of samples were under high class after flood while only 4% of samples were under high class in pre flood condition(fig. 1(c)). The sediments brought about by river overflow in the present study might have increased the organic carbon as well as available P and S status of the soil. Flood results in deposition of organic matter in the affected area and lead to an increase in organic carbon in soil (Brady, 1984; Boyd, 1995). Increase in organic matter content increases the nutrient concentration and cause reduction in BD (Chaudhari et al., 2013). Many authors have reported high available P after flood. This is due to high affinity of P (as PO_4^{3-}) to soil clay (Harry et al., 2006). High organic matter, moisture content and low pH might have favored the availability of S in soil.

Compared to the pre flood data of 2013 (Rajasekharan et al., 2013*)* available Ca and Mg were found more deficient after flood, in the soil samples collected from AEU 13. According to the pre flood data, 92% of the samples had adequate amount of available Ca, where as it was reduced to 70% after flood (fig. 2(a)). Similarly in case of available Mg, 58% samples had adequate content before flood and it was reduced to 40% after flood (fig. 2(b)). The works of Alfaiya and Falcao (1993) and Humphries (2008) reported that available Ca reduced with increase in moisture content. Available Ca and Mg may get easily leached out from the soil especially in acidic pH condition. In the study area**,** Ca and Mg might have leached out after flood and thus resulted in a decrease in soil pH. The production

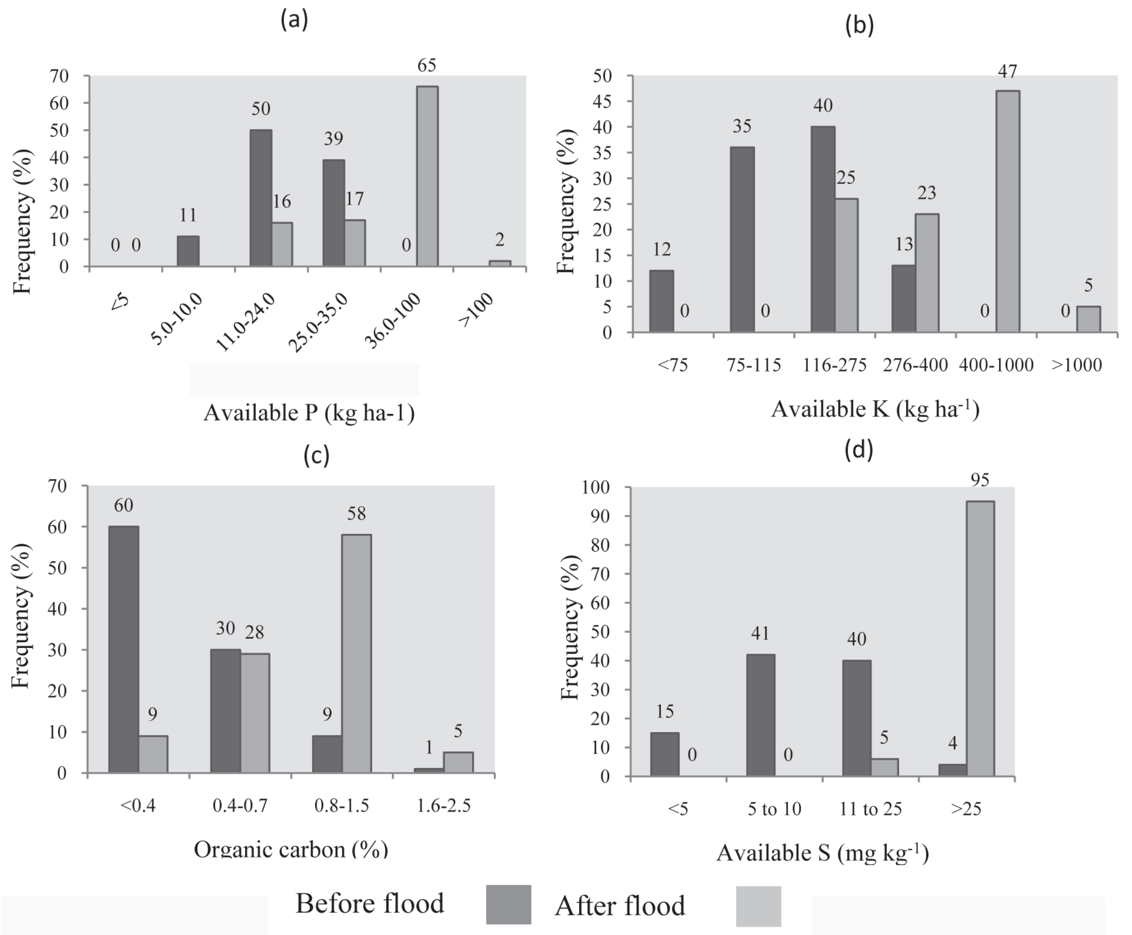

*Figure 1***.** Frequency distribution of available P, K, S and OC before flood and after flood in soils of AEU 13 in Palakkad district of Kerala

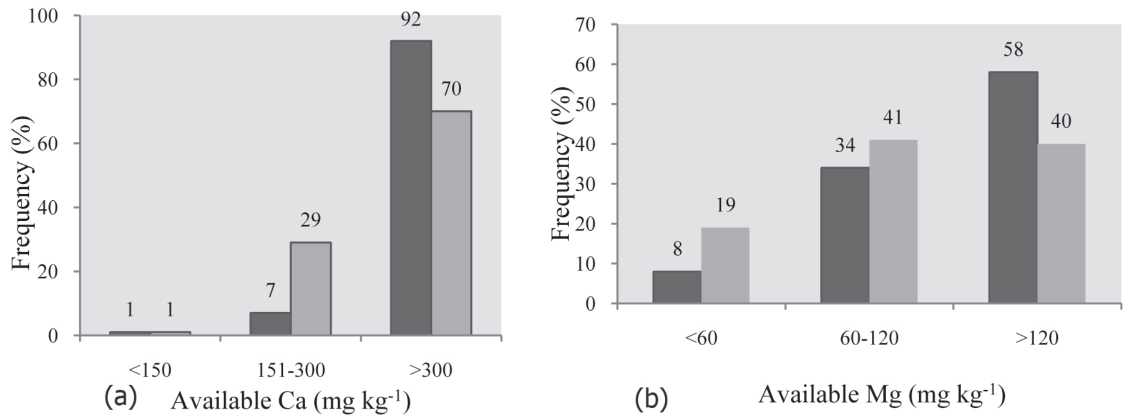

Figure 2. Frequency distribution of available Ca and Mg before and after flood in soils of AEU 13 in Palakkad district of Kerala

of organic acid by fermentation induced by water logging also results an increase in acidity (Akpoveta et al., 2014). The leaching of different salts from soil complement to flood might have resulted a decrease in EC.

All the four cationic micronutrients (Fe, Mn, Zn and Cu) were sufficient before and after flood, where as available B exhibit a declining trend. After flood, 99% of samples were deficient in B, but in pre flood data only 88% samples were below the lower critical limit 0.5 mg/kg. Generally cationic micronutrients were high in flooded soils due to high moisture content in soil after flood which assured favorable condition for the metals to exist in their highly available forms, moreover the reduced state of the soil soon after flooding results in release of metal cations from complexes. But in case of B, due to its high solubility, it is subjected to profound leaching during water logging.

C. **Soil quality index and Relative soil quality index**

Eight attributes were selected as minimum data set (Table 3) from the results of the Principal component analysis. Available N, Ca, S, Zn, B, pH, BD and PD were the attributes which came in MDS, for soil quality index of the study area. Nonlinear scoring function was used to score each attribute and SQI was calculated using simple additive method. SQI of the area varied from 0.314 to 0.703.The average RSQI was 43.92% rated as low and all the 10 Panchayats coming under the study area had poor soil quality with less than 50% RSQI. Eighty percentage of the samples had low RSQI and the remaining 20% had medium RSQI (Table 4). The lowest RSQI observed is 37.36% from Karimba panchayat and highest is 49.36% from Kumaramputhur panchayat. While considering the eight MDS parameters, available N and B shows severe deficiency in majority of the samples where as available Ca was found to be deficient in few samples. High bulk density and particle density (which are assigned under 'less is better' function) and low available N and B (which are assigned under 'more is better' function) might be the reason for low soil quality index computed for the area.

Table 3 Eigen vectors of correlation matrix for the attributes

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
BD	0.22	-0.459	0.231	-0.046	0.141	-0.054	0.175
PD	0.163	-0.136	0.454	0.066	-0.102	-0.195	-0.065
Porosity	-0.121	0.431	0.073	0.099	-0.24	-0.07	-0.263
MC	-0.024	-0.175	0.084	-0.267	-0.108	-0.16	-0.318
WHC	-0.244	0.372	-0.069	0.075	-0.16	0.027	-0.098
OC	-0.214	0.184	0.362	-0.188	0.359	-0.161	0.093
Ph	-0.315	-0.204	0.006	0.428	-0.082	0.098	-0.113
EC	-0.101	-0.176	-0.296	0.021	-0.186	-0.138	0.414
Available N	-0.238	0.223	0.271	0.001	0.432	-0.079	0.064
Available P	0.072	0.013	0.017	0.172	0.328	0.233	0.04
Available K	-0.296	-0.088	0.228	-0.101	-0.106	0.253	0.048
Available Ca	-0.451	-0.189	-0.069	0.089	-0.071	0.042	-0.041
Available Mg	-0.304	-0.212	0.156	0.077	0.094	-0.296	-0.135
Available S	0.043	-0.178	0.074	-0.073	-0.017	0.353	-0.413
Available Fe	0.108	-0.128	-0.293	-0.043	0.068	-0.266	-0.315
Available Mn	-0.059	-0.093	0.183	-0.38	-0.327	0.281	-0.13
Available Zn	-0.179	-0.048	-0.191	-0.122	0.14	0.387	0.313
Available Cu	-0.177	0.008	-0.373	-0.187	0.212	-0.226	-0.174
Available B	0.113	0.042	0.001	0.252	0.228	0.412	-0.219
DHA	-0.071	-0.205	-0.206	-0.057	0.379	0.047	-0.31
ECEC	-0.339	-0.124	-0.017	-0.381	-0.025	0.045	0.07
EA	0.191	0.23	-0.081	-0.41	0.113	0.107	-0.014

Table 4. SQI and RSQI of different panchayats in AEU 13 of Palakkad district of Kerala

Panchayats	Mean SQI	Mean RSQI (%)
Thachampara	0.51	46.41
Mannarkkad	0.46	41.69
Kottappadam	0.44	40.03
Kanjirappuzha	0.49	44.61
Thenkara	0.45	41.11
Thachanattukara	0.51	46.73
Kumaramputhur	0.54	49.36
Karimba	0.41	37.36
Karakkurussi	0.46	42.28
Alanallur	0.53	48.67

Conclusions

The soil samples collected after flood 2018, from the panchayats coming under AEU 13 of Palakkad district were analyzed for the physical, chemical and biological parameters. The study area had low OC and available N where as high available P, K and S. Available Mg and B were highly deficient and available Ca was also deficient in few samples. All the cationic micronutrients were sufficient. Most of the samples came under high class of B.D and P.D with optimum porosity and water holding capacity. While comparing the pre flood data, it is clear that Organic C, available P, K and S increased after flood where as available Ca, Mg, B, soil pH and EC reduced after flood. Mean RSQI of the ten Panchayats were poor which indicated the necessity of adopting appropriate soil health management strategies with major thrust on site specific and integrated nutrient management practices.

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