J. Indian Soc. Coastal Agric. Res. 40(1): 110-118 (2022) https://doi.org/10.54894/JISCAR.40.1.2022.114308

Soil Quality Assessment in the Post-flood Scenario of South Central Laterites of Ernakulam District, Kerala, India

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Received: 24-08-2021 Accepted: 25.06.2022

Kerala was hit by a terrible flood in 2018, wreaking havoc on the agricultural economy and taking lives. The flood caused great damage to Ernakulam district, especially in Agro-Ecological Unit (AEU) 9 which comprises the South Central Laterites. The AEU 9 represents midland laterite terrain with typical laterite soils. An initial survey was conducted in the flood-affected areas and twelve panchayats were selected. Geo-referenced composite soil samples were collected from different panchayats and were characterized for physical, chemical and biological properties. Principal component analysis (PCA) was performed for 23 soil attributes which resulted in 7 principal components (PCs) and a minimum data set (MDS) was developed using selected indicators *i.e.*, available calcium, available sulphur, available iron, available nitrogen, available zinc, available boron, bulk density, microbial biomass carbon and soil moisture. After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods. The highest soil quality index was observed in Sreemoolanagaram (0.79) and the lowest in Karumaloor (0.55). Based on the relative soil quality index (RSQI) value different panchayats were categorized into three groups, *i.e.*, poor, medium and good. The RSQI values of less than 50% are categorized as poor, 50-70% as medium and more than 70% as good. No panchayat in the flood-affected area was found to fall in the good category and 50% of the panchayats were found to have poor RSQI.

(***Key words:*** *AEU 9, Flood, Laterite, Minimum dataset, Soil quality*)

Kerala being an agrarian economy, its economic growth has always been under the caprices of the weather. The extreme and persistent rainfall occurrence affects all aspects of human lives including socio-economic conditions, transportation, infrastructure, agriculture and livelihood. Significant changes in the soil properties occurred after the 2018 flood due to soil erosion and soil deposition. Soil fertility and productivity have been disturbed, which needs site-specific investigation on different soil fertility parameters. Plant nutrition needs to be relooked into and revised based on the altered soil fertility status, and suitable location-specific management practices should be recommended. Several changes may take place when soil is under saturated conditions for an extended period of time affecting biological, chemical and physical soil health. Flooded soil may experience what is called the “post-flood syndrome”, similar to the fallow syndrome, where the land is left unplanted to any crop for the entire season. Heavy rains and flooding have left many farm fields in need of physical repair. Flood waters erode exposed soils, leaving deep gullies, drifted crop residues, building materials, as well as other types of debris. The flood had resulted in landslides, water stagnation and deposition of sand/silt/clay in these areas in different dimensions, which needs urgent attention for restoring and sustaining soil productivity. In this context, assessment of soil quality is the basic and urgent step which should be carried out for restoring soil productivity in the flood-affected areas.

Kerala was ravaged by floods in August 2018 as a result of excessive rainfall which was a 36% increase over normal rainfall, according to data from the India Meteorological Department (IMD). From June 1 to August 29, 2018, Kerala received 2346.6 mm of rain. The disastrous flood caused great damage to the soil environment in different ways. The south central laterites (AEU 9) agro-ecological unit is delineated to represent midland laterite terrain with typical laterite soils and a short dry period. The unit covering 161 panchayats of midlands extends from Thiruvananthapuram to Ernakulam district. The climate is tropical humid monsoon type (mean annual temperature 26.5°C; rainfall 2827 mm) with a dry period of around three

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and half months. The strongly acid, lateritic clay soils are gravelly and often underlain by plinthite. The lowlands have strongly acid, low-activity, non-gravelly clay soils with impeded drainage conditions. Mono-cropped rubber and coconut intercropped to a variety of annual and other perennial crops is the major land use on uplands and rice, tapioca, banana and vegetables on lowlands. The unit covers around 3,65,932 ha (9.42 %) in the state. (Government of Kerala, 2013). The objectives of the study are the assessment of the soil quality of post-flood soils of AEU 9 of Ernakulam district and to workout the soil quality index (SQI).

MATERIALS AND METHODS

Representative geo-referenced surface soil samples were collected from selected/identified post-flood areas of AEU 9 during June 2019 (Fig. 1). Areas most affected by the flood in AEU 9 of Ernakulam district were identified with the help of Agricultural Officers at each panchayat. Twelve panchayats were selected *i.e.*, Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty, Parakkadav, Aluva, Karumaloor, Kunnukara, Choornikkara, Alangad and Edathala. From each sampling site, soil samples were collected at a depth of 0-15 cm using a core sampler. A total of 64 composite soil samples were collected from AEU 9 and were analysed for physical, chemical and biological attributes by following the standard analytical procedures.

The following physical and chemical analyses were carried out on the samples collected: pH, electrical conductivity, organic carbon, particle size distribution, cation exchange capacity (CEC), exchangeable bases, available Nitrogen (N), Phosphorus (P), Potassium (K) and secondary nutrients by using standard soil analytical procedures (Jackson 1973; Sarma, *et al*., 1987). The available micronutrients Iron (Fe), Copper (Cu), Zinc (Zn) and Manganese (Mn) were extracted using 0.1 N HCl. The metal concentration was determined using atomic absorption spectrophotometry (Sims and Johnson, 1991). The ratio of the mass of the dry soil to the total volume of soil was recorded as the bulk

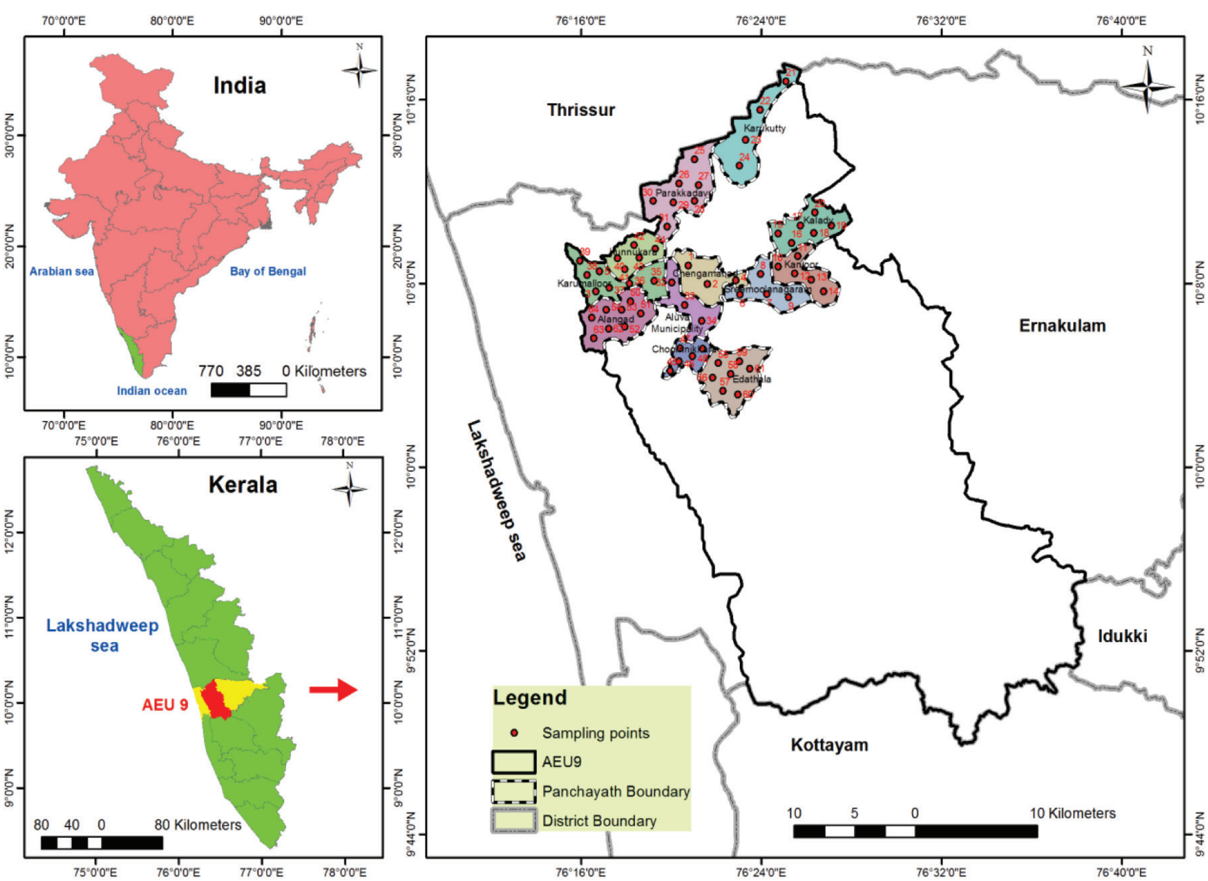

Fig. 1. Location of sampling sites in different panchayats under AEU 9

density of the sample (Dakshinamurti and Gupta, 1968). Dehydrogenase activity was estimated colorimetrically using a spectrophotometer based on the reduction of 2, 3, 5-triphenyltetrazolium chloride (TTC) to the creaming red-coloured tri phenyl formazan (TPF) (Page *et al*., 1982). Chloroform fumigation and extraction method was used for the estimation of microbial biomass carbon (Jenkinson and Pawlson, 1976).

Soil quality assessment was done by the method described by Andrews *et al*. (2002). There are three main steps involved in the soil quality index assessment, which include (i) selection of a minimum data set (MDS) of indicators which includes the most significant variables that best represent the soil functions (ii) development of the MDS indicators and scores are given to each indicator (iii) integration of the indicator scores and calculation of the index of soil quality.

The data obtained were analysed using a statistical package, SPSS 16.0 software. Principal component analysis (PCA) was performed for soil attributes to develop a minimum data set (MDS) (Doran and Parkin, 1994). Since the principal components (PCs) with higher values best represent the systems, the PCs having eigenvalue more than one and variance greater than 5% were selected. The weighted variables within 10% of the highest loading factor were taken into consideration and when there was more than one variable with a higher loading factor present within a PC, the correlation between the variables was taken. Correlation coefficient of the variables <0.60 was selected and others were eliminated from MDS (Andrews *et al*., 2002). After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods (Andrews *et al*., 2002). Three types of scoring curves were used: i) more is better ii) less is better, and iii) optimum curve (Bastida *et al*., 2006; Raiesi, 2017).

Soil quality index (SQI) was calculated using the method described by Doran and Parkin (1994):

$$\text{Soil quality index (SQI)} = \sum_{i=1}^{n} Wi \times Si$$

where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA. Weighing factors were calculated by dividing per cent of variance by cumulative per cent of PCs having eigenvalue > 1.

The relative soil quality index (RSQI) was calculated using the method given by Karlen and Stott (1994).

RSQI = (Computed SQI) / (Theoretical maximum SQI) × 100

where computed SQI is the value of each soil variable and theoretical maximum SQI is the maximum SQI obtained by calculation considering the maximum score of each variable.

RESULTS AND DISCUSSION

Principal component analysis (PCA) was performed for soil attributes to develop minimum data set (MDS). Soil physical, chemical and biological attributes that contributed to PCA are bulk density, particle density, porosity, water holding capacity, soil moisture, pH, EC, organic carbon, effective cation exchange capacity, available macro, secondary and micronutrients (N, P, K, Ca. Mg, S, Fe, Mn, Zn, Cu, B), dehydrogenase activity and microbial biomass carbon.

The principal components (PCs) having eigenvalue greater than 1 were selected. Principal component analysis for sample data of AEU 9 resulted in seven PCs and explained 16.25%, 13.32%, 10.30%, 8.56%, 6.71%, 6.07% and 5.10% for PC1, PC2, PC3, PC4, PC5, PC6 and PC7, respectively (Table 1). Each variable in a particular PC consisted of a weight or loading factor which represents the contribution of the variable to the PC. Highly weighted variables were selected from each PC. The weighted variables within 10% of the highest loading factor were taken into consideration and when more than one variable with a higher loading factor was present within a PC, then the correlation between the variables was taken (Table 4). If the highly weighted variables were not correlated (assumed to be a correlation coefficient of < 0.60), then each was considered important and was retained in the MDS (Andrews *et al*., 2002).

From PC1, available Ca and pH consisted highest loading factor, but only available Ca was selected for MDS. Among well-correlated variables within a PC, the variable with the highest sum of correlation coefficients (absolute values) was chosen for the MDS (Andrews *et al*., 2002). From PC2, available S and available Fe consisted highest loading factor, and both showed a correlation coefficient <0.60, so both were selected for MDS. In PC3, bulk density and porosity had the

Table 1. *Results of principal component analysis*

Particulars	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigenvalues	3.738	3.064	2.369	1.970	1.544	1.398	1.173
% Variance	16.253	13.324	10.301	8.563	6. 712	6.078	5.102
Cumulative %	16.253	29.577	39.877	48.440	55.152	61.230	66.332
Weights	0.24	0.2	0.15	0.13	0.1	0.09	0.08
Eigenvectors							
DHA	0.128	0.454	-0.279	-0.149	0.290	0.335	-0.017
N	-0.076	0.108	0.079	0.720	0.037	0.175	0.313
P	-0.225	-0.076	-0.241	-0.051	0.078	-0.530	-0.239
K	0.254	0.476	-0.041	0.339	-0.268	-0.305	-0.189
Ca	0.873	-0.073	0.085	-0.047	0.219	0.014	0.013
Mg	0.691	0.169	-0.237	0.245	-0.007	0.115	0.055
S	-0.146	0.722	0.369	0.017	-0.192	0.085	0.061
Fe	-0.129	0.690	0.274	0.036	0.173	-0.076	-0.116
Mn	0.189	0.561	-0.039	0.350	0.253	0.405	-0.148
Zn	0.197	-0.035	0.129	-0.152	0.811	-0.121	0.168
Cu	0.035	-0.024	0.022	0.039	0.714	0.001	-0.077
B	0.002	-0.099	-0.080	0.273	-0.152	-0.015	0.723
pH	0.783	-0.192	0.146	-0.151	-0.204	-0.040	-0.027
EC	0.032	-0.025	-0.143	-0.205	0.338	-0.082	0.589
Ex.acidity	-0.471	0.176	0.428	0.213	-0.089	-0.016	0.013
OC	-0.042	0.596	-0.055	-0.182	-0.106	-0.099	0.008
ECEC	0.775	0.127	0.162	0.248	0.300	0.081	0.015
BD	-0.066	-0.053	-0.912	-0.180	-0.053	0.065	0.057
PD	0.025	0.297	0.128	-0.587	0.205	0.441	-0.209
Porosity	0.074	0.155	0.897	-0.043	0.130	0.105	-0.139
WHC	0.283	0.454	0.326	0.196	-0.343	0.299	0.284
Soil moisture	0.148	-0.094	0.248	0.721	-0.079	0.083	-0.194
MBC	-0.077	-0.173	-0.128	0.105	-0.144	0.742	-0.196

highest loading factor, but bulk density was selected for MDS. From PC4, soil moisture and available N were selected for MDS. In PC5 available Zn was selected. In PC6 microbial biomass carbon and from PC7 available B was selected for MDS. From the total of seven PCs, 9 attributes were taken for MDS (Table 2). After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods. Three types of scoring curves were used (Andrews *et al*., 2002).

Table 2. *Ratings of relative soil quality index*

Relative soil quality index (RSQI)	Rating
<50%	Poor
50-70%	Medium
>70%	Good

***'More is better'* function**

'*More is better*' function was assigned to microbial biomass carbon, available B, available Ca and available N. In 'more is better' function, the highest score was given to the highest value of the soil attribute and the lowest score to the lowest value of particular soil attribute. Non-linear scoring was done here using the equation:

$$SNL = a/1 + (X/X_m)^b$$

where SNL is the score of the soil indicator, a is the maximum score reached by the function which is equal to 1, X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation and is set as -2.5 for a '*more is better*' curve. The values of each MDS indicator were arranged in ascending order and the non-linear scoring equation was applied. '*More is better*' function was used for soil organic matter and water-stable aggregates because of their role in soil fertility, water partitioning and stability of the structure (Tiessen *et al*., 1994). The scoring curves assigned to each soil attributes were based on the influence of that soil attribute on soil quality.

'Less is better' function

'*Less is better*' function was given for available Fe, bulk density, available Zn and available S. Scoring was done by non-linear scoring function using the equation:

$$SNL = a/1 + (X/X_m)^b$$

where b is the slope of the equation and here value is 2.5 for a '*less is better*' curve. The values of each MDS indicator were arranged in descending order and the non-linear scoring equation was applied. Due to the inhibitory effect of higher bulk density on soil porosity and plant root growth, bulk density is given '*less is better*' function (Soil Survey Staff, 1998). The observed available Fe level was found to be in the high range (>100 mg kg^{-1}), available Zn and available S also were in toxic levels so the '*less is better*' was used for scoring.

'Optimum' curve

In MDS, soil moisture was given '*optimum*' curve. The values of each MDS indicator were arranged in ascending order; the optimum value of a particular parameter was selected and given the highest score. The values lower than optimum were given '*more is better*' function equation and values greater than optimum were given '*less is better*' function equation.

Computation of soil quality index

Soil quality index (SQI) was calculated by summation of the score for the subscripted variable and the weighing factor obtained from the PCA (Table 3). The highest mean soil quality index was found in Sreemoolanagaram (0.79) and lowest mean was noticed in Karumaloor (0.55) (Table 4). Soil quality index mean values of Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty, Parakkadav, Aluva, Karumaloor, Kunnukara, Choornikkara, Alangad and Edathala were 0.71, 0.79, 0.75, 0.78, 0.72, 0.62, 0.73, 0.55, 0.62, 0.63, 0.56 and 0.56 respectively. The highest mean RSQI was obtained in Sreemoolanagaram panchayat (60.30%) and the lowest mean RSQI was obtained in Karumaloor (42.27%) (Fig 2).

RSQI values <50% was categorized as poor, 50-70 % as medium and >70% was categorized as good (Table 2). By comparing RSQI mean of different panchayats Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty and Aluva were rated poor RSQI value and Alangad, Edathala, Parakkadav, Karumaloor,

Table 3. *Relative soil quality index values of different panchayats of AEU 9*

Panchayats	Soil quality index (SQI)	Relative soil quality index (RSQI)	Rating
Chengamanad	0.71	54.17	Medium
Sreemoolanagaram	0.79	60.30	Medium
Kanjoor	0.75	56.82	Medium
Kalady	0.78	59.09	Medium
Karukutty	0.72	54.55	Medium
Parakkadav	0.62	45.86	Low
Aluva	0.73	55.05	Medium
Karumaloor	0.55	42.27	Low
Kunnukara	0.62	46.97	Low
Choornikkara	0.63	48.18	Low
Alangad	0.56	42.90	Low
Edathala	0.56	42.64	Low

Table 4. *Correlation analysis of properties of post flood soils from AEU 9 of Ernakulam district*

	DHA	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	pH	EC	EA	OC	CEC	BD	PD	Porosity	WHC	Moisture	MBC
DHA	1	-0.045	-0.067	0.065	0.149	0.118	0.08	0.206	0.396**	0.083	-0.012	-0.064	-0.09	0.114	-0.174	0.523*	0.186	0.129	0.301**	-0.004	0.074	-0.143	0.105
N		1	-0.202	0.149	-0.026	0.171	0.156	0.106	0.296**	-0.056	-0.019	0.344**	-0.11	-0.073	0.239*	0.403*	0.124	-0.152	-0.259*	0.049	0.217	0.310**	0.059
P			1	-0.001	-0.181	-0.152	-0.192	-0.079	-0.154	0.006	-0.051	-0.036	-0.148	0.049	0.01	-0.024	-0.242*	0.128	-0.099	-0.157	-0.322**	-0.129	-0.167
K				1	0.046	0.267*	0.315**	0.179	0.205	-0.166	-0.067	0.02	0.129	-0.221	0.067	0.14	0.176	-0.104	-0.147	0.049	0.253*	0.138	-0.104
Ca					1	0.464**	-0.191	-0.089	0.159	0.421**	0.113	-0.083	0.631**	0.095	-0.308**	-0.072	0.802**	-0.105	0.048	0.118	0.145	0.052	-0.078
Mg						1	-0.077	0.024	0.302**	0.091	-0.014	0.095	0.338**	0.079	-0.393**	-0.011	0.497**	0.087	0.031	-0.061	0.269*	0.207	0.048
S							1	0.516**	0.363**	-0.057	-0.091	-0.095	-0.088	-0.102	0.370**	0.316**	-0.01	-0.290*	0.179	0.328**	0.506**	-0.004	-0.033
Fe								1	0.281*	0.128	0.066	-0.152	-0.217	-0.139	0.182	0.304**	0.046	-0.277*	0.223	0.334**	0.233*	0.044	-0.181
Mn									1	0.091	0.13	-0.098	-0.035	-0.068	0.045	0.143	0.385**	-0.078	0.236*	0.161	0.366**	0.235*	0.131
Zn										1	0.589**	-0.151	0.231*	0.194	-0.221	-0.084	0.361**	-0.08	0.17	0.137	-0.102	-0.254*	-0.153
Cu											1	-0.065	-0.016	0.06	-0.085	-0.005	0.22	0.003	0.166	0.058	-0.129	-0.059	-0.051
B												1	0.028	0.088	-0.053	-0.043	-0.023	0.025	-0.307**	-0.146	0.203	0.008	-0.002
pH													1	-0.104	-0.274*	-0.107	0.468**	-0.086	0.024	0.084	0.151	0.025	-0.023
EC														1	-0.08	-0.027	0.078	0.153	0.002	-0.139	-0.048	-0.137	-0.181
EA															1	0.096	-0.06	-0.289*	-0.041	0.246*	0.124	0.084	0.019
OC																1	0.037	-0.319*	-0.122*	0.124**	0.147*	-0.102	0.444*
CEC																	1	-0.212	-0.006	0.195	0.301**	0.306**	-0.025
BD																		1	0.027	-0.927**	-0.292*	-0.363**	0.113
PD																			1	0.344**	0.066	-0.352**	0.118
Porosity																				1	0.291*	0.218	-0.058
WHC																					1	0.262*	0.08
Moist.																						1	0.107
MBC																							1

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)

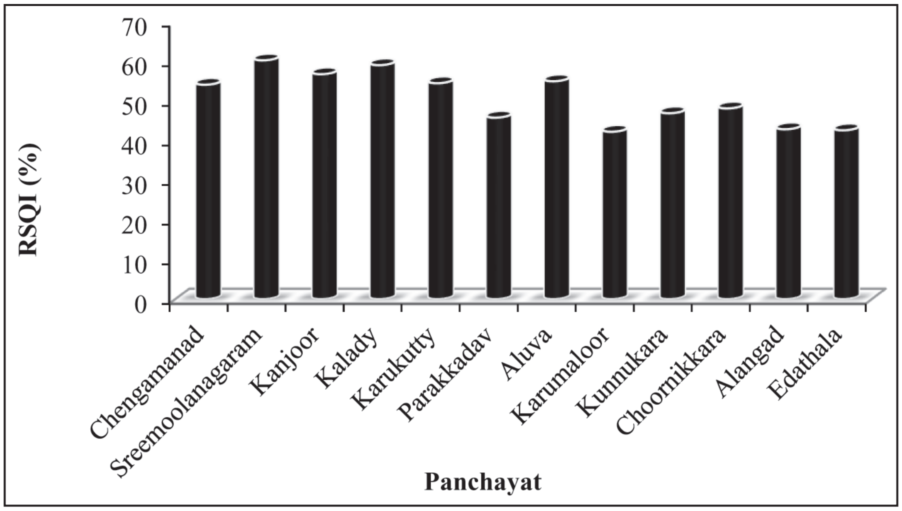

***Fig. 2.** Relative soil quality indices of different panchayats under AEU 9*

Kunnukara and Choornikkara recorded medium RSQI values. No panchayat came under the good RSQI category (Table 3). This might be due to the influence of MDS indicators. Available Ca, S, microbial biomass carbon, N, Zn and soil moisture drive the soil quality index and major limiting factors in MDS were available Fe, B and bulk density. Bulk density was observed high in the soils, which negatively affects the plant growth. Available B was observed very low, even below the detectable range and higher levels of Fe were noticed in AEU 9. This could be the reason for poor RSQI values in AEU 9. A study on land use impact on soil quality in the eastern Himalayan region of India revealed that SQI rating was the highest for least disturbed sites such as natural forests (0.93) and grasslands (0.87) and lowest for intensively cultivated sites (0.44) (Singh *et al*., 2014).

The order of contribution of soil attributes to soil quality index in AEU 9 was available Ca > available S = available Fe > bulk density > available N = soil moisture > available Zn > microbial biomass carbon > available B (Fig. 3). The influence of MDS parameters on soil quality varies for each parameter. The order of contribution shows the impact of each MDS parameter on the soil quality.

Post-flood assessment in AEU 9 revealed that available K, available B and organic carbon were found to decrease (Table 5). The decrease in the sufficiency level of K after flood might be due to the leaching of K after heavy rainfall. A decrease in organic matter content in the soil might also be the reason for low K content (Gairola *et al*., 2012). Boruah and Nath (1992) reported that there is a positive relationship between available K and organic matter. The organic matter provides the site for the retention of K in the soils. Whereas, Shamna (2020) reported that organic carbon, available phosphorous, potassium and sulphur levels increased while widespread deficiency of nitrogen and calcium were observed in a majority of the panchayats in AEU 9 of Alappuzha district, Kerala. The post-flood effects were site-specific depending on the topography of the area. Increased deficiency of B after the floods might be due to the leaching of B from the soils after heavy rainfall. Acidic condition of the soil also leads to loss of B as boric acid in the soil. The high P status of the soil is also one of the reasons for low B. The post-flood study in Pokkali soils (AEU 5) of Ernakulam district revealed that 67% of soil samples came under the poor soil quality range. Among the 15 panchayats, the relative soil quality index of ten panchayats was under the poor category and five were under the medium category (Unni and Sreelatha, 2021).

Several soil quality indicators collectively form a comprehensive measurement known as the minimum data set. Even a slight change in the nutrient level of MDS indicators greatly affects the soil quality index. In the present study, the soil quality was found to range from 0.39 to 0.92. The highest soil quality was observed in Aluva (0.92) and the lowest value was observed in Edathala panchayat (0.39). The RSQI values varied from 42.27 to 60.30%. The highest mean RSQI was obtained in Sreemoolanagaram panchayat (60.30%) and the lowest

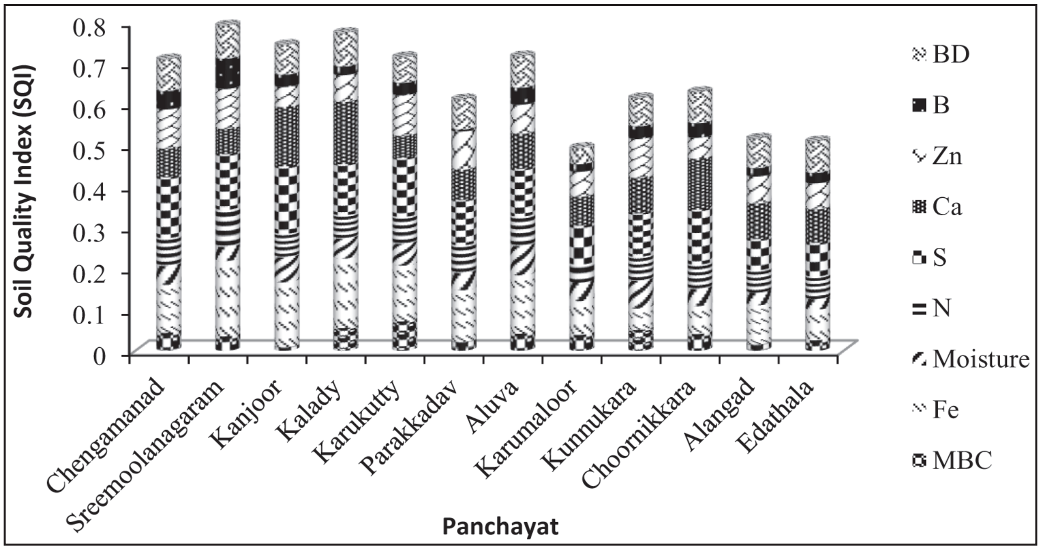

Fig. 3. *Contribution of each soil attributes in MDS toward SQI*

Table 5. *Comparison of results with pre-flood data*

Parameters	Category	Pre-flood	Post-flood
Available potassium	High	41 %	14 %
Available boron	Deficient	65 %	100%
Organic carbon	High	37 %	16 %

mean RSQI was obtained in Karumaloor (42.27%). The post-flood study in AEU 9 revealed that drastic changes occurred in the soil environment in different ways and 50% of the panchayats were found to fall under the poor RSQI category. The results clearly showed the decrease in soil quality after floods. Hence, proper adoption of site-specific soil management practices is essential to avoid the degradation of soil quality.

CONFLICT OF INTEREST

The authors do not have any conflict of interest

ACKNOWLEDGEMENT

The authors hereby acknowledge the financial assistance and research facilities extended by the Kerala Agricultural University.

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