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Flood effects on soil quality in the southern and central foothills of Pathanamthitta district of Kerala

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Abstract
A study was undertaken to assess the quality of post-flood soils in AEU 12 of Pathanamthitta district and develop GIS maps depicting the spatial distribution of soil quality. A minimum data set of indicators for assessing soil quality was set up from seventeen selected physical, chemical and biological parameters analysed using principal component analysis. Six principal components with eigen value greater than 1 were selected and nine parameters with higher factor loadings were retained for the minimum data set *viz.*, soil pH, available Mg, sand per cent, available K, available P, available B, acid phosphatase activity and silt per cent. A weighted soil quality index was formulated after assigning appropriate weights and scores to the selected indicators. Mean soil quality was found to be higher in areas with sediment deposition after the floods in the Pampa basin. Soil quality was observed to be medium for majority of the samples (54.7%) analysed.

Keywords: Post-flood soils, minimum data set, principal component analysis, soil quality, soil quality index

Introduction
Soil, a dynamic living natural body playing a crucial role in the functioning of terrestrial ecosystems, functions as an environmental filter for removing undesirable contaminants from air and water. The thin layer of soil covering the earth's surface determines the survival and extinction of majority of the terrestrial life. The quality of soil which affects the health and productivity of the environment is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation (Karlen *et al*., 1997) [12]. Soil quality declines due to nutrient losses through runoff and leaching, depletion of soil organic matter, crusting, compaction, accumulation of toxic substances, excessive use of chemical fertilizers and pesticides, improper waste disposal etc. Increased temperature, altered precipitation patterns and extreme weather events associated with climate change alter soil quality. A change in global climatic pattern has turned out to be a major issue affecting food security and quality in the recent past.

Kerala experienced severe floods due to the unusually high rainfall during the south west monsoon of 2018. As per India Meteorological Department data, the state received 2346.6 mm of rainfall from 1st June 2018 to 19th August 2018 which exceeded the expected rainfall by about 41%. The unexpected hike in rainfall led to catastrophic floods which peaked during 17th to 21st August and thirteen out of the fourteen districts were affected by the flood and landslides (CTCRI, 2018) [7]. Pathanamthitta district was one of the worst hit during the 2018 floods. Continuous flooding and water logging in the area resulted in washing away of the top soil thereby a loss in soil fertility. Thus the post-flood soils of the region required a site specific and detailed analysis of soil fertility parameters to understand the extent of changes so as to arrive at a new crop management plan. Therefore, a study was conducted to assess the effect of the severe flood on soil quality of AEU 12 in Pathanamthitta district of Kerala.

Materials and Methods

Study area

The study was carried out in AEU 12 (Southern and central foothills) of Pathanamthitta district in Kerala. Eight panchayats in AEU 12 severely affected by the August 2018 floods viz. Kalanjoor, Pramadom, Konni, Pathanamthitta, Ranni-Angadi, Vadaserikkara, Ranni-Perunnadu and Naranammoozhi were selected based on the extent of damage to the cropped area.

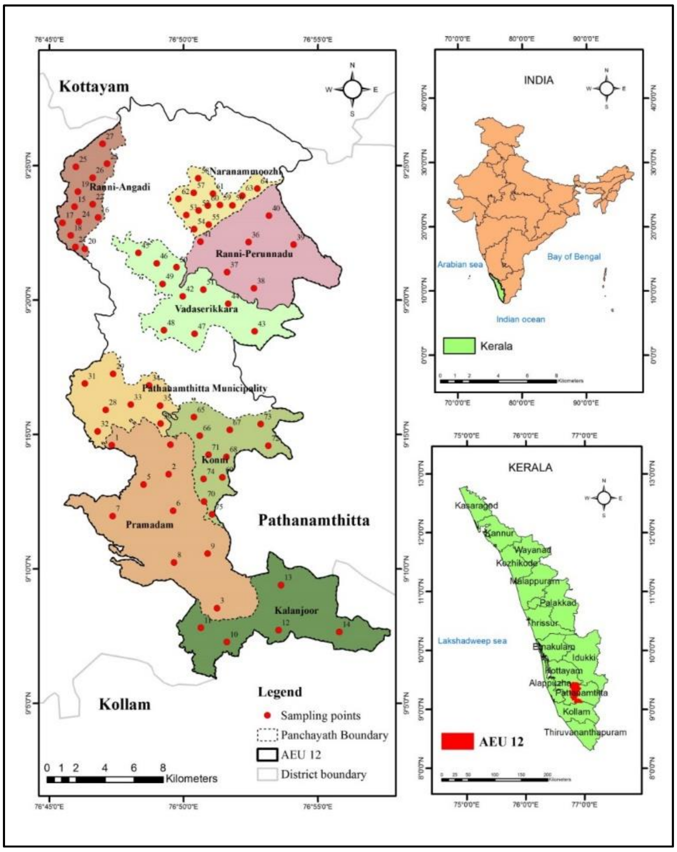

Fig 1: Location map of samples in AEU 12 of Pathanamthitta district

Soil sampling, processing and analysis

Seventy five georeferenced post flood surface soil samples were collected from the eight selected panchayaths (Fig. 1) and geographic coordinates of the samples were recorded using a GPS recorder. Soil samples were dried and sieved using 2 mm sieve before analysis in the laboratory. The samples were analysed for selected physical, chemical and biological parameters following standard analytical procedures. Physical properties analysed were bulk density (Blake, 1965) [3], maximum water holding capacity (Dakshinamurthi and Gupta, 1968) [8], soil texture (Bouycous, 1936) [4] and percentage of water stable aggregates (Yoder, 1936) [23].

Soil pH was measured in a 1:2.5 soil water suspension using a pH meter, and electrical conductivity was measured using an EC meter in the supernatant of the 1:2.5 soil water suspension (Jackson, 1973) [11]. Organic carbon was estimated using Walkley and Black wet oxidation method (Walkley and Black, 1934) [21], available nitrogen by alkaline permanganate method (Subbiah and Asija, 1956) [18] and available phosphorus was extracted using Bray No. 1 solution and estimated using spectrophotometer (Bray and Kurtz, 1945) [5]. Available potassium was estimated using flame photometer (Jackson, 1973) [11] available calcium and magnesium by versenate titration method (Hesse, 1971) [10] and available sulphur was extracted with calcium chloride and estimated using spectrophotometer (Massoumi and Cornfield, 1963) [15]. Available B was extracted with hot water and estimated using a spectrophotometer (Gupta, 1972) [9]. Acid phosphatase activity was analysed colorimetrically using spectrophotometer (Tabatabai and Bremner, 1969) [19].

Assessment of soil quality and development of soil quality index

Direct measurement of soil quality is not possible, but it can be inferred from the assessment of soil physicochemical and biological properties which act as indicators (Bredja *et al*., 2001) [6]. Attributes that are most sensitive to changes within the soil are the most desirable indicators and the selection of soil quality indicators vary with the purpose of assessment (Arshad and Martin, 2002) [2]. According to Vasu *et al.* (2016) [20], calculation of soil quality index involves four steps – (i) defining the aim, (ii) selection of indicators for a minimum data set, (iii) scoring of the selected indicators and (iv) calculation of soil quality index (SQI).

The aim of the present study was to assess the soil quality in the post-flood soils of AEU 12 in Pathanamthitta district of Kerala. A minimum data set (MDS) of indicators for assessing soil quality was developed using the statistical method *viz.* principal component analysis (Andrews *et al*. 2002) [1]. Principal components with higher eigen values best represent the attributes to be selected. Therefore, principal components with eigen value greater than one were selected for setting up the minimum data set. From the selected principal components, parameters with the highest weightage or factor loadings which represent the contribution of each variable to the principal component were identified. Only the highly weighted variables (within 10% of the highest observed factor loading) in each principal component were retained (Wander and Bollero, 1999) [22]. When more than one variable was retained in a principal component, correlation between the retained variables was considered to check redundancy. In case the retained parameters were highly correlated (correlation coefficient r> 0.6) only the variables with highest factor loading were selected for the MDS.

A weighted soil quality index was developed using the minimum data set of parameters following the method outlined by Kundu *et al*. (2012) [14]. Each attribute was categorised into four classes *viz.* class –I (very good), class II (good), class III (poor) and class IV (very poor) and assigned scores of 4, 3, 2 and 1 respectively (Kundu *et al*., 2012 [14] and Mukherjee and Lal, 2014 [16]) with slight modifications. The attributes selected for the MDS were assigned appropriate weights based on existing soil conditions, cropping systems and agro-climatic conditions (Singh *et al*., 2017) [17].

Soil quality index was calculated using the equation:

$$SQI = \sum W_i \times S_i$$

where, W_i is the weight of indicators and S_i the score assigned to the indicator classes.

The change in soil quality was measured in terms of relative soil quality index (RSQI) (Karlen and Scott, 1994 [13]).

$$RSQI = (SQI/SQI_m) \times 100$$

where, SQI is the calculated SQI and SQI_m is the theoretical maximum.

RSQI of each sampling location was rated as poor (RSQI < 50%), medium (RSQI 50% - 70%) and good (RSQI > 70%)

(Kundu *et al*., 2012) [14] and a soil quality map was developed using ArcGIS 10.5.1 software.

Results and Discussion

Soil physical, chemical and biological properties

The mean, range and standard deviation of soil physical properties are presented in table 1. Bulk density varied between 0.84 and 1.45 Mg m^{-3}, maximum water holding capacity between 29.6 and 68.0 per cent, and water stable aggregates ranged between 1.68 and 97.7 per cent in the post-flood soils of AEU 12 of Pathanamthitta district. Clay content in the soils varied between 11.2 and 46.2 per cent, silt content between 5.0 and 40.0 per cent and sand between 33.8 and 73.8 per cent. The predominant soil textural class in the study area was sandy clay loam.

Table 1: Soil physical properties in the post-flood area of AEU 12 in Pathanamthitta district

Parameters	Mean ± SD	Range
Bulk density (Mg m^{-3})	1.15 ± 0.16	0.84-1.45
Maximum water holding capacity (%)	47.3 ± 9.54	29.6-68.0
Water stable aggregates (%)	62.8 ± 26.0	1.7-97.7
Clay (%)	29.3 ± 8.29	11.2-46.2
Silt (%)	18.3 ± 7.37	5.0-40.0
Sand (%)	52.4 ± 10.48	33.8-73.8

The chemical properties of the post flood soils (Table 2) showed a variation in soil pH between 3.62 and 7.20, EC between 0.01and 0.70 dS m^{-1}, soil organic carbon between 0.14 and 3.15 per cent and available N between 25.1 and 439 kg ha^{-1}. Available P ranged between 0.69 and 362 kg ha^{-1} and available K between 56.0 kg ha^{-1} and 699 kg ha^{-1}. Available Ca values were between 120 and 1960 mg kg^{-1} whereas available Mg varied between 12.0 and 780 mg kg^{-1}. Available S ranged between 0.5 and 78.5 mg kg^{-1} while available B varied between 0.01 and 1.5 mg kg^{-1}. Acid phosphate activity (Table 2) ranged between 4.27 µg PNP produced g $soil^{-1}$ h^{-1} and 96.9 µg PNP produced g $soil^{-1}$ h^{-1}.

Table 2: Soil chemical and biological properties in the post-flood area of AEU 12 in Pathanamthitta district

Parameters	Mean ± SD	Range
pH	5.28 ± 0.97	3.62-7.20
EC (dS m^{-1})	0.19 ± 0.15	0.01-0.70
Organic carbon (%)	1.6 ± 0.73	0.14-3.15
Available N (kg ha^{-1})	216 ± 77.5	25.1-439
Available P (kg ha^{-1})	93.6 ± 75.9	0.69- 362
Available K (kg ha^{-1})	246 ± 145	56.0-699
Available Ca (mg kg^{-1})	865 ± 436	120-1960
Available Mg (mg kg^{-1})	204 ± 151	12.0-780
Available S (mg kg^{-1})	12.9 ± 14.5	0.50-78.5
Available B (mg kg^{-1})	0.47 ± 0.44	0.01 - 1.50
Acid phosphatase activity (µg PNP produced g $soil^{-1}$ h^{-1})	27.1 ± 14.6	4.27 - 96.9

Setting up of a minimum data set and formulation of soil quality index

Seventeen parameters, *viz*. bulk density, maximum water holding capacity, water stable aggregates, sand, silt and clay per cent, pH, EC, organic carbon, available primary and secondary nutrients, available B and acid phosphatase activity were analysed using PCA to develop a MDS of parameters. The PCA yielded six principal components with eigen value greater than 1, which were selected to obtain a MDS. These six principle components had a variance of 22.2 per cent, 15.2 per cent, 11.7 per cent, 8.2 per cent, 6.8 per cent and 6.1 per cent respectively (Table 3).

Table 3: Results of principal component analysis

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen values	3.872	2.583	1.988	1.401	1.164	1.040
% variance	22.2%	15.2%	11.7%	8.2%	6.8%	6.1%
Cumulative variance	22.2%	37.4%	49.1%	57.4%	64.2%	70.3%
Eigen vectors						
Bulk density	0.064	0.122	-0.075	0.280	0.652	-0.450
Water holding capacity	-0.069	-0.492	-0.041	-0.140	-0.035	0.257
Water stable aggregates	-0.265	-0.016	0.205	0.173	0.062	-0.032
Sand	-0.053	0.527	0.079	-0.027	-0.192	0.074
Silt	0.167	-0.339	0.235	0.030	-0.061	-0.451
Clay	-0.082	-0.421	-0.309	0.008	0.297	0.308
pH	0.427	0.078	-0.092	0.146	-0.066	0.139
EC	0.120	-0.251	0.327	-0.170	-0.108	-0.290
Organic carbon	-0.332	-0.050	0.259	0.159	0.158	0.157
Available N	-0.312	-0.117	0.170	0.241	-0.207	-0.080
Available P	-0.035	0.081	0.328	-0.474	0.363	-0.071
Available K	0.027	-0.037	0.520	-0.105	-0.067	0.197
Available Ca	0.411	-0.010	0.157	0.164	-0.090	0.220
Available Mg	0.393	-0.082	0.204	0.102	-0.046	-0.008
Available S	0.356	-0.059	0.030	0.227	0.208	0.133
Available B	0.133	0.124	0.076	-0.473	0.329	0.257
Acid phosphatase activity	-0.092	0.063	0.362	0.434	0.242	0.342

The factor loadings of variables under a particular principal component (PC) denote the contribution of that variable to the PC. Only highly weighted variables (within 10% of the highest factor loading) were retained in a PC (Wander and Bollero, 1999) [22]. When more than one variable was retained, linear correlations were worked out between the variables. If the variables were highly correlated (r>0.6), only the variable with highest factor loading was retained. All the non-correlated highly weighted variables under a PC were considered important and retained (Andrews *et al*., 2002) [1].

Table 4: MDS of parameters obtained from PCA

PC1	PC2	PC3	PC4	PC5	PC6
pH	Per cent sand	Available K	Available P	Bulk density	Per cent silt
Available Mg			Available B		
			Acid phosphatase Activity		

In the first PC, soil pH and available Ca and Mg had the highest factor loading. Due to the high correlation between pH and available Ca, only pH with the highest factor loading and available Mg were selected (Table 4). The highly weighted variable in the second PC was per cent sand and the variable retained in the third PC was available K. In the fourth PC, available P, available B and acid phosphatase activity were retained while bulk density and per cent silt respectively were retained in the fifth and sixth PCs.

SQI was formulated using the MDS of parameters which were assigned appropriate weights and scores (Table 5). Scoring was done following the method suggested by Kundu *et al*. (2012) [14] and Mukherjee and Lal (2014) [16] with slight modifications based on the fertility status of Kerala soils. After scoring, a weighted SQI was computed using the equation,

$$SQI = \sum Wi \times Si$$

where, Wi is the weight and Si is the score assigned to the parameters.

Table 5: Soil quality indicators, their weights and classes with scores

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Bulk Density ($Mg\ m^{-3}$)	3	1.3-1.4	1.2-1.3 or 1.4-1.5	1.1-1.2 or 1.5 -1.6	< 1.1/ > 1.6
Texture Sand % Silt %	15 13 2	Loam	Clay loam/ Sandy loam/ Sandy clay loam	Sandy clay/ loamy sand	Grit
pH	20	6.5-7.5	6-6.5/7.5-8	5.5-6/8-8.5	<5.5/>8.5
Available P ($kg\ ha^{-1}$)	10	>25	15 – 25	10- 15	<10
Available K ($kg\ ha^{-1}$)	12	>280	200-280	120- 200	<120
Available Mg ($mg\ kg^{-1}$)	20	>120	90-120	60-90	<60
Available B ($mg\ kg^{-1}$)	10	>1.5	0.7-1.5	0.5-0.7	<0.5
Acid Phosphatase (µg PNP produced g $soil^{-1}h^{-1}$)	10	>60	30-60	15-30	<15

A relative soil quality index (RSQI) was also computed to assess the change in soil quality and samples were rated based on RSQI value as poor (<50%), medium (50-70%) and good (>70%). The highest and lowest mean of SQI and RSQI were obtained for Naranammoozhi (283, 70.8%) and Kalanjoor (235, 58.7%) respectively. The SQI ranged between 149 and 351 in the post flood soils with a mean of 263. RSQI ranged between 37.5 and 87.8 per cent with a mean of 65.7 per cent (Table 6).

Medium soil quality (in terms of RSQI) was obtained for 54.7 per cent of the samples followed by 36 per cent with good quality and 9.3 per cent poor (Fig. 2). Soil quality was observed to be higher in Naranammoozhi, Vadaseikkara, Ranni-Perunnadu and RanniAngadi area (Table 6) with less acidic soils, high available P, K, Mg and B contents and with a sediment deposition of 10-15 cm. The spatial distribution of soil quality is depicted in Fig. 3.

Table 6: SQI and RSQI in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	SQI		RSQI (%)	
	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	235 ± 29.9	188 – 264	58.7 ± 7.46	47.0 - 66.0
Konni	240 ± 53.1	149 – 307	60.0 ± 13.3	37.3 - 76.8
Pramadam	251± 25.3	217 – 286	62.9 ± 6.33	54.3 - 71.5
Pathanamthitta	246 ± 11.9	227 – 264	61.6 ± 2.98	56.8 - 66.0
Vadaserikkara	278 ± 27.1	232 – 310	69.4 ± 6.77	58.0 - 77.5
Ranni-Angadi	272 ± 61.3	174 – 351	68.0 ± 15.3	43.5 - 87.8
Ranni-Perunnadu	278 ± 50.7	195 – 338	69.6 ± 12.7	48.8 - 84.5
Naranammoozhi	283 ± 29.3	232 – 324	70.8 ± 7.33	58.0 - 81.0
AEU 12	263 ± 42.9	149 – 351	65.7 ± 10.7	37.5 - 87.8

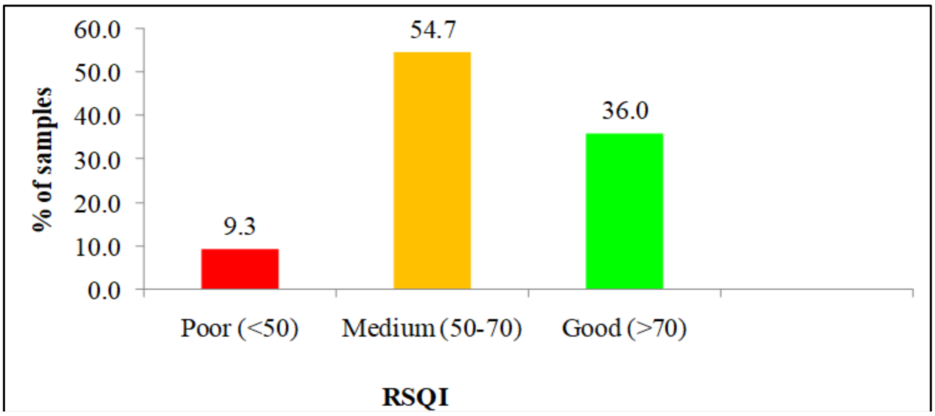

Fig 2: Frequency distribution of RSQI (%) in the post-flood soils of AEU 12 in Pathanamthitta district

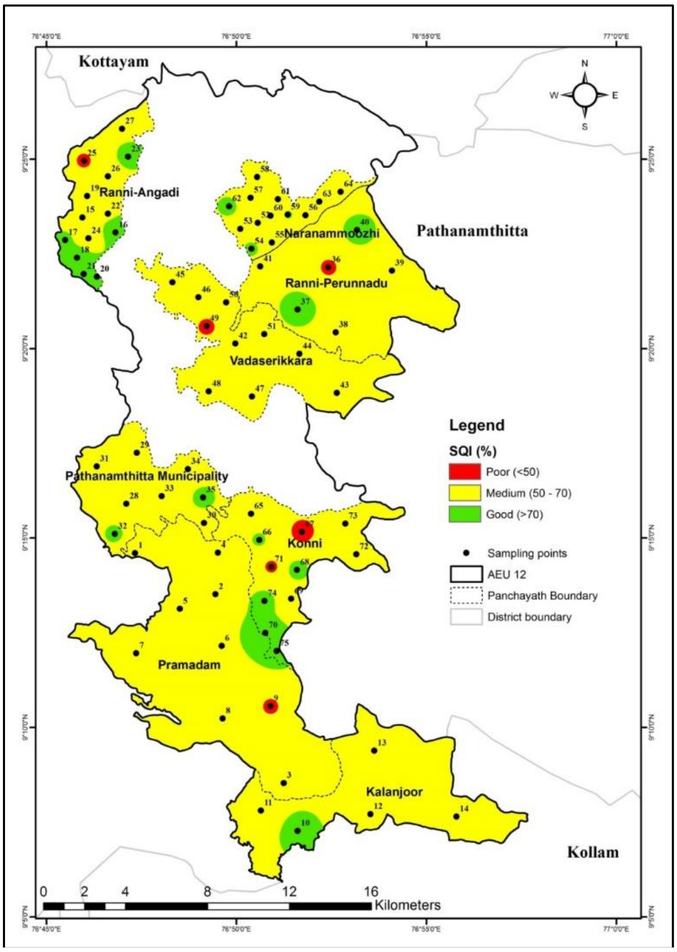

Fig 3: Spatial distribution of SQI in the post-flood soils of AEU 12 in Pathanamthitta district

Conclusion

Severe floods bring about a series of physical, chemical and biological changes that significantly affect the quality of soil as a medium for plant growth. The present study revealed that most of the study area had medium soil quality. The mean soil quality was found to be comparatively higher in Naranammoozhi, Vadaserikkara, Ranni-Perunnadu and Ranni-Angadi areas which can be attributed to sediment deposits rich in nutrients and due to a moderation in soil pH after the flood.

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