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Assessment of Soil Quality in the Post Flood Soils of Sothern and Central Foothills of Kerala, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

The study was undertaken to evaluate the soil quality of post-flood soils of Agro-ecological Unit 12 (southern and central foothills) in Kottayam district, Kerala. Representative surface soil samples were collected from the area after the flood event. The samples were analysed in the laboratory for various physical, chemical, and biological soil properties. Principal component analysis was employed to select the minimum data set influencing soil quality in the study area. Using the scoring and weighted additive approach, a soil quality index was computed, and soils were classified into low, medium, and good categories based on the relative soil quality index. The results indicated that 95 per cent of the soils fell under the medium quality category, with RSQI values ranging from 50 to 70, while only five per cent of the soils were rated as poor.

Keywords: Physico-chemical changes; relative soil quality index; soil quality.

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1. Introduction

"Kerala experienced severe floods across the entire state due to unusually high rainfall during the southwest monsoon of 2018. According to IMD data, the state received 2346.6 mm of rainfall from 1 June 2018 to 19 August 2018, exceeding the normal rainfall by about 41 per cent. This unexpected increase in rainfall led to catastrophic flooding, with peak intensity observed between 17 and 21 August 2018. Thirteen out of the fourteen districts were affected by flash floods and landslides". "Soil erosion emerged as the major impact in 86 per cent of the flood-affected areas" (Kerala State Planning Board, 2018; Shrestha, 2006). AEU 12 (Southern and central foothills) comprises undulating lands with low hills situated between the midland laterites and the high hills of the Western Ghats, covering an area of 72,611 ha. The Erattupetta and Kanjirapally blocks within this AEU were severely affected by landslides.

Prolonged flooding and waterlogging resulted in the washing away of topsoil, leading to significant losses in soil fertility. Soil compaction was observed throughout the affected areas. Floodwaters eroded exposed soils, formed deep gullies, and transported crop residues, building materials, and other debris. Landslides, water stagnation, and the deposition of sand, silt, and clay of varying thicknesses were also recorded.

Extended soil saturation caused notable changes in soil chemical, physical, and biological properties. Flooded soils may experience a "post-flood syndrome," comparable to the "fallow syndrome," when land is left uncultivated for an entire season. Such conditions disturb soil fertility and productivity, necessitating site-specific investigations of soil fertility parameters. Nutrient recommendations for existing cropping systems require redrafting, along with revisions in cropping patterns and the adoption of location-specific management practices. Quality assessment of post-flood soils to identify nutrient imbalances and adverse physical conditions is essential for restoring crop productivity and ensuring long-term sustainability.

2. Materials and Methods

Kottayam district spreads over three agro ecological units (AEU) *viz*., 4 (Kuttanad), 9 (South Central Laterites) and 12 (Sothern and Central Foothills). It consists of 11 blocks and 79 panchayaths. AEU 4 and 9 were badly affected by flood while AEU 12 by landslide.

The study was carried out in AEU 12(Southern and Central Foothills) of Kottayam district. It represent the undulating lands with low hills, between midland laterites and high hills of Western ghats. Here, the soils in general are strongly acidic, dominated by low activity lateritic clay soils and are rich in organic matter. These soils have moderate CEC and basic cations. Acidity is a major constraint of these soils. Majority of the soils are deficient in Ca, Mg and B. Sampling sites were selected based on a field survey and was done during the month of April, 2019, before the pre monsoon showers. The worst affected panchayaths in this agro ecological unit were Thalanadu, Thidanadu and Erumeli and 20 geo referenced soil samples were collected.

"Surface soil samples at 0-15 cm depth were taken. Core samples were also taken from each sampling point. The samples were immediately stored in plastic covers and transported to laboratory for further analysis. Soil samples were dried and sieved using 2 mm sieve before analysis in the laboratory. The samples were analysed for soil texture, bulk density, maximum water holding capacity, pH, EC, organic carbon, available N, P, K, Ca, Mg, S and acid phosphatase in the laboratory using AR grade reagents following standard analytical procedures" (Swathi et al., 2020). Soil textural analysis was done using Bouycous hydrometer method. Bulk density and maximum water holding capacity were analysed using core samples. "Soil pH was measured in 1:2.5 soil water suspensions using a pH meter. EC was measured using an EC meter in the supernatant of 1:2.5 soil water suspensions" Organic carbon was estimated using Walkley and Black (1934) rapid titration method. "Available nitrogen was determined by alkaline permanganate method". "Available phosphorus was extracted using Bray No. 1 solution and estimated using spectrophotometer" (Bray and Kurtz, 1975). Available potassium was estimated using flame photometer after extraction with neutral normal ammonium acetate. Versenate titration method (Hesse, 1971) was followed to determine available calcium and magnesium. "Available sulphur was extracted using calcium chloride and estimated using spectrophotometer". Acid phosphatase was determined by colorimetric estimation of p-nitrophenol released by soil is incubated with buffered (pH 6.5) sodium pnitrophenyl phosphate solution and toluene at 37^{0}C for 1 hr. (Tabatabai & Chae, 1991). The frequency distribution of soil pH, organic carbon and available P, K, Ca, Mg and S were compared with the pre flood data of Kerala State Planning Board (2013).

2.1 Soil Quality

"Soil quality index (SQI) for each sampling site was generated by aggregating the scores following standard methods. This included: (i) selection of MDS of indicators that best represent the soil functions; (ii) scoring the MDS indicators based on their performance of soil functions; and (iii) integrating the indicator scores into a comparative index of soil quality".

(i) **Selection of Minimum Data Set from Different Soil Properties:** Principal Componenet Analysis (PCA) method was used for determination of minimum data set which consists of most suitable soil indicators which influenced the soil quality of this area. MDS is chosen on the basis of capacity soil properties to predict soil stability and productivity. Principle components (PCs) which have Eigen value greater than one were selected from PCA analysis. According to Wander and Bollero (1999), only the variables which have high weightage within each PC were selected for MDS. When there is more than one indicator in single PC, correlation is worked out among them. If they have significant correlation (r ≥ 0.6) between each other, then the one with highest loading factor was selected for MDS and the remaining are excluded. Thus, means that the non-correlated parameters were retained and elected for MDS.

(ii) **Scoring of the Selected Indicators:** To formulate the soil quality index, proper weights were assigned to the selected parameters in the MDS and proper score was given to each class (Larson and Pierce, 1994). Scoring of the parameters was achieved using the method suggested by Patil *et al.* (2017); Lal (2020) with slight modification based on the soil fertility ratings for secondary and micronutrients for soils of Kerala.

(iii) **Calculation of Soil Quality Index (SQI) and Relative Soil Quality Index (RSQI):** Weighted additive method was used to calculate soil quality. The equation was proposed by Wymore, (1993)

$$SQI = \Sigma W_i S_i$$

Where, W_i is the weighted factor and S_i is the weighted score.

Relative soil quality index was used to measure the changes in the soil quality (Karlen and Stott, 1994)

$$RSQI = \left(\frac{\text{SQI}}{\text{SQImax}}\right) 100$$

Where SQI was the determined soil quality index and SQImax was the maximum soil quality index that can be obtained theoretically.

3. Results and Discussion

3.1 Physical Parameters

Bulk density (BD) of 50 percent of samples analysed had values within1.2-1.4 Mg m^{-3}range and hence not much affected by the recent floods. 25 and 5 per cent of the selected samples observed bulk density >1.4 and <1.2 Mg m^{-3}, respectively (Fig. 1). In areas with high organic matter content and clay deposition, bulk density was comparatively less (Chaudhari *et al*., 2013). And is also inversely related with soil porosity (Eluozo and Oba, 2018). Management practices like frequent raking of soil and removal of sand deposits may be practiced to improve the bulk density so that it will not hinder root penetration. Particle density of 15 per cent had particle density less than 2.2 Mg $m^{-3}$and 9.8 per cent of samples were with density more than 2.6 Mg m^{-3} (Fig. 1). The particle density relates the amount of organic matter and minerals present in soils and those with more organic carbon and silt deposition will have comparatively lower values (Bielders *et al*., 1990).More deposition of sand and related particles carried along with the flowing water might have resulted in more density in areas under AEU 12.Soil texture refers to the relative proportion of sand, silt and clay particles, which determines the major physical properties. The mean sand, silt and clay contents were 66.4, 9.8 and 23.5 per cent, respectively (Fig. 2). The majority of soils belong to sandy clay loam texture. These regions suffered more from the consequences of landslide rather than flooding. The mean value of soil moisture content varied from 8.25 to 29.1 percent. 20 per cent of soils were with moisture content more than 25; 45 per cent of samples had moisture content in 15-25 range; 30 per cent in 10-15 range (Fig. 2). Excessive retention of water brought about by flooding may result in increased moisture content (Mitsch, and Wu, 1995).

The present study showed that water holding capacity of 90.2 per cent of soils had WHC less than 30 and 15 per cent of samples were in 30 to 50 range in AEU 1 (Fig. 3). Aggregate stability of only 15 per cent soils were with MWD <1 mm; 5 per cent with 1-1.5 mm; 20 per cent with 1.5-2 mm and 60 per cent of samples with aggregate size >2 mm in AEU 12 (Fig. 3). Micro aggregates are glued together by root exudates and microbial activity to form stable macro aggregates, but cannot withstand the disruptive action by flooding (Zhou *et al*., 2018). With the adoption of management practices like addition of organic manure and maintenance of plant cover, it is possible to further improve the aggregate stability.

3.2 Chemical Parameters

Majority of the samples reported pH in acidic range which includes 30 per cent each of the samples were very strongly and strongly acidic, and 10 per cent each were extremely acidic, moderately acidic, slightly acidic and slightly alkaline (Fig. 4). There was an increase in the percentage of samples under moderately and slightly ranges were noticed. There was a net

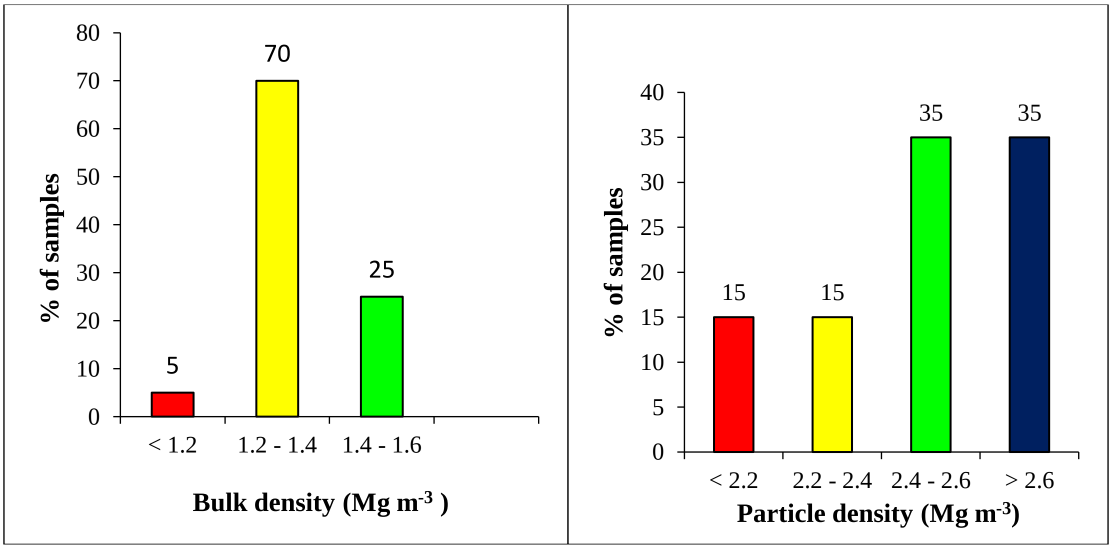

Fig. 1. Frequency distribution of bulk density and particle density in post-flood soils of Kottayam district

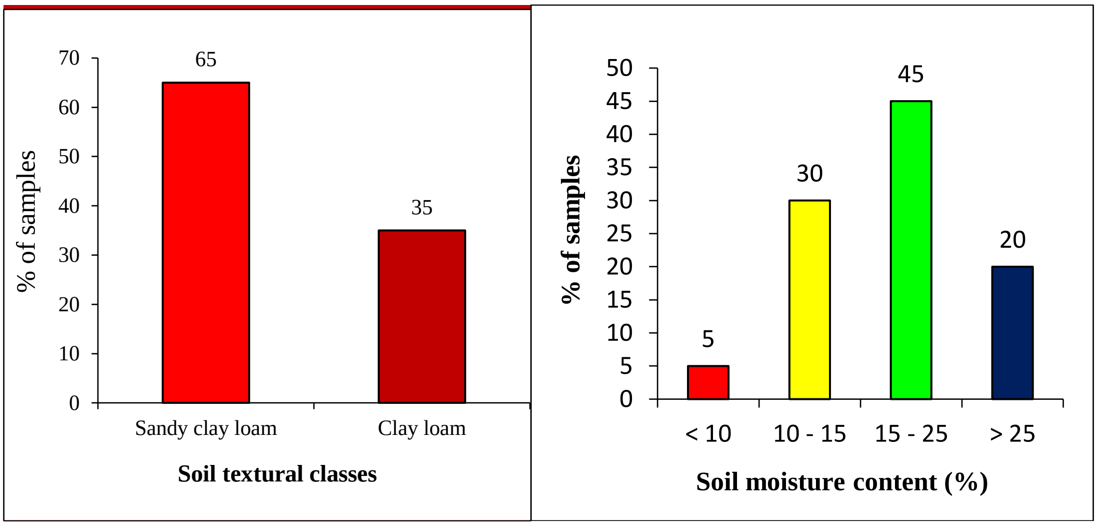

Fig. 2. Frequency distribution of textural classes and soil moisture content in post-flood soils of Kottayam district

moderate enhancement in the soil pH in this AEU with flooding. This might be due to the deposition of basic cations due to flooding. The intense flooding might have caused heavy leaching of ions resulting in reduced conductivity of these soils. five per cent of soils obtained EC between 1- 2 dS m^{-1} (Fig. 5). The higher EC may be due to the exogenous input of salts, ions and total dissolved solids carried along with landslide and flood water (Wilson, 1982). Organic carbon content was high in 45 per percent of the samples, 25 percent of medium and 30 percent of samples were low category (Fig. 5). The mineral materials brought by landslide may enhance the decomposition of organic matter and conversion to stabilized forms (Błońska *et al.*, 2017).

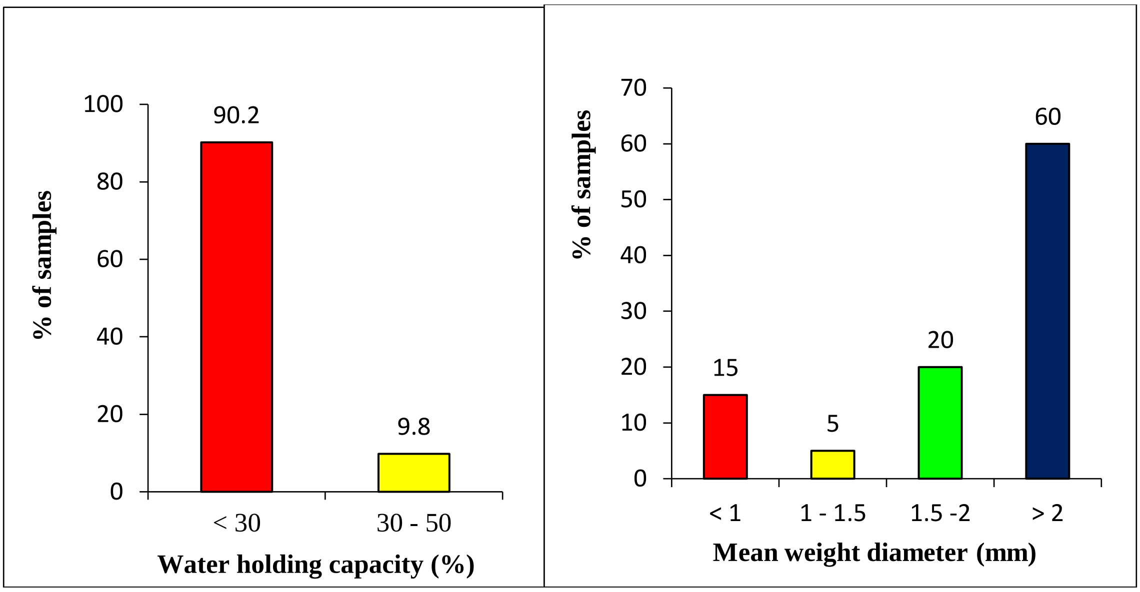

Fig. 3. Frequency distribution of WHC and MWD in post-flood soils of Kottayam district

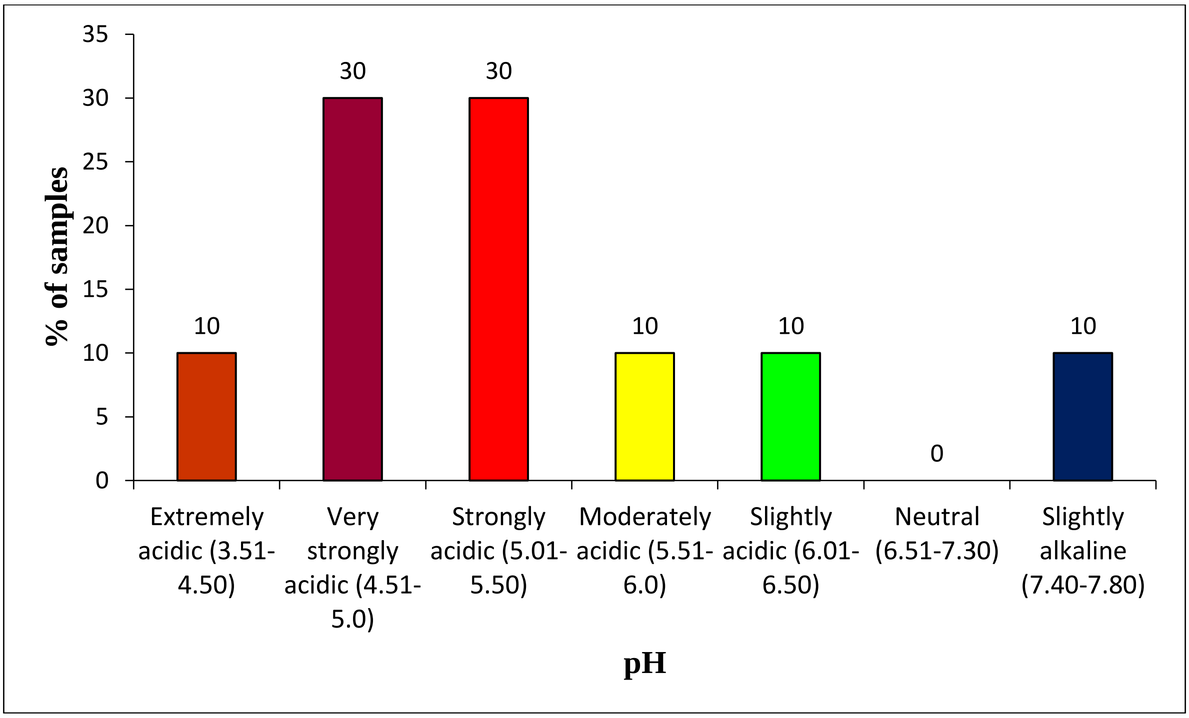

Fig. 4. Frequency distribution of pH of post-flood affected soils of AEU 12 in Kottayam district

“Flooding may cause significant alterations in the availability of nutrients due to intense soil erosion and varied microbial activity”. “Soil nutrient content varies with the depth and duration of flooding” (Tsheboeng *et al*., 2014). Nitrogen content was medium in 80 per cent of the samples and low in 20 per cent (Fig.6). “The availability of N in flood affected soils may decline either due to increase in denitrification and nitrate reductase or altered residue decomposition” (Baldwin and Mitchell, 2000). Phosphorus content was low in 7.84 per cent samples, medium in 50.98% and high in 41.18% after the heavy flood of 2018 (Fig. 7). According to Adams and Sidle (1987); Singh *et al*. (2001) and Wilcke *et al*. (2003), landslides may result in reduction of exchangeable cations and available phosphorus. In areas where the parent material is deficient in cations like Ca, Mg and K and P, landslides do not result in their replenishment in the surface layer. Potassium content was high in 55 per cent of samples and medium in 30 percent and low in 15% samples (Fig. 7). The exchange reaction increases K in solution under flooded conditions (Valizadeh *et al.,* 2012). Available calcium content was adequate in 95 per cent and deficient in 5% of samples (Fig. 8). Flooding has resulted in a reduction in the fraction of soils with sufficient level of available sulphur content was increased. Flooding of soils may increase or decrease sulphate sorption. Available magnesium content was adequate in 40 per cent (Fig. 8). The transport and deposition of suspended particles along with flowing water

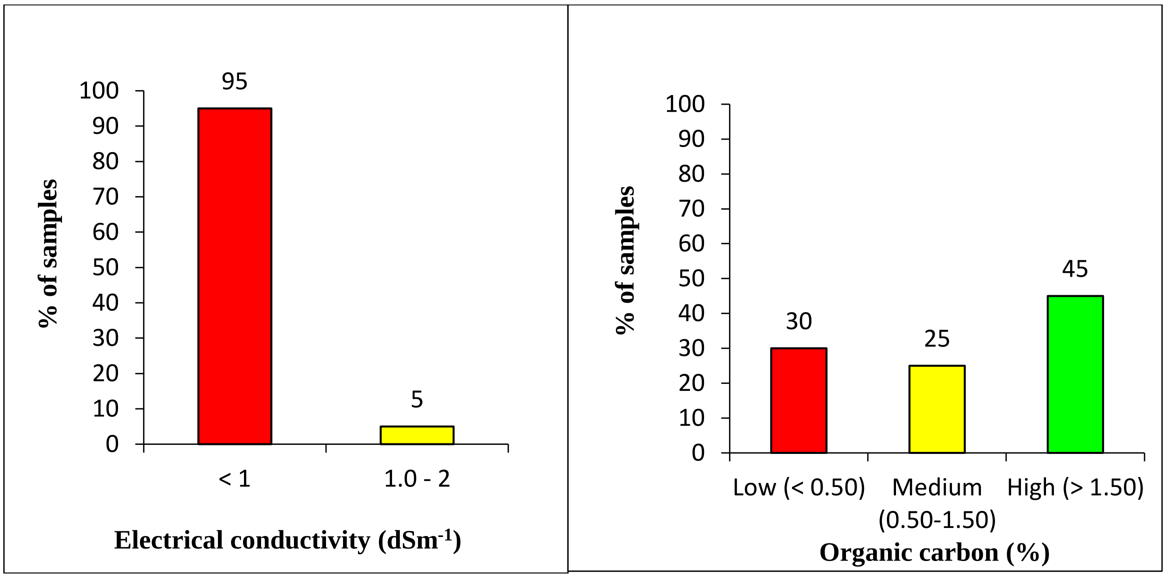

Fig. 5. Frequency distribution of EC (dSm^{-1}) and OC (%) in in post-flood soils of AEU 12 in Kottayam district

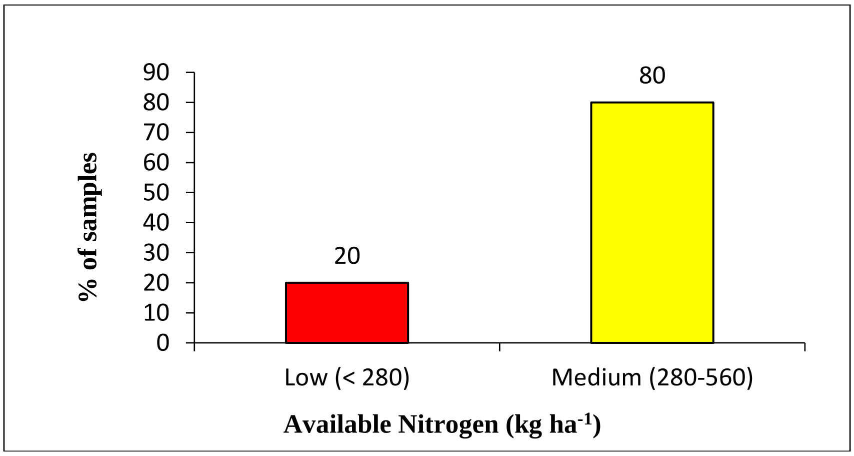

Fig. 6. Frequency distribution of available N in post-flood soils of AEU 12 in Kottayam district

may result in variations in the nutrient concentration of Ca and Mg. Similar increase in Ca and Mg with flooding was also reported by (Arshad et al., 2023). Available sulphur content was sufficient in 95% and deficient in 5 per cent of samples (Fig. 9). In laterite soils, the sulphate ions get adsorbed on the kaolinitic clay and the release decreases with increase in soil pH and available P. Under anaerobic conditions, reduced sulphur compound *viz*., H_2S is formed, which reacts with Fe to form insoluble FeS. Later on, the adsorbed SO_4^{2-} become available to plants as desorption occurs (Tabatabai and Chae, 1991). Available boron was deficient in 100 per cent of samples (Fig. 9). Wide spread deficiency of boron was noticed due to high mobility of borate ions results in ready leaching of this nutrient from the soil surface layer and becomes unavailable to plants and hence, huge deficiency of available B is noticed in acidic soils.

3.3 Biological Parameters

All the biochemical transformations in soil are dependent on enzyme activities and hence, an assay of enzyme activities was help to assess the soil fertility.All the samples analysed had activity less than 75 µg TPF released g^{-1} soil $24h^{-1}$ (Fig. 10). The soil dehydrogenase activity was found to be significantly correlated with organic carbon (0.299*) and soil pH (0.404**). Flooding influences oxidation- reduction of the system and thus affects the dehydrogenase activity. Increase in soil moisture content and temperature around 30˚C stimulates the activity

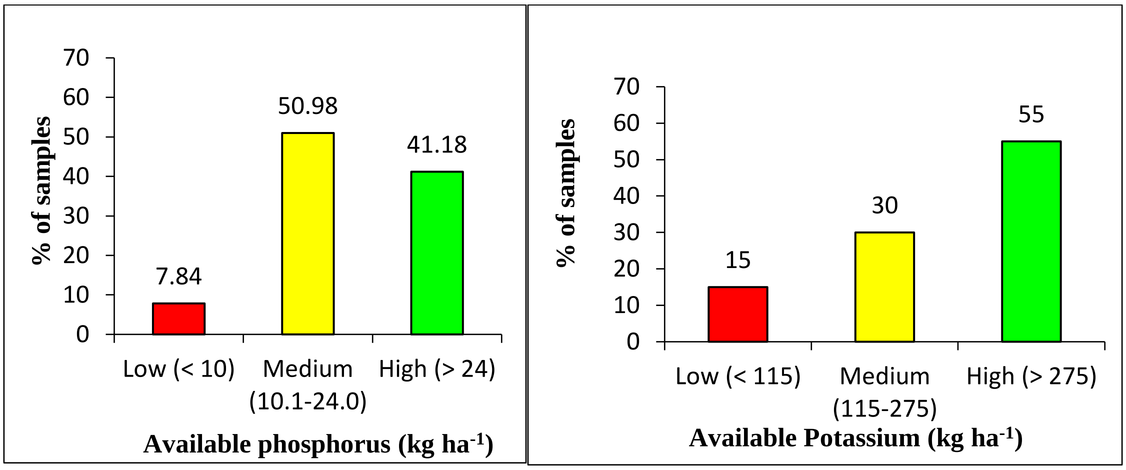

Fig. 7. Frequency distribution of available P and K in post-flood soils of AEU 12 in Kottayam district

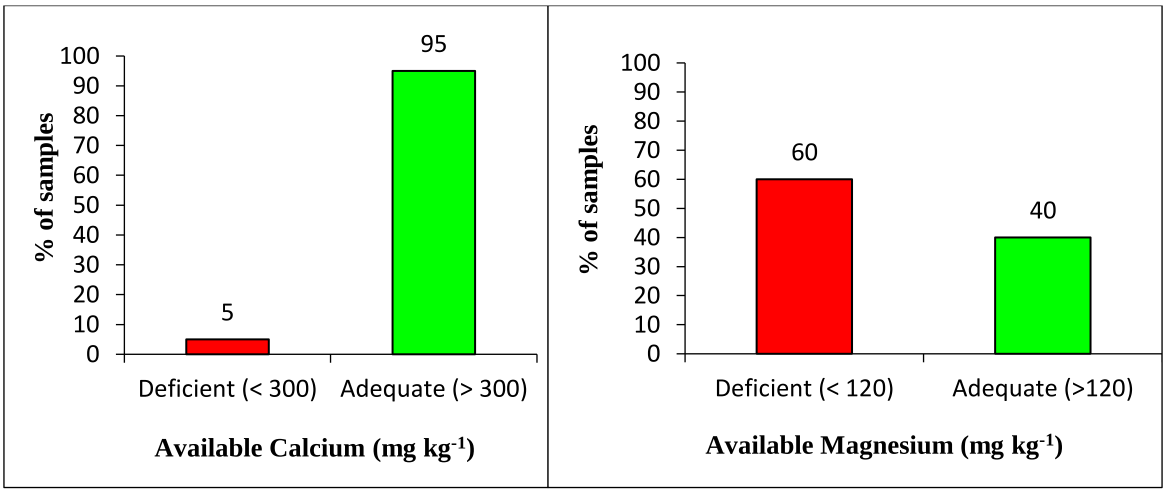

Fig. 8. Frequency distribution of available Ca and Mg in in post-flood soils of AEU 12 in Kottayam district

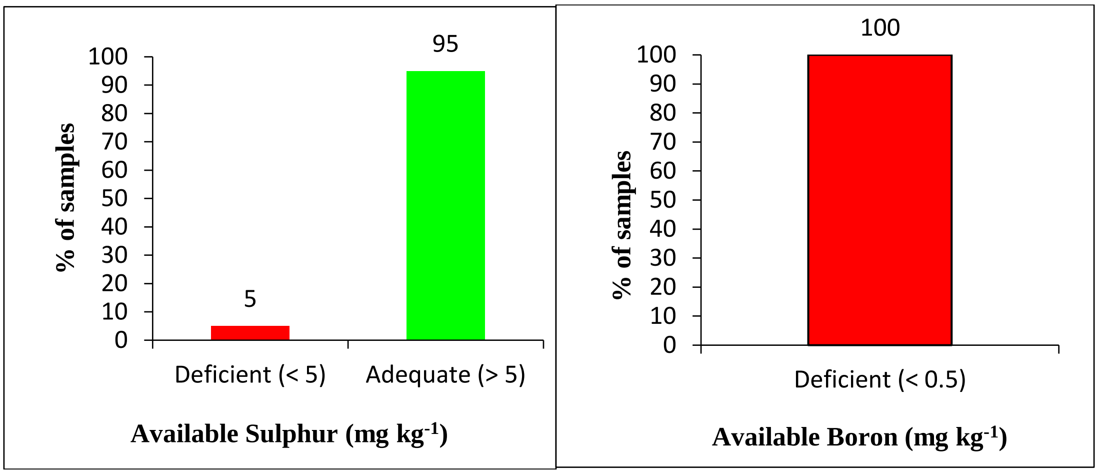

Fig. 9. Frequency distribution of available S and B in post-flood soils of AEU 12 in Kottayam district

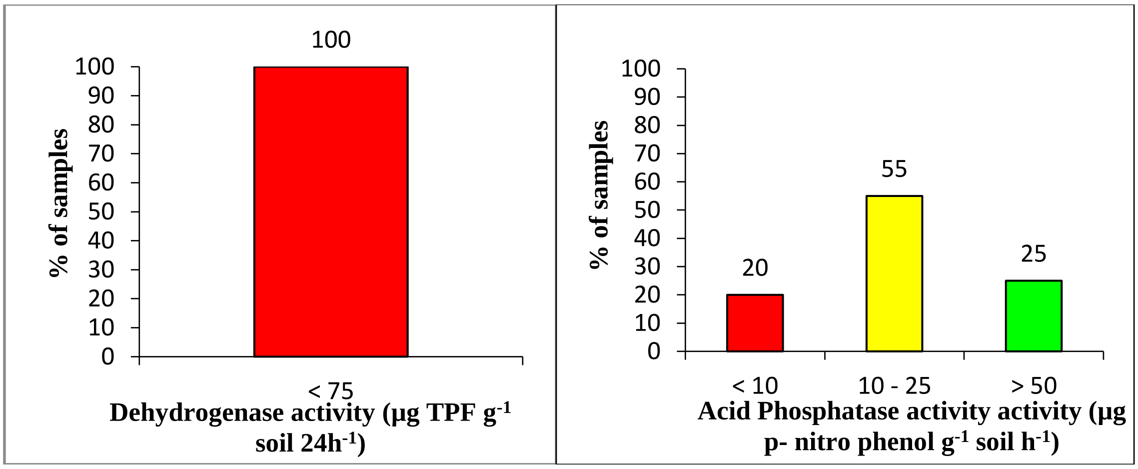

Fig. 10. Frequency distribution of dehydrogenase and acid phosphatase in post-flood soils of AEU 12 in Kottayam district

of dehydrogenase (Gu *et al*., 2009; Furtak *et al*., 2020). The mean acid phosphatase activity was 16.5 ± 9.14 µg p- nitro phenol released g^{-1} soil h^{-1}. The acid phosphatase activity was found that 20 per cent of the soils had activity <10; 55 per cent in the range 10 to 25 and 25 per cent >25 µg p- nitro phenol released g^{-1} soil h^{-1} (Fig .10). It gives an indication of P cycling in soil and sensitive to oxygen stress and the activity decreases significantly with water logging, resulting in reduced P availability (Sardans and Penuelas, 2005; Borowik and Wyskowska, 2016; Gu *et al.*, 2019).

3.4 Soil Quality Index

Selection of minimum data set from different soil properties through principal component analysis method,out of all the characterized parameters eleven attributes were selected as minimum data set. These seven indicators influenced the soil quality maximum in these area as compared to other parameters. PCA yielded MDS consists of% of silt and clay, bulk density, soil moisture, EC, pH, available N and Ca.

RSQI expresses the change in soil quality of the samples and grouped into poor (RSQI <50), medium 50-70) and poor (>70). The highest soil quality was observed at panchayat Erumeli and the other two panchayaths viz., Thalanadu and Thidanadu, almost the same values. The mean SQI value was 225 ± 14.20. Mean RSQI values indicate that post flood soils of selected panchayaths of AEU 12belonged to medium quality (Table 2). Medium soil quality was observed for 95 percent of samples, 5 per cent of soils were of poor soil quality (Fig. 11).

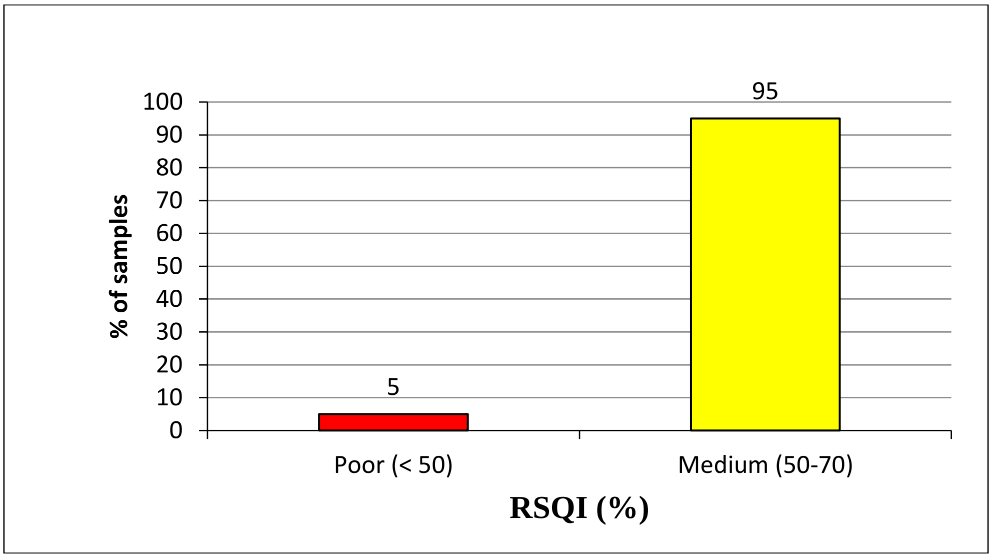

Fig. 11. Frequency distribution of RSQI (%) in the post-flood soils of AEU 12 in Kottayam district

Table 1. Soil quality indicators, weights and scores (Singh *et a*l., 2017)

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Texture	10	Loam	Clay loam / Sandy loam	Sand/Clay	Grit
Soil moisture content	10	< 30	30 – 40	40-50	> 50
Bulk density	10	1.3 - 1.4	1.2 - 1.3 or 1.4 - 1.5	1.1 - 1.2 or 1.5 - 1.6	< 1.1 or >1.6
pH	5	6.5 - 7.5	6 - 6.5 or 7.5-8	5.5-6 or 8-8.5	< 5.5 or >8.5
EC	10	<2	2-4	4 – 8	8 – 16
Available N	20	> 560	560 – 420	420 – 280	< 280
Available K	10	> 280	280-200	200-120	<120
Available Ca	10	>300	300 – 250	250 -150	<150
Available S	10	>5.0	5.0 - 2.0	2.0 - 1.0	< 1.0
Available B	10	>1.5	1.5-0.7	0.7-0.5	<0.5

Table 2. Soil quality index (SQI) and Relative soil quality index (RSQI) in the post-flood area of AEU 12 in Kottayam district

Panchayath	SQI		RSQI	
	Mean ± SD	Range	Mean ± SD	Range
Thalanadu	221 ± 20.10	200 – 250	55.4 ± 5.04	50.0 - 62.5
Thidanadu	220 ± 12.40	205 – 240	55.2 ± 3.10	51.2 - 60.0
Erumeli	231 ± 8.43	215 – 240	57.9 ± 2.11	53.7 - 60.0
AEU 12	225 ± 14.20	200 – 250	56.3 ± 3.56	50.0 - 62.5

4. Conclusion

The predominant soil groups in the post-flood soils of AEU 12 of Kottayam district of Kerala were sandy clay loam and clay loam. There is an increase in percentage of samples under moderately and slightly acidic range was observed in most of the area which is an indication of leaching of basic cations. High organic carbon status was noticed in majority of the areas. Available nitrogen and phosphorus status were medium while that of K was high in most of the flood affected areas. Adequate level of available Ca and S were observed in post flood soils. Deficiency of Mg and B were noticed, which demands immediate agricultural intervention for maintaining sustenance crop production. An enhancement in dehydrogenase activity while a decline in acid phosphatase activity was noticed. The reduction in overall nutrients indicated that the nutrients might be lost due to flooding. It is necessary to restore the soil even though the soil lies in medium soil quality. Site specific and nutrient specific management practices are necessary to overcome the changes in soil due to flood. This will make the farmers aware about the changes in soil brought about by the flood and for adopting effective management measures for post flood soil. Alteration in nutrients application according to the current status of soil will help to achieve productivity.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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