ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 12 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS

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by

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(2018-11-012)

THESIS

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KERALA, INDIA
2020

DECLARATION

I, hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 12 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **“ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 12 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS”** is a record of research work done independently by Ms. Akhila Merin Mathew (2018-11-012) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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"But the lord stood with me and gave me strength"

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LIST OF ABBREVIATIONS

@	- at the rate of
%	- per cent
º C	- degree Celsius
µg	- microgram
AEU	- Agro-ecological Unit
AHP	- Analytical Hierarchy Process
B	- Boron
BD	- Bulk density
Ca	- Calcium
CTCRI	- Central Tuber Crops Research Institute
CSV	- Comma Separated Values
cm	- centimetre
dS m^{-1}	- deci Siemen per meter
EC	- Electrical Conductivity
et al.	- and others
Fig.	- Figure
g	- gram
GIS	- Geographic Information System
GPS	- Global Positioning System
h	- hour
ha	- hectare
IDW	- Inverse distance weighted
IMD	- India Meteorological Department
INM	- Integrated Nutrient Management
K	- Potassium
KAU	- Kerala Agricultural University

kg ha^{-1}	- kilogram per hectare
kg m^{-2}	- kilogram per square metre
KSPB	- Kerala State Planning Board
LQI	- Land Quality Index
m	- metre
MCDA	- Multi-criteria decision analysis
MDS	- Minimum Data Set
Mg	- Magnesium
Mg ha^{-1}	- Mega gram per hectare
mg kg^{-1}	- milligram per kilogram
Mg m^{-3}	- Mega gram per cubic metre
mm	- millimeter
Max.	- Maximum
Min.	- Minimum
MoP	- Muriate of Potash
MWD	- Mean Weight Diameter
N	- Nitrogen
NI	- Nutrient Index
No.	- Number
OC	- Organic carbon
P	- Phosphorus
PC	- Principal component
PCA	- Principal Component Analysis
PD	- Particle density
PNP	- *p*- nitrophenyl
POP	- Package of practices
r	- correlation coefficient
RS	- Remote Sensing
RSQI	- Relative Soil Quality Index

S	- Sulphur
SD	- Standard deviation
SQ	- Soil Quality
SQI	- Soil Quality Index
SMC	- Soil moisture content
USDA	- United States Department of Agriculture
viz.	- Namely
WHC	- Water holding capacity
WSA	- Water stable aggregates

Introduction

1. 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.

Agricultural productivity depends largely on the topsoil which provides rooting zone for plants, supplies a balanced plant nutrition in addition to retaining moisture for plant use. It also improves seed germination, promotes root penetration and supports a multitude of beneficial microorganisms which decompose organic wastes to recycle plant nutrients and provide a favourable environment for plant growth, thus maintaining soil fertility and productivity.

Similar to air or water quality, the quality of soil affects the health and productivity of the environment. Soil quality or soil health can be defined as 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).

Soil quality evaluation provides a framework to assess the sustainability of different land use systems and creates an opportunity to redesign land and soil management systems for better agricultural productivity. Soil quality assessment involves sensitive physical, chemical and biological attributes which reflect the current functional status of the soil. Various levels of soil quality can be defined by stable inherent features linked to soil-forming factors and dynamic changes that are induced by soil management. Soil quality assessment should provide an indicator of the soil's capacity to produce optimum quantity of safe and nutritious food and its structural and biological integrity, which reflects certain degradative processes occurring within the soil.

Soil quality declines due to nutrient depletion through runoff and leaching, depletion of organic matter, soil crusting, compaction, toxic substance accumulation, excessive use of agrochemicals, improper waste disposal etc. Increased temperature, altered precipitation patterns and extreme weather events associated with climate change alter soil quality. A change in global climate pattern has turned out to be a major issue affecting food security and soil quality in the recent past.

Kerala experienced severe floods affecting the entire state due to unusually high rainfall during the south west monsoon of 2018. As per IMD 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 per cent. The unexpected hike in rainfall led to catastrophic floods that peaked during 17th to 21st August 2018. Thirteen out of the fourteen districts were affected by the flash flood and landslides (CTCRI, 2018). Wayanad (Kabini basin), Idukki (Periyar basin), Ernakulam and Thrissur (Chalakkudy and Periyar basins), Pathanamthitta and Alappuzha (Pamba basin) districts were the worst affected. 33 per cent of the affected area was high lands, 49 per cent midlands and 13 per cent low lands. Floods and landslides were reported in 47 per cent of the area while flood alone was reported in 44 per cent of the area affected. Soil erosion was the major impact in 86 per cent of the flood affected area (Kerala State Biodiversity Board, 2018).

Floods and landslides brought extensive damage to the ecosystem including river bank collapse and erosion, sand deposition and sand bar formation in low lands, change in river course, pollution due to waste deposition, lowering of water table in the neighbouring areas, changes in water quality, mudslides, sand piping, reduction in depth of river beds, loss of vegetation and deposition of clayey and alluvial materials. Agro ecosystem and agro biodiversity suffered due to erosion of fertile topsoil, partial loss of landraces of crops like pepper, rice, banana etc., increased soil acidification, deposition of stones, sand, silt and clay in agricultural lands, mass mortality of earthworms and spread of invasive pest and weed species.

Pathanamthitta district received 1968 mm rainfall during 1st June to 31st August 2018 which was 45 per cent above the normal average rainfall during these months in the previous years (Kerala State Biodiversity Board, 2018). Four agro ecological units (AEU) are included in Pathanamthitta district *viz*: AEU 4, AEU 9, AEU 12 and AEU 14. The devastating flood had caused great damage to the soil environment of AEU 4, AEU 9 and AEU 12 of Pathanamthitta district. Severely affected areas in the district include Ranni-Angadi, Aranmula, Kozhencherry, Ayroor, Thottapuzhassery, Koipuram, Pullad, Pandalam, Othera, Eraviperoor and upper Kuttanad region (CTCRI, 2018). Prolonged flooding and water logging resulted in washing away of the top soil thereby a loss in soil fertility. Soil compaction was also observed throughout the affected area. Flood waters eroded the exposed soils leaving deep gullies, and drifted crop residues, building materials and other types of debris. Landslides, water stagnation and deposition of sand, silt and clay in these areas in different dimensions were also observed.

Several changes occur due to prolonged saturation of soil, affecting chemical, physical and biological, soil properties. A “post-flood syndrome”, similar to the “fallow syndrome” is experienced by flooded soils if the land is left fallow for the entire season. Soil fertility and productivity will be disturbed, necessitating site specific investigations on different soil fertility parameters. Plant nutrient recommendation for the existing cropping system needs to be redrafted and revisions in cropping systems and suitable location specific management practices should be recommended. Quality assessment of post-flood soils to identify nutrient imbalances and undesirable soil physical conditions helps in achieving higher crop productivity and sustainability.

Therefore the present study entitled “Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala and generation of GIS maps” was undertaken with the following objectives:

- To assess the soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala
- To develop maps on soil characters and quality using GIS techniques
- To workout soil quality index (SQI)

Review of Literature

2. REVIEW OF LITERATURE

The available literature related to the present study entitled "Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala and generation of GIS maps" undertaken to assess the effect of flooding on soil and land quality is reviewed hereunder.

2.1 EFFECTS OF FLOODING ON SOIL PROPERTIES

Flooding brings about a series of physical, chemical and biological processes that significantly affects the quality of soil as a medium for plant growth. The nature, pattern and extent of these changes depend on the physico chemical properties of the soil and on the duration of submergence. Draining of a flooded soil reverses most of these changes (Ponnamperuma, 1984).

2.1.1 Effect of flooding on physical properties of soil

Submergence of soil hinders the gaseous exchange between soil and air. Within a short duration of flooding the microorganisms and plant roots utilise all the oxygen available resulting in anaerobic conditions leading to the accumulation of carbon dioxide, methane, nitrogen and hydrogen in soils and a wide range of toxic compounds that inhibit plant metabolism are formed (Kozlowski, 1984). Water logging also affects net solar radiation absorbed, heat capacity, soil temperature and heat fluxes in and out of the soil. Increase in water content darkens the soil and lowers the albedo values of soils. Flooding destroys soil structure due to disruption of aggregates and alters soil consistency. Flooded soils are also beyond the liquid limit and possess lower shear strength (Ponnamperuma, 1984).

2.1.2 Effect of flooding on chemical properties of soil

Flooding of air dry soil alters the electrochemical properties directly and indirectly. It causes the dilution of soil solution instantaneously, increases pH, decreases electrical conductivity and alters the diffuse double layer of soil colloids.

The most drastic change occurs in the redox potential of soil. Redox potential decreases rapidly after flooding, reaches a minimum within a few days, rises rapidly to a maximum and then decreases asymptomatically. pH increases with flooding of acidic soils and decreases in alkaline soils (Ponnamperuma, 1984).

Sah and Mikkelsen (1989) reported that soil temperature and organic matter content affects the P sorption capacity of soils subjected to flooding. They observed that flooding of soil along with organic matter addition and elevated temperature for shorter duration resulted in a rapid increase in P sorption.

Redox potentials and dissolved oxygen levels decrease with flooding of soils (Unger *et al*., 2009a). They also observed that the nitrate nitrogen content increased in 3 weeks flowing flood and non flooded condition and decrease under 5 weeks flooding treatments. Ammoniacal nitrogen showed an increasing trend in all the treatments including control. Soil polyphenolic content decreased in all flooding treatments except 5 week flowing flood.

Akpoveta *et al*. (2014) studied the soil quality of post-flood soils in the farmlands of Nigeria. They observed that there was a decline in pH, cation exchange capacity, total organic carbon, total organic matter, total nitrogen and total phosphorus at the rate of 4 -53 per cent at $p \leq 0.05$ in flood affected farmlands while the EC values showed an increase at the rate of 52- 92 per cent compared to control. The levels of potassium and essential micronutrients *viz.* Ni and Mn were seen to be reduced in post flood soils. An undesirable effect due to increased levels of heavy metals like Pb, Cd and Cu (18% to 114%) was also observed in post flood soils.

2.1.3 Effect of flooding on biological properties of the soil

Flooding of soils increased the level of dehydrogenase activity coupled with a reduction in redox potential values (Pedrazzini and Mckee, 1984). This increase in dehydrogenase activity indicated a shift in soil microflora from aerobic to anaerobic.

Unger *et al*. (2009b) reported that stagnant flooding reduced soil microbial biomass of aerobic bacteria, gram negative bacteria, gram positive bacteria and mycorrhizal fungi compared to intermittent flooding and non flooded conditions. Intermittent flooding resulted in a positive response in the amount of aerobic bacterial biomass compared to other microorganisms.

2.2 EVOLUTION OF THE CONCEPT OF SOIL QUALITY

The concept of soil quality (SQ) evolved through centuries with the advent of agriculture and settled life. Ancient civilisations delineated soils based on production potential through trial and error method. Productivity changes within a soil type due to management practices were recognized later during the agricultural development phase after the Second World War and the soil quality was equated to productivity. Development of taxonomic studies, survey, and mapping systems facilitated the precise delineation of the natural productive potential of soils (Schoenholtz *et al*., 2000).

Soil quality is an inherent attribute of a soil inferred from soil characteristics. Soil quality was focused on and equated with soil productivity during this period. Later the concept of soil quality underwent modifications to include food safety and quality, human and animal health and environmental quality (Parr *et al*., 1992).

Many definitions for soil quality were formulated during 1990s with similar elements (Arshad and Coen, 1992; Doran and Parkin, 1994; Karlen *et al*., 1997) and the present concept of soil quality evolved during this period in response to increased global emphasis on sustainable land use (Doran and Parkin, 1994; Warkentin, 1995; Karlen *et al*., 1997). Various definitions for soil quality developed during this period were based on soil management practices, land use, ecosystem and environment interactions and socio economic and political factors (Doran and Parkin, 1997).

Larsen and Pierce (1991) defined soil quality as the capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem. Johnson *et al*. (1997) proposed soil quality as a measure of the condition of soil relative to the requirements of one or more societies and/or to any human needs or purposes. Later, Karlen *et al*. (1997) suggested soil quality as 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.

The terms soil quality and soil health were used by Roming *et al.* (1995) interchangeably since farmers favoured the use of the term soil health and scientists preferred the use of the term soil quality. But Karlen *et al.* (1997) contradicted the use of the terms soil health and soil quality interchangeably.

The concept of soil quality deviates from conventional agricultural approach focusing more on soil productivity, shifting the focus to a more holistic approach recognising the various roles played by soil in the agroecosystems and natural environment (Karlen *et al.*, 1999). The concept of soil quality is associated with the concept of sustainable use and management of soils according to USDA (2008).

The advent of remote sensing and GIS technology facilitated monitoring of changes in soil quality on a landscape basis. Advanced research works yielded assessment tools for indexing soil quality which showed how the multiple functions that soils provide, like cycling of nutrients and water, filtering and buffering of contaminants, crop residue decomposition, and recycling of essential plant nutrients forms the foundation for sustainable land management (Parr *et al.*, 1992).

2.3 TYPES OF SOIL QUALITY

Soil quality involves two aspects *viz.* inherent and dynamic soil quality (Seybold *et al.*, 1999). Inherent soil quality involves properties associated with soil mineralogy like particle size distribution whereas dynamic soil quality encompasses those soil properties that changes over short periods of time (Carter, 2002).

The inherent and dynamic properties of soils and the reflection of biological, chemical, and physical properties, processes and their interactions through soil quality index are the two closely related factors of soil quality assessment (Karlen *et al.*, 2003).

2.4 SOIL QUALITY INDICATORS

Soil quality cannot be measured directly. However, it can be inferred from the assessment of soil physicochemical and biological properties which act as indicators. Changes in soil quality indicators determine whether the soil quality is improving, declining or maintaining stability (Bredja *et al.*, 2001).

Different soil properties were suggested as soil quality indicators by researchers. Granatstein and Bezdicek, (1992) suggested that increase in infiltration, aeration, macropores, soil organic matter, aggregate size and stability, and decreased resistance of soil to tillage, root penetration, and decreased erosion and runoff are indicators of improved soil quality.

Arshad and Martin (2002) defined soil quality indicators as the measurable soil attributes which influence the capacity of a soil to enable crop production and other environmental functions. They suggested soil-depth, organic matter, respiration, aggregation, texture, bulk density, infiltration, nutrient availability and retention capacity as the measurable soil attributes primarily influencing soil quality.

Attributes that are most sensitive to changes within the soil are the most desirable indicators. The selection of soil quality indicators will vary with the purpose of assessment. Organic matter content, topsoil-depth, infiltration, aggregation, pH, electrical conductivity, suspected pollutants and soil respiration are suitable indicators for assessing the quality of agricultural soils. The changes in soil quality can be evaluated by measuring appropriate indicators and comparing them with desired values (critical limits or threshold level), at different time intervals in a selected agro-ecosystem (Arshad and Martin, 2002).

Different chemical, physical and biological properties of soil integrate and interact with each other resulting in a particular level of productivity often referred to as soil quality. But, the main focus of characterising soil quality was on soil physical and chemical properties till recently. Biological properties were not emphasised due to the difficulties in quantifying and predicting soil biological behaviour (Parr *et al.*, 1992).

Separation of soil functions into chemical, physical, and biological processes is often very difficult because of their dynamic and interactive nature. This interconnection is prominent especially between chemical and biological indicators of soil quality (Doran and Parkin, 1994). Researchers use different sets of indicators for soil quality assessment as the purpose of assessment varies (Wang and Gong, 1998). Since environmental conditions and soil functions of interest differ, a universal set of indicators cannot be used for assessing soil quality (Bouma, 2000).

Singer and Ewing (2000) suggested three categories of soil quality indicators *viz.* physical indicators: passage of air, structural stability, bulk density, particle size distribution, colour, consistency, hydraulic conductivity, soil tilth, infilteration, penetration resistance, oxygen diffusion rate, pore size distribution, pore conductivity, soil strength, depth of root limiting layer, soil temperature, total porosity and water holding capacity; chemical indicators: CEC, base saturation, pH, EC, plant nutrient availability, SAR, plant nutrient content, ESP, presence of contaminants and nutrient cycling rates and biological indicators: organic carbon, microbial biomass carbon, total biomass, oxidizable carbon, potentially mineralizable nitrogen, soil respiration, soil enzymes, total organic carbon, microbial community finger printing, substrate ulitilization, fatty acid analysis and nucleic acid analysis.

Although soil quality indicators can be broadly classified into three categories, these categories are not clearly designated since soil properties affect multiple soil functions. For example, sodium levels in soil serve as a chemical indicator based on plant toxicity or deficiency aspect whereas it acts as a physical indicator with regard to soil dispersion, crusting and erosion (USDA, 2008). Thus, the three categories of soil quality indicators are as follows:

2.4.1 Physical attributes

Physical indicators provide information on soil aeration and hydrological status. Physical properties of soil affect the rooting depth and rooting volume of plants thereby influencing nutrient availability. They also indicate the ability of soil to withstand physical forces of stress like splashing rain drops or rapid entry of water that lead to aggregate breakdown, soil dispersion and erosion (USDA, 2008).

Physical indicators like soil texture and depth are useful for comparing soil quality among soil types and within a soil type before and after some management practices have been imposed. Soil texture is the most fundamental qualitative soil physical property controlling water, nutrient, and oxygen exchange, retention, and uptake (Schoenholtz *et al*., 2000).

Static physical parameters like soil tilth (Papendick *et al.*,1991), soil depth (Larson and Pierce, 1991; Arshad and Coen, 1992; Doran and Parkin, 1994; Gomez *et al*., 1996), soil bulk density, available water holding capacity, saturated hydraulic conductivity, aggregate stability (Larson and Pierce, 1991; Arshad and Coen, 1992; Doran and Parkin, 1994; Kay and Grand, 1996), soil strength (Powers *et al*.,1998; Burger and Kelting,1998) and porosity (Powers *et al.*, 1998) are used as indictors for assessing soil quality.

2.4.2 Chemical attributes

Soil chemical indicators are related to nutrient relation and therefore they are referred to as indices of nutrient supply (Powers *et al*., 1998). Soil chemical attributes influence soil microbiological processes and chemical properties and they along with physical properties determine the capacity of soils to hold, supply, and cycle nutrients and also the movement and availability of water (Schoenholtz *et al*., 2000).

Doran and Parkin (1994) characterised chemical attributes like pH, EC, organic nitrogen, mineralizable nitrogen, mineral phosphorus, exchangeable potassium and organic carbon as a basic chemical indicators of soil quality.

2.4.3 Biological attributes

Biological attributes are very dynamic and sensitive to changes in the soil. Therefore, they are more preferred for the short term evaluation of soil quality (Arshad and Martin, 2002).

Biological monitoring of soil is the measurement of the response of living organisms to changes in their environment (Pankhurst *et al.*, 1997). Biological attributes of soil quality include the different soil components and processes related to organic matter cycling such as total organic carbon and nitrogen, microbial biomass, mineralizable carbon and nitrogen, enzyme activities, soil fauna and flora. These soil attributes are particularly fitting as indicators of soil quality, since they respond to both natural and human induced changes (Gregorich *et al.*, 1997).

The use of biological indicators provides information which helps to integrate many environmental factors with soil quality. Soil enzyme activity holds great potential as a biological indicator of soil health. Soil enzyme activities provide an integrative indicator of a change in the biology and biochemistry of soil resulting from external management or environmental factors (Alkotra *et al.*, 2003).

Soil enzymes are constantly playing vital roles for the maintenance of soil ecology and soil health. They are better indicators of soil health since changes in enzyme activity occur much sooner than other parameters, thus providing early indications of changes in soil health (Das and Varma, 2010).

Soil enzymes have also been reported as useful soil quality indicators due to their relationship with soil biology, being operationally practical, sensitive, integrative, ease to measure and have been described as biological fingerprints of past soil management, and relate to soil tillage and structure (Utobo and Tewari, 2015).

2.5 MINIMUM DATA SET

Larsen and Pierce (1991) proposed the adoption of a minimum data set (MDS) of soil parameters to assess the health of world’s soils and standardised the methodologies and procedures established to assess changes in the quality of those factors. Minimum data set provides a small subset of parameters which will make possible a more practical assessment of soil quality (Gregorich *et al.*, 1994). MDS is selected based on their ability to predict soil stability and productivity. It can be selected using principal component analysis, expert opinion methods or a combination of both (Lima *et al.*, 2013).

The use of MDS reduces the requirement for assessing a large number of indicators to assess soil quality (Rezaei *et al*., 2006). The first step in the development of a MDS is the selection of appropriate soil quality indicators that effectively and efficiently monitor soil functions based on the goals for which the soil quality assessment is carried out. This set of selected indicators constitutes a MDS. Researchers have selected different indicators in the MDS for assessing soil quality (Sharma and Mandal, 2009).

Larsen and Pierce (1994) used pH, EC and organic carbon as indicators in a MDS for agronomic soils. Andrews and Caroll (2001) used multivariate statistical techniques to determine the smallest set of physical, chemical and biological parameters which accounts for at least 85 per cent variability at each site. They evaluated the efficacy of the selected MDS to assess sustainable management by performing multiple regressions of each MDS against numerical estimates of environmental and agricultural management sustainability goals like net revenues, P runoff potential, metal contamination and amount of litter disposed of. The selected MDS was used to develop an additive SQI.

Sharma *et al*. (2012) used two sets of MDS for assessing soil quality- (i) for rainfed pearl millet-mung bean systems the selected MDS included available N, Zn, Ca, K, pH and dehydrogenase assay and (ii) for rainfed pearl millet alone the selected MDS included available N, Mn, exchangeable Mg, EC, dehydrogenase activity, microbial biomass carbon and bulk density as indicators.

2.6 SOIL QUALITY INDEX

Science based soil quality indices provide an integration of information to facilitate decision making in agro ecosystem management. While the concept of integrative indices (Karr 1981) has been in use for years to monitor water quality, Larson and Pierce (1991) were among the first to apply this idea to soil ecosystems. Later, the three basic components of soil quality index as proposed at the International conference on the Assessment and Monitoring of soil quality held at Rodale institute are the ability of soil to enhance crop production (productivity component), ability of soil to function in the presence of attenuated levels of contaminants, pathogens etc. (environmental component) and linkage between soil quality plant, animal and human health (health component).

During the conference on assessment and monitoring of soil quality held at Rodale institute, Parr *et al*. (1992) proposed a soil quality index as given below:

SQI = f (SP, P, E, H, ER, BD, FQ, MI)

where, SP denotes soil properties while P, the potential productivity, E, the environmental factors, H the health (human/animal), ER the erodibility, BD the biological diversity, FQ the food quality/safety and MI are the management inputs.

Haberern (1992) introduced the idea of a Soil Health Index to characterize a soil's capability for sustainable production of healthy and nutritious crops.

Performance based soil quality index was developed by Doran and Parkin (1994) which evaluates soil functions in relation to sustainable production, environmental quality and human and animal health. This index includes six elements SQE1 to SQE6.

SQI = f (SQE1, SQE2, SQE3, SQE4, SQE5, SQE6)

where, SQE1 is the food and fibre production, SQE2 the erosivity, SQE3 the ground water quality, SQE4 the surface water quality, SQE5 the air quality, and SQE6 is the food quality.

Later, more SQI models were developed based on different sets of soil indicators. Andrews *et al*. (2004) developed a score based indicator set known as Soil Management Assessment Framework (SMAF) which operated in two steps *viz*. indicator selection, interpretation and aggregation. The indicator selection and interpretation entails the transformation of soil attributes into unitless indicator scores and aggregation combines these individual scores into a single index value (Karlen *et al*., 2008).

SQIs combine soil attributes into a format that enhances the understanding of soil processes. The "scoring function" concept is used in SQI assessment to decipher the interconnection between soil processes, soil properties, management practices and social perceptive (DePaulObade and Lal, 2016).

2.6.1 Calculation of SQI

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 SQI (Vasu *et al.*, 2016).

Three methods are mainly used in the calculation of soil quality index *viz.* simple additive method, weighted additive method and statistical method using PCA (Mukherjee and Lal, 2014).

2.6.1.1 Simple additive method

Simple additive method was outlined by Amacher *et al.* (2007). In this method, threshold values are given to the soil characters based on expert opinion and literature review.

SQI = Σ Individual soil parameter index values

2.6.1.2 Weighted additive method

Wymore (1993) proposed the equation for a weighted SQI. The equation for weighted SQI is as follows:

$$SQI = \Sigma\, W_i S_i$$

where, W_i and S_i are the weighted factor and score respectively.

The weighted factor is derived using correlation coefficient (Nakajima *et al.*, 2015) or PCA method (Armenise *et al.*, 2013).

The proposed equation was used to generate three curves – 'more is better', 'less is better' and 'optimum' and the soil parameters were divided into three groups –

(i) more is better (eg. water holding capacity), (ii) less is better (eg. bulk density) and (iii) optimum (eg. pH).

A unitless score is given to each parameter ranging from 0 to 1 by using linear scoring functions (Karlen and Scott, 1994). For the ‘more is better’ parameters the observations are divided with the highest observed value so that the highest observed value gets a score of 1. For ‘less is better’ parameters the observations are divided by the lowest observed value so that the lowest observation gets a score of 1, and the ‘optimum’ parameters are scored up to the optimum value like ‘more is better’ parameters and thereafter scoring follows the method for ‘less is better’ parameters. The scores were integrated into a single index value after normalizing the soil parameters for each soil using a weighted additive approach (Ferrnades *et al.*, 2011).

Lima *et al.* (2013) used the weighted additive method to develop a SQI. They selected indicators associated with soil quality such as water entry, water transfer, water absorption and support to plant growth. They evaluated the effect of different management practices on soil quality and developed a soil quality index.

2.6.1.3 Statistical method using PCA

In this method, SQI is estimated using principal component analysis. The PCA model is used to create a MDS to reduce the indicator load in the model and avoid data redundancy (Andrews *et al.*, 2002).

Principal components for a dataset are defined as linear combinations of variables that account for maximum variance within the set. Principal components with high eigen values (eigen values > 1) are selected for developing a MDS (Andrews and Caroll, 2001).

PCA method is a more objective method using statistical tools which reduces bias. PCA is a data reduction tool to select the most appropriate indictors to estimate SQI (Navas *et al.*, 2011).

Andrews *et al.* (2002) used standardised PCA of all untransformed data that showed statistically significant differences between management systems using

ANOVA for the selection of a MDS. The result of PCA was normalized and integrated into a weighted SQI. Shukla *et al.* (2006) and many other researchers (Wang *et al.*, 2012; Sharma *et al.*, 2012; Armenise *et al.*, 2013) used this method to derive SQIs.

2.7 LAND QUALITY INDEX (LQI)

The need for assessing land quality was stressed by World Bank in 1995 and Karlen *et al.* (1997). Mandal *et al.* (2001) developed a crop specific LQI for sorghum in Indian semi arid tropics which was closely correlated to yield. They suggested that LQI is a function of climate quality index (CQI) and soil quality index (SQI) and can be crop specific since climatic requirements varies with crops.

The need to devise inexpensive, precise and efficient methods for monitoring land quality over large areas has generated interest on the potential of technologies such as remote sensing and GIS (DePaulObade and Lal, 2013).

Multi-criteria decision analysis (MCDA) is a commonly used numerical modelling technique for land use decision making. MCDA methods can be broadly divided into either multi-objective or multi-attribute methods and are primarily concerned with ways of combining several criteria to form a single evaluation index (Malczewski, 2006). The integration of GIS and MCDA methods provides powerful spatial analysis functions (Yu *et al.*, 2009).

Kumar and Jhariya (2015) applied remote sensing and GIS techniques for assessing land quality of Patan block of Durg district, Chhattisgarh State in India using analytic hierarchy process (AHP), a type of multi-criteria decision analysis method. They used ten criteria including soil organic matter content, pH, soil texture, soil depth, run off potential, geomorphology, slope, phosphorus content, potassium content and land use/ land cover to develop LQI for the area.

2.8 REMOTE SENSING, GIS AND GPS TECHNOLOGIES IN SOIL FERTILITY MAPPING, DEVELOPMENT OF SOIL QUALITY INDEX AND LAND QUALITY INDEX

Remote sensing (RS), Global positioning system (GPS) and Geographic information system (GIS) technologies have become indispensable in agriculture. Advancement in RS and GIS technologies have revolutionized the collection of information on agricultural activities including land use/land cover, weather conditions, soil conditions, etc., which are essential for site characterization and consequent assessment of land suitability for farming (Joshua *et al.*, 2013).

Remote sensing has the capability of obtaining a synoptic view of a large area and provides a continuous spatial data-set (Jafari and Narges, 2010). Remote sensing and photogrammetric techniques provide spatially explicit, digital data representations of the earth's surface that can be combined with digitized paper maps in GIS to allow efficient characterization and analysis of vast amount of data (Sahu *et al.*, 2015).

GIS has been defined as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). The use of GIS software can help to eliminate data integration problems caused by different geographic units related to various data sets. GIS include both manual and computer based information systems (Dickinson and Calkins, 1988). GIS integrates spatially referenced data sets for purposes of modelling and informative decision-making. It provides an innovative method for assessing land quality (Jafari and Narges, 2010).

GIS enables effective and efficient manipulation of spatial and non-spatial data for scientific mapping and characterization of soils for the benefit of local people (Star *et al.*, 1997). GIS can be used in producing soil fertility map of an area, which will help in formulating balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally (Binita *et al.*, 2009).

The primary goal of GIS is to transform raw data via overlay or other analytical operations, into new information which can support decision-making processes. GPS and GIS technologies have also augmented the efficiency of soil survey (Sahu *et al*., 2015).

GPS records the in-field variability as geographically encoded data. It is possible to determine and record the correct position continuously (Shrestha, 2006). Soil sample collection using GPS is very important for preparing thematic soil fertility maps and has great significance in agriculture for monitoring soil nutrient status of different locations/villages (Mishra, *et al.*, 2014).

Information collected from different satellite data and referenced with the help of GPS can be integrated to create management strategies. The development and implementation of site-specific farming has been made possible by combining GPS and GIS (Liaghat and Balasundram, 2010).

2.9 EFFECT OF LAND USE ON SOIL PROPERTIES

Physical, chemical and biological attributes of soil varies with variation in land use. Tillage is an important factor affecting soil properties. Long-term no tillage systems decrease bulk density (Lal, 1976), and improve soil organic carbon, aggregate stability, available N, P, water holding capacity and water infiltration (Alvarez and Steinbach, 2009; He *et al*., 2011). Alam *et al*. (2014) observed improvement in organic matter accumulation, maximum rooting densities and other physical and chemical properties whereas bulk density and particle density declined in conventionally tilled soils in a wheat-mungbean-rice system.

Incorporation of organic manures and crop residues also improves soil physicochemical properties. Maheswarappa *et al*. (2005) reported improvement in water holding capacity, organic carbon and plant available nutrient status in coconut growing soils of Kerala with the adoption of integrated nutrient management. Zhao *et al*. (2009) reported that application of farmyard manure in combination with chemical fertilizers increases soil organic carbon, available N and P and improves urease, protease and alkaline phosphatase activities in soil. Coconut intercropped with pineapple maintained the highest organic carbon content compared to coconut with maize in clay loam soils. Surface mulching with crop residues and reduced tillage promoted the build up of organic carbon in this soil (Sudha and George, 2011).

2.10 REVIEW OF PHYSICOCHEMICAL PROPERTIES OF SOILS IN AEU 12

John *et al.* (2012) reported that the soils of Pathanamthitta district are strongly acidic, high in organic carbon, available P and K with adequate levels of exchangeable Ca, Mg, S and micronutrients. Forest loam soils dominate Ranni and Konni blocks which spread over AEU 12 and AEU 14 of Pathanamthitta (Murugan, 2013). Another pre-flood analysis of soils of Ranni, Naranammoozhi and Vechoochira of AEU 12 of Pathanamthitta district showed very high organic carbon and organic matter contents. The pH of the soil samples were slightly acidic (6.24 - 6.90), electrical conductivity ranged from 0.145 to 0.298 dSm^{-1}, available nitrogen content varied from 386.91 to 712.46 kg ha^{-1}, available phosphorus ranged from 62.70 to 113.98 kg ha^{-1}, available potassium varied from 702.06 to 801.20 kg ha^{-1}, sulphur from 19.66 to 42.06 kg ha^{-1}, organic carbon content from 2.21 to 2.31per cent, organic matter had a range of 3.67 to 3.89 per cent, exchangeable calcium varied from 1.72 to 1.78 per cent and exchangeable magnesium was observed to be 1.12 to 1.33 per cent. A mean water holding capacity of 44 per cent was detected in all soil samples. The soils were also contaminated with heavy metals such as zinc, iron, lead, and copper (Shakhila and Mohan, 2014).

Materials and Methods

3. MATERIALS AND METHODS

The study entitled "Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala and generation of GIS maps" was undertaken to assess the post flood soil quality and generate GIS maps of the area during 2018-2020. The study was carried out in five phases as follows:

Part I – Survey, collection and characterisation of soil samples
Part II – Setting up of a MDS for the assessment of soil quality
Part III – Formulation of SQI, NI and LQI
Part IV – Generation of GIS maps
Part V – Statistical analysis of data

The materials used and methods adopted for the execution of the research work are explained in this chapter.

3.1 SURVEY AND COLLECTION OF SOIL SAMPLES

3.1.1 Details of the sampling locations

Soil sampling was carried out in AEU 12 of Pathanamthitta district which covers an area of 43,742 ha (16.49% of the district's area). The soils of AEU 12 (Southern and Central foothills) are strongly acidic, gravelly, lateritic low activity clay soils rich in organic matter. Shorter dry period, absence of plinthite layer in the soil and higher organic matter distinguish the foothills from the midland laterites (KAU, 2016). Samples were collected from eight flood affected panchayaths of the AEU, identified by contacting the respective Krishi Bhavans. The selected panchayaths with number of samples and the geocoordinates of sampling locations are given in table 1.

3.1.2 Collection of samples

A survey was conducted in the selected locations based on a pre designed questionnaire (Appendix I) and details regarding the crops grown, cropping systems adopted, nutrient management practices and changes in observable soil conditions due to flooding, erosion and deposition were collected.

Seventy five georeferenced surface soil samples were collected from the selected areas during the first two weeks of April 2019 before the pre monsoon showers. Soil samples were taken from 0-15cm depth from each sampling site. Core samples were also taken from the surface soils. The samples were sealed immediately in plastic covers and the geographical coordinates of the locations were recorded.

Table1. Details of sampling locations from AEU 12 in Pathanamthitta district

SL. No.	Panchayat/Municipality	No. of samples	Sampling points	N latitude (^{o})	E longitude (^{o})
1.	Pramadam	9	1	9.24333333300	76.78888889000
			2	9.24584310000	76.80016700000
			3	9.14222222200	76.85416667000
			4	9.24638888900	76.82666667000
			5	9.24722222200	76.80888889000
			6	9.24583333300	76.82972222000
			7	9.21083333300	76.81666667000
			8	9.20333333300	76.81305556000
			9	9.23888888900	76.82444444000
2.	Kalanjoor	5	10	9.12194444400	76.85138889000
			11	9.12763400000	76.84523100000
			12	9.12362852600	76.85687374000
			13	9.13138888900	76.85388889000
			14	9.13000000000	76.89277778000
3.	Ranni-Angadi	13	15	9.39338207500	76.76624022000
			16	9.37583333300	76.76916667000
			17	9.37611111100	76.76833333000
			18	9.37305555600	76.76055556000
			19	9.40044747300	76.76787704000
			20	9.36500000000	76.77222222000
			21	9.36611111100	76.76638889000
			22	9.37388888900	76.76944444000
			23	9.40638888900	76.78222222000
			24	9.37163200000	76.76783600000
			25	9.40638888900	76.77277778000

Table 1 continued

Sl No.	Panchayath/Municipality	No. of samples	Sampling points	N latitude (º)	E longitude (º)
			26	9.40083333300	76.77388889000
			27	9.40777777800	76.77388889000
			28	9.26111111100	76.80944444000
4.	Pathanamthitta	8	29	9.27113600000	76.79342100000
			30	9.25666666700	76.81916667000
			32	9.25055555600	76.78611111000
			33	9.26416666700	76.81194444000
			34	9.26972222200	76.81333333000
			35	9.26781453000	76.81876244000
5.	Ranni-Perunnadu	6	36	9.37689227900	76.84841573000
			37	9.36500000000	76.84861111000
			38	9.36583333300	76.85166667000
			39	9.37095774500	76.86768070000
			40	9.37911092200	76.85765862000
			41	9.37027777800	76.84250000000
6.	Vadaserikkara	10	42	9.34388888900	76.83138889000
			43	9.31804660400	76.84296113000
			44	9.34138888900	76.82833333000
			45	9.35083333300	76.81666667000
			46	9.35277777800	76.82722222000
			47	9.32100849400	76.83073562000
			48	9.32096569900	76.82536483000
			49	9.34361111100	76.81888889000
			50	9.34777777800	76.82444444000
			51	9.34388888900	76.84750000000
7.	Naranammoozhi	13	52	9.38500000000	76.84305556000
			53	9.38694444400	76.84166667000
			54	9.37722222200	76.84000000000
			55	9.38067940000	76.84389700000
			56	9.39000000000	76.84777778000
			57	9.39444444400	76.84472222000
			58	9.39666666700	76.84388889000
			59	9.38694444400	76.84666667000
			60	9.38777777800	76.84555556000
			61	9.39527777800	76.84444444000
			62	9.39000000000	76.84250000000

Table 1. continued

Sl No.	Panchayath/ Municipality	No. of samples	Sampling points	N latitude (°)	E longitude (°)
			63	9.39111111100	76.85222222000
			64	9.39277777800	76.85500000000
8.	Konni	11	65	9.25583333300	76.83111111000
			66	9.25166666700	76.83527778000
			67	9.25416666700	76.84416667000
			68	9.22222222200	76.85638889000
			69	9.21166666700	76.84861111000
			70	9.20833333300	76.84611111000
			71	9.23916666700	76.84666667000
			72	9.23722222200	76.85444444000
			73	9.25103650000	76.86132000000
			74	9.23011194000	76.84432600000
			75	9.20036000000	76.85100200000

3.1.3 Weather data of the area

The weather data of the area during May 2018 to May 2019, average monthly rainfall and number of rainy days per month for a period of ten years from 2008 to 2017 were collected from Rice Research Station, Mancompu. The monthly mean maximum temperature, minimum temperature, relative humidity, rainfall and number of rainy days are represented in Fig. 2. The deviation in rainfall during 2018 compared with the average value for 2008-2017 is presented in table 2.

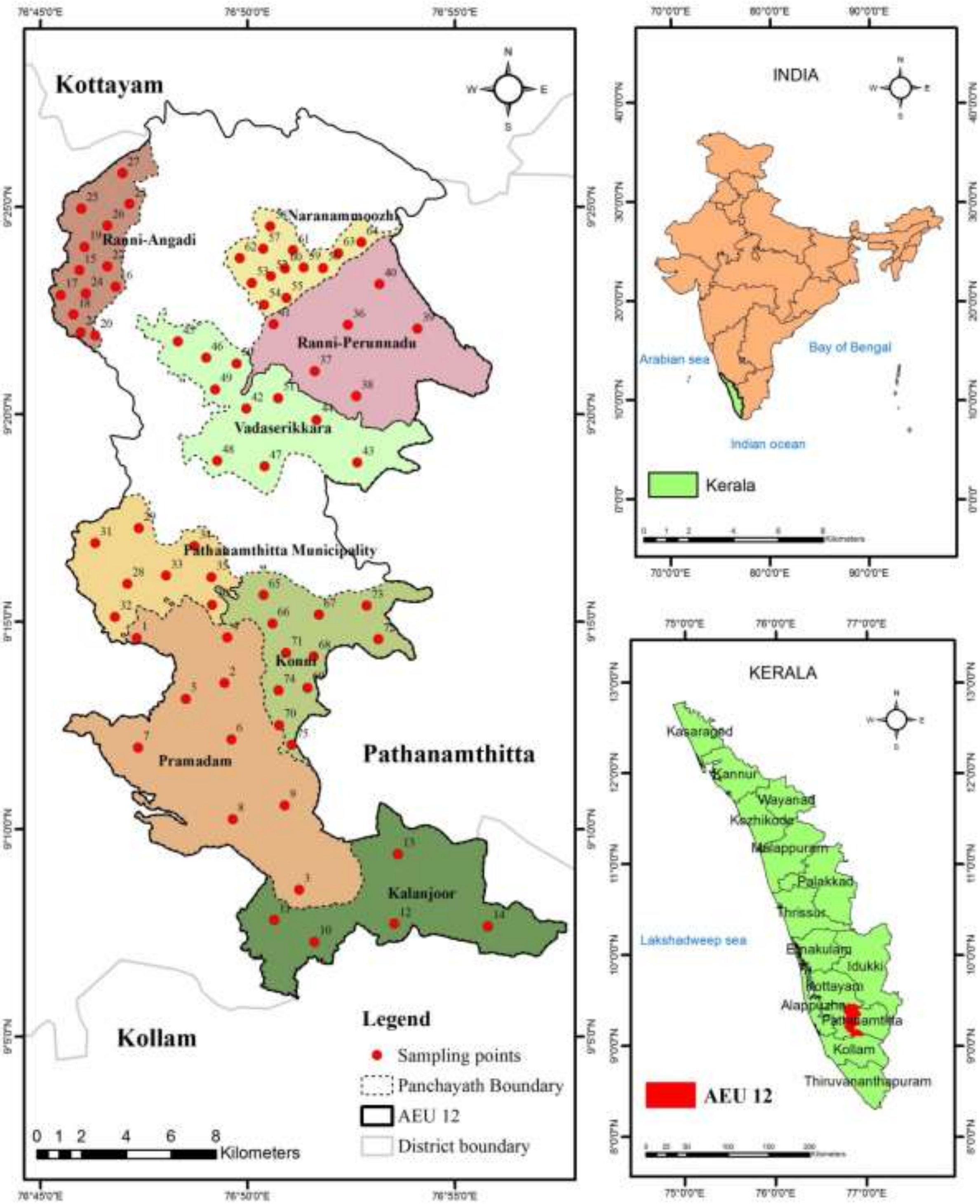


Fig. 1.Location map of samples in AEU 12 of Pathanamthitta district

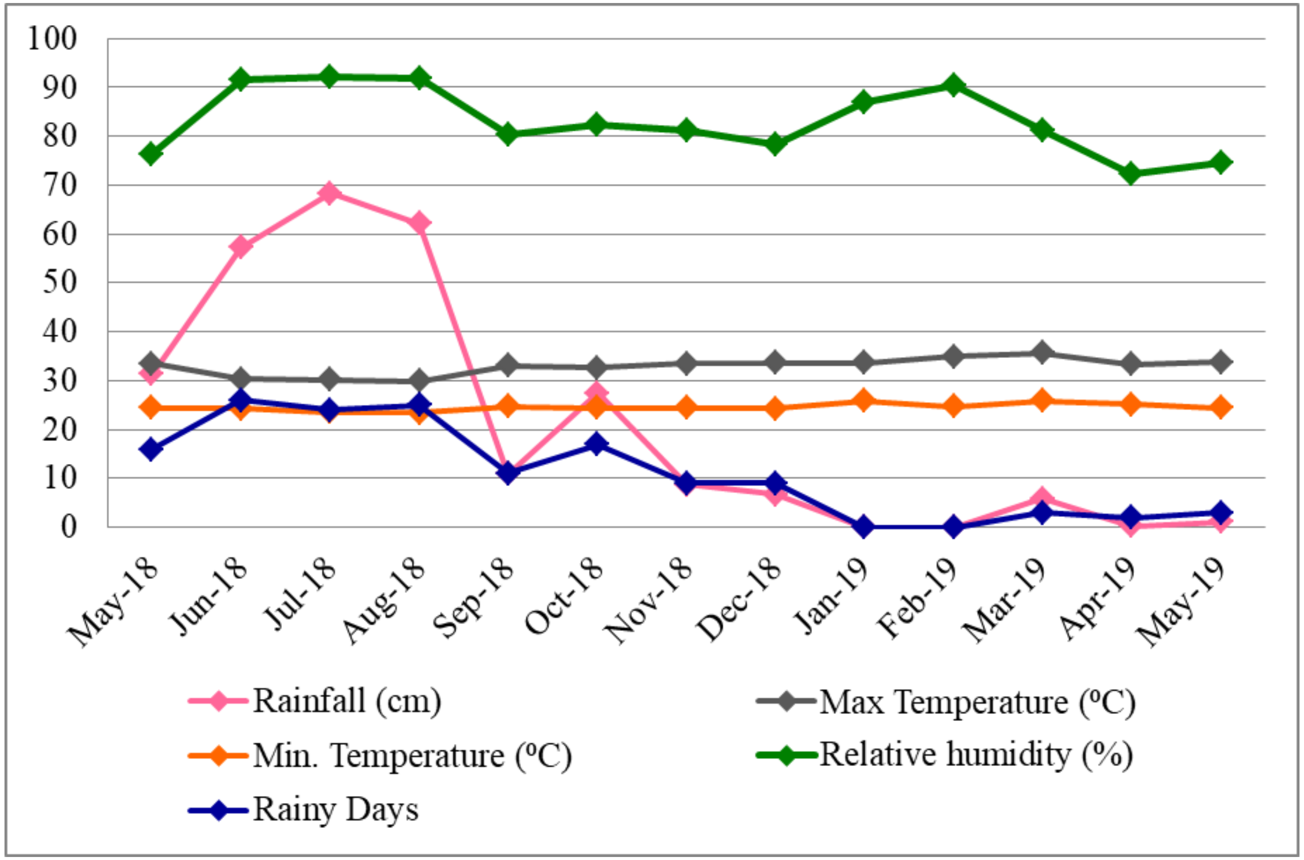


Fig. 2. Monthly mean of weather parameters in AEU 12

Table 2. Deviation in rainfall during 2018 from the average monthly rainfall over the previous ten years

Month	Average rainfall (mm) (2008-2017)	Rainfall during 2018 (mm)	Deviation in rainfall (mm)	Average no. of rainy days (2008-2017)	No. of rainy days during 2018	Deviation in no. of rainy days
January	12.39	0.00	-12.39	0.80	0	-0.80
February	39.68	1.00	-38.68	1.20	1	-0.20
March	49.20	29.8	-19.4	5.50	3	-2.50
April	136.55	71.6	-64.9	8.70	4	-4.70
May	234.36	312.8	+78.44	12.20	18	+5.80
June	497.64	573.2	+75.56	23.40	26	+2.60
July	382.65	683.3	+300.65	22.80	24	+1.20
August	296.88	621.3	+324.42	18.30	24	+5.70
September	241.35	108.8	-133.35	17.50	11	-6.50
October	255.12	273.9	+18.78	13.70	17	+3.30
November	128.55	88.2	-40.35	10.60	9	-1.60
December	63.52	67.2	+3.68	3.70	9	+5.30

3.2 CHARACTERISATION OF SAMPLES

Soil samples were characterised for selected physical, chemical and biological parameters.

3.2.1 Physical, chemical and biological parameters of samples

The soil samples were characterised for physical parameters *viz.,* bulk density, particle density, porosity, soil texture, soil moisture, maximum water holding capacity and aggregate analysis, chemical parameters *viz.,* pH, EC, organic carbon, available N, P, K, Ca, Mg, S and B, biological parameter *viz.,* acid phosphatase activity. The analysis results obtained were tabulated and interpreted at panchayath, AEU and land use levels. The analytical method followed for the determination of these parameters are given below

Table 3. Analytical methods followed for physical, chemical and biological analysis of soil

Sl. No.	Attribute	Method	Reference
1	Bulk density	Undisturbed core sample	Blake (1965)
2	Particle density	Pycnometer method	Vadyunina and Korchagina (1986)
3	Porosity	Calculation using bulk density and particle density	Danielson and Sutherland (1986)
4	Aggregate analysis	Wet sieving using Yoder’s apparatus	Yoder (1936)
5	Water holding capacity	Core method	Dakshinamurthi and Gupta (1968)
6	Soil texture	Bouyoucos hydrometer method	Bouyoucos (1936)
7	pH	pH meter (1:2.5 soil water ratio)	Jackson (1973)
8	EC	Conductivity meter (1:2.5 soil water ratio)	Jackson (1973)
9	Organic carbon	Walkley and Black method	Walkley and Black (1934)
10	Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
11	Available phosphorus	Extraction using Bray No. 1 solution and estimation using spectrophotometer	Bray and Kurtz (1945)
12	Available potassium	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
13	Available calcium and magnesium	Versanate titration method	Hesse (1971)
14	Available sulphur	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)

Table 3. continued

Sl. No.	Attribute	Method	Reference
15	Available boron	Hot water extraction and estimation in spectrophotometer (Azomethane H reagent method)	Gupta (1972)
16	Acid phosphatase activity	Colorimetric estimation of PNP released	Tabatabai and Bremner (1969)

3.3 SETTING UP OF A MINIMUM DATA SET FOR ASSESSMENT OF SOIL QUALITY

A minimum data set for the assessment of soil quality was developed using principal component analysis. 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 highest weightage or factor loadings were identified. Factor loadings represent the contribution of each variable to the principal component. Only the highly weighted variables (within 10 per cent of the highest observed factor loading) in each principal component were retained. 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 sum of correlation coefficients or highest factor loading were selected for the MDS (Andrews *et al.*, 2002).

3.4 FORMULATION OF SQI, NI AND LQI

3.4.1 Soil quality index

Soil quality evaluation was carried out as per the procedure given by Larson and Pierce, 1994. 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; Mukherjee and Lal, 2014) with slight modifications. The attributes selected for the MDS were assigned appropriate weights based on existing soil conditions, cropping system and agro-climatic conditions (Singh *et al*., 2017). Soil quality index was calculated using the equation given below:

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

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

The change in soil quality was measured in terms of relative soil quality index (RSQI) as outlined by Karlen and Scott, 1994.

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

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).

3.4.2 Nutrient Index

To evaluate the soil fertility status of the area nutrient indices were calculated for soil organic carbon, available nitrogen, available phosphorus and available potassium in soils indices at panchayath and land use levels using the following equation given by Parker *et al*. (1951):

$$\text{Nutrient index} = \frac{1 \times N_l + 2 \times N_m + 3 \times N_h}{N_T}$$

where, N_l = Number of samples in low category

N_m = Number of samples in medium category

N_h = Number of samples in high category

N_T = Total number of samples

Table 4. Nutrient index ratings (Ramamurthy and Bajaj, 1969)

Nutrient index	Range	Remarks
I	<1.67	Low
II	1.67-2.33	Medium
III	>2.33	High

3.4.3 Land quality index

LQI was calculated based on soil carbon stock. Soil carbon stock was calculated using the formula given by Batjes (1996) and LQI was computed using the method outlined by Shalimadevi and Anil Kumar (2006).

$$\text{Soil carbon stock (Mg ha}^{-1}\text{)} = \text{Soil organic carbon (\%)} \times \text{Bulk density (Mg m}^{-3}\text{)} \times \text{Soil depth (m)} \times 100$$

Table 5. Land quality index ratings

Soil carbon stock (kg m^{-2})	Land quality index
<3	Very low
3-6	Low
6-9	Medium
9-12	Moderate
12-15	High
>15	Very high

3.5 GENERATION OF GIS MAPS

GIS based thematic maps were generated for soil pH, soil texture, organic carbon, available macronutrients, secondary nutrients, boron, soil quality index, land quality index and nutrient index using ArcGIS 10.5.1 software through interpolation.

The interpolation tool used was inverse distance weighted (IDW) method, a spatial analyst tool in ArcGIS software. IDW estimates interpolation cell values by averaging the values of sample points in the vicinity of each cell. This method assumes that the influence of value of the variable being mapped at a sampling point reduces with increase in distance from the sampling point (ESRI, 2001). The values at unknown location are determined using a weighting value and values at known locations. Weights are calculated using an equation based on the distance between the known and unknown locations and the total number of sampling points (Ogbozige *et al.*, 2018).

The soil analysis data along with the respective geo coordinates were entered in MS excel, converted into a CSV (Comma delimited) file and imported into the ArcGIS mapping software. The shape file with the boundaries of sampled panchayaths in AEU 12 of Pathanamthitta district *viz.,* Kalanjoor, Konni, Pramadam, Pathanamthitta municipality, Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi was also imported into the mapping software. The sampled area extended between 9.098° N and 9.458° N latitude and 76.762° E and 76.93° E longitude. IDW was selected from the spatial analyst tool. Longitude, latitude and soil attribute values were selected as x, y and z respectively and boundaries of the sampled panchayaths were taken as the processing extent in the IDW dialog box. The number of sampling points was also entered and the data was interpolated. The output map obtained for each parameter was classified manually based on the standard ratings and different colours were allotted for each class.

3.6 STATISTICAL ANALYSIS OF THE DATA

Correlations between physical, chemical and biological parameters were calculated in terms of Pearson's correlation coefficient (Pearson, 1931). Descriptive statistics was also calculated for all attributes at AEU level (Appendix V).

Results

4. RESULTS

A survey was conducted and georeferenced surface soil samples were collected from selected panchayaths of AEU 12 of Pathanamthitta district. The details regarding observable changes in soil properties after the flood, crops grown and nutrient management schedule adopted by the farmers were collected based on a predesigned questionnaire. The soil samples were analysed for physical, chemical and biological characteristics in the laboratory. Soil quality index, nutrient index and land quality index were calculated and GIS maps were generated. The status of soil with respect to physical, chemical and biological characteristics was interpreted at panchayath, AEU and land use levels. The experimental results generated during the course of the investigation are presented in this chapter.

4.1 SURVEY OF POST-FLOOD AREA OF AEU 12 OF PATHANAMTHITTA DISTRICT

The details of crops grown, nutrient management practices and size of holdings are provided in table 6. The devastating flood and resultant water logging during August 2018 caused huge crop losses all over AEU 12 leading to rotting of banana, vegetables and tuber crops. Such damage was more severe in Ranni block compared to Konni. Plantations of coconut, cocoa, rubber and oilpalm dried up after the floods in Ranni-Angadi, Vadaserikkara and Naranammoozhi panchayaths.

In parts of Konni, Pathanamthitta and Pramadam drained by Achankovil river, farmers reported high velocity flow of flood water leading to erosion of the fertile topsoil in most of the areas which were completely inundated for about 2 days during the flood. Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi region were submerged for more than 3 days and extensive deposition of sand, silt and clay (Plate 2) was observed when the flood water receded. Kalanjoor panchayath experienced only minor issues of submergence resulting from overflowing streams due to landslides in hilly and forest areas. Crop lands close to the streams were inundated and eroded in the area. Farmers reported increased pest incidence, yellowing of leaves and wilting of vegetable crops cultivated in post flood soils in parts of Pathanamthitta, Ranni-Angadi and Vadaserikkara (Plate 1).

Homestead farming is prevalent in the area with 93.3 percent of the farmers having a holding size less than 2 ha (Table 6). Majority of the farmers cultivated banana (53.3%) followed by tapioca (40.0%), vegetables (20.0%) and coconut (20.0%). The major land use systems in the area are banana intercropped with tapioca and vegetables, banana with tapioca, coconut with banana, coconut with tapioca, tapioca with vegetables and sole cropping of banana, tapioca, coconut, vegetables, rubber and oil palm. Other crops like cocoa, arecanut, pepper, nutmeg, mangosteen, elephant foot yam also are cultivated in the area. Most of the farmers cultivating vegetables, cassava and other tuber crops rely on organic nutrient sources like fresh and dried cowdung, vermicompost, biogas slurry, wood ash and green manure crops. Few farmers grow azolla which is used as manure and cattle feed. Use of other biofertilizers is not prevalent in the region. Organic manures are applied during land preparation for vegetable crops followed by top dressing with cow dung slurry, biogas slurry or diluted cow's urine.

Integrated nutrient management (INM) (46.7%) and conventional systems (33.3%) of nutrient management are followed by majority of the farmers for crops like rubber, banana, coconut and tapioca. Liming of soils is done twice a year for coconut, banana and rubber plantations followed by the application of chemical fertilizers supplying primary nutrients. Most of the farmers following integrated nutrient management (INM) and conventional systems use fertilizers like urea, factamphos, rock phosphate and MoP. Regular nutrient management practices are not adopted for established oil palm and cocoa plantations.

Plate 1. Wilting symptoms in vegetables cultivated on post-flood soils of AEU 12 in Pathanamthitta district

(A)

(B)

Plate 2. (A) Banana cultivation on sediment deposits in Vadaserikkara

(B) Sediment deposits in Naranammoozhi

Table 6. Details of field survey conducted in AEU 12 of Pathanamthitta district

Particulars	No. of farmers	Percentage
Crops		
1. Coconut	15	20.0%
2. Banana	40	53.3%
3. Rubber	5	6.67%
4. Vegetables	15	20.0%
5. Tapioca	30	40.0%
6. Oil palm	4	5.33%
7. Cocoa	5	6.67%
8. Other crops	10	13.3%
Nutrient management		
1. INM	35	46.7%
2. Organic	15	20.0%
3. Conventional	25	33.3%
Size of holdings		
1. <2 ha	70	93.3%
2. >2 ha	5	6.67%

4.2 CHARACTERISATION OF SOIL SAMPLES

4. 2.1 Physical attributes

The soil samples were analysed for physical parameters including bulk density, particle density, porosity, soil texture, depth of sand, silt and clay deposition, soil moisture content, maximum water holding capacity and aggregate stability.

4.2.1.1 Bulk density

Bulk density varied between 0.84 and 1.45 Mg m^{-3} (Table 7) in the study area with a mean of 1.15 Mg m^{-3}.The lowest and highest mean at panchayath level were observed for Pathanamthitta (1.00 Mg m^{-3}) and Konni (1.29 Mg m^{-3}) respectively.

4.2.1.2 Particle density

Particle density ranged between 1.80 and 2.81 Mg m^{-3} (Table 7) in the study area with a mean of 2.29 Mg m^{-3}. Ranni-Angadi (2.13 Mg m^{-3}) and Ranni-Perunnadu (2.51 Mg m^{-3}) reported the lowest and highest mean respectively at panchayath level.

4.2.1.3 Porosity

Porosity ranged between 25.6 and 67.4 per cent in the study area (Table 7) with a mean of 49.3 per cent. The highest and lowest mean at panchayath level were recorded in Pathanamthitta municipality (59.9%) and Konni (44.1%) respectively.

Table 7. Bulk density, particle density and porosity in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	Bulk density ($Mg\ m^{-3}$)		Particle density ($Mg\ m^{-3}$)		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	1.27 ± 0.09	1.18-1.39	2.45 ± 0.14	2.30-2.61	48.1 ± 5.08	42.6-53.3
Konni	1.29 ± 0.09	1.18-1.43	2.33 ± 0.37	2.02-2.78	44.1 ± 5.77	34.6-52.9
Pramadam	1.08 ± 0.09	1.00-1.26	2.15 ± 0.08	2.00-2.26	49.7 ± 4.94	42.0-53.6
Pathanamthitta	1.00 ± 0.11	0.86-1.12	2.50 ± 0.11	2.31-2.64	59.9 ± 5.52	51.5-67.4
Vadaserikkara	1.23 ± 0.16	1.08-1.44	2.34 ± 0.32	1.80-2.61	46.9 ± 8.32	33.3-56.8
Ranni-Angadi	1.12 ± 0.17	0.97-1.44	2.13 ± 0.27	1.80-2.81	46.4 ± 12.1	25.6-61.9
Ranni-Perunnadu	1.19 ± 0.12	1.01-1.36	2.51 ± 0.10	2.35-2.60	52.6 ± 4.43	44.7-57.0
Naranammoozhi	1.08 ± 0.15	0.84-1.26	2.21 ± 0.18	1.80-2.40	51.3 ± 5.87	47.1-64.9
AEU 12	1.15 ± 0.16	0.84-1.45	2.29 ± 0.25	1.80-2.81	49.3 ± 7.91	25.6-67.4

4.2.1.4 Soil particle size distribution and texture

The mean, range and standard deviation of clay, silt, sand contents and the predominant soil textural classes observed at panchayath level and AEU level are given in table 8.

Clay content in the soils of AEU 12 of Pathanamthitta district varied between 11.2 and 46.2 per cent. The mean value of clay content in the post-flood area of AEU 12 in Pathanamthitta district was observed to be 29.3 per cent. The highest and lowest mean of clay at panchayath level were recorded for Kalanjoor (35.2%) and Naranammoozhi (22.7%) respectively.

Kalanjoor (12.0%) and Ranni-Angadi (23.5%) respectively recorded the lowest and highest mean of silt content at panchayath level. Silt content varied between 5.0 and 40.0 per cent in the sampled area with a mean of 18.3 per cent.

The highest and lowest mean for sand content at panchayath level were obtained for Pathanmthitta (58.8%) and Ranni-Angadi (44.6%) respectively. Sand content varied between 33.8 and 73.8 per cent in the post-flood area of AEU 12 in Pathanamthitta district with a mean of 52.4 per cent.

The predominant textural class in all panchayaths was sandy clay loam except in Kalanjoor (sandy clay). Other textural classes observed were clay, loam, sandy clay, clay loam, loamy sand and sandy loam. Loamy sand texture was observed only in sampling locations with excessive deposition of sandy sediments in Vadaserikkara.

Table 8. Clay, silt, sand contents and soil textural classes in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	Clay (%)		Silt (%)		Sand (%)		Soil textural class
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Kalanjoor	35.2 ± 4.18	31.2-41.2	12.0 ± 2.74	10.0-15.0	52.8 ± 6.52	43.8-58.8	Sandy clay
Konni	29.8 ± 8.09	21.2-41.2	18.1 ± 8.15	10.0-30.0	51.9 ± 14.37	33.8-68.8	Sandy clay loam
Pramadam	35.1 ± 7.41	26.2-46.2	17.7 ± 3.63	10.0-20.0	47.1 ± 9.01	33.8-58.8	Sandy clay loam
Pathanamthitta	26.8 ± 4.96	21.2-31.2	14.3 ± 5.63	10.0-25.0	58.8 ± 5.35	48.8-63.8	Sandy clay loam
Vadaserikkara	26.7 ± 13.0	11.2-46.2	15.5 ± 3.69	10.0-20.0	57.8 ± 13.08	38.8-73.8	Sandy clay loam
Ranni-Angadi	31.9 ± 6.72	26.2-46.2	23.5 ± 8.51	10.0-40.0	44.6 ± 8.38	33.8-58.8	Sandy clay loam
Ranni-Perunnadu	31.2 ± 3.16	26.2-36.2	17.5 ± 4.18	15.0-25.0	51.3 ± 5.24	43.8-58.8	Sandy clay loam
Naranammoozhi	22.7 ± 5.55	16.2-31.2	20.8 ± 9.54	5.0-35.0	56.5 ± 7.25	43.8-68.8	Sandy clay loam
AEU 12	29.3 ± 8.29	11.2-46.2	18.3 ± 7.37	5.0-40.0	52.4 ± 10.48	33.8-73.8	Sandy clay loam

4.2.1.5 Depth of sand, silt and clay deposits

Deposition of sediments with varying depth and texture were observed in Ranni-Angadi, Ranni-Perunnadu, Naranammoozhi, Vadaserikkara and a few areas in Konni and Pathanamthitta (Table 9). Maximum deposition was observed in Ranni-Angadi where silt was deposited upto 3-5 m height in an area stretching up to 1 km from the river bank. In Pramadam, and Kalanjoor no deposition was observed.

4.2.1.6 Maximum water holding capacity

The mean, range and standard deviation of WHC at panchayath level and AEU level are given in table 10. The highest mean value of 58.2 per cent was obtained for Pramadam and the lowest value was observed for Naranammoozhi (41.8 %). The results showed that the maximum water holding capacities ranged between 29.6 and 68.0 per cent for AEU 12 with a mean of 47.3 per cent.

4.2.1.7 Soil moisture content

The mean, range and standard deviation of soil moisture content at panchayath level and AEU level are shown in table 10. The highest mean value at panchayath level was observed for Kalanjoor (34.7%) and the lowest mean value was recorded for Naranammoozhi (14.6%). Soil moisture content varied between 7.85 and 45.4 per cent in the post-flood area of AEU 12 in Pathanamthitta district. The mean soil moisture content for AEU 12 was observed to be 20.5 per cent.

4.2.1.8 Aggregate stability

Aggregate stability was measured by calculating the mean weight diameter and percentage of water stable aggregates. The mean, range and standard deviation of MWD and percentage of water stable aggregates for the post-flood area of AEU 12 at panchayath and AEU levels are presented in table 11. The highest and lowest mean values of MWD at panchayath level were obtained for Pathanamthitta (3.16 mm) and

Vadaserikkara (0.47 mm) respectively. MWD ranged between 0.02 and 4.76 mm for the post-flood area of AEU 12 in Pathanamthitta district with a mean of 1.83 mm (Table 11). Percentage of water stable aggregates varied between 1.68 and 97.7 per cent with a mean of 62.8 per cent. The highest and lowest mean at panchayath level were recorded for Pathanamthitta (83.4%) and Vadaserikkara (28.6%) respectively (Table 11).

Table 9. Depth of silt, sand and clay deposition in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	Depth of deposition	Nature of deposits
Kalanjoor	No deposition	-
Konni	No deposition in most of the areas 10-12 cm (sampling locations 65 and 66)	- Silt and clay
Pramadam	No deposition	-
Pathanamthitta	No deposition in most of the areas 3-5 cm (sampling location 28 and 29)	- Silt and clay
Vadaserikkara	2-4 m 4-5 cm	Fine sand, clay and silt (close to the river) Silt and clay (other areas)
Ranni-Angadi	3-5 m 10-15 cm	Silt (upto 1 km from river bank) Silt (other areas)
Ranni-Perunnadu	0.5-1m 10-15 cm	Sand and gravel (regions very close to the river) Silt and clay (other areas)
Naranammoozhi	2-4 m 5 -10 cm	Fine sand, clay and silt (close to the river) Silt and clay (other areas)

Table 10. Maximum water holding capacity and soil moisture content in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	Maximum water holding capacity (%)		Soil moisture content (%)	
	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	50.8 ± 9.53	40.8-63.1	34.7 ± 9.55	23.1-45.4
Konni	42.2 ± 8.49	34.0-50.4	18.5 ± 4.81	12.81-24.4
Pramadam	58.2 ± 4.73	52.8-64.7	25.0 ± 5.37	18.9-36.3
Pathanamthitta	47.2 ± 11.3	37.4-67.1	25.8 ± 11.8	10.3-43.4
Vadaserikkara	41.9 ± 12.3	29.6-68.1	15.0 ± 10.2	8.62-42.8
Ranni-Angadi	52.2 ± 5.72	44.7-60.3	20.1 ± 9.77	11.08-39.5
Ranni-Perunnadu	47.9 ± 7.79	37.4-55.9	22.4 ± 5.86	16.5-30.6
Naranammoozhi	41.8 ± 6.81	35.7-56.3	14.6 ± 7.72	7.85-28.6
AEU 12	47.3 ± 9.54	29.6-68.0	20.5 ± 9.71	7.85-45.4

Table 11. Mean Weight Diameter and water stable aggregates in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	Mean weight diameter (mm)		Water stable aggregates (%)	
	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	2.24 ± 0.86	1.44-3.40	78.1 ± 6.57	72.5-88.4
Konni	2.71 ± 1.54	0.31-4.76	76.9 ± 19.1	42.3-97.7
Pramadam	1.21 ± 0.59	0.29-2.08	58.7 ± 22.5	19.9-78.26
Pathanamthitta	3.16 ± 0.58	2.61-4.02	83.4 ± 8.23	75.4-96.8
Vadaserikkara	0.47 ± 0.71	0.02-2.08	28.6 ± 27.5	1.68-75.3
Ranni-Angadi	2.39 ± 1.22	0.71-4.63	72.5 ± 17.5	33.8-88.1
Ranni-Perunnadu	2.06 ± 0.51	1.51-2.88	80.1 ± 3.72	73.6-84.9
Naranammoozhi	0.94 ± 0.54	0.37-1.66	43.8 ± 19.9	16.5-63.5
AEU 12	1.83 ± 1.27	0.02-4.76	62.8 ± 26.0	1.68-97.7

4.2.2 Chemical attributes

The soil samples were analysed in the laboratory for chemical parameters including pH, EC, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and boron. The results obtained are discussed below.

4.2.2.1 Soil pH

The mean, range and standard deviation of soil pH at panchayath level and AEU level are presented in table 12. The lowest and highest mean value of pH was observed for Kalanjoor (4.36) and Vadaserikkara (5.87) respectively. pH ranged between 3.62 and 7.20 in the post-flood area of AEU 12 of Pathanamthitta district with a mean of 5.28.

4.2.2.2 Electrical conductivity

The mean, range and standard deviation of EC at panchayath level and AEU level are presented in table 12. The lowest mean value of 0.14 dS m^{-1} was obtained for Pathanamthitta and the highest for Pramadam (0.24 dS m^{-1}). EC ranged between 0.01 and 0.70 dS m^{-1} for the post-flood area of AEU 12 in Pathanamthitta district with a mean of 0.19 dS m^{-1}.

Table 12. Soil pH and EC in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	pH		EC (dS m^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	4.36 ± 0.27	4.13-4.68	0.19 ± 0.16	0.06-0.44
Konni	4.91 ± 0.58	4.18-6.17	0.17 ± 0.19	0.01-0.70
Pramadam	4.73 ± 0.64	3.83-5.78	0.24 ± 0.19	0.11-0.70
Pathanamthitta	4.66 ± 0.53	4.05-5.48	0.14 ± 0.10	0.01-0.34
Vadaserikkara	5.87 ± 1.23	3.62-7.11	0.21 ± 0.12	0.08-0.47
Ranni-Angadi	5.61 ± 0.87	4.1-6.82	0.23 ± 0.18	0.08-0.68
Ranni perunnadu	5.63 ± 1.00	4.62-6.92	0.17 ± 0.08	0.10-0.27
Naranammoozhi	5.74 ± 1.01	4.13-7.20	0.17 ± 0.13	0.08-0.53
AEU 12	5.28 ± 0.97	3.62-7.20	0.19 ± 0.15	0.01-0.70

4.2.2.3 Organic carbon

The mean, range and standard deviation of organic carbon at panchayath and AEU levels are presented in table 13. The mean organic carbon content was the highest for Pathanamthitta (2.23%) and the lowest for Vadaserikkara (0.98%). Organic carbon content varied from 0.14 to 3.15 per cent in the post-flood area of AEU 12 in Pathanamthitta district. The mean of organic carbon content for the post-flood area of AEU 12 in Pathanamthitta district was 1.60 per cent.

4.2.2.4 Available nitrogen

The mean, range and standard deviation of available N in soil at panchayath and AEU levels are represented in table 13. Available N varied from 25.1 to 439 kg ha^{-1} in the AEU. The mean soil available N was 216 kg ha^{-1} in the area. The mean was highest for Pathanmthitta (271 kg ha^{-1}) and lowest for Vadaserikkara (145 kg ha^{-1}).

4.2.2.5 Available phosphorus

Available phosphorus varied between 0.69 and 362 kg ha^{-1} for the post-flood soils of AEU 12 in Pathanamthitta district (Table 13). The mean of available phosphorus for the area was 93.6 kg ha^{-1}. The lowest mean of 63.0 kg ha^{-1} at panchayath level was observed for Ranni-Angadi and the highest mean of 151 kg ha^{-1} was obtained for Kalanjoor.

4.2.2.6 Available potassium

The mean, range and standard deviation of available K in soil at panchayath and AEU levels are presented in table 13. The highest and lowest mean were recorded for Naranammoozhi (304 kg ha^{-1}) and Konni (183 kg ha^{-1}) respectively. Available K varied between 56.0 and 699 kg ha^{-1} in the post-flood area of AEU 12 in Pathanamthitta district with a mean of 246 kg ha^{-1}.

Table 13. Organic carbon, available N, P and K status in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	Organic carbon (%)		Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available potassium (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	1.60 ± 0.24	1.31-1.98	233 ± 36.1	175-263	151 ± 86.4	57.4-264	301 ± 250	78.4-699
Konni	1.79 ± 0.63	0.84-2.3	232 ± 53.9	138-326	81.5 ± 85.3	5.33-288	183 ± 92.6	56.0-291
Pramadam	2.02 ± 0.66	1.32-3.15	262 ± 43.6	213-326	109 ± 71.7	15.8-233	254 ± 102	123-376
Pathanamthitta	2.23 ± 0.49	1.62-3.08	271 ± 70.3	176-364	80.6 ± 59.6	38.7-201	226 ± 149	56.0-560
Vadaserikkara	0.98 ± 0.64	0.38-2.15	145 ± 63.7	75.3-251	86.8 ± 59.2	11.35-192	206 ± 162	67.2-638
Ranni-Angadi	1.83 ± 0.64	0.32-2.72	234 ± 98.4	100-439	63.0 ± 48.2	0.69-151	269 ± 139	67.2-537
Ranni-Perunnadu	1.39 ± 0.66	1.01-1.39	199 ± 21.6	163-226	97.3 ± 72.2	6.71-203	218 ± 78.2	168-358
Naranammoozhi	1.08 ± 0.68	0.14-2.43	177 ± 81.9	25.1-263	113 ± 105	7.18-362	304 ± 171	101-650
AEU 12	1.6 ± 0.73	0.14-3.15	216 ± 77.5	25.1-439	93.6 ± 75.9	0.69- 362	246 ± 145	56.0-699

4.2.2.7 Available calcium

The mean, range and standard deviation of available calcium at panchayath and AEU levels are presented in table 14. The highest and lowest means were observed for Naranammoozhi (1046 mg kg^{-1}) and Pathanmthitta (535 mg kg^{-1}) respectively. Available Ca ranged between 120 and 1960 mg kg^{-1}in the post-flood area with a mean of 865 mg kg^{-1}.

4.2.2.8 Available magnesium

Available Mg varied between 12.0 and 780 mg kg^{-1}in the post-flood soils of AEU 12 in Pathanamthitta district (Table 14) and the mean was observed to be 204 mg kg^{-1}. The mean value at panchayath level was the highest for Ranni-Perunnadu (292 mg kg^{-1}) and lowest for Pathanamthitta (113 mg kg^{-1}).

4.2.2.9 Available sulphur

The status of available S in soil at panchayath and AEU levels are presented in table 14. The highest and lowest mean were observed for Ranni-Perunnadu (29.8 mg kg^{-1}) and Kalanjoor (5.30 mg kg^{-1}) respectively. Available S varied between 0.50 ppm and 78.5 mg kg^{-1}. The mean of available S at AEU level was 12.9 mg kg^{-1}.

Table 14. Available Ca, Mg and S status in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/ Municipality	Available calcium (mg kg^{-1})		Available magnesium (mg kg^{-1})		Available sulphur (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kalanjoor	564 ± 441	240-1340	153 ± 100	48.0-312	5.30 ± 5.95	0.50-14.0
Konni	653 ± 228	260-940	130 ± 75.3	12.0-240	9.68 ± 6.97	2.00-19.0
Pramadam	820 ± 328	320-1460	164 ± 49.8	108-264	7.50 ± 5.62	0.50-19.0
Pathanamthitta	535 ± 355	200-1240	113 ± 35.7	60.0-156	6.44 ± 6.13	0.50-16.0
Vadaserikkara	1020 ± 453	360-1820	245 ± 155	132-600	16.8 ± 16.0	2.50-49.0
Ranni-Angadi	1035 ± 507	120-1960	259 ± 178	36.0-624	15.1 ± 20.7	2.50-78.5
Ranni-Perunnadu	943 ± 319	680-1480	292 ± 228	108-780	29.8 ± 20.1	10.00-58.5
Naranammoozhi	1046 ± 463	600-1960	230 ± 188	24.0-732	13.8 ± 14.1	1.50-51.0
AEU 12	865 ± 436	120-1960	204 ± 151	12.0-780	12.9 ± 14.5	0.50-78.5

4.2.2.10 Available boron

The lowest mean of available B at panchayath level was observed for Pramadam (0.24 mg kg^{-1}) and the highest was observed in Ranni-Perunnadu (0.63 mg kg^{-1}) and Naranammoozhi (0.63 mg kg^{-1}). Available B varied between 0.01 mg $kg^{-1}$and 1.50 mg kg^{-1} in the post-flood soils of AEU 12 in Pathanamthitta district with a mean of 0.47 mg kg^{-1} (Table 15).

Table 15. Available B status in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	Available boron (mg kg^{-1})	
	Mean ± SD	Range
Kalanjoor	0.44 ± 0.30	0.05 - 0.87
Konni	0.50 ± 0.40	0.01 - 1.36
Pramadam	0.24 ± 0.40	0.01 - 1.12
Pathanamthitta	0.62 ± 0.50	0.02 - 1.33
Vadaserikkara	0.46 ± 0.50	0.01 - 1.06
Ranni-Angadi	0.29 ± 0.36	0.02 - 1.18
Ranni-Perunnadu	0.63 ± 0.41	0.23 - 1.30
Naranammoozhi	0.63 ± 0.47	0.04 - 1.50
AEU 12	0.47 ± 0.44	0.01 - 1.50

4.2.3 Biological attributes

4.2.3.1 Acid phosphatase activity

The acid phosphatase activity in soil at panchayath and AEU levels are presented in table 16. The lowest and highest mean were observed for Vadaserikkara (5.87 µg PNP produced g $soil^{-1}$ h^{-1}) and Ranni-Perunnadu (35.8 µg PNP produced g $soil^{-1}$ h^{-1}) respectively. Acid phosphate activity varied between 4.27 µg PNP produced g $soil^{-1}$ h^{-1} and 96.9 µg PNP produced g $soil^{-1}$ h^{-1}. The mean at AEU level was observed to be 27.1 µg PNP produced g $soil^{-1}$ h^{-1}.

Table 16. Acid phosphatase activity in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	Acid phosphatase activity (μg PNP produced g soil^{-1} h^{-1})	
	Mean ± SD	Range
Kalanjoor	20.2 ± 5.62	14.1 - 27.6
Konni	25.1 ± 13.5	8.1 - 43.2
Pramadam	26.5 ± 9.80	11.1 - 45.3
Pathanamthitta	32.1 ± 35.7	14.3 - 56.3
Vadaserikkara	5.87 ± 1.23	8.45 - 56.9
Ranni-Angadi	32.7 ± 13.5	14.5 - 60.9
Ranni-Perunnadu	35.8 ± 21.6	4.27 - 96.9
Naranammoozhi	22.7 ± 8.87	11.9 - 39.8
AEU 12	27.1 ± 14.6	4.27 - 96.9

4.3 SETTING UP OF A MINIMUM DATA SET FOR ASSESSMENT OF SOIL QUALITY

Seventeen parameters were analysed using PCA to develop a MDS of parameters. The parameters used in PCA were 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. 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 17).

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). When more than one variable was retained in a PC, 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.*, 2001).

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. The highly weighted variable in the second PC was per cent sand and available K was the variable retained in the third. In the fourth principal component, available P, available B and acid phosphatase activity were retained. In the fifth and sixth principal components bulk density and per cent silt respectively were retained (Table 18).

Table 17. 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

Table 18. 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		

4.4 SOIL QUALITY INDEX

SQI was formulated using the MDS of parameters which were assigned appropriate weights and scores. Scoring was done following the method suggested by Kundu *et al*. (2012) and Mukherjee and Lal (2014) with slight modifications based on the fertility status of Kerala soils (Table 19). Weights were assigned based on existing soil conditions, cropping pattern and agro-climatic conditions (Singh *et al*. 2017). After scoring, a weighted SQI was computed using the equation,

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

where, W_i is the weight and S_i is the score assigned to the parameters.

A relative soil quality index (RSQI) was also computed to study the change in soil quality and samples were rated based on RSQI value as poor (<50%), medium (50%-70%) and good (>70%).

Table 19. 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

The mean, range and standard deviation of SQI and RSQI at panchayath and AEU levels are presented in table 20. 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 of AEU 12 with a mean of 263. RSQI ranged between 37.5 and 87.8 per cent in the post-flood soils of AEU 12 in Pathanamthitta district with a mean of 65.7 per cent.

Table 20. 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

4.5 NUTRIENT INDEX

Panchayath wise nutrient indices were calculated for organic carbon and available primary nutrients. Nutrient indices for organic carbon were high for Pathanamthitta (3.0), Kalanjoor (2.8), Pramadam (2.67), Konni (2.64) and Ranni-Angadi (2.54) and medium for Ranni-Perunnadu (2.17), Naranammoozhi (1.92) and Vadaserikkara (1.70). Nutrient indices for available nitrogen were low and for available phosphorus were high for the entire post-flood area of AEU 12 in Pathanamthitta. The nutrient indices for available potassium were in the medium range for the entire area (Table 21).

Table 21. Nutrient indices at panchayath level

Panchayath/ Municipality	Nutrient index							
	Organic carbon	Status	Available N	Status	Available P	Status	Available K	Status
Kalanjoor	2.80	High	1.00	Low	3.00	High	2.20	Medium
Konni	2.64	High	1.36	Low	2.36	High	1.91	Medium
Pramadam	2.67	High	1.33	Low	3.00	High	2.33	Medium
Pathanamthitta	3.00	High	1.38	Low	3.00	High	2.13	Medium
Vadaserikkara	1.70	Medium	1.00	Low	2.80	High	1.90	Medium
Ranni-Angadi	2.54	High	1.39	Low	2.62	High	2.23	Medium
Ranni-Perunnadu	2.17	Medium	1.20	Low	2.67	High	2.17	Medium
Naranammoozhi	1.92	Medium	1.08	Low	2.77	High	2.31	Medium

4.6 LAND QUALITY INDEX

Soil organic carbon stock ranged between 2.6 Mg ha^{-1}and 36.8 Mg ha^{-1} in the study area. The lowest and highest mean of LQI at panchayath level were observed for Naranammoozhi (1.69 kg m^{-2}) and Konni (3.51 kg m^{-2}) respectively. LQI varied between 0.26 kg m^{-2} and 5.86 kg m^{-2} in the post-flood area of AEU 12 in Pathanamthitta district with a mean of 2.74 kg m^{-2} (Table 22).

Table 22. Soil organic carbon stock and LQI in the post-flood soils of AEU 12 in Pathanamthitta district

Panchayath/Municipality	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})	
		Range	Mean ± SD
Kalanjoor	23.2 - 39.2	2.32 - 3.92	3.05 ± 0.62
Konni	15.8 - 58.6	1.58 - 5.86	3.51 ± 1.39
Pramadam	21.4 - 49.1	2.14 - 4.91	3.31 ± 1.18
Pathanamthitta	23.1 - 49.0	2.31 - 4.90	3.34 ± 0.77
Vadaserikkara	6.20 - 36.8	0.62 - 3.68	1.76 ± 1.12
Ranni-Angadi	5.30 - 53.6	0.53 - 5.36	3.14 ± 1.35
Ranni-perunnadu	15.9 - 49.0	1.59 - 4.90	2.51 ± 1.25
Naranammoozhi	2.60 - 36.8	0.26 - 3.68	1.69 ± 1.01
AEU 12	2.60- 58.6	0.26 - 5.86	2.74 ± 1.32

4.7 GENERATION OF GIS MAPS

GIS based thematic maps were prepared using ArcGIS 10.5.1 software. Spatial variability in pH, organic carbon, available macro and secondary nutrients, available boron, soil texture, soil quality index and land quality index were mapped. Nutrient indices at panchayath levels for organic carbon and available primary nutrients were also mapped.

4.8 CORRELATION STUDIES

Correlation between parameters was worked out at AEU level in terms of Pearson’s correlation coefficient. The results are summarised in tables 23, 24 and 25.

4.8.1 Correlation between physical parameters

Porosity showed a significant positive correlation with particle density (0.499^{**}) and significant negative correlation with bulk density (-0.793^{**}) of soils (Table 23). Bulk density had a significant negative correlation with SMC (-0.251^{*}) and WHC (-0.295^{**}) in addition to porosity. SMC had a significant positive correlation with porosity (0.366^{**}), WHC (0.415^{**}), MWD (0.368^{**}), WSA (0.246^{*}), particle density (0.265^{*}) and clay (0.402^{**}). WHC also had a significant positive correlation with clay (0.540^{**}) and a negative correlation with sand (-0.583^{**}). Silt content showed a significant negative correlation with porosity (-0.291^{*}) and particle density (-0.489^{**}). WSA and MWD were strongly and positively correlated with each other (0.833^{**}). Sand content in soils was observed to be in significant positive correlation with particle density (0.254^{*}) and significant negative correlation with silt content (-0.618^{**}) and clay content (-0.715^{**}).

Table 23. Correlation between physical parameters

Parameters	PD	BD	Porosity	SMC	WHC	MWD	WSA	Clay	Silt	Sand
PD	1.00									
BD	0.123	1.00								
Porosity	0.499^{**}	-0.793^{**}	1.00							
SMC	0.265^{*}	-0.251^{*}	0.366^{**}	1.00						
WHC	-0.152	-0.295^{*}	0.174	0.415^{**}	1.00					
MWD	0.130	-0.153	0.183	0.368^{**}	0.024	1.00				
WSA	0.043	0.004	0.007	0.246^{*}	0.085	0.833^{**}	1.00			
Clay	0.114	0.002	0.069	0.402^{**}	0.540^{**}	0.046	-0.042	1.00		
Silt	-0.489^{**}	-0.017	-0.291^{*}	-0.133	0.222	-0.080	-0.016	-0.109	1.00	
Sand	0.254^{*}	0.010	-0.150	-0.225	-0.583^{**}	0.020	0.044	-0.715^{**}	-0.618^{**}	1.00

* Significant at 5% level, **Significant at 1% level

4.8.2 Correlation between physical chemical and biological parameters

Soil pH showed a significant negative correlation (Table 24) with SMC (-0.304**), MWD (-0.244**) and WSA (-0.357**) whereas organic carbon showed a significant positive correlation with WSA (0.385**) and MWD (0.352**). EC showed a significant positive correlation with silt content (0.329**) and negative correlation with sand content (-0.227*) and particle density (-0.213*). Available N showed a significant positive correlation with MWD (0.238*) and WSA (0.376**). Available Ca was significantly negatively correlated with SMC (-0.290*), MWD (-0.257*) and WSA (-0.322**) and significantly positively correlated with silt content (0.228*). Silt content was significantly and positively correlated with available Mg (0.357**) and S (0.309**) in addition to available Ca. Available B showed a significant positive correlation with particle density (0.339**).

Table 24. Correlation between physical, chemical and biological parameters

Parameters	BD	PD	SMC	WHC	MWD	WSA	Clay	Silt	Sand
pH	0.071	0.031	-0.304**	-0.187	-0.244*	-0.357**	-0.139	0.148	0.006
EC	-0.058	-0.213*	-0.026	0.219	-0.153	-0.075	-0.005	0.329**	-0.227*
OC	-0.117	-0.149	0.185	0.095	0.352**	0.385**	0.053	-0.066	0.004
N	-0.118	-0.199	0.205	0.174	0.238*	0.376**	0.057	-0.037	-0.019
P	0.047	0.061	-0.034	-0.052	-0.100	-0.007	-0.143	0.015	0.103
K	-0.160	-0.156	0.065	-0.059	0.092	0.102	-0.174	0.117	0.055
Ca	0.026	-0.134	-0.290*	-0.087	-0.257*	-0.322**	-0.132	0.228*	-0.056
Mg	0.035	-0.075	-0.099	0.018	-0.199	-0.203	-0.177	0.357**	-0.111
S	0.190	0.072	-0.089	0.028	-0.074	-0.033	-0.106	0.309**	-0.134
B	0.011	0.339**	0.052	-0.035	0.019	-0.036	-0.123	-0.038	0.124
Acid phosphatase activity	0.094	0.119	-0.121	-0.071	0.052	0.209	-0.091	-0.044	0.103

* Significant at 5% level, **Significant at 1% level

4.8.3 Correlation between chemical and biological parameters

Available nitrogen (-0.490**) and organic carbon (-0.528**) showed a significant negative correlation with soil pH (Table 25) whereas available Ca (0.695**), Mg (0.541**) and S (0.516**) showed significant positive correlation with soil pH. Available K (0.273*) and Mg (0.358**) showed significant positive correlation with EC. Organic carbon showed a significant positive correlation with available N (0.390**) and acid phosphatase activity (0.394**). Organic carbon also had a significant negative correlation with available Ca (-0.389**), Mg (-0.364**) and S (-0.249**). Available N was significantly and negatively correlated with available Ca (-0.321**), Mg (-0.278**), S (-0.300**) and B (-0.311**). Available P showed a significant positive correlation with available K (0.290*) and B (0.271*) while available K was significantly and positively correlated with available Ca (0.267*) and acid phosphatase activity (0.240*). Available Ca had a significant positive correlation with available Mg (0.627**) and S (0.526**). Available Mg also showed a positive correlation with available S (0.555**).

Table 25. Correlation between chemical and biological parameters

Parameters	pH	EC	OC	N	P	K	Ca	Mg	S	B	Acid phosphatase activity
pH	1.000										
EC	-0.005	1.000									
OC	-0.528**	-0.029	1.000								
N	-0.490**	0.053	0.390**	1.000							
P	-0.169	0.161	0.095	-0.037	1.000						
K	-0.074	0.273*	0.153	0.046	0.290*	1.000					
Ca	0.695**	0.179	-0.389**	-0.321**	-0.068	0.267*	1.000				
Mg	0.541**	0.358**	-0.364**	-0.278**	-0.020	0.107	0.627**	1.000			
S	0.516**	0.147	-0.249**	-0.300**	-0.113	0.020	0.526**	0.555**	1.000		
B	0.143	0.004	-0.125	-0.311**	0.271*	0.049	0.107	0.170	0.143	1.000	
Acid phosphatase Activity	-0.078	-0.057	0.394**	0.224	0.087	0.240*	0.060	0.039	0.006	0.090	1.000

* Significant at 5% level, **Significant at 1% level

4.9 PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF POST-FLOOD SOILS OF AEU 12 IN PATHANAMTHITTA DISTRICT UNDER DIFFERENT LAND USES

The major land use systems in the study area were intercropping of banana with tapioca and vegetables, banana intercropped with tapioca, coconut with tapioca, coconut with banana, tapioca with vegetables, and sole cropping of banana, tapioca, coconut, vegetables, rubber and oil palm. Other crops like cocoa, arecanut, pepper, nutmeg, mangosteen and elephant foot yam also were cultivated in the area.

4.9.1 Physical attributes

4.9.1.1 Bulk density, Particle density and Porosity

The mean, standard deviation and range of bulk density, particle density and porosity is presented in table 26. The mean of bulk density was the highest for coconut alone (1.28 Mg m^{-3}) and lowest for other crops (1.01 Mg m^{-3}) and vegetables alone (1.01 Mg m^{-3}). Mean particle density was the highest in tapioca intercropped with vegetables (2.56 Mg m^{-3}) and lowest in banana intercropped with tapioca and vegetables (2.13 Mg m^{-3}) and in oil palm (2.13 Mg m^{-3}) whereas mean porosity was highest in coconut intercropped with tapioca (54.8%) and lowest in banana intercropped with tapioca and vegetables (44.4%).

4.9.1.2 Particle size distribution and Soil texture

The mean, standard deviation and range of clay, silt and sand content and common soil textural classes under different land uses are depicted in table 27. The highest mean clay content was obtained for oil palm (35.0 %) and lowest for banana intercropped with tapioca and vegetables (20.0%). Silt content showed the highest mean for coconut intercropped with banana (22.0%) and lowest for tapioca with vegetables (12.5%). The highest and lowest mean of sand content were observed in banana with tapioca and vegetables (63.8%) and sole cropping of oil palm (43.8%) respectively. The most frequently encountered textural class in the different land uses was sandy clay loam except in coconut intercropped with tapioca (sandy clay) and sole cropping of coconut (clay), vegetables (clay loam) and oil palm (clay loam).

Table 26. Bulk density, particle density and porosity in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	1.16 ± 0.11	1.01-1.27	2.13 ± 0.39	1.80-2.56	44.4 ± 11.2	33.3-57.0
Banana + Tapioca	1.20 ± 0.14	1.01-1.39	2.34 ± 0.21	2.00-2.61	48.3 ± 6.14	42.0-57.8
Coconut + Tapioca	1.08 ± 0.01	1.07-1.09	2.42 ± 0.34	2.19-2.81	54.8 ± 6.26	50.2-61.9
Coconut + banana	1.09 ± 0.13	0.97-1.26	2.41 ± 0.21	2.05-2.60	54.6 ± 4.97	47.5-60.9
Tapioca + Vegetables	1.26 ± 0.20	1.08-1.44	2.56 ± 0.06	2.50-2.61	50.8 ± 6.91	44.8-56.8
Banana alone	1.14 ± 0.15	0.84-1.36	2.24 ± 0.19	2.00-2.60	49.0 ± 7.18	34.2-64.9
Tapioca alone	1.13 ± 0.14	0.86-1.31	2.37 ± 0.21	2.10-2.78	52.1 ± 6.93	46.0-67.4
Coconut alone	1.28 ± 0.17	1.09-1.43	2.42 ± 0.25	2.19-2.78	47.0 ± 4.75	39.9-50.2
Vegetables alone	1.01 ± 0.20	0.84-1.34	2.16 ± 0.25	1.80-2.33	47.9 ± 15.6	25.6-61.6
Rubber	1.13 ± 0.21	0.86-1.38	2.33 ± 0.26	2.11-2.64	50.2 ± 14.1	34.6-67.4
Oil palm	1.15 ± 0.20	0.97-1.34	2.13 ± 0.14	2.02-2.34	45.5 ± 11.5	33.7-57.7
Other crops	1.01 ± 0.07	0.93-1.11	2.17 ± 0.12	2.10-2.35	53.3 ± 4.38	47.1-57.0

Table 27. Particle size distribution and soil textural classes in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Clay (%)		Silt (%)		Sand (%)		Soil textural class
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Banana + Tapioca + Vegetables	20.0 ± 10.3	11.2-31.2	16.3 ± 2.50	15.0-20.0	63.8 ± 12.1	48.8-73.8	Sandy clay loam
Banana + Tapioca	33.3 ± 6.99	26.2-46.2	15.0 ± 5.0	10.0-20.0	51.7 ± 8.59	33.8-58.8	Sandy clay loam
Coconut + Tapioca	24.5 ± 7.64	16.2-31.2	18.3 ± 7.64	10.0-25.0	57.1 ± 2.89	53.8-58.8	Sandy clay
Coconut + banana	26.2 ± 6.12	16.2-31.2	22.0 ± 5.70	15.0-30.0	51.8 ± 5.70	43.8-58.8	Sandy clay loam
Tapioca + Vegetables	30.0 ± 14.4	11.2-46.2	12.5 ± 2.89	10.0-15.0	57.6 ± 14.4	38.8-73.8	Sandy clay loam
Banana alone	30.4 ± 8.09	16.2-46.2	18.3 ± 9.07	5.00-40.0	51.3 ± 12.2	33.8-68.8	Sandy clay loam
Tapioca alone	27.7 ± 7.47	21.2-41.2	19.5 ± 6.85	10.0-35.0	52.8 ± 8.43	43.8-68.8	Sandy clay loam
Coconut alone	30.0 ± 13.1	16.2-41.2	16.3 ± 6.29	10.0-25.0	53.8 ± 12.2	43.8-68.8	Clay
Vegetables alone	31.2 ± 0.00	31.2-31.2	17.5 ± 11.9	5.0-30.0	51.3 ± 11.9	38.8-63.8	Clay loam
Rubber	30.0 ± 6.29	21.2-36.2	21.3 ± 7.50	15.0-30.0	48.8 ± 12.9	33.8-63.8	Sandy clay loam
Oil palm	35.0 ± 7.50	31.2-46.2	21.3 ± 2.50	20.0-25.0	43.8 ± 7.07	33.8-48.8	Clay loam
Other crops	26.2 ± 4.08	21.2-31.2	20.0 ± 10.8	10.0-35.0	53.8 ± 7.07	43.8-58.8	Sandy clay loam

4.9.1.3 Maximum water holding capacity and Soil moisture content

Mean maximum water holding capacity (Table 28) was the highest under oil palm (51.6%) and the lowest under banana intercropped with tapioca and vegetables (39.0%). The mean soil moisture content was highest and lowest under banana intercropped with tapioca (32.0%) and banana intercropped with tapioca and vegetables (14.3%) respectively (Table 28).

Table 28. Maximum water holding capacity and soil moisture content in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Maximum water holding capacity (%)		Soil moisture content (%)	
	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	39.0 ± 12.4	29.6-55.7	14.3 ± 6.87	8.62-23.1
Banana + Tapioca	51.0 ± 8.34	41.5-63.09	32.0 ± 9.35	20.6-45.4
Coconut + Tapioca	45.2 ± 9.32	36.1-54.7	18.8 ± 9.49	7.85-24.86
Coconut + banana	51.1 ± 9.48	39.9-62.4	17.7 ± 3.06	14.0-20.9
Tapioca + Vegetables	49.9 ± 16.0	30.8-68.0	19.3 ± 15.7	9.11-42.8
Banana alone	46.6 ± 9.45	35.7-64.7	19.0 ± 7.48	9.52-36.1
Tapioca alone	46.5 ± 11.7	36.1-67.1	21.7 ± 10.3	7.85-43.4
Coconut alone	43.88 ± 10.4	34.0-55.1	22.1 ±- 5.31	14.5-26.8
Vegetables alone	47.4 ± 6.99	42.5-57.8	17.2 ± 5.54	9.56-21.6
Rubber	46.4 ± 7.78	37.4-55.9	25.9 ± 12.9	14.5-43.4
Oil palm	51.6 ± 7.62	42.4-60.3	19.4 ± 13.5	11.1-39.5
Other crops	50.8 ± 6.20	42.0-55.7	14.7 ± 7.75	7.85-24.9

4.9.1.4 Aggregate stability

The mean, standard deviation and range of aggregate stability measured in terms of mean weight diameter and percentage of water stable aggregates under different land uses are shown in table 29. The mean of mean weight diameter and water stable aggregates was the highest in oil palm (3.05 mm, 81.3%) and the lowest in tapioca intercropped with vegetables (0.15mm, 18.6%).

Table 29. Mean weight diameter and water stable aggregates in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Mean weight diameter (mm)		Water stable aggregates (%)	
	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	2.10 ± 0.59	1.26-2.88	75.2 ± 8.63	63.0-81.6
Banana + Tapioca	2.13 ± 1.03	0.29-3.40	71.6 ± 23.2	19.9-88.4
Coconut + Tapioca	1.73 ± 1.48	0.29-3.24	57.2 ± 34.6	19.9-88.2
Banana + Coconut	1.40 ± 0.89	0.11-2.61	61.9 ± 29.7	11.2-88.0
Tapioca + Vegetables	0.15 ± 0.13	0.02-0.34	18.6 ± 20.9	1.68-49.0
Banana alone	1.85 ± 1.38	0.02-4.76	62.3 ± 29.9	1.68-97.7
Tapioca alone	1.58 ± 1.19	0.37-4.02	59.7 ± 23.2	16.5-96.8
Coconut alone	1.38 ± 0.76	0.31-2.10	62.6 ± 14.2	42.3-73.5
Vegetables alone	1.76 ± 1.06	0.37-2.63	52.7 ± 30.2	16.5-77.6
Rubber	2.65 ± 1.74	0.31-4.02	71.7 ± 20.0	42.3-84.9
Oil palm	3.05 ± 1.45	1.74-4.63	81.3 ± 7.63	67.0-86.8
Other crops	1.56 ± 0.63	0.69-2.08	63.9 ± 21.8	33.8-81.6

4.9.2 Chemical attributes

4.9.2.1 Soil pH and Electrical Conductivity

Soil pH and electrical conductivity in soils under different land uses are given in table 30. The mean of soil pH was the highest and lowest in soils under coconut intercropped with banana (6.25) and rubber (4.49) respectively. EC showed the highest mean in soils under banana alone (0.30 dS m^{-1}) and lowest in soils under rubber (0.09 dS m^{-1}).

Table 30. pH and EC in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	pH		EC (dS m^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	5.58 ± 1.45	3.62-6.85	0.20 ± 0.10	0.11-0.30
Banana + Tapioca	4.59 ± 0.56	4.05-5.52	0.15 ± 0.14	0.01-0.44
Coconut + Tapioca	5.37 ± 0.92	4.31-5.99	0.12 ± 0.03	0.08-0.14
Coconut + banana	6.25 ± 1.13	4.72-7.20	0.18 ± 0.12	0.08-0.34
Tapioca + Vegetables	5.28 ± 0.96	4.14-6.47	0.25 ± 0.16	0.10-0.47
Banana alone	5.43 ± 1.07	3.83-7.11	0.30 ± 0.23	0.01-0.7
Tapioca alone	5.44 ± 0.83	4.15-7.06	0.16 ± 0.08	0.06-0.27
Coconut alone	4.53 ± 0.36	4.18-4.97	0.15 ± 0.06	0.10-0.24
Vegetables alone	5.72 ± 0.78	4.99-6.82	0.16 ± 0.15	0.01-0.37
Rubber	4.49 ± 0.19	4.21-4.62	0.09 ± 0.02	0.06-0.10
Oil palm	5.43 ± 0.86	4.71-6.45	0.11 ± 0.05	0.04-0.16
Other crops	4.59 ± 0.58	4.13-5.35	0.17 ± 0.07	0.11-0.26

4.9.2.2 Organic carbon and Available primary nutrients

Organic carbon and available primary nutrient status under different land uses are presented in table 31. The mean of organic carbon was the highest in banana intercropped with tapioca (2.08%) and lowest in tapioca with vegetables (1.13%). Available N showed the highest and lowest mean in vegetables alone (267 kg ha^{-1}) and tapioca with vegetables (163 kg ha^{-1}) respectively. The mean of available P was the highest and lowest under other crops (153 kg ha^{-1}) and oil palm (23.2 kg ha^{-1}) respectively while the mean available K was the highest and lowest under other crops (443 kg ha^{-1}) and banana with coconut (134 kg ha^{-1}) respectively.

Table 31. Organic carbon and available primary nutrient status in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Organic carbon (%)		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	1.41 ± 0.53	1.01-2.15	213 ± 10.2	201-226	113 ± 72.0	43.1-203	218 ± 29.6	190-258
Banana + Tapioca	2.08 ± 0.64	1.55-3.15	238 ± 35.5	176-289	129 ± 81.4	46.1-264	179 ± 112	56.0-392
Coconut + Tapioca	1.64 ± 0.53	1.32-2.25	209 ± 76.6	125-276	127 ± 25.8	99.8-151	269 ± 121	134-370
Coconut + banana	1.28 ± 1.08	0.14-2.72	193 ± 140	25.1-339	35.75 ± 27.4	0.69-65.1	134 ± 54.9	67.2-190
Tapioca + Vegetables	1.13 ± 0.51	0.38-1.50	163 ± 70.2	100-251	89.8 ± 75.1	11.4-192	272 ± 252	67.2-638
Banana alone	1.61 ± 0.72	0.39-2.70	205 ± 89.4	100-439	102 ± 79.3	9.96-288	248 ± 108	123-538
Tapioca alone	1.21 ± 0.67	0.36-2.61	237 ± 69.6	125-364	103 ± 82.2	7.18-283	314 ± 151	168-571
Coconut alone	1.88 ± 0.85	1.01-2.73	251 ± 51.2	213-326	104 ± 64.8	13.7-165.6	329 ± 270	67.2-699
Vegetables alone	1.46 ± 0.90	0.32-2.25	267 ± 91.2	151-351	73.6 ± 62.0	15.5-139	176 ± 60.2	101-235
Rubber	1.78 ± 0.65	1.05-2.57	232 ± 63.6	176-314	52.5 ± 54.1	6.71-118	162 ± 74.0	78.4-258
Oil palm	1.57 ± 0.30	1.35-2.01	251 ± 58.8	201-314	23.2 ± 19.7	5.3-47.7	190 ± 164	56.0-403
Other crops	1.67 ± 0.57	1.05-2.43	194 ± 79.7	87.8-276	153 ± 163	15.8-362	443 ± 174	258-650

4.9.2.3 Available secondary nutrients

The status of available secondary nutrients in soils under different land uses is shown in table 32. The mean available Ca in soil was the highest under oil palm (1105 mg kg^{-1}) and the lowest under banana intercropped with tapioca (486 mg kg^{-1}). Available Mg in soil showed the highest and lowest mean under banana with tapioca and vegetables (309 mg kg^{-1}) and sole crop of rubber (147 mg kg^{-1}) respectively. The mean of available S in soil was the highest under banana with tapioca and vegetables (25.0 mg kg^{-1}) and lowest under coconut with tapioca (4.50 mg kg^{-1}).

4.9.2.4 Available boron

The highest and lowest mean of available B in soils was obtained under tapioca intercropped with vegetables (0.84 mg kg^{-1}) and oil palm alone (0.17 mg kg^{-1}) respectively (Table 33).

4.9.3 Biological attributes

4.9.3.1 Acid phosphatase activity

Acid phosphatase activity in soil (Table 34) was observed to be the highest in other crops (32.9 µg PNP produced g soil^{-1}h^{-1}) and lowest in rubber (10.9 µg PNP produced g soil^{-1}h^{-1}).

Table 32. Available secondary nutrient status in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Available Ca ($mg\ kg^{-1}$)		Available Mg ($mg\ kg^{-1}$)		Available S ($mg\ kg^{-1}$)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	960 ± 488	360-1480	309 ± 283	144-732	25.0 ± 23.7	7.50-58.5
Banana + Tapioca	486 ± 239	200-840	158 ± 55.2	108-264	6.71 ± 8.00	0.50-19.0
Coconut + Tapioca	1067 ± 75.7	980-1120	252 ± 2.65	216-324	4.50 ± 0.53	2.50-7.50
Coconut + banana	772 ± 359	300-1180	185 ± 105	72.0-324	18.8 ± 19.3	3.50-50.5
Tapioca + Vegetables	865 ± 323	440-1220	198 ± 44.4	156-252	8.63 ± 6.65	2.50-18.0
Banana alone	941 ± 504	300-1960	243 ± 217	48.0-780	15.5 ± 18.6	2.00-78.5
Tapioca alone	970 ± 444	420-1960	170 ± 97.0	24.0-324	10.2 ± 15.1	0.50-51.0
Coconut alone	700 ± 458	260-1340	186 ± 123	24.0-312	10.9 ± 6.86	2.00-18.0
Vegetables alone	895 ± 390	400-1280	189 ± 170	96.0-444	8.63 ± 7.67	0.50-19.0
Rubber	560 ± 202	260-680	147 ± 54.9	108-228	12.3 ± 9.06	2.00-21.5
Oil palm	1105 ± 605	540-1960	156 ± 154	12.0-312	13.5 ± 5.96	6.0-19.0
Other crops	915 ± 375	600-1460	183 ± 38.4	156-240	15.1 ± 11.2	1.50-25.0

Table 33. Available B status in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Available B (mg kg $^{-1}$)	
	Mean ± SD	Range
Banana + Tapioca + Vegetables	0.58 ± 0.65	0.01-1.30
Banana + Tapioca	0.43 ± 0.45	0.01-1.14
Coconut + Tapioca	0.57 ± 0.53	0.24-1.18
Coconut + banana	0.36 ± 0.65	0.01-1.50
Tapioca + Vegetables	0.84 ± 0.50	0.26-1.40
Banana alone	0.43 ± 0.37	0.01-1.36
Tapioca alone	0.52 ± 0.40	0.01-1.12
Coconut alone	0.27 ± 0.21	0.01-0.53
Vegetables alone	0.55 ± 0.63	0.02-1.27
Rubber	0.55 ± 0.53	0.12-1.33
Oil palm	0.17 ± 0.16	0.02-0.35
Other crops	0.68 ± 0.47	0.03-1.09

Table 34. Acid phosphatase activity in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Acid phosphatase activity (µg PNP produced g soil $^{-1}$h $^{-1}$)	
	Mean ± SD	Range
Banana + Tapioca + Vegetables	26.7 ± 11.3	10.5-36.2
Banana + Tapioca	30.1 ± 14.1	15.5-56.3
Coconut + Tapioca	29.8 ± 16.2	11.1-39.8
Coconut + banana	22.7 ± 11.4	9.91-37.5
Tapioca + Vegetables	27.6 ± 20.8	8.45-56.9
Banana alone	30.2 ± 20.4	8.27-96.9
Tapioca alone	24.8 ± 8.2	11.9-37.3
Coconut alone	28.1 ± 10.1	22.2-43.2
Vegetables alone	25.5 ± 9.06	16.4-37.3
Rubber	10.9 ± 5.61	4.27-16.3
Oil palm	31.3 ± 17.2	8.1-47.0
Other crops	32.9 ± 12.1	16.4-45.3

4.9.4 Soil Quality Index

The mean SQI and RSQI were the highest under banana intercropped with tapioca and vegetables (290, 72.4%) and lowest under rubber (223, 55.8%) (Table 35).

Table 35. SQI and RSQI in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	SQI		RSQI	
	Mean ± SD	Range	Mean ± SD	Range
Banana + Tapioca + Vegetables	290 ± 44.2	232-338	72.4 ± 11.1	58.0-84.5
Banana + Tapioca	248 ± 25.2	222-298	61.9 ± 6.29	55.5-74.5
Coconut + Tapioca	276 ± 52.3	217-316	69.1 ± 13.1	54.3-79.0
Coconut + banana	263 ± 55.6	182-316	65.8 ± 13.91	45.5-79.0
Tapioca + Vegetables	265 ± 20.3	242-286	66.2 ± 5.07	60.5-71.5
Banana alone	271 ± 48.5	188-351	67.8 ± 12.1	47.0-87.8
Tapioca alone	272 ± 24.0	238-318	68.2 ± 6.00	59.5-79.5
Coconut alone	238 ± 45.1	171-266	59.4 ± 11.3	42.8-66.5
Vegetables alone	264 ± 24.1	243-293	65.9 ± 6.03	60.8-73.3
Rubber	223 ± 36.2	189-257	55.8 ± 9.06	47.3-64.3
Oil palm	225 ± 73.8	149-296	56.1 ± 18.4	37.3-74.0
Other crops	285 ± 15.5	266-304	71.3 ± 3.88	66.5-76.0

4.9.5 Nutrient Index

Nutrient indices for organic carbon and available primary nutrients were computed for different land uses and are given in table 36. The results showed that nutrient index of organic carbon was high in banana intercropped with tapioca (3.00), rubber alone (2.75), other crops (2.75), coconut alone (2.50), banana alone (2.33), coconut with tapioca (2.33) and medium in banana with tapioca and vegetables (2.25), vegetables alone (2.25), oil palm alone (2.25), banana with coconut (2.00), tapioca with vegetables (2.00) and tapioca alone (1.90). Nutrient index of available N was low in all the land uses whereas the nutrient index of available P was high except in rubber

Table 36. Nutrient indices in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Nutrient index							
	Organic carbon	Status	Available N	Status	Available P	Status	Available K	Status
Banana + Tapioca + Vegetables	2.25	Medium	1.00	Low	3.00	High	2.00	Medium
Banana + Tapioca	3.00	High	1.29	Low	3.00	High	1.86	Medium
Coconut + Tapioca	2.33	High	1.00	Low	3.00	High	2.67	High
Coconut + banana	2.00	Medium	1.40	Low	2.60	High	1.60	Low
Tapioca + Vegetables	2.00	Medium	1.00	Low	2.75	High	2.00	Medium
Banana alone	2.33	High	1.16	Low	2.78	High	2.22	Medium
Tapioca alone	1.90	Medium	1.20	Low	2.80	High	2.40	High
Coconut alone	2.50	High	1.25	Low	2.75	High	2.25	Medium
Vegetables alone	2.25	Medium	1.50	Low	2.75	High	1.75	Medium
Rubber	2.75	High	1.25	Low	2.00	Medium	1.75	Medium
Oil palm	2.25	Medium	1.00	Low	2.00	Medium	1.75	Medium
Other crops	2.75	High	1.00	Low	2.75	High	2.75	High

and oil palm (medium). Nutrient index of available K was medium in most of the land uses except for other crops, coconut with tapioca, tapioca alone (high) and banana with coconut (low).

4.9.6 Land Quality Index

The range of soil organic carbon stock and the mean, standard deviation and range of LQI in post-flood soils under different land uses are presented in table 37. The highest and lowest mean LQI were obtained for coconut alone (3.77 kg m^{-2}) and banana with coconut (1.95 kg m^{-2}).

Table 37. Soil organic carbon stock and LQI in the post-flood soils under different land uses in AEU 12 of Pathanamthitta district

Land use	Soil organic carbon stock (Mg ha^{-1})	Land quality index (kg m^{-2})	
		Mean ± SD	Range
Banana + Tapioca + Vegetables	9.14-36.8	2.27 ± 1.16	0.91-3.68
Banana + Tapioca	28.5-49.1	3.68 ± 0.87	2.85-4.91
Coconut + Tapioca	21.4-36.8	2.66 ± 0.88	2.14-3.68
Coconut + banana	2.65-39.6	1.95 ± 1.54	0.26-3.96
Tapioca + Vegetables	8.20-82.6	2.06 ± 0.90	0.82-2.91
Banana alone	6.84-49.0	2.80 ± 1.39	0.68-4.90
Tapioca alone	6.80-33.7	1.96 ± 0.88	0.68-3.37
Coconut alone	16.4-58.6	3.77 ± 2.10	1.64-5.86
Vegetables alone	5.26-42.8	2.50 ± 1.81	0.53-4.28
Rubber	17.5-41.6	2.98 ± 1.02	1.75-4.16
Oil palm	20.8-40.4	2.68 ± 0.92	2.08-4.04
Others crops	15.9-33.9	2.50 ± 0.74	1.59-3.39

Discussion

5. DISCUSSION

A study entitled "Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala" was undertaken during 2018-'20. The results pertaining to characterisation of soil samples, formulation of soil quality index, land quality index and nutrient index, and generation of GIS maps are discussed in this chapter based on available literature and theoretical knowledge.

5.1 CHARACTERISATION OF SOIL SAMPLES

The results of physical, chemical and biological parameters of soil samples analysed are discussed below.

5.1.1 Physical attributes

5.1.1.1 Bulk density

Bulk density of soils varied between 0.84 Mg m^{-3} and 1.45 Mg m^{-3} (Table 7) for the study area in AEU 12 of Pathanamthitta district. Bulk density is a dynamic property of a soil that varies with soil structure. It is influenced by the amount of organic matter in soils, texture, constituent minerals and porosity (Chaudhari *et al.*, 2013). Lower bulk density was observed in areas with high organic carbon and clay content in the study area while higher values were observed in soils with more sand content. The frequency distribution of bulk density in the study area is depicted in Fig. 3. Majority of samples (65.3 %) showed a bulk density less than 1.2 Mg m^{-3}.

5.1.1.2 Particle density

Particle density varied between 1.80 Mg m^{-3} and 2.81 Mg m^{-3} (Table 7) in the area. A significant positive correlation was observed between particle density and sand content. Soil organic carbon is the major factor leading to a reduction in particle density, but other soil constituents and their composition can also influence thevalues (Bielders *et al.*, 1990). Particle density was observed to be lower for samples high in organic carbon and silt content. The frequency distribution of particle density in the area (Fig. 4) show that 42.7 per cent of the samples had values < 2.2 Mg m^{-3}, 25.3 per cent between 2.2 Mg m^{-3} and 2.4 Mg m^{-3} and 21.3 per cent between 2.4 Mg m^{-3} and 2.6 Mg m^{-3}.

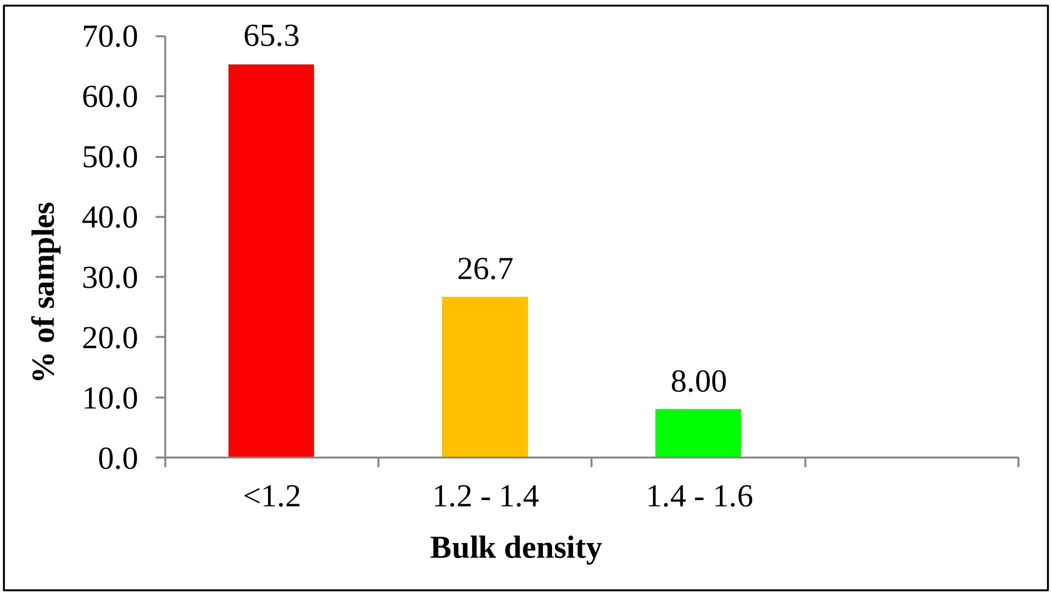


Fig. 3. Frequency distribution of bulk density (Mg m^{-3}) in the post-flood soils of AEU 12 in Pathanamthitta district of Kerala

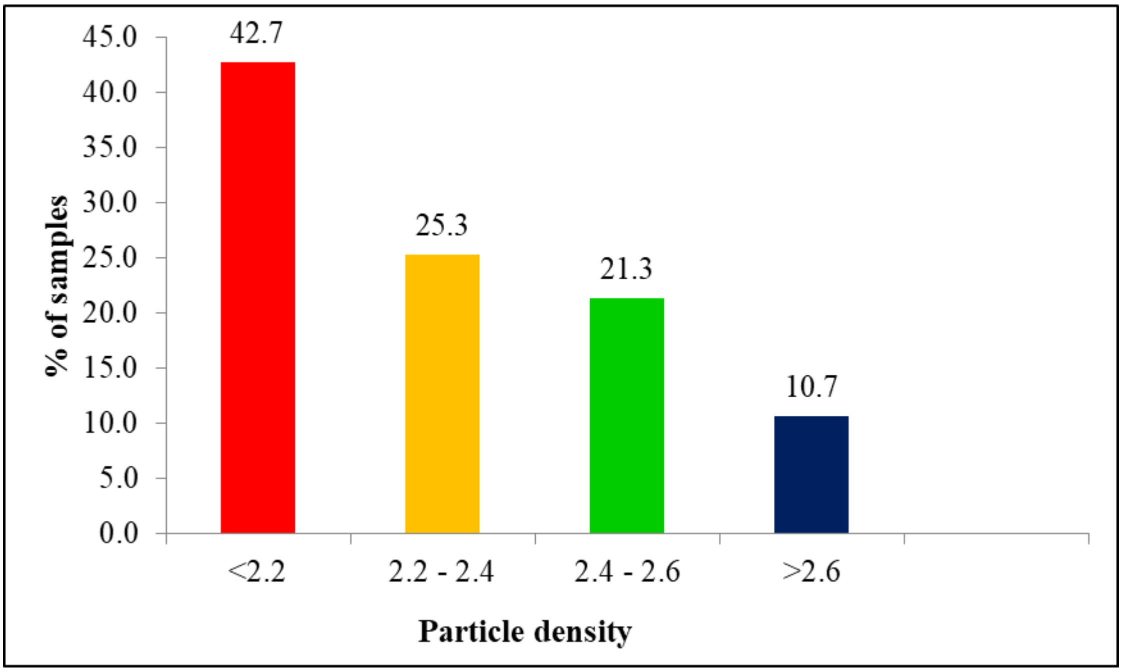


Fig. 4. Frequency distribution of particle density (Mg m^{-3}) in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.1.3 Porosity

Porosity ranged between 25.6 and 67.4 per cent (Table 7) in the area. Porosity of soils were significantly and positively correlated with particle density and negatively correlated with silt content and bulk density. Frequency distribution of porosity in the area (Fig. 5) shows that 56 per cent of the samples showed porosity between 50 and 70 per cent followed by 42.67 per cent in the 30-50 per cent range.

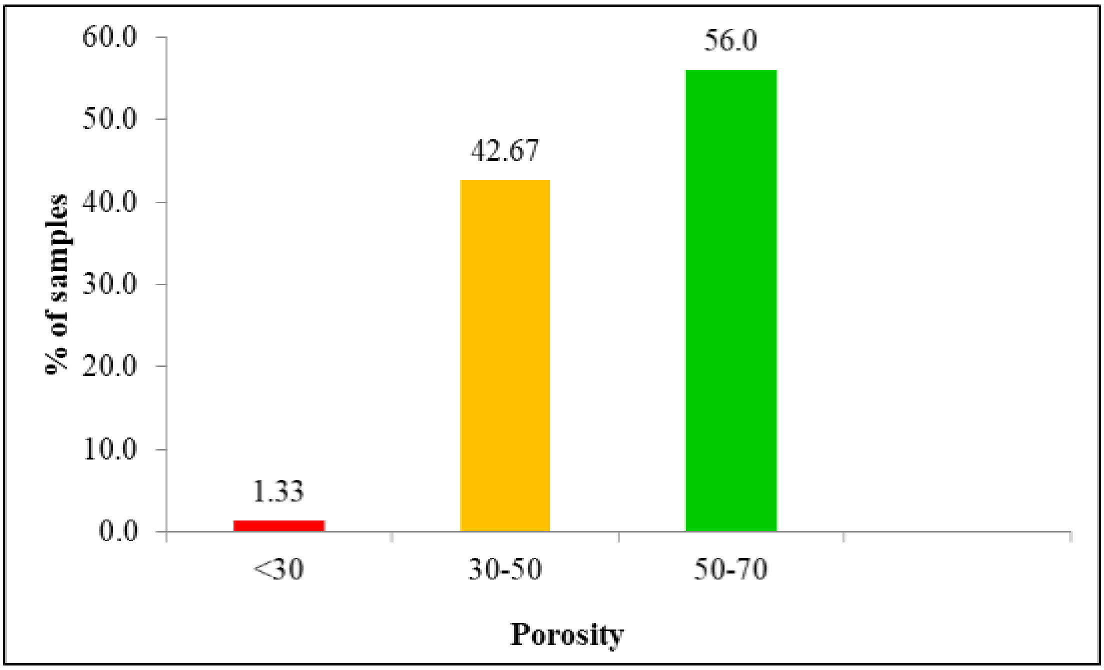


Fig. 5. Frequency distribution of porosity (%) in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.1.4 Soil textural classes

Clay, sand and silt contents showed wide variation across the area. Clay content varied between 11.2 and 46.2 per cent, silt between 5 and 40 per cent and sand content between 33.8 and 73.8 per cent (Table 8). According to KSPB (2013), the major soil type observed in AEU 12 of Pathanamthitta is forest soils with loamy to clayey texture. Murugan (2013) reported forest loam as the predominant soil type in Ranni and Konni blocks of Pathanamthitta. The predominant soil textual class observed (57.34%) in the present study was sandy clay loam followed by loam, sandy clay, clay loam, clay, loamy sand and sandy loam (Fig. 6). Loamy sand texture was observed only in sampling locations of Vadaserikkara with excessive sediment deposits. Sandy loam texture was observed in sampling locations in Naranammoozhi panchayath with deposits of fine sand, silt and clay. The spatial distribution of soil texture of the post-flood regions of AEU 12 is shown in Fig. 7.

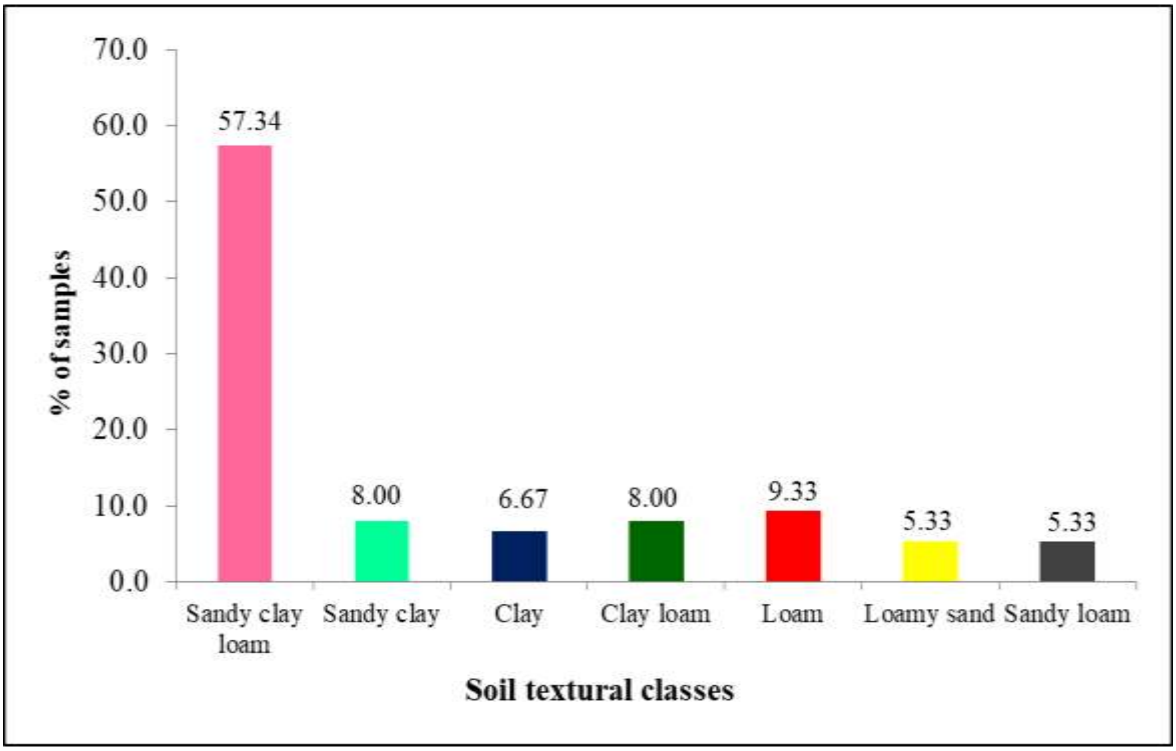


Fig. 6. Frequency distribution of soil textural classes in the post-flood soils of AEU 12 in Pathanamthitta district

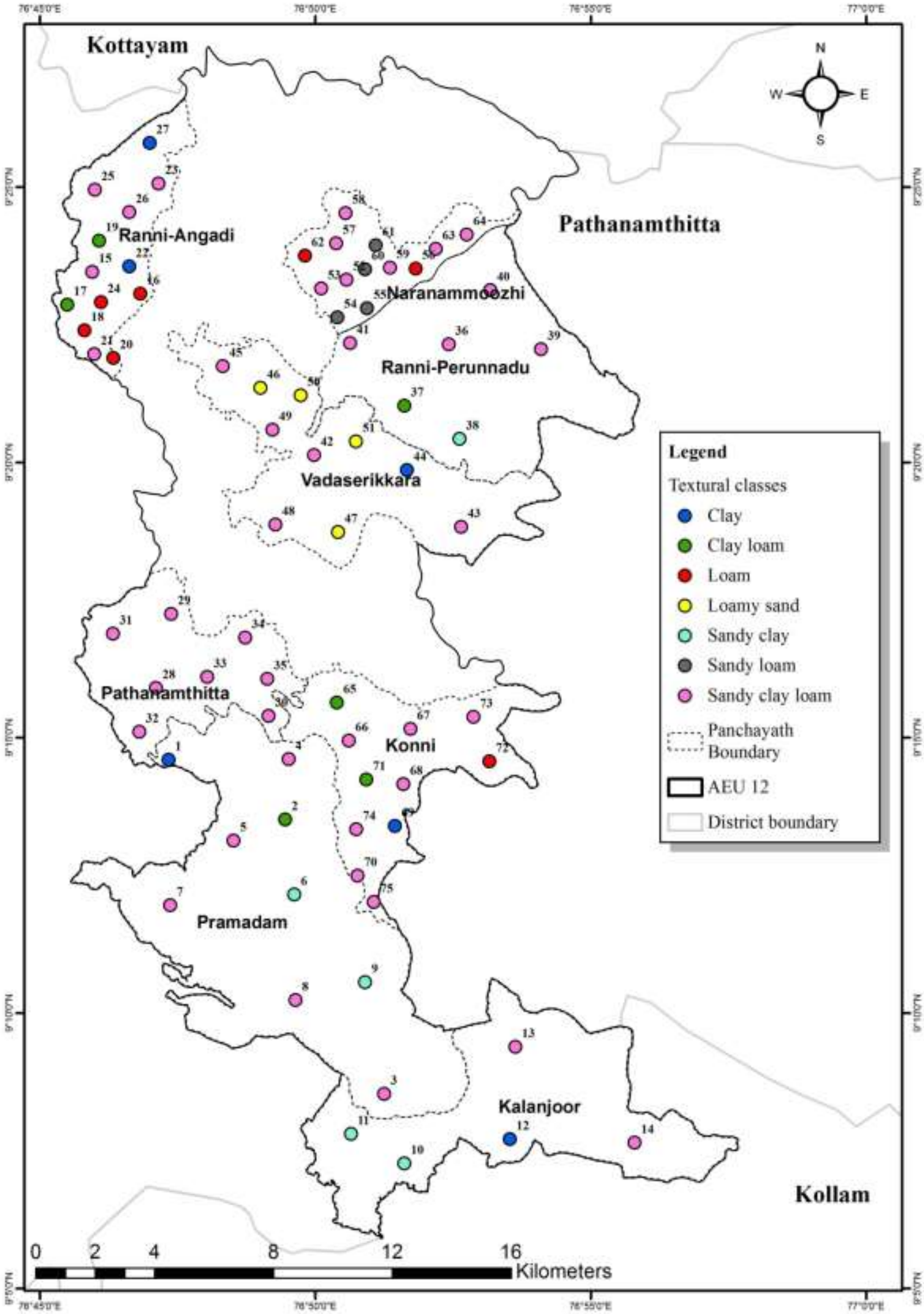


Fig. 7. Spatial distribution of soil textural classes in the post-flood area of AEU 12 in Pathanamthitta district

5.1.1.5 Depth of sand, silt and clay deposition

Sediment deposition was observed mainly in the area drained by Pampa river and its tributaries. The deposits varied in texture from clay to coarse sand and gravel. Silt deposits were prominent in Ranni-Angadi in the downstream area whereas sand and gravel deposits were observed only in areas close to the river in Ranni-Perunnadu (Table 9). Huge quantities of sediment deposits were observed in areas close to the river in Ranni-Angadi, Naranammoozhi and Vadaserikkara. Farmers are raising crops over the deposits in agricultural fields which are in close proximity to the river where sediment deposition occurred to a depth of about 1-2 m. In most of the areas in Konni and Pramadam drained by Achankovil River farmers reported high velocity flow of flood waters leading to erosion of the fertile topsoil without any observable deposition. Silt and clay deposits were observed in a few sampling locations in Konni and Pathanamthitta. Sediment deposits were absent in Kalanjoor and Pramadam.

5.1.1.6 Maximum water holding capacity

Maximum water holding capacity varied between 29.6 per cent and 68.0 per cent (Table 10) for the post-flood soils of AEU 12 in Pathanamthitta district. Similar results were observed in a study conducted by Kerala State Biodiversity Board (2019) to assess the soil properties in the post-flood soils of Pathanamthitta. The values were higher in soils with more clay and organic carbon content. Higher soil organic carbon content improves the water holding capacity of soil due to improved soil structure resulting in better porosity (Stepniewski *et al.*, 1994). The lowest water holding capacity of 29.6 per cent was observed in soils with loamy sand texture in Vadaserikkara. Frequency distribution of maximum water holding capacity showed that majority of samples (57.33 %) had values between 30 and 50 per cent followed by 40 per cent of samples in the range of 50 – 70 per cent (Fig. 8).

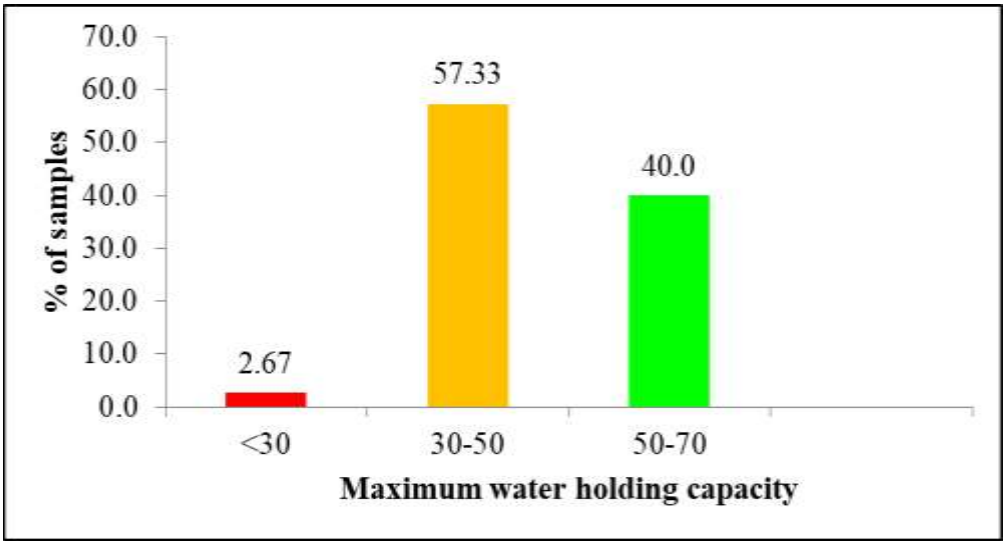


Fig. 8. Frequency distribution of water holding capacity (%) in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.1.7 Soil moisture content

Soil moisture content varied between 7.85 and 45.4 per cent (Table 10) in the area. Increase in clay content led to an increase in soil moisture due to the increased particle density. 36.1 per cent of samples showed a moisture content between 15 and 25 per cent, 25.3 per cent > 25 per cent, 25.3 per cent in 10 -15 per cent range and 13.3 per cent in <10 per cent range (Fig. 9).

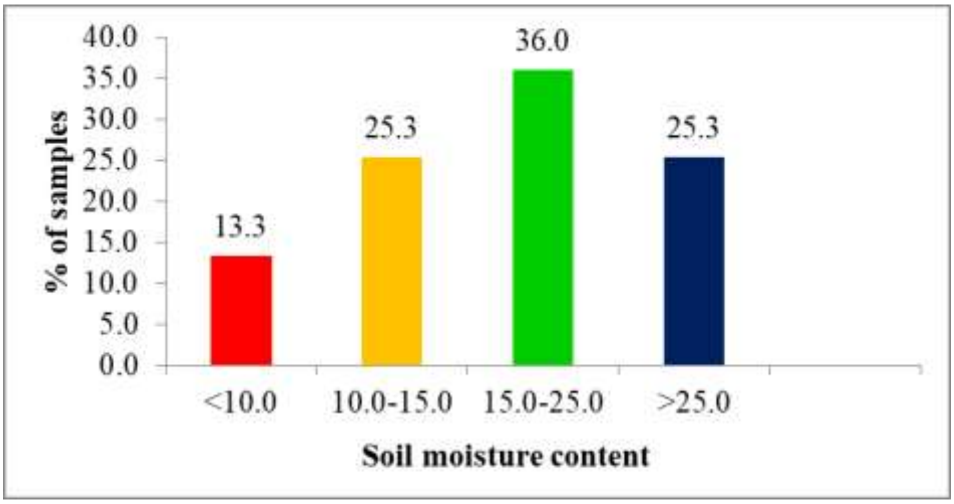


Fig. 9. Frequency distribution of soil moisture content (%) in the post-flood soils of AEU 12 of Pathanmthitta district

5.1.1.8 Aggregate stability

Aggregate stability was measured in terms of MWD and WSA (%).Soil aggregate stability is affected by soil characters such as texture and organic matter content**.** Increased organic matter content of soils causes stabilization of aggregates through its binding action and improved microbial activity (Bissonnais, 1996). Greater amount of stable aggregates indicate better soil quality (Arshad and Grossman, 1996). MWD and WSA (%) were high in areas rich in organic carbon. MWD ranged between 0.02 and 4.76 mm (Table 11) and WSA (%) ranged between 1.68 and 97.7 per cent (Table 11) in the area. Aggregate stability was lower in areas with sediment deposition in Ranni-Angadi, Vadaserikkara and Naranammoozhi. The lowest MWD and WSA (%) were observed in samples collected from areas close to the Pampa river in Vadaserikkara which experienced excessive deposition of fine sand. The frequency distribution of MWD and WSA (%) presented in Fig. 10 shows that 40 per cent of the samples had a MWD >2 mm followed by 26.7 per cent with a MWD <1 mm. Water stable aggregates was >70% for majority of the samples (54.7%) (Fig. 11).

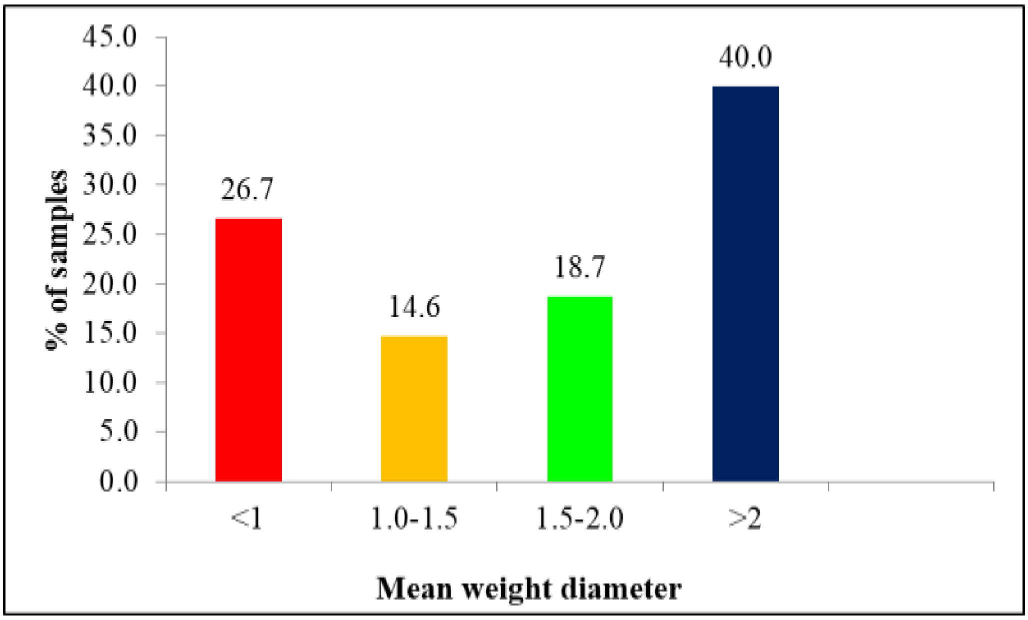


Fig. 10. Frequency distribution of mean weight diameter (mm) in the post-flood soils of AEU 12 in Pathanamthitta district

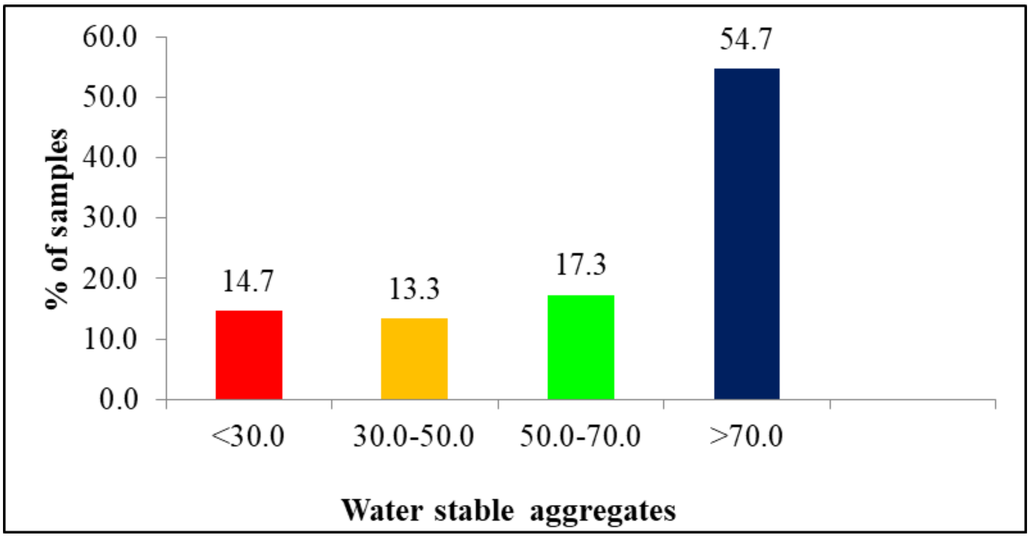


Fig. 11. Frequency distribution of water stable aggregates (%) in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2 Chemical attributes

The results of chemical parameters in the post-flood soils of AEU 12 of Pathanamthitta district are discussed below. The frequency distribution of soil reaction, available P, K, Ca, Mg, S and B are compared with the pre-flood data of KSPB (2013) provided in Appendix IV.

5.1.2.1 Soil reaction

Soil reaction varied between 3.62 and 7.20 (Table 12) and 25.3 per cent of samples showed very strongly acid pH followed by 22.7 per cent in the extremely acid, 16 per cent in the neutral, 14.7 per cent in the strongly acid, 12 per cent in the moderately acid and 9.3 per cent in the slightly acid range (Fig. 12). Per cent of samples with extremely acid pH showed an increase in the post-flood soils (22.7%) compared to the pre-flood (18.4%) indicating leaching of basic cations from soils. An increase was also observed in the per cent of samples with slightly acid pH from 4.00 to 9.33 per cent. A moderation of soil pH was observed in 16 per cent of soils with pH in neutral range whereas neutral pH was not observed in pre-flood study.

Spatial distribution of soil pH is depicted in Fig. 13. Soil acidity was observed to be lower in areas with sediment deposits in the Pampa basin whereas extremely acid and very strongly acid pH were observed mostly in areas that experienced high velocity flow of flood water leading to erosion of fertile top soil in Pramadam, Kalanjoor and Konni. Basic cations were leached out from the soils in these areas resulting in lowering of soil pH. Concentration of basic cations was observed to be higher in areas with sediment deposition thus decreasing soil acidity.

5.1.2.2 Electrical conductivity

EC varied between 0.01 dS m^{-1} and 0.70 dS m^{-1} (Table 12) in the study area and the values were in the non saline range for all the samples. This can be attributed to the washing away of salts by the flowing flood water. The frequency distribution of EC is presented in Fig. 14.

5.1.2.3 Organic carbon

Organic carbon ranged between 0.14 and 3.15 per cent (Table 13) with 50.7 per cent of the samples having high organic carbon followed by 38.7 per cent in the medium and 10.6 per cent in the low ranges in the post-flood study (Fig. 15). A decline was observed in the per cent of samples with high organic carbon from 65.3 per cent in pre-flood soils to 50.7 per cent in the post-flood soils. Very low organic carbon was observed mostly in crop lands close to the river in Vadaseikkara, Naranammoozhi and Ranni-Angadi area with excessive deposition. The decline in per cent samples with high organic carbon compared to the pre flood data might be due to the washing away of organic matter by the intense flowing flood water during the torrential rains and due to sediment deposition with low organic matter content. Organic carbon was high for most of the area in Pramadam, Konni, Kalanjoor, Pathanamthitta and Ranni-Angadi with low levels of deposition and medium for large parts in Ranni-Perunnadu, Vadaserikkara and Naranammoozhi (Fig. 16).

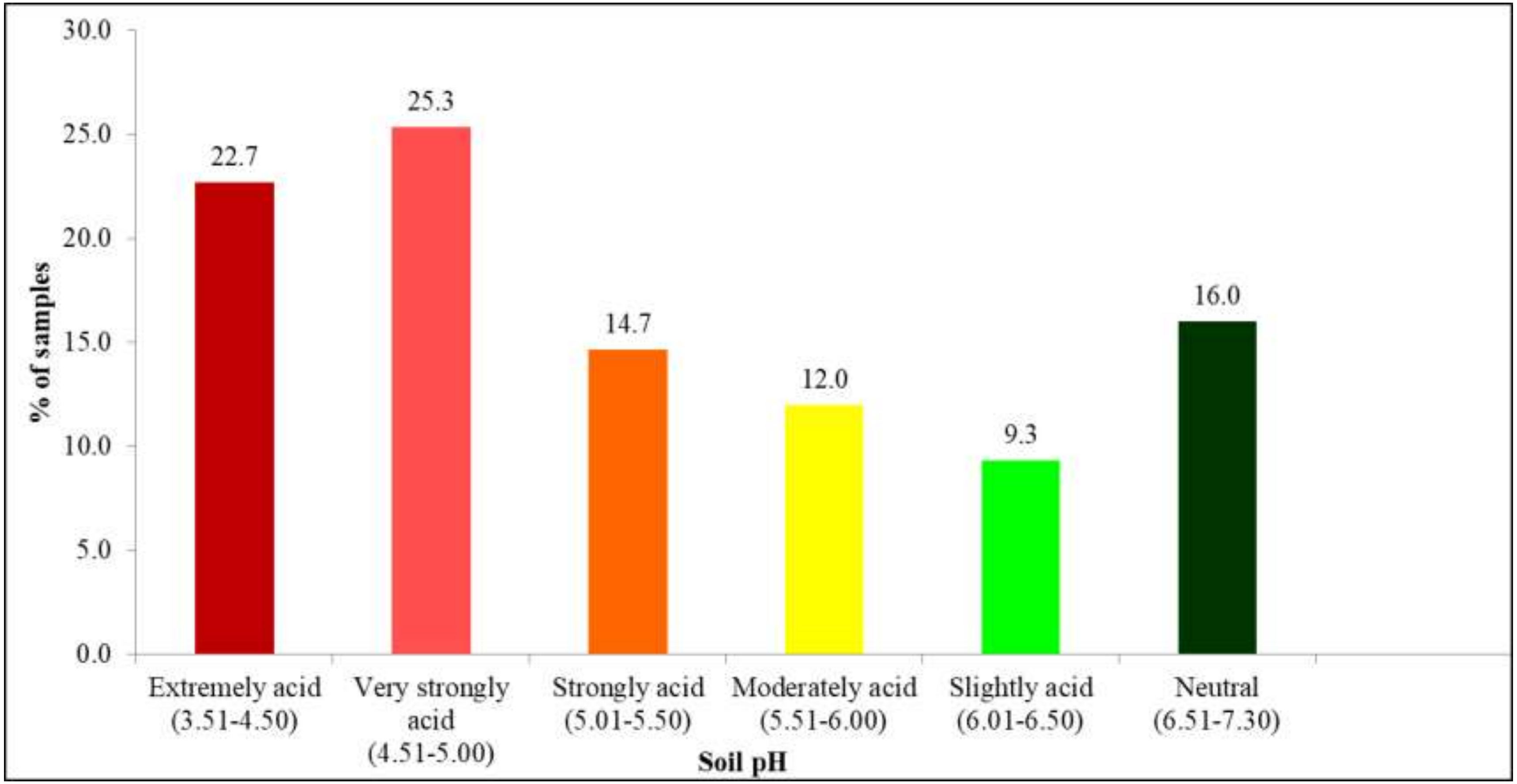


Fig. 12. Frequency distribution of soil pH in the post-flood soils of AEU 12 in Pathanamthitta district

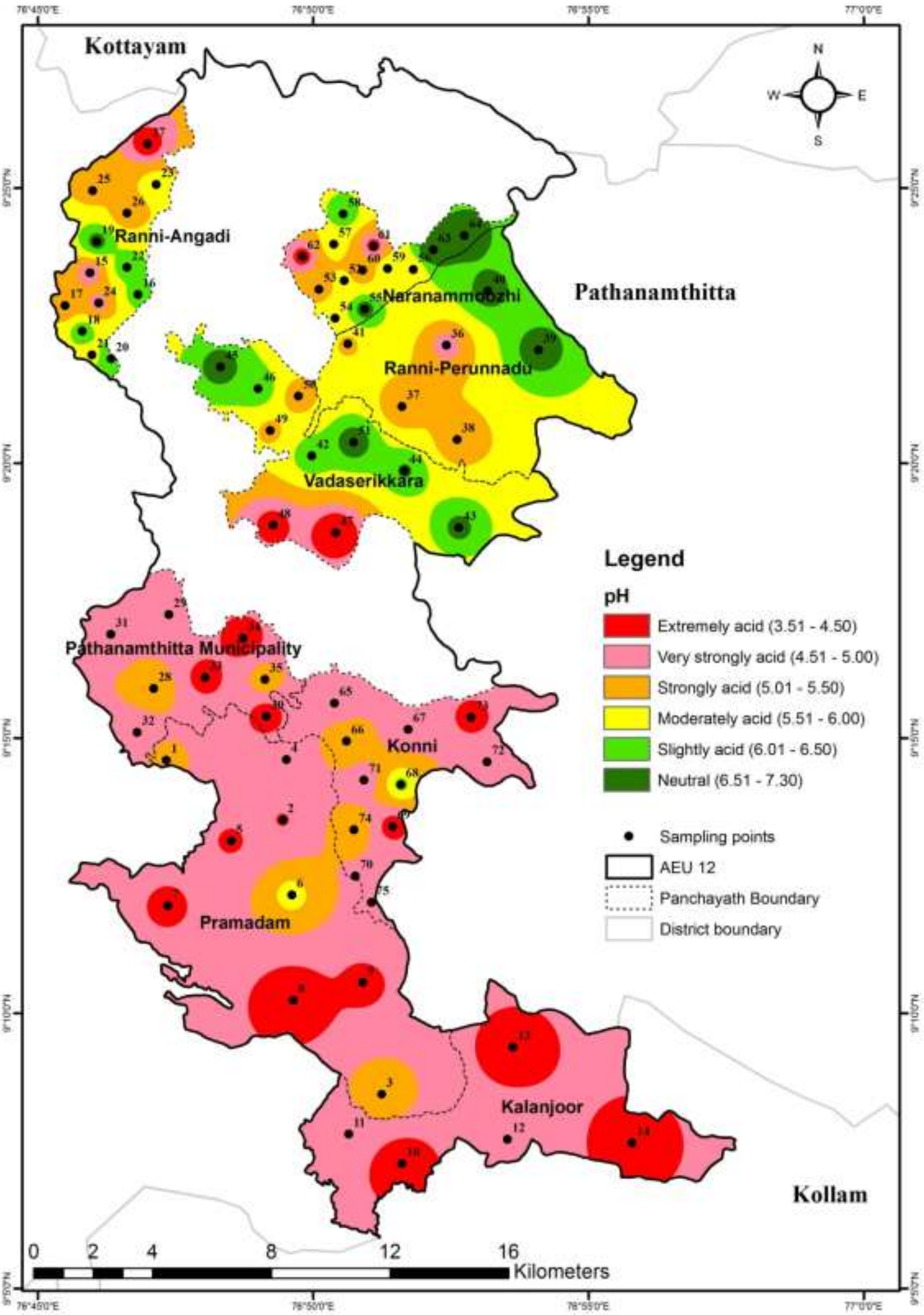


Fig. 13.Spatial distribution of soil pH in the post-flood soils of AEU 12 in Pathanamthitta district

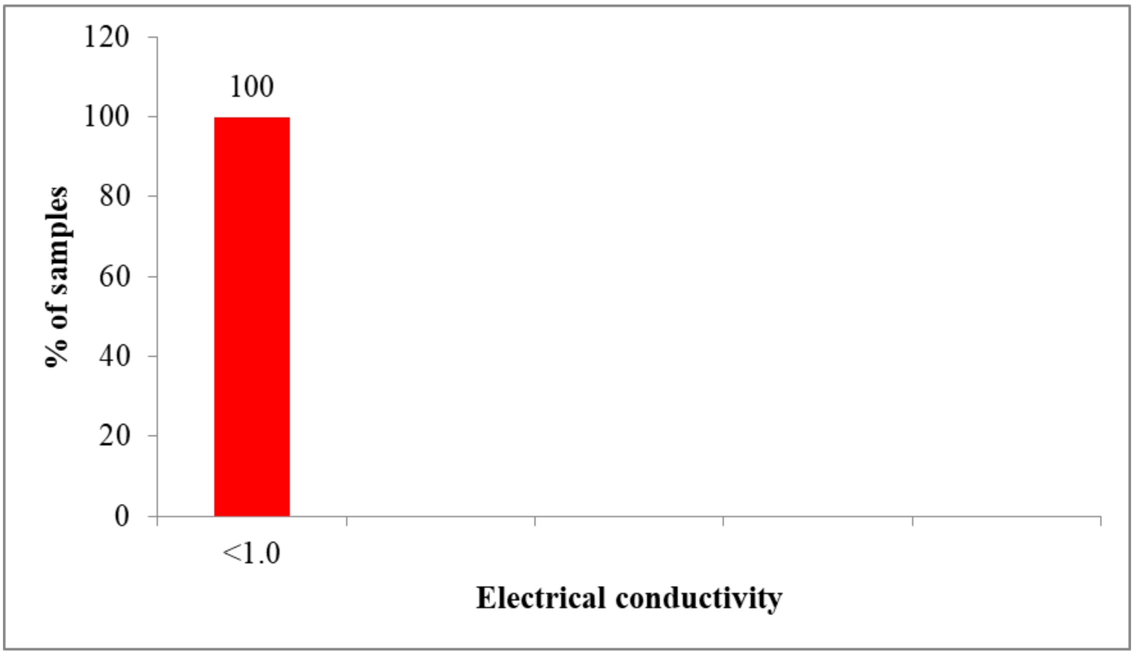


Fig. 14. Frequency distribution of electrical conductivity (dSm^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

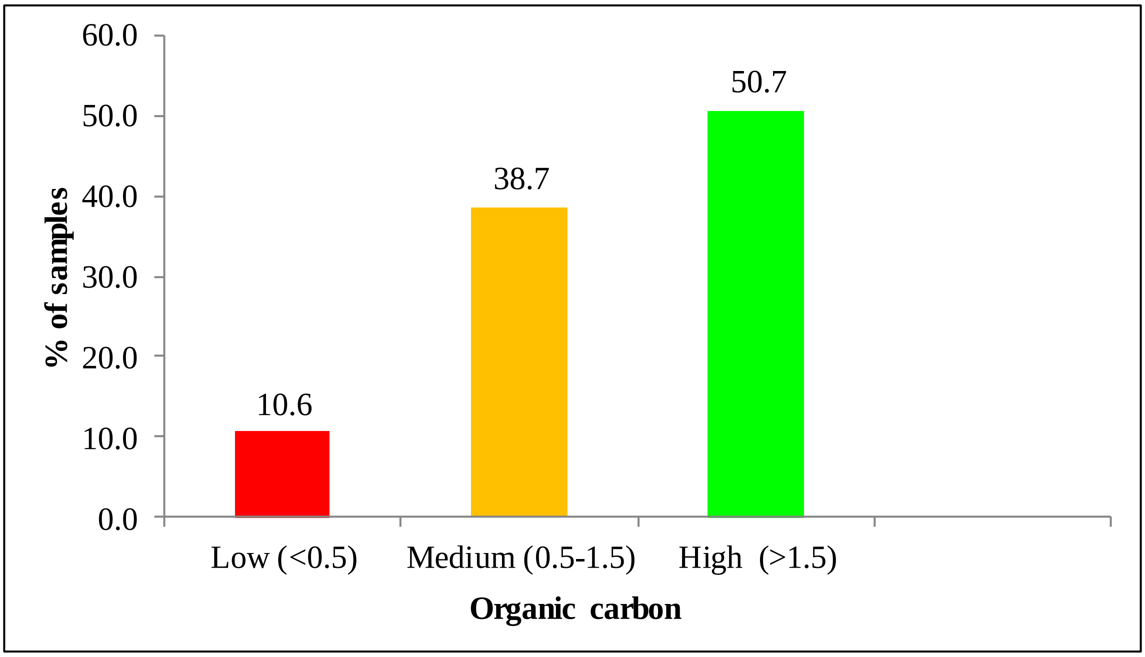


Fig. 15. Frequency distribution of organic carbon (%) in the post-flood soils of AEU 12 in Pathanamthitta district

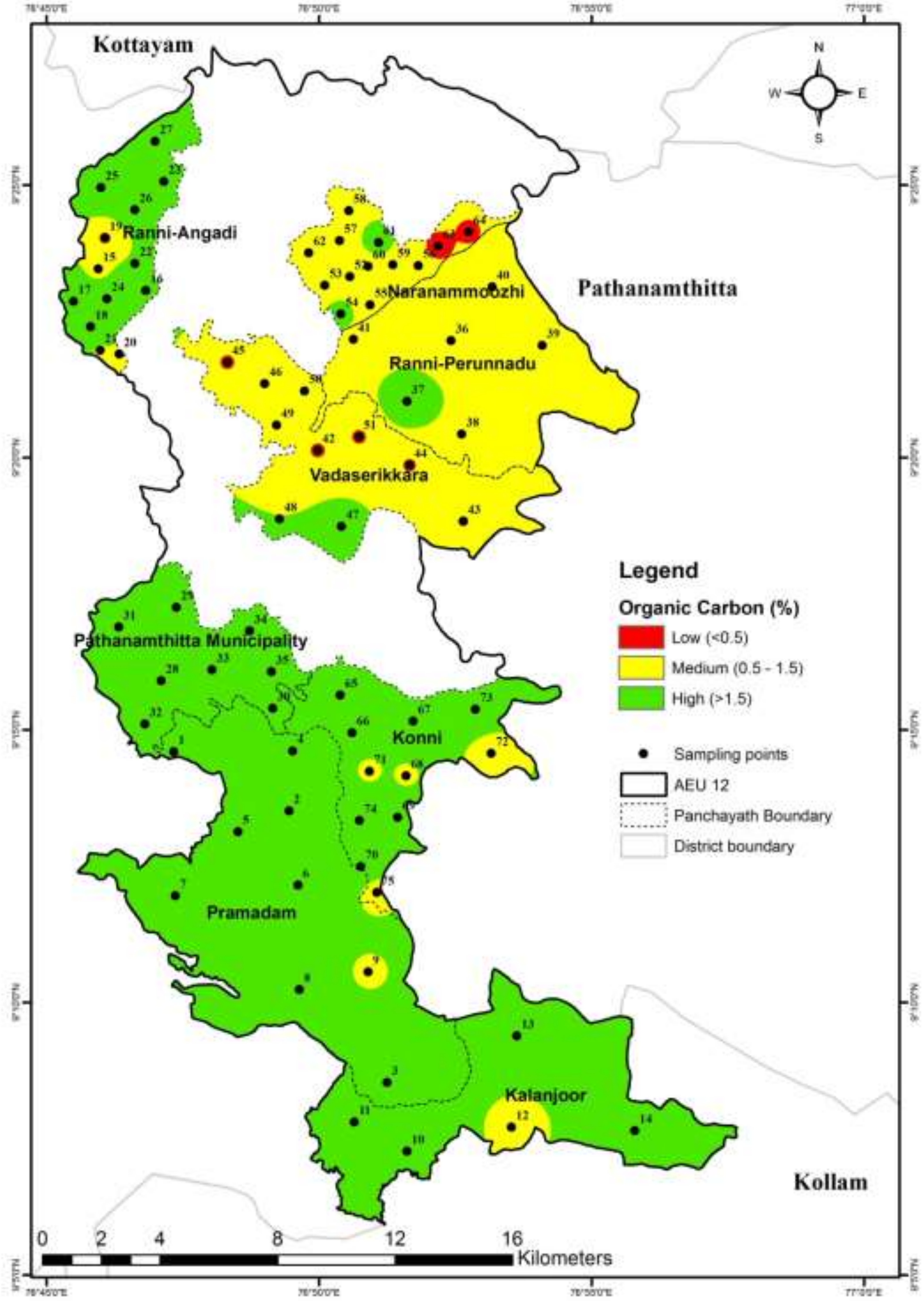


Fig. 16. Spatial distribution of organic carbon in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2.4 Available nitrogen

Available N varied between 25.1 kg ha^{-1} and 439 kg ha^{-1} (Table 13) with 81.3 per cent of samples in the low and 18.7 per cent in the medium range (Fig. 17). Available N showed a significant positive correlation with organic carbon and negative correlation with pH and available Ca, Mg, S and B. A negative correlation was observed between pH and available N in the study area because higher pH was observed mostly in soils of Ranni-Perunnadu, Vadaserikkara and Naranamoozhi with lower organic carbon and sediment deposition. Mineralisation of organic matter in the soils provides a part of N required for plants. Acidic soils inhibit the growth of beneficial soil bacteria thereby restricting mineralisation. This results in accumalation of organic matter which binds nitrogen. Rajashekaran *et al*. (2014) reported that increasing soil acidity obstructs mineraliasation of organic matter in the soils of Kerala. Very low available N contents were observed in crop lands with excessive sand content and very low organic carbon, in Naranammoozhi and Vadaserikkara. Nitrogen deficiency symptoms were observed in cowpea plants raised in this area. Spatial distribution of available N is presented in Fig. 19. Available N was low for most of the areas and medium in small areas with higher organic carbon.

5.1.2.5 Available phosphorus

Available P was high for 82.67 per cent of the samples, low for 9.33 per cent and medium for 8 per cent of the samples (Fig. 18). Samples with high available P increased in the post-flood soils compared to pre-flood (62.8%). Spatial distribution of available P is depicted in Fig. 20. Available P was high for almost the entire area since majority of the farmers in the area cultivating rubber, coconut, banana and cassava apply phosphatic fertilizers regularly. Available P ranged between 0.69 kg ha^{-1} and 362 kg ha^{-1} (Table 13). Low available P was mostly encountered in fields without the application of P fertilizers and in cropped areas close to the river with excessive deposition of sandy sediments.

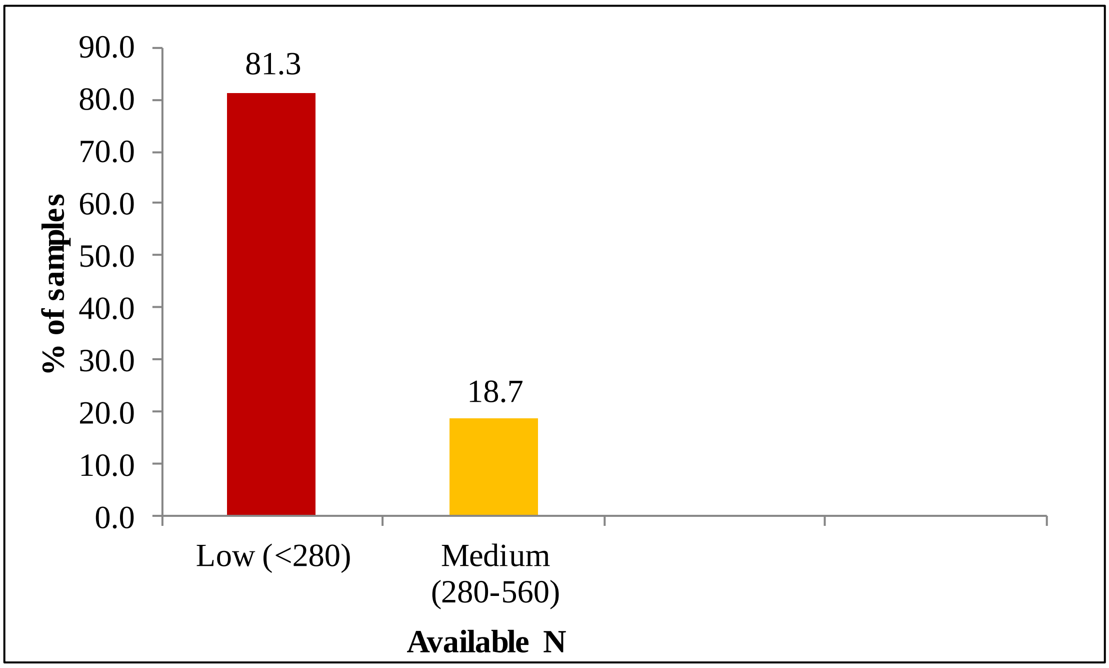


Fig. 17. Frequency distribution of available N (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

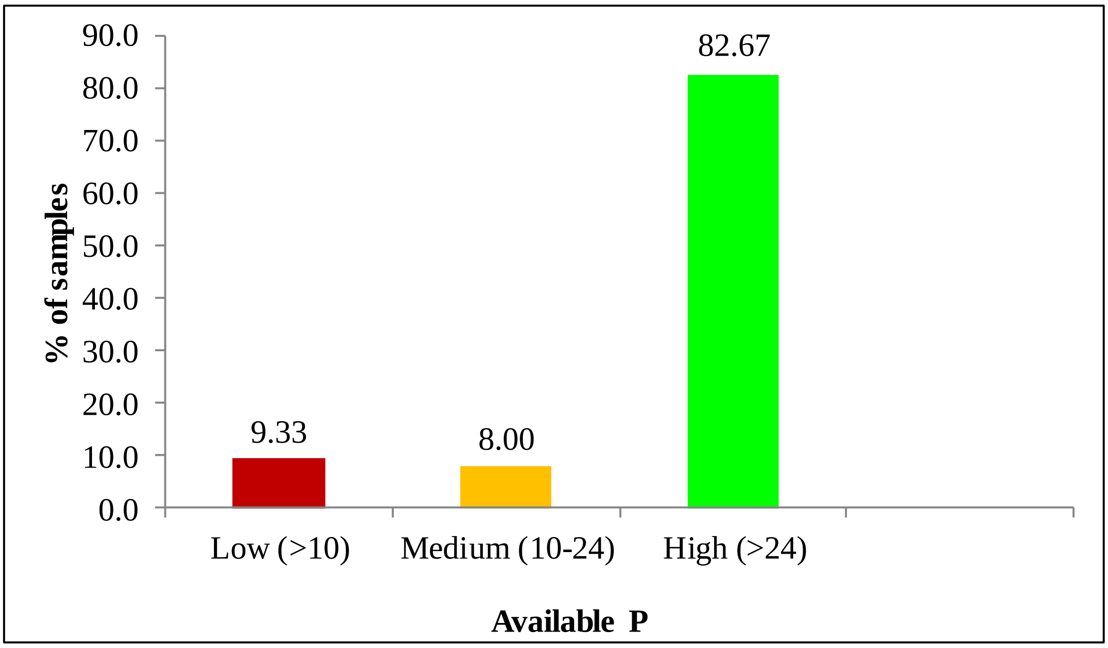


Fig. 18. Frequency distribution of available P (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

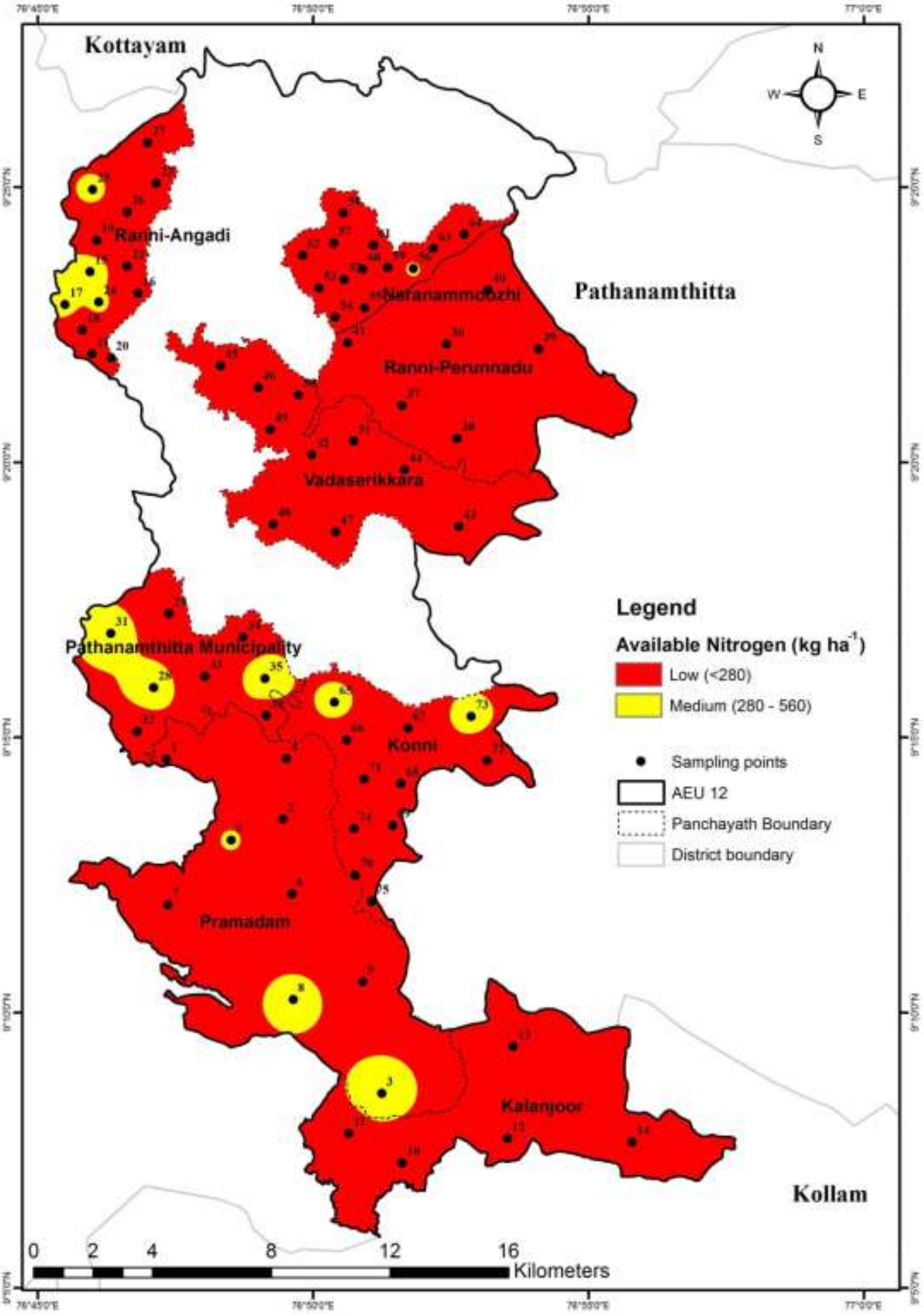


Fig. 19. Spatial distribution of available N in the post-flood soils of AEU 12 in Pathanamthitta district

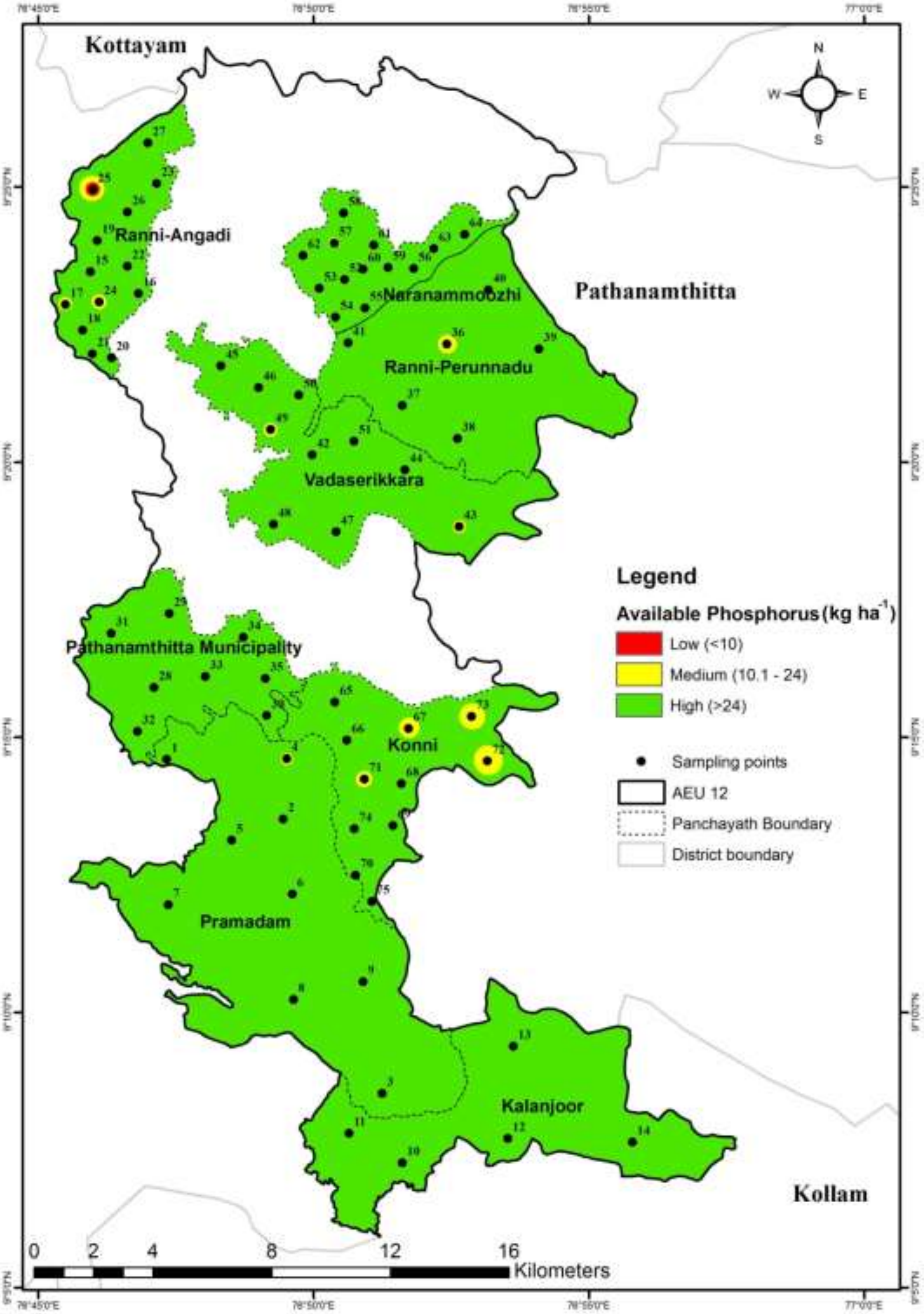


Fig. 20. Spatial distribution of available P in the post flood soils of AEU 12 in Pathanamthitta district

5.1.2.6 Available potassium

Available K ranged between 56.0 kg ha^{-1} and 699 kg ha^{-1} (Table 13). 58.7 per cent of the samples were medium in available K, 28 per cent high and 13.3 per cent low (Fig. 21). Per cent of samples with high available K declined drastically from 62.8 per cent in the pre-flood soils to 28 per cent in the post-flood soils indicating heavy leaching of K during the floods. Spatial variability of available K presented in Fig. 22 shows medium K values for more than half of the area and high in areas with application of MoP. Available K showed significant positive correlation with EC and available Ca. Similar correlations were obtained by Behara and Shukla (2014) in loamy sand to sandy loam textured soils of India.

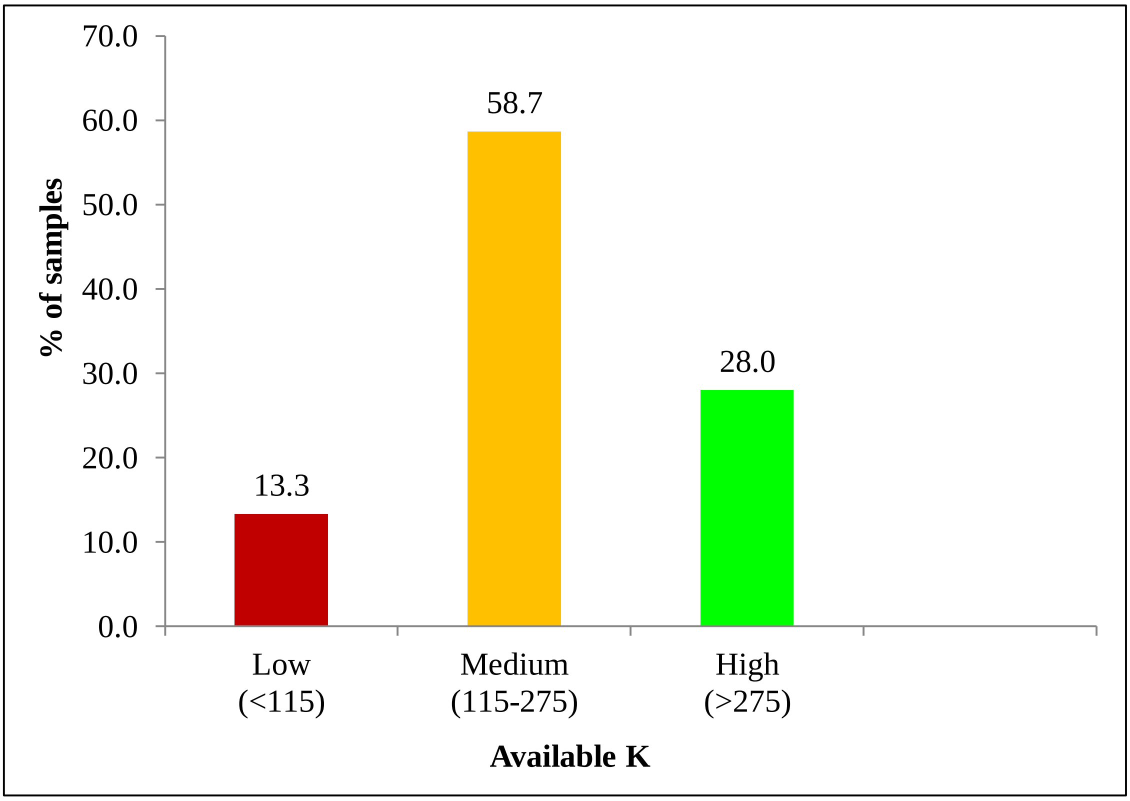


Fig. 21. Frequency distribution of available K (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

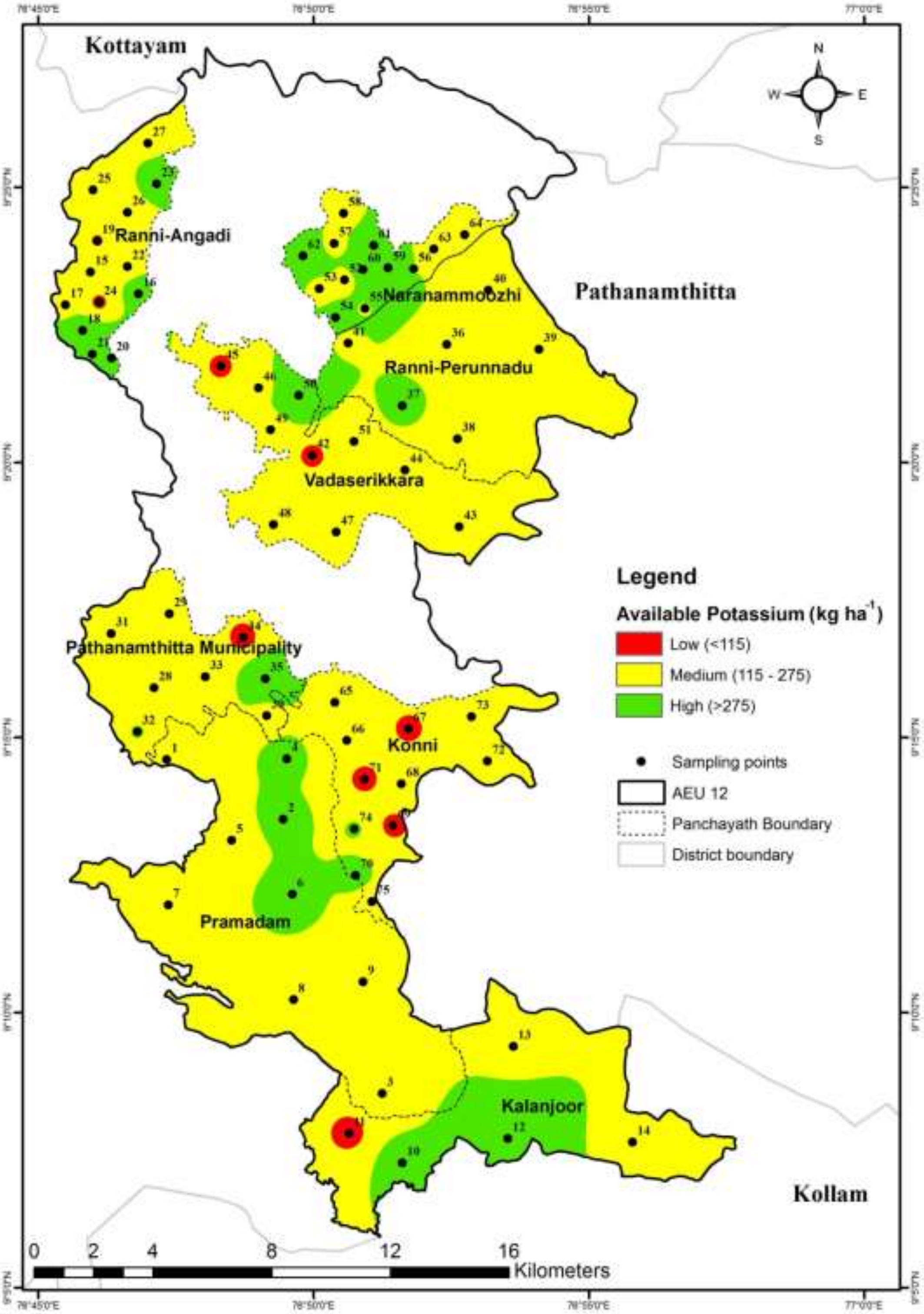


Fig. 22. Spatial distribution of available K in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2.7 Available Calcium

Available Ca in the post flood area was adequate for 90.7 per cent of the samples (Fig. 23) similar to pre-flood soils and the values ranged between 120 mg kg^{-1} and 1960 mg kg^{-1} (Table 14) in the study area. Liming of soils was practiced in the area by most of the farmers cultivating rubber, coconut and banana. Available Ca was significantly and positively correlated with soil pH and silt content. Spatial distribution of available Ca is shown in Fig. 24. Available Ca was relatively higher in areas with sediment deposition in Ranni-Angadi, Ranni-Perunnadu, Naranammoozhi and Vadaserikkara.

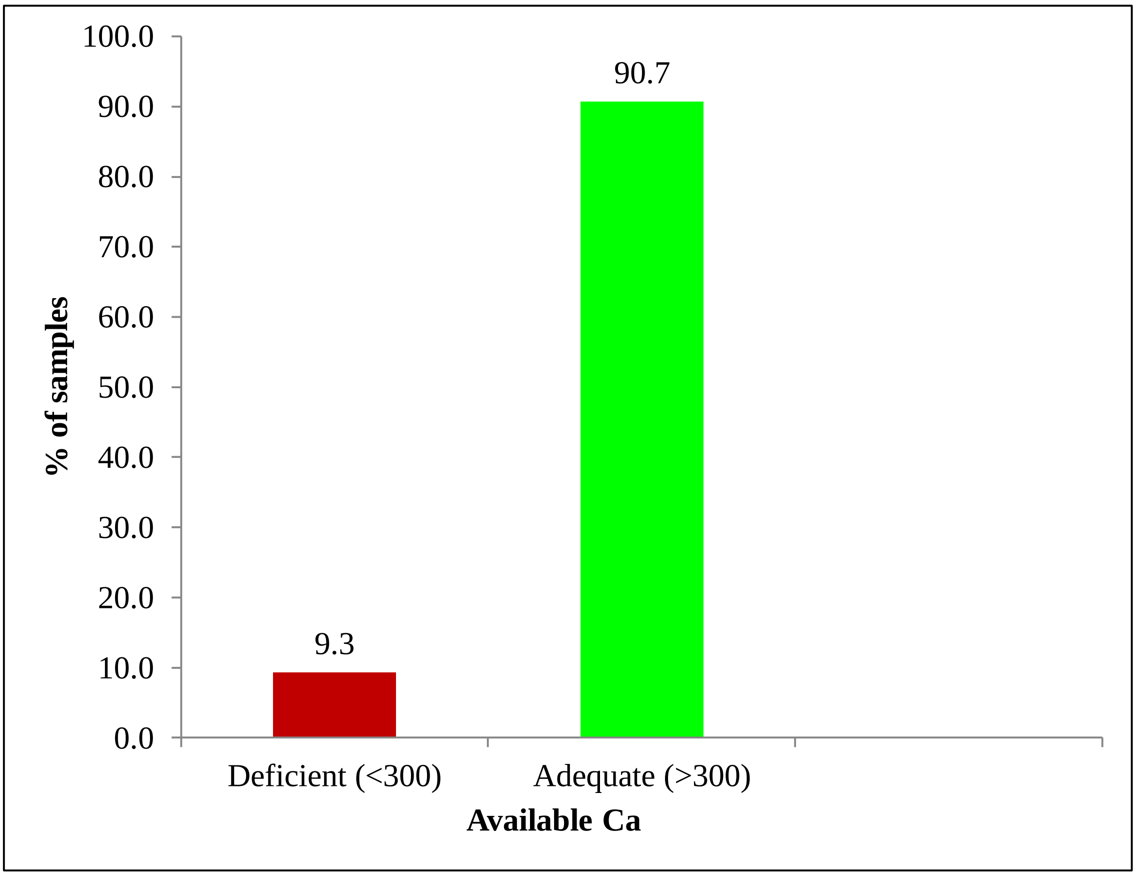


Fig. 23. Frequency distribution of available Ca (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

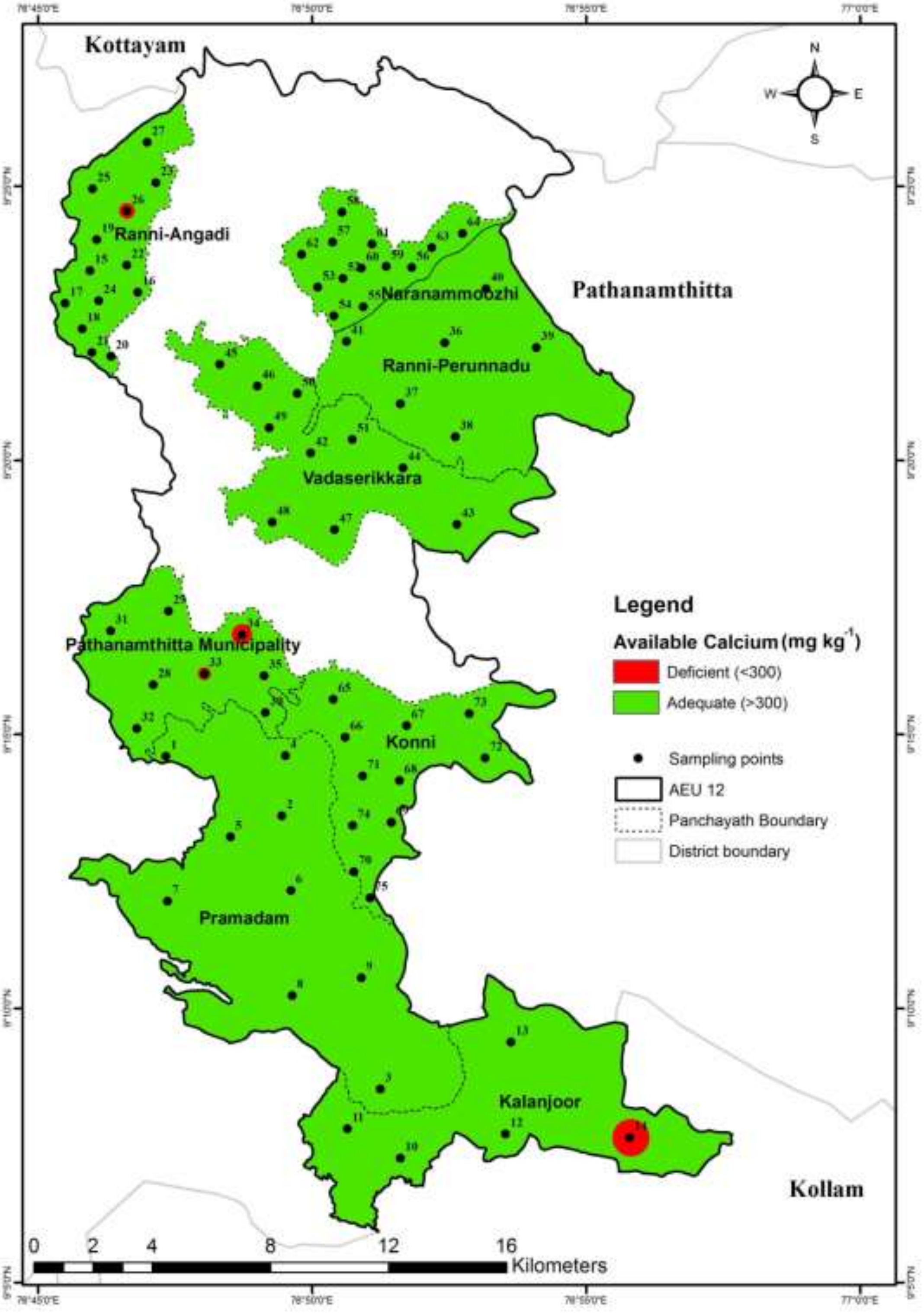


Fig. 24. Spatial distribution of available Ca in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2.8 Available Magnesium

Available Mg status of soils of Pathanamthitta was observed to be reasonably good before the floods (John *et al.* 2012). Available Mg was adequate for 68 per cent of the samples in the present study (Fig. 25). Percent of samples with adequate available Mg increased in the post-flood soil (68%) compared to pre-flood soils (62.5%). This increase was due to higher levels of Mg in areas with moderate sediment deposition. Available Mg varied between 12 mg kg^{-1} and 780 mg kg^{-1} (Table 14) and showed a significant positive correlation with soil pH, silt content, available Ca and EC. Higher Mg levels were encountered in soils with sediment deposition high in Ca and slightly acid to neutral pH. The spatial variability in available Mg is presented in Fig. 26.

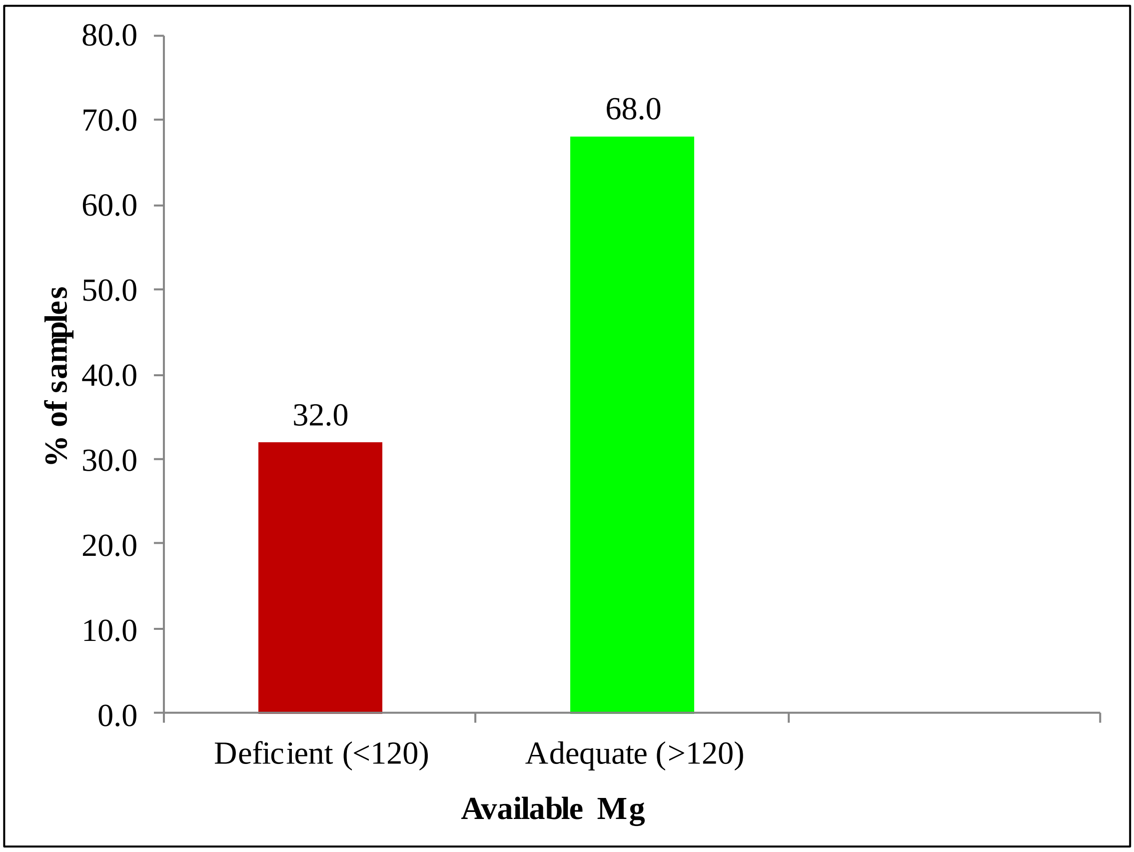


Fig. 25. Frequency distribution of available Mg (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

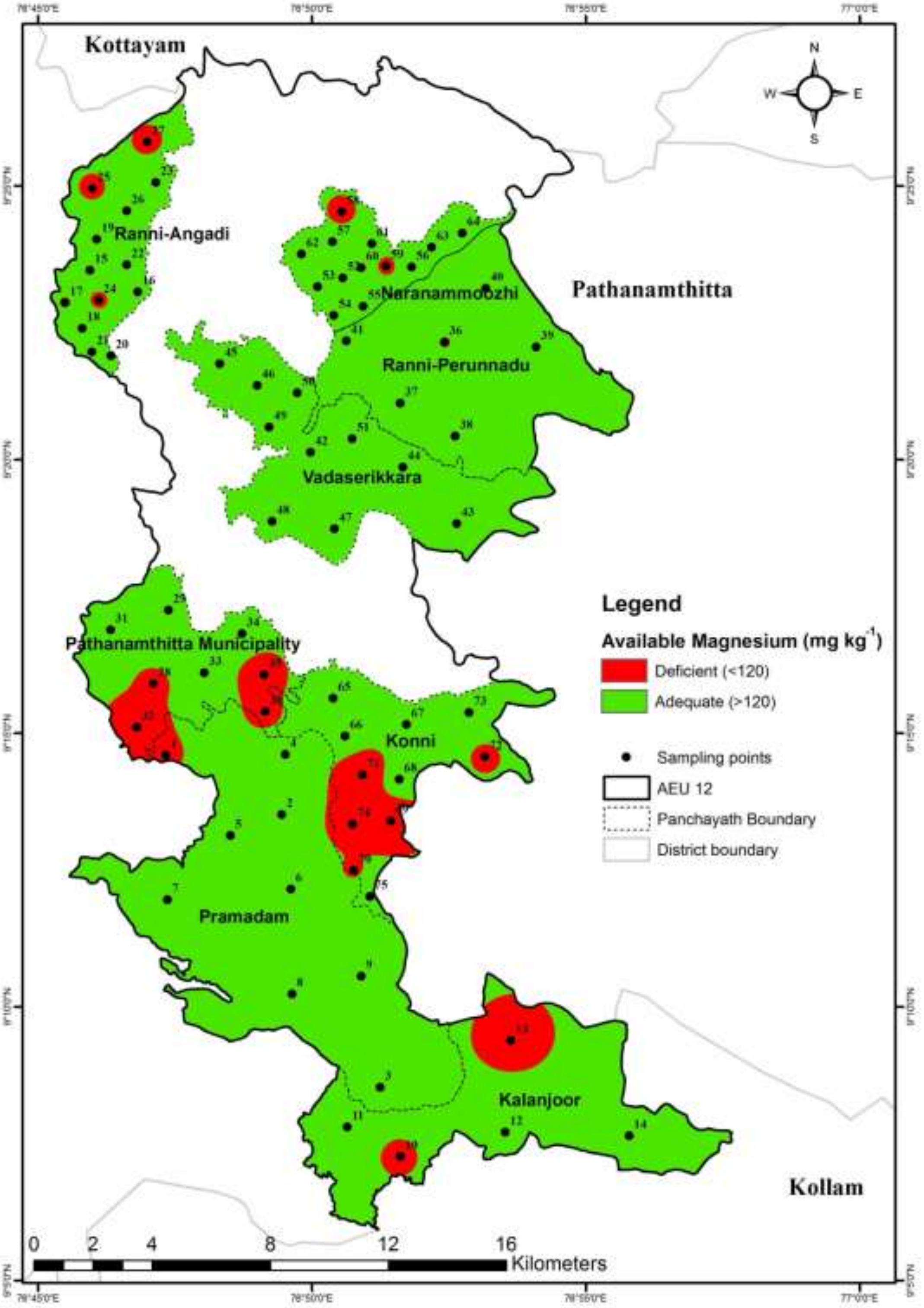


Fig. 26.Spatial distribution of available Mg in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2.9 Available sulphur

Available S varied between 0.5 mg kg^{-1} and 78.5 mg kg^{-1} (Table 14) and the values were adequate for 65.3 per cent of the samples (Fig. 27). Per cent of samples with adequate S declined in the post-flood soils (65.3%) compared to pre-flood (83.4%). The decline was mainly due to lower S in highly eroded soils of Konni, Pramadam, Pathanamthitta and Kalanjoor. Soluble sulphates undergo rapid leaching lossess thereby reducing available S content in soils. Available S was observed to be higher in areas with application of factamphos as in Ranni-Perunnadu during the previous years resulting in build up of available S. Available S was observed to be sufficient in soils of Kerala with continuous application of sulphur containing fertilizers like ammonium phosphate sulphate (Rajashekaran *et al.*, 2014). The spatial variability of available S is presented in Fig. 28.

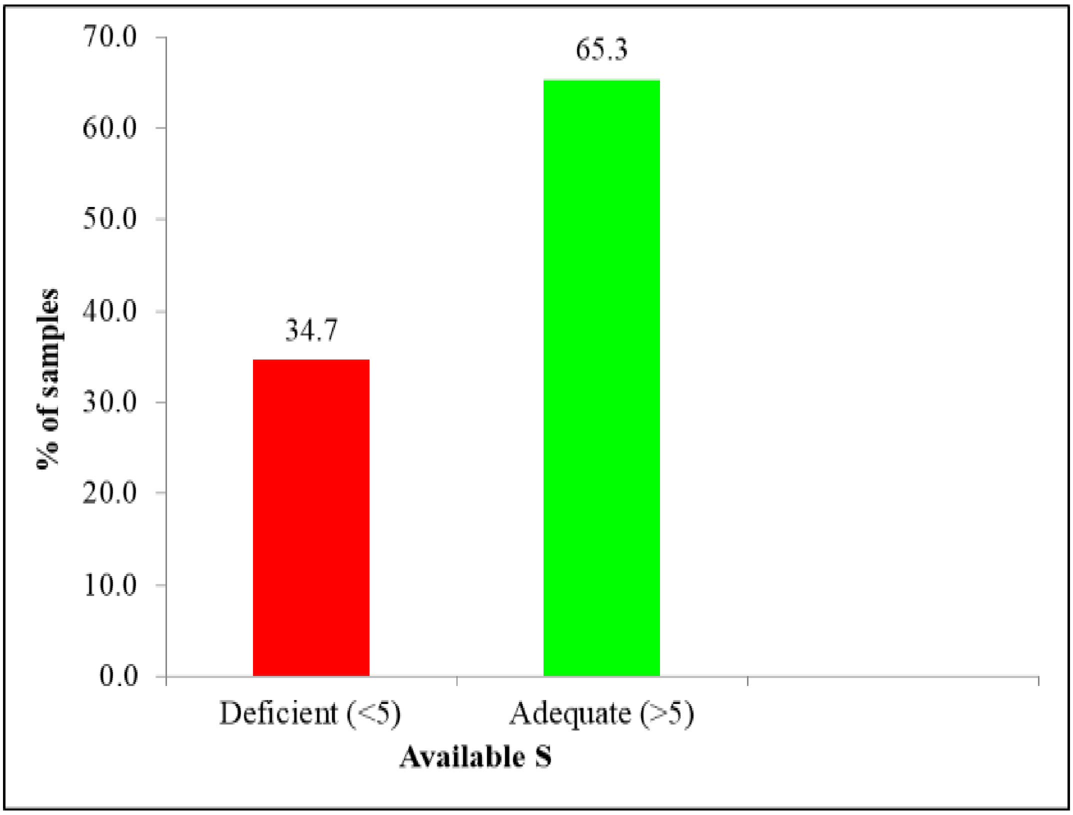


Fig. 27. Frequency distribution of available S (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

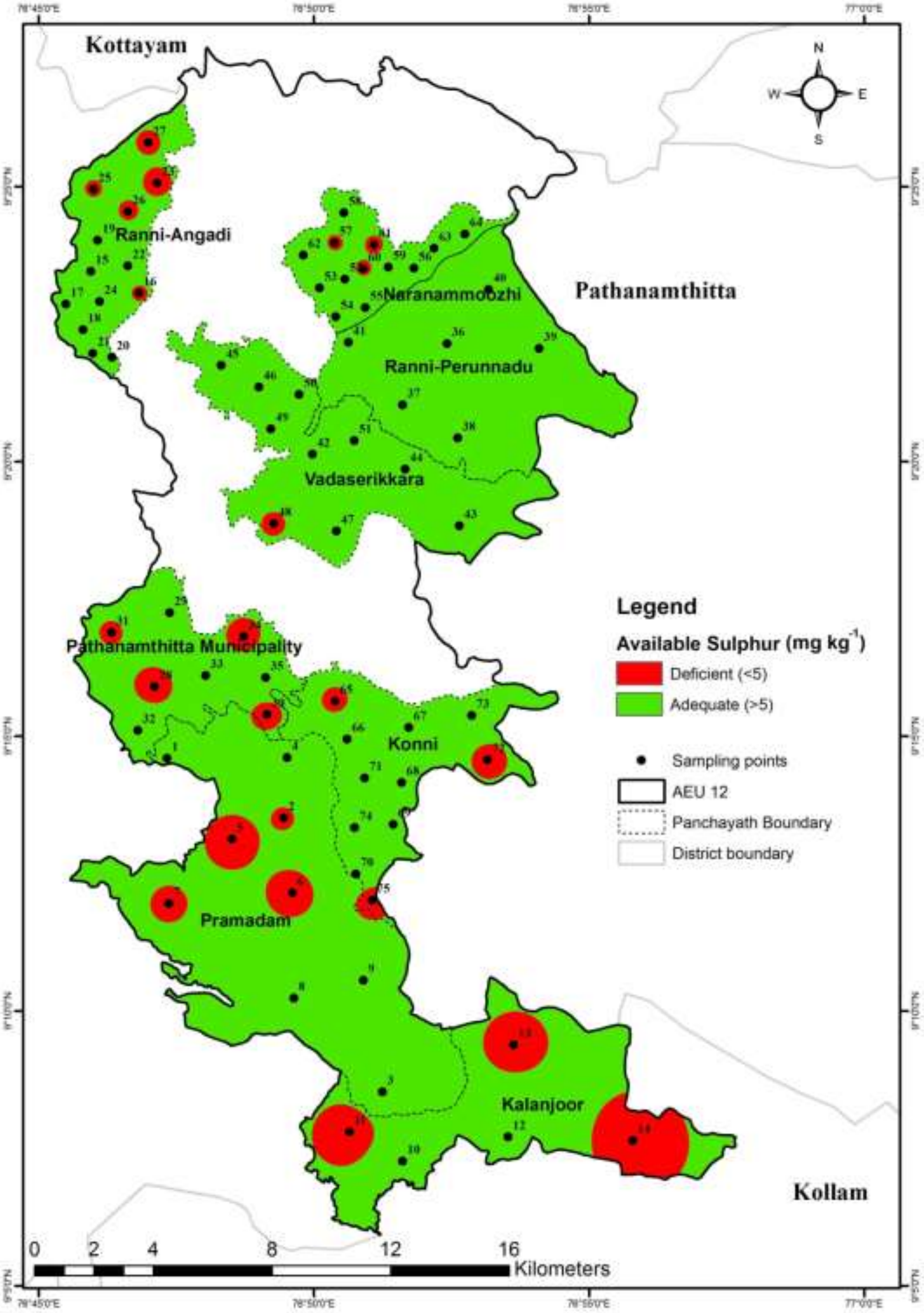


Fig. 28.Spatial distribution of available S in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.2.10 Available boron

Available B varied between 0.01 mg kg^{-1} and 1.5 mg kg^{-1} (Table 15) and was deficient in 62.7 per cent of the samples (Fig. 29). Samples with adequate available B showed an increase from 27.5 per cent in the pre-flood soils to 37.3 per cent in the post-flood soils. This might be due to the addition of B through the deposits during the severe flood. The highest B concentration (1.5 mg kg $^{-1}$) was observed in soils with sediment deposition, very low organic matter and neutral pH. Organic matter tightly binds a large part of B in soils which gets released slowly in available forms due to microbial activity (Berger and Pratt, 1963). Lower organic matter in soils results in reduced sorption of B thereby the B added through sediments may remain in available forms in the soil. Hot water soluble B in soil is positively correlated with soil pH (Vaughan and Howe, 1994). Low organic matter content along with addition of B through sediments into the soil and neutral pH might have resulted in higher available B. The spatial distribution of available B in the study area is depicted in Fig. 30.

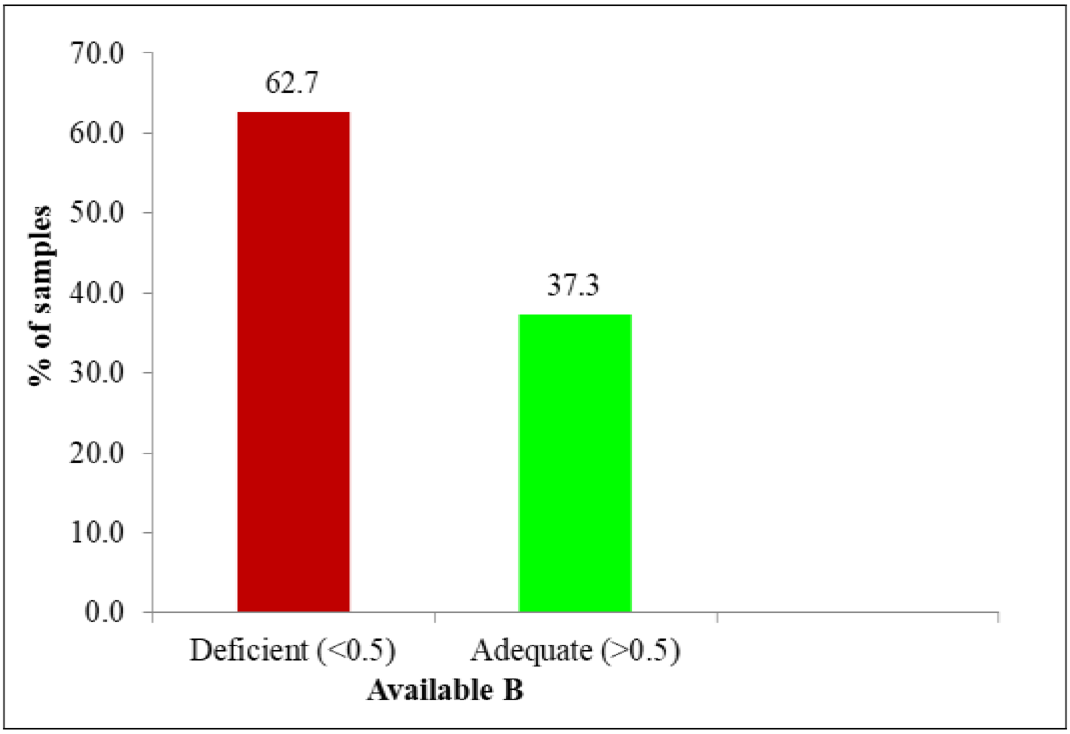


Fig. 29. Frequency distribution of available B (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

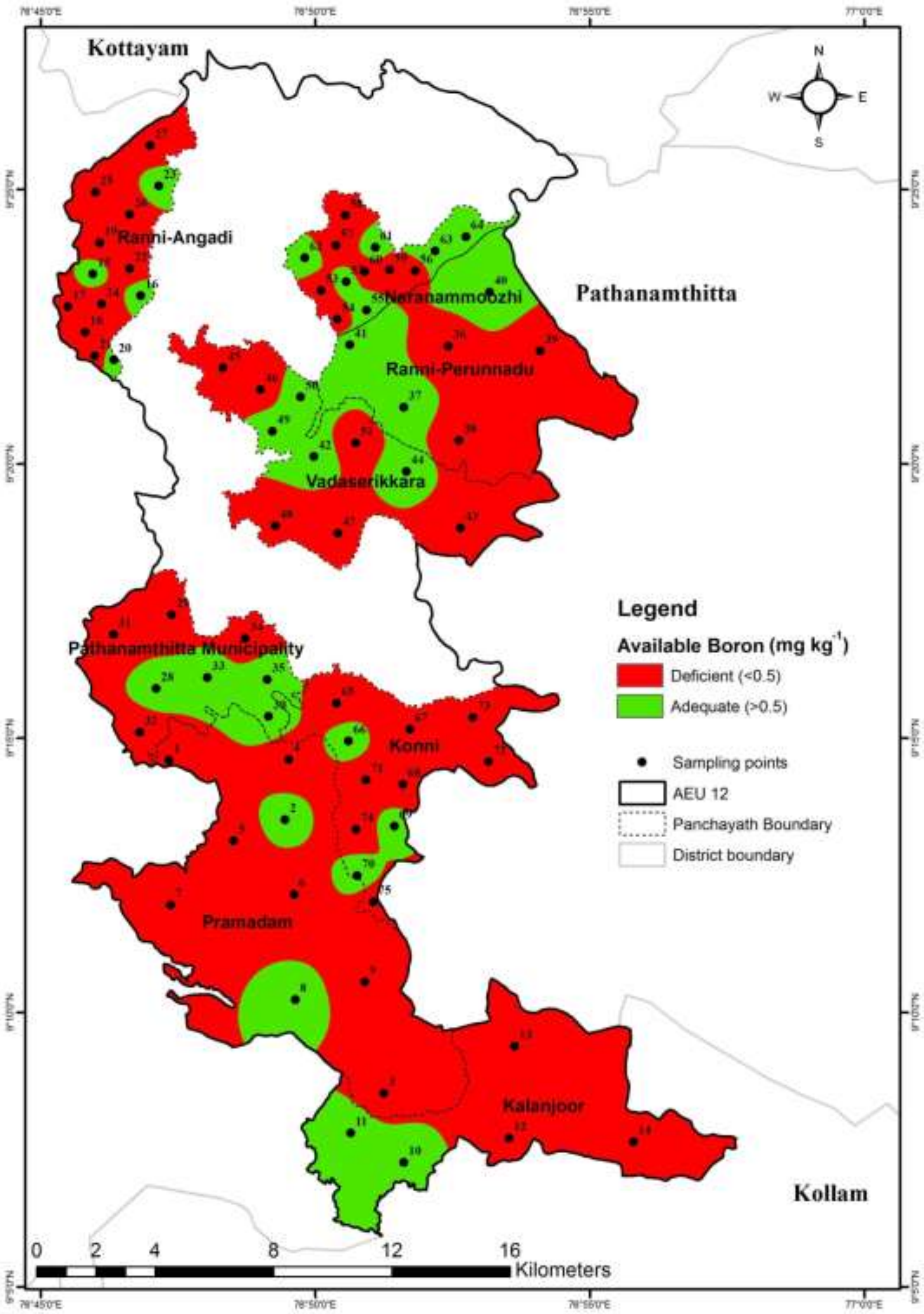


Fig. 30. Spatial distribution of available B in the post-flood soils of AEU 12 in Pathanamthitta district

5.1.3 Biological parameters

5.1.3.1 Acid phosphatase activity

Acid phosphatase activity ranged between 4.27 and 96.9 µg PNP produced g soil^{-1} h^{-1} (Table 16) and was significantly and positively correlated with organic carbon. The improved organic matter in these soils have increased the microbial activity, greater mineralisation and improved enzyme activity (Shi, 2011). 44 per cent of samples had an acid phosphatase activity between 25 and 50 µg PNP produced g soil^{-1} h^{-1} and 42.7 per cent between 10.0 and 25 µg PNP produced g soil^{-1} h^{-1} (Fig. 31).

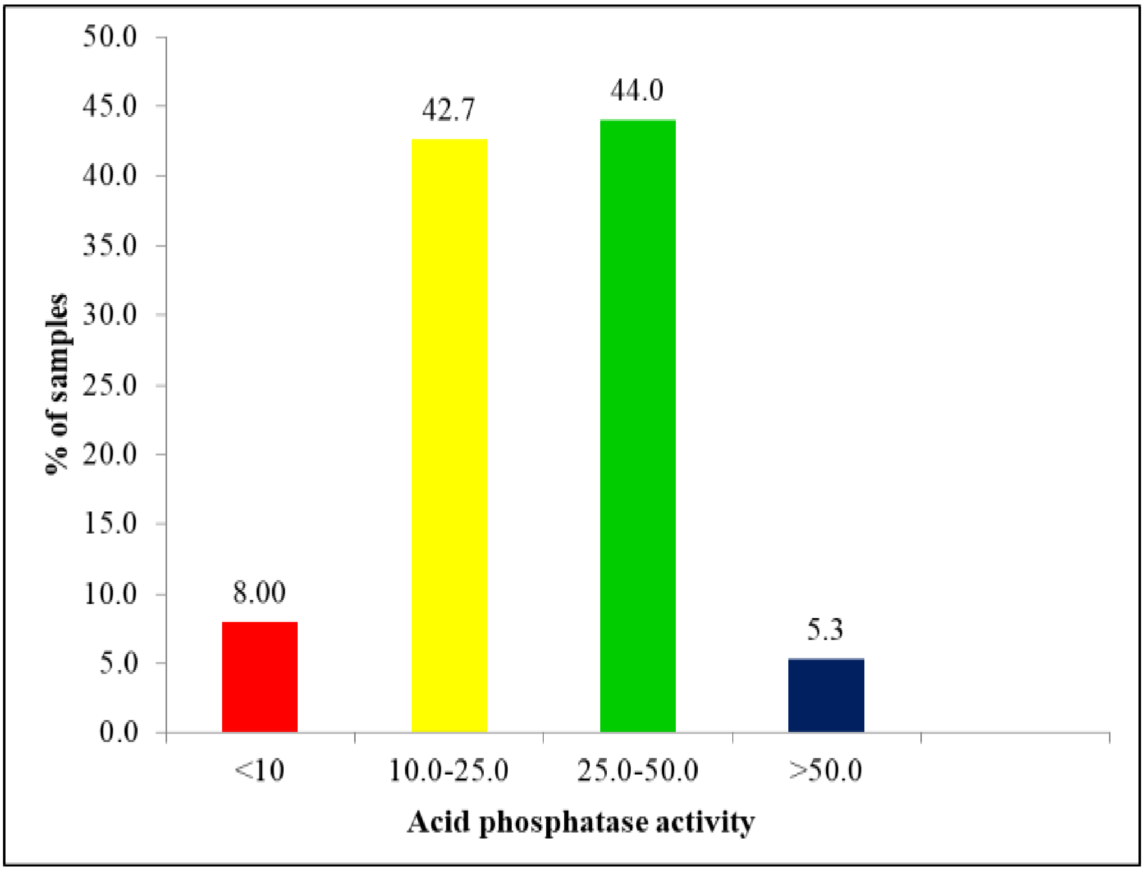


Fig. 31. Frequency distribution of acid phosphatase activity (µg PNP produced g soil^{-1} h^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta district

5.2 SOIL QUALITY INDEX

A weighted soil quality index was calculated using a minimum data set of parameters obtained from principal component analysis. The minimum data set consisted of pH, available P, available K, available Mg, available B, acid phosphatase activity, bulk density, silt (%) and sand (%) (Table 18). Weights and scores were assigned to the parameters following the procedure laid out by Kundu *et al*. (2012), Mukherjee and Lal (2014) and Singh *et al*. (2017). Sand and silt contents were rated based on soil textural classes with loam receiving the highest score. A relative soil quality index was developed and soils were rated as poor (<50%), medium (50%-70%) and good (>70%). Medium soil quality was obtained for 54.7 per cent of samples followed by 36 per cent good and 9.3 per cent poor (Fig. 32). Soil quality was observed to be higher in Naranammoozhi, Vadaseikkara, Ranni-Perunnadu and Ranni-Angadi area (Table 20) with less acidic soils, high available P, K, Mg and B contents and with a sediment deposition of 10-15 cm depth. Spatial distribution of soil quality is depicted in Fig. 33.

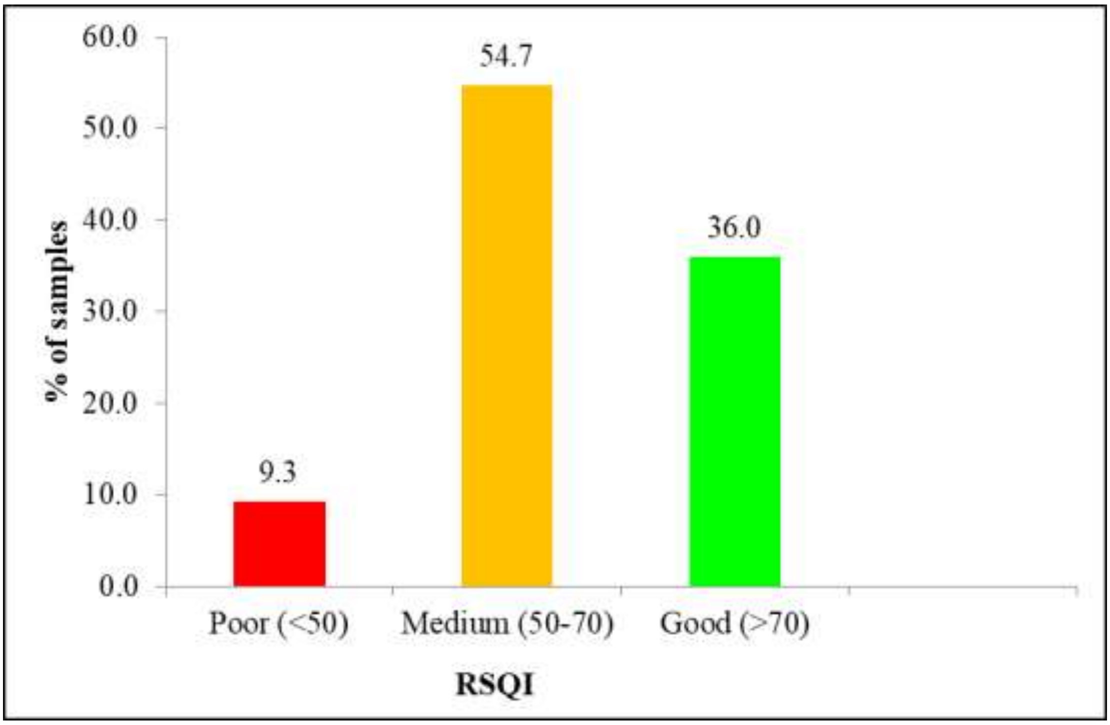


Fig. 32. Frequency distribution of RSQI (%) in the post-flood soils of AEU 12 in Pathanamthitta district

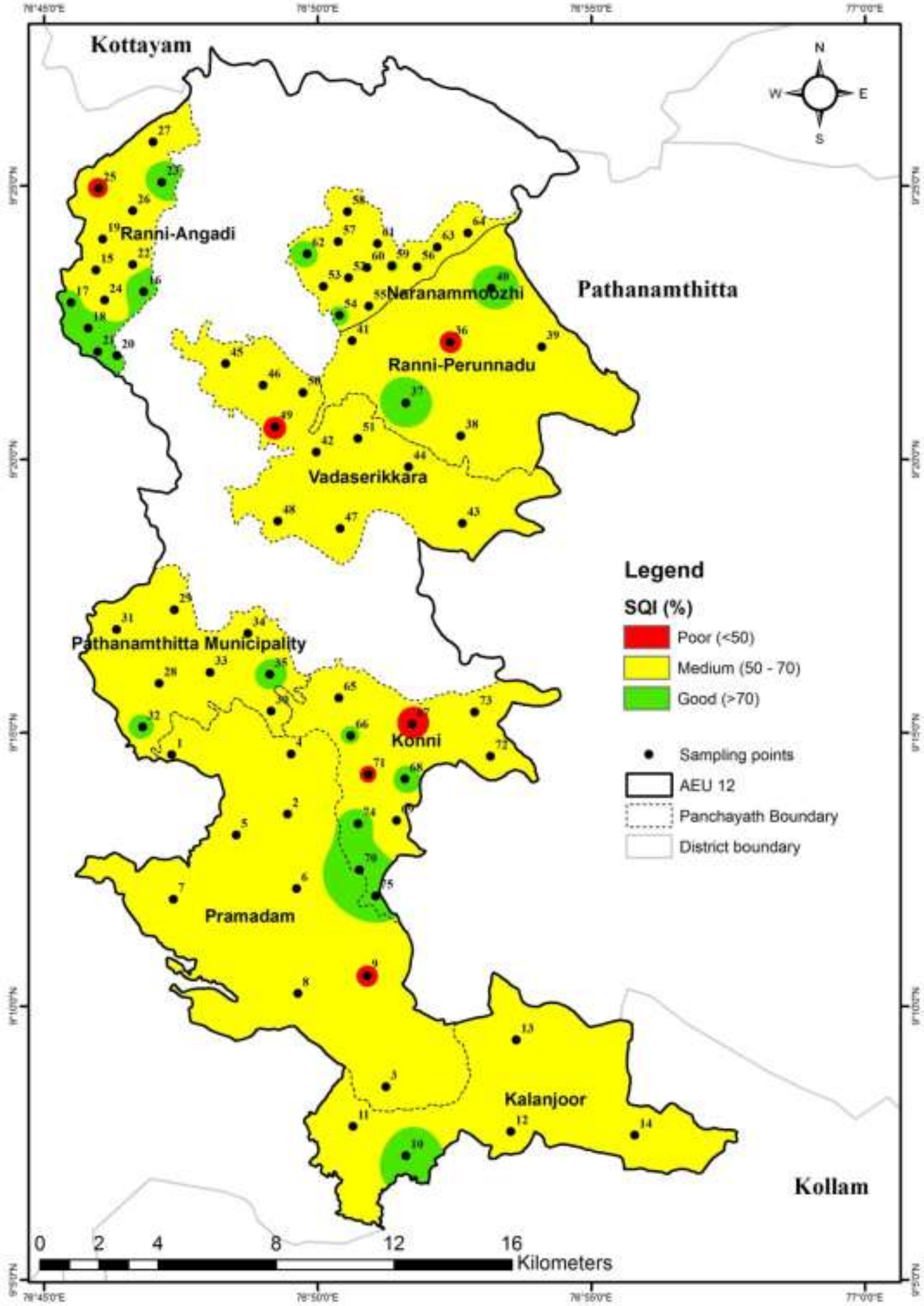


Fig. 33.Spatial distribution of SQI in the post-flood soils of AEU 12 in Pathanamthitta district

5.3 NUTRIENT INDEX

Nutrient index was developed for organic carbon and available primary nutrients at panchayath level. The spatial distributions of nutrient indices are depicted in Fig. 34, 35, 36 and 37. Nutrient indices for available N, P and K were low, high and medium respectively for the entire area. This is in line with the available nutrient content of samples. Majority of samples were low in available N, high in available P and medium in available K. Nutrient index for organic carbon was high in all areas except for Vadaserikkara, Naranammoozhi and Ranni-Perunnadu (medium) (Table 21). The relatively lower organic carbon levels of these areas have resulted in the the lower nutrient index.

5.4 LAND QUALITY INDEX

Land quality index was developed based soil organic carbon stock calculated using soil organic carbon, bulk density and soil depth. LQI was very low (<3 kg m^{-2}) for 62.7 per cent of the samples and low (3 kg m^{-2} – 6 kg m^{-2}) for 37.3 per cent (Fig. 38). Thus, majority of the area have degraded to very low quality for agricultural purposes which can be attributed to the reduction in soil organic carbon due to the removal of organic matter by the scouring action of the flowing flood waters. The spatial distribution of LQI is presented in Fig. 39.

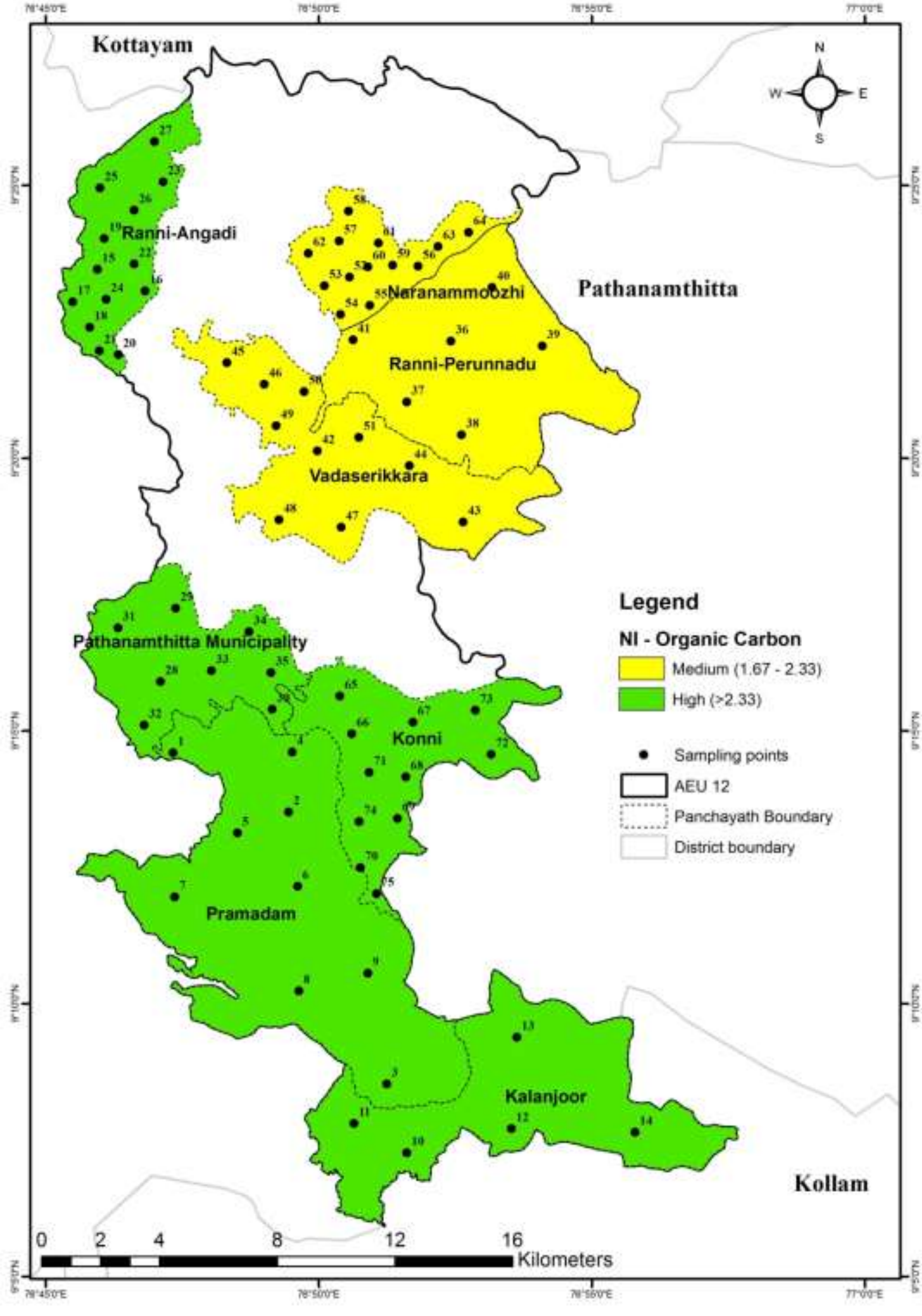


Fig. 34. Spatial distribution of NI - organic carbon in the post-flood soils of AEU 12 in Pathanamthitta district

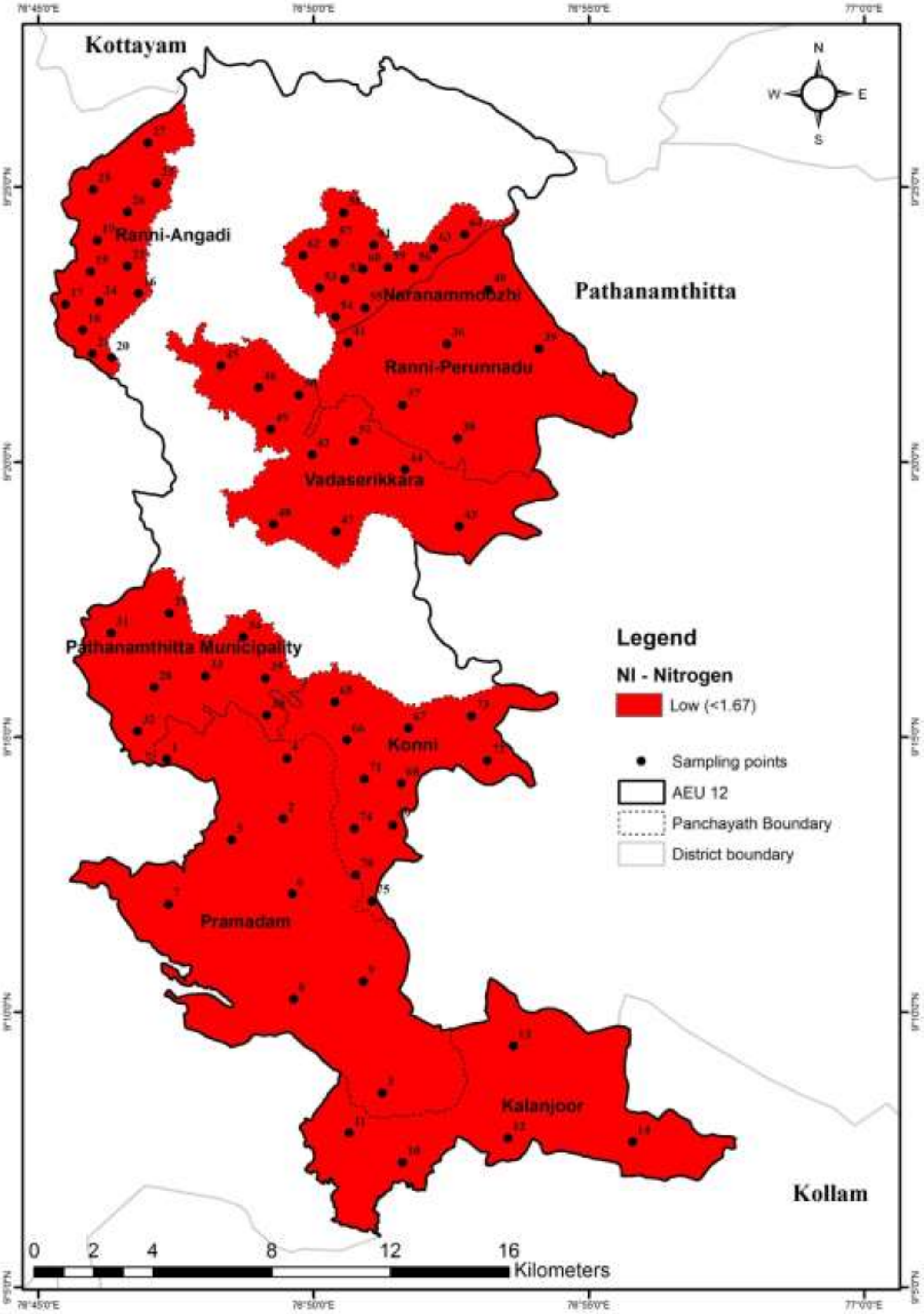


Fig. 35. Spatial distribution of NI - N in the post-flood soils of AEU 12 in Pathanamthitta district

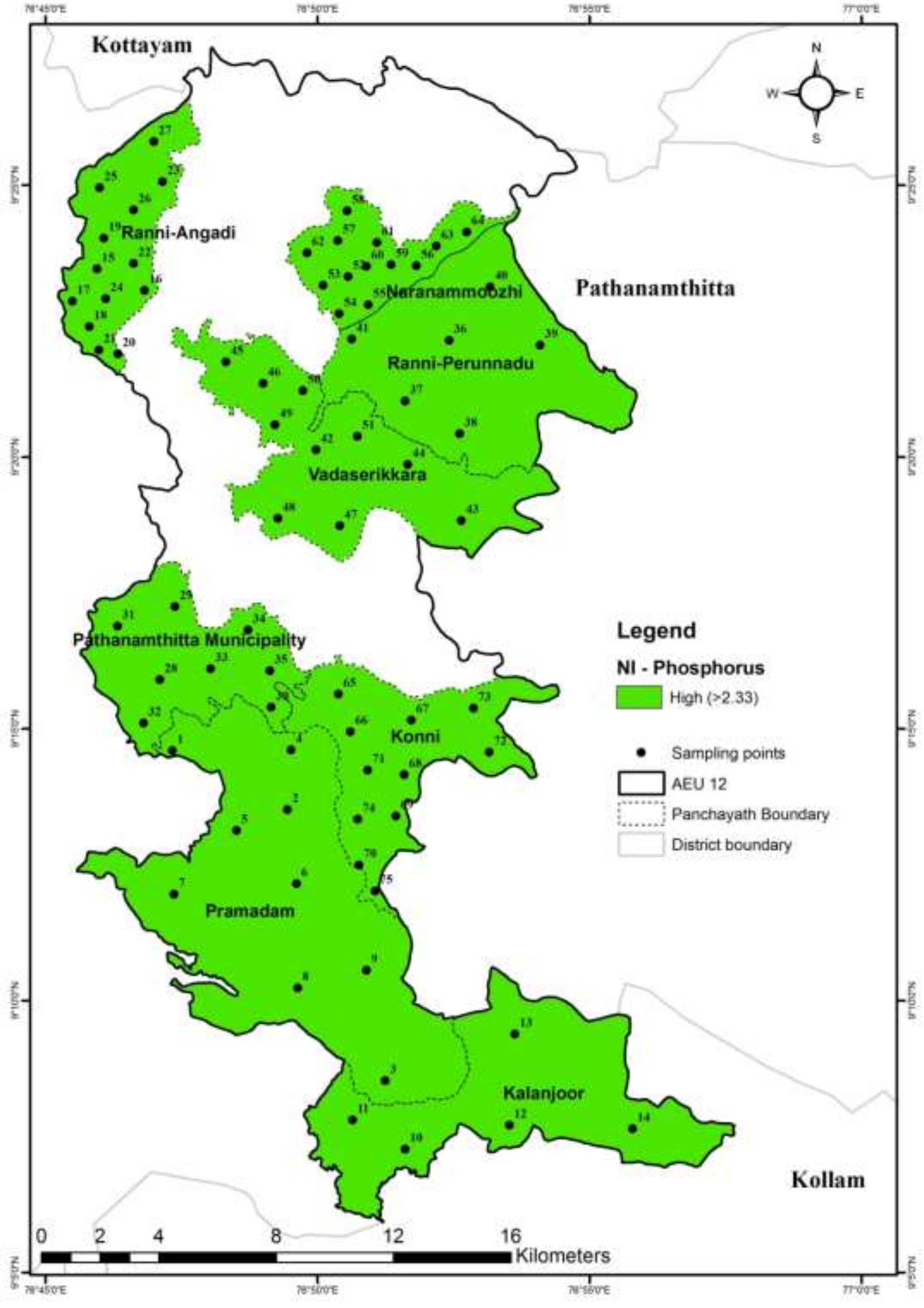


Fig. 36. Spatial distribution of NI - P in the post-flood soils of AEU 12 in Pathanamthitta district

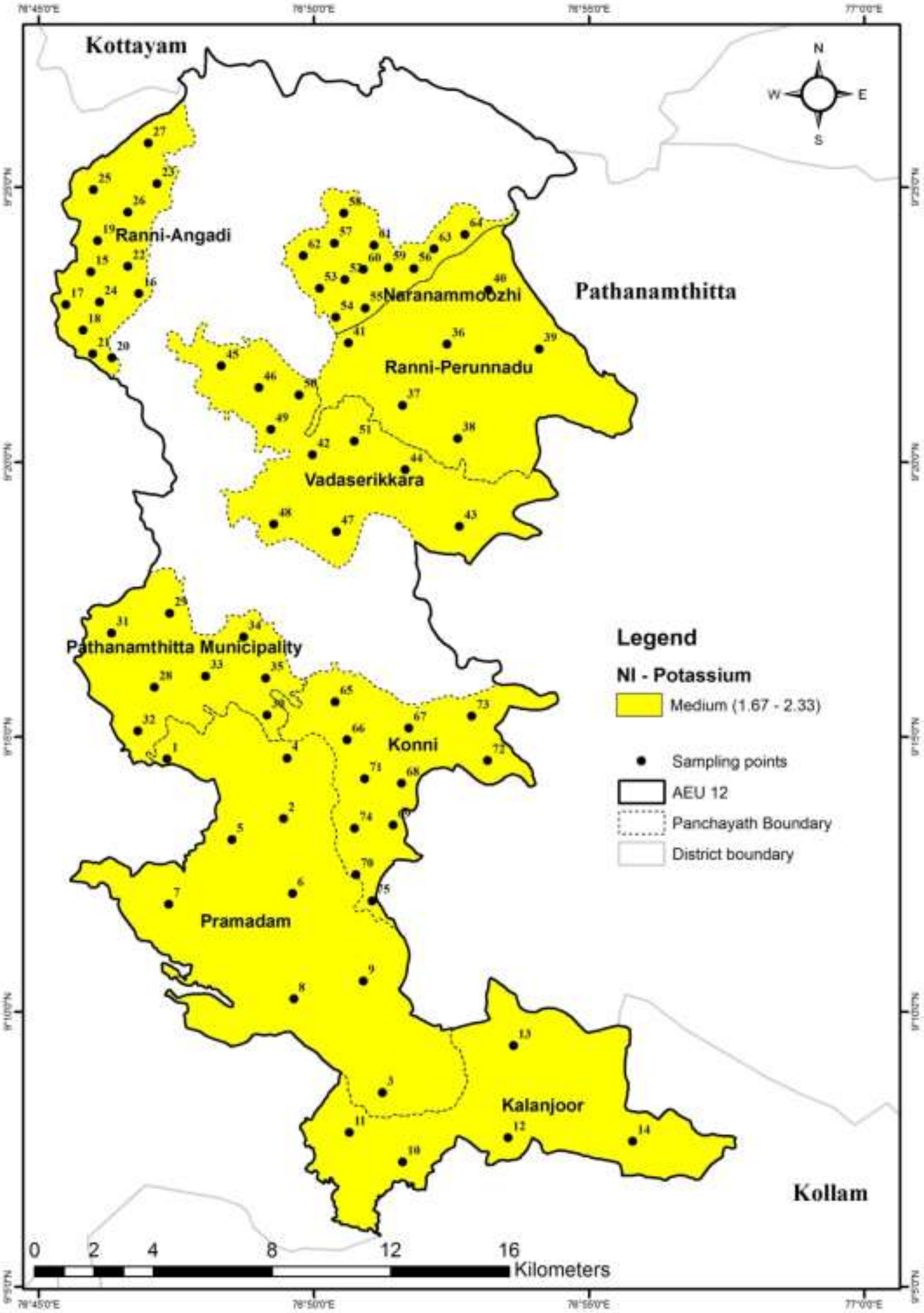


Fig. 37. Spatial distribution of NI - K in the post-flood soils of AEU 12 in Pathanamthitta district

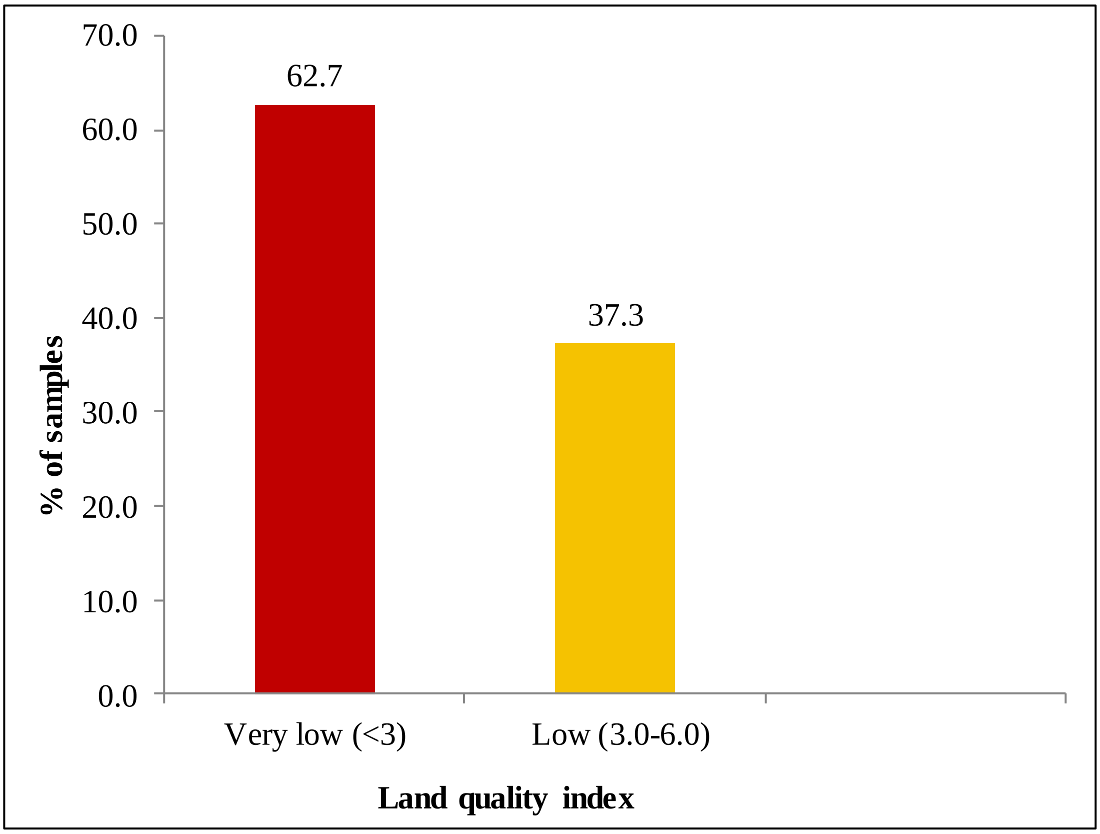


Fig. 38. Frequency distribution of Land quality index (kg m^{-2}) in the post-flood soils of AEU 12 in Pathanamthitta district

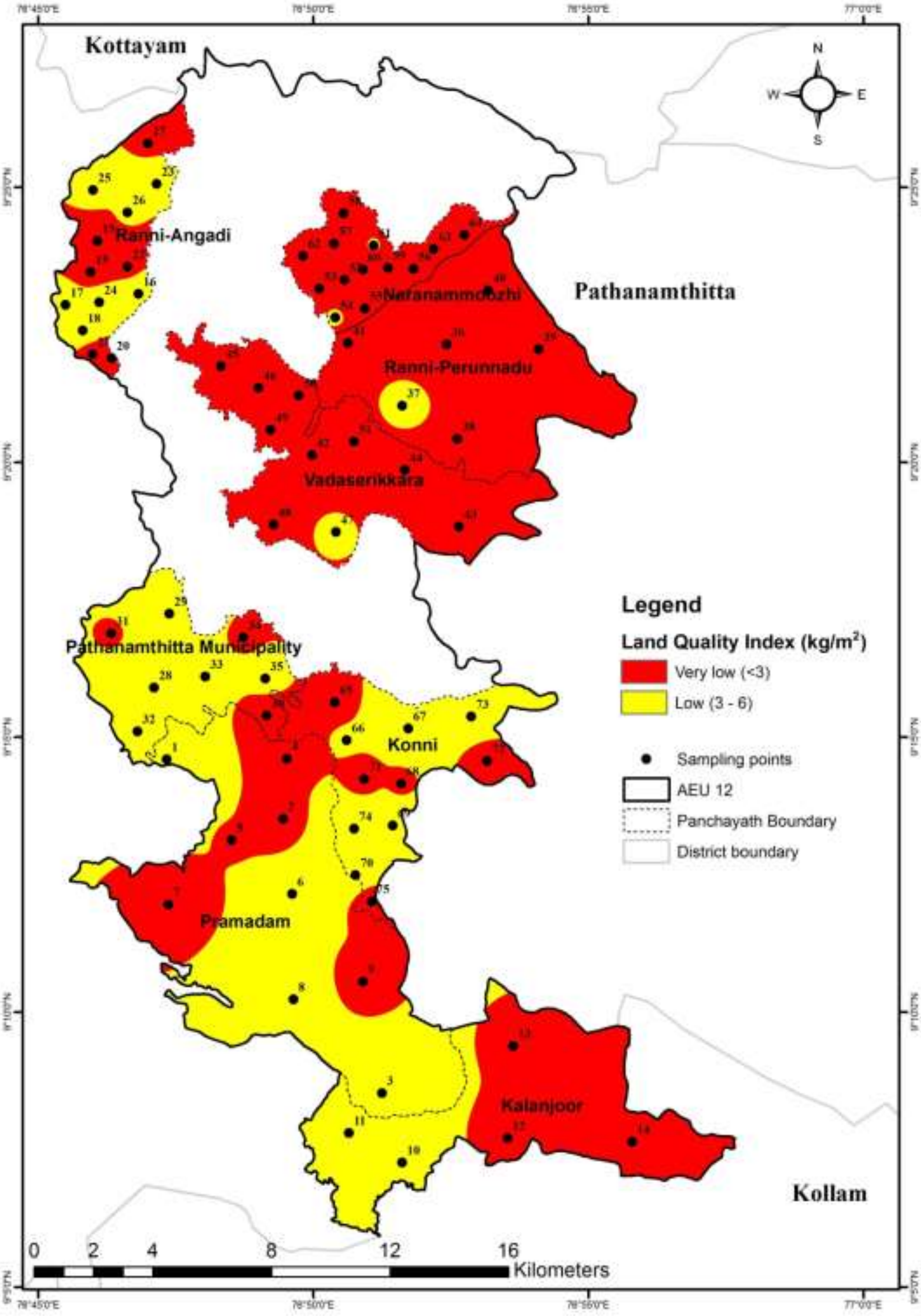


Fig. 39. Spatial distribution of LQI in the post-flood soils of AEU 12 in Pathanamthitta district

5.5 PRE AND POST FLOOD SOIL PROPERTIES –A COMPARISON

The devastating flash floods and landslides during 2018 have brought about marked variation in the physical and chemical properties of soils of AEU 12 in Pathanamthitta district. Clayey and loamy soils predominated the area according to pre flood studies reported by KSPB (2013) (Appendix IV) while sandy clay loam was the predominant soil textural class observed in the post-flood study. Loamy sand and sandy loam textural classes were also observed in soils with excessive flood deposition in Vadaserikkara and Naranammoozhi respectively.

Soils with extremely acidic pH showed an increase in the post-flood study (22.7%) compared to the pre flood data (18.4%) whereas percentage of samples with very strongly acid and strongly acid pH declined. Soil acidification was prominent in the southern and central parts of AEU 12 in Pathanamthitta district *viz.* Kalanjoor, Konni, Pramadam and Pathanamthitta. These areas, drained by Achankovil river, experienced heavy erosion due to high velocity flow of flood water. Slightly acid pH was observed for 9.33 per cent of the samples compared to 4 per cent in the pre flood data. Moreover, neutral pH was observed for 16 per cent of the samples in the post-flood study, indicating a reduction in soil acidity. Soils in the neutral pH range were not reported in the pre flood study. But a moderation in soil reaction was observed in the northern parts of the AEU, drained by Pampa river *viz.* Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi. These areas also experienced moderate to excessive sediment deposition.

Per cent of samples high in organic carbon decreased from 65.3 per cent in the pre flood to 50.7 per cent in the post flood soil. Such a reduction in organic carbon status was observed mostly in areas with sediment deposition. Available P status improved in the area, with an increase in per cent of samples with high available P from 62.8 per cent in the pre flood to 82.67 per cent in the post flood soils. Available K status deteriorated with a decline in per cent of samples high in available K from 62.8 per cent in pre flood to 28 per cent in the post flood study. Available Ca was adequate for more than 90 per cent of the samples similar to the pre flood soils. Available Mg and B status improved with a rise in the per cent of samples with adequate available Mg (from 62.5 per cent to 68 per cent) and B (27.5 per cent to 37.3 per cent) compared to pre flood data. A decline in available S in soils was observed with a reduction in the per cent of samples with adequate S from 83.4 per cent in the pre flood to 65.3 per cent after the floods.

In general, available P, Mg and B status improved in the post-flood soils whereas organic carbon, available K and available S status deteriorated compared to the pre flood data.

5.5.1 Variations in soil properties in areas with deposition and erosion

Soil properties showed variation in areas with erosion and deposition when compared with pre flood data at panchayath level (Appendix IV). Erosion was prominent in Konni, Pathanamthitta municipality and Pramadam lying in the southern part of the AEU, whereas deposition was more in Ranni-Angadi, Vadaserikkara, Naranammoozhi and Ranni-Perunnadu area towards the northern part. The impact of flood was comparatively lesser in Kalanjoor panchayath with water logging in fields close to over flowing streams. Soil reaction was very strongly acid to strongly acid for most of the areas in the pre flood study whereas it was extremely acid to very strongly acid for majority of the area in Pramadam (52.0%), Pathanamthitta municipality (64.0%) and Konni (74.0%) in the present study (Fig. 13). Kalanjoor panchayath showed extremely acid to very strongly acid pH in the present study (Fig. 13) whereas 81 per cent of samples were extremely acid to very strongly acid and 19 per cent moderately acid in the pre flood study. The increase in soil acidity can be due to the excessive erosion resulting in leaching of basic cations. In Ranni-Angadi soil reaction was found to be moderately acid to neutral for most of the area (Fig. 13) in the present study whereas pre flood data showed very strongly acid to strongly acid pH (65.0%) for most of the areas. In Vadaserikkara (58.0%) and Naranammoozhi (79.0%) soil reaction was mostly extremely acid to very strongly acid in the pre flood study whereas the post-flood study mostly showed moderately acid to neutral pH. In Ranni-Perunnadu, soil reaction was strongly acid to neutral for most of the area (Fig. 13) in the present study showing an increase in soil pH in some areas with sediment deposits after the floods whereas pH was mostly extremely acid to strongly acid (85.0%) in the pre flood study. Therefore, a moderation in soil reaction was observed in these areas which can be ascribed to sediment deposition in the Pampa basin.

Organic carbon was high for majority of the area in Kalanjoor, Pramadam, Konni and Pathanamthitta municiplality where sediment deposits were absent or rare and medium in most parts of Vadaserikkara, Ranni-Perunnadu and Naranammoozhi with sediment deposits (Fig. 14). Organic carbon was also high in most parts of Ranni-Angadi except in areas with excessive sediment deposition (Fig. 14). Pre flood soil data showed that majority of the area in Vadaserikkara (76.0%), Ranni-Perunnadu (56.0%) and Naranammoozhi (88.0%) were high in organic carbon indicating a decline in organic carbon with sediment deposition in this area. Available N also showed a similar trend with low levels in areas with medium organic carbon and sediment deposition and medium levels in few areas with high organic carbon in Konni, Pramadam, Pathanamthitta municipality and Ranni-Angadi. Available P status improved and available K status declined in the entire study area under post-flood study compared to pre flood irrespective of erosion or deposition (Appendix IV).

Available Ca status was found to be similar to pre flood data whereas available Mg and B status improved (Appendix IV). Available Ca and Mg were observed to be comparatively higher in panchayaths with sediment deposition (Table 14). Available B was deficient in majority of the area in Ranni-Perunnadu (80.0%), Vadaserikkara (79.0%), Naranammoozhi (79.0%), Konni (97.0%), Pramadam (84.0%), Pathanamthitta municipality (68.0%) and Ranni-Angadi (57.0%) and adequate for majority of area in Kalanjoor (64.0%) in the pre flood study. Area with adequate available B increased in Ranni-Perunnadu, Vadaserikkara, Naranammoozhi, Konni, Pramadam and Pathanamthitta municipality and declined in Ranni-Angadi and Kalanjoor (Fig. 30) in the present study compared to pre flood. Available S was adequate for the entire study area except Kalanjoor (100 per cent deficient) and Pramadam (41 per cent deficient) in the pre flood study. A decline was observed in available S status in the area which can be due to the loss of soluble sulphates from the soil through erosion (Fig. 28). Available S was comparatively higher in Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi area with sediment deposits (Table 14).

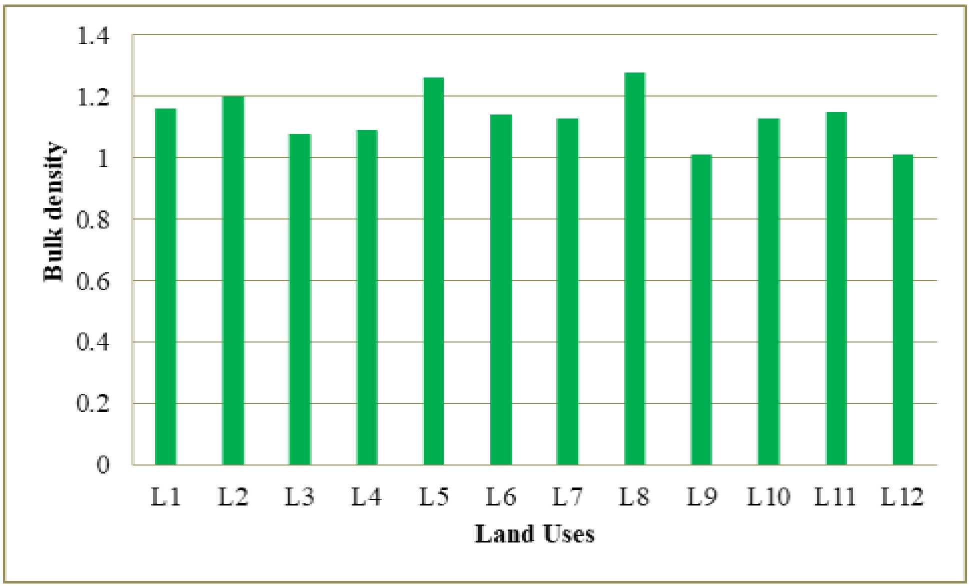
5.6 SOIL PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES IN POST-FLOOD SOILS UNDER DIFFERENT LAND USES IN AEU 12 OF PATHANAMTHITTA

5.6.1 Physical attributes

5.6.1.1 Bulk density, Particle density and Porosity

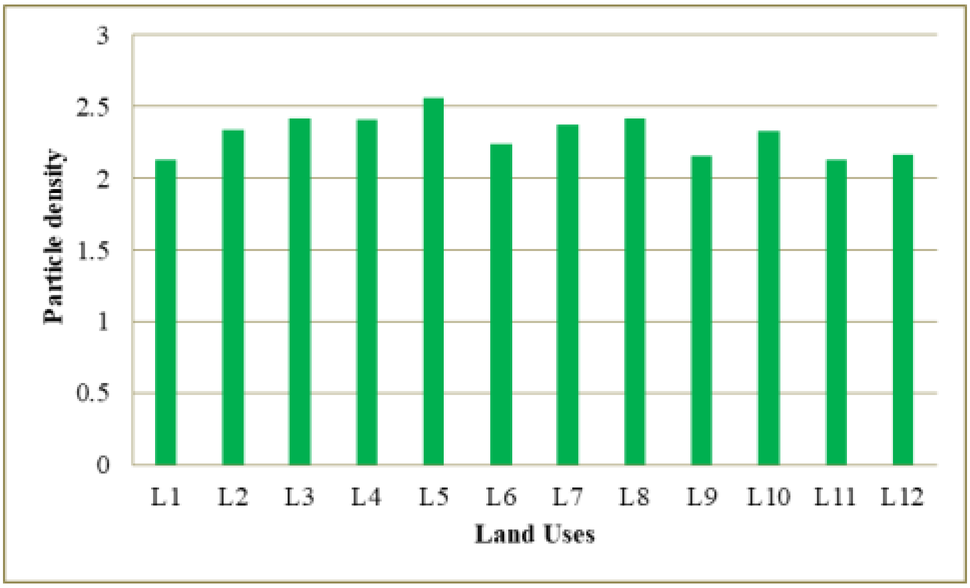
Cultivation of soils with different crops cause significant changes in soil structure, which is reflected in higher mass by volume ratio resulting in higher bulk density and lower porosity (Valpassos *et al*., 2001). In the present study, mean bulk density was observed to be higher under land uses with regular intensive intercultivation practices (Table 26, Fig. 40). Excessive tillage destroys organic matter and disrupts the stability of natural soil aggregates making them susceptible to erosion. Eroded soil particles clog soil pores leading to a reduction in porosity and an increase in bulk density (USDA, 2006). Long-term conventional tillage destroys large aggregates in soil and increases bulk density whereas long-term no tillage system improves aggregate stability and reduces bulk density of soils (Malhi *et al*., 2007). The lowest mean of bulk density was observed under other crops like cocoa, pepper, elephant foot yam, nutmeg, cashew etc. where the soils are less disturbed and in areas under vegetable cultivation relying on organic manures.

Particle density of soil exhibits variation due to soil management induced changes in soil organic carbon (Blanco-Canqui *et al*., 2006). Minimum inter cultivation practices, maximum utilisation of land area through multiple cropping which increases root density in soils and addition of organic manures enhances soil organic carbon. The mean particle density was comparatively lower under banana intercropped with tapioca and vegetables, and in areas under vegetable cultivation (mostly organic), oil palm plantations and homesteads with mixed cropping using crops like nutmeg, cocoa, cashew, pepper etc. requiring lesser inter cultivation practices (Table 26, Fig. 41). Mean porosity was comparatively lower under monocropping of banana, tapioca, coconut etc. However, banana with tapioca and vegetables recorded lower porosity which can be attributed to comparatively lower particle density (Table 26, Fig. 42).



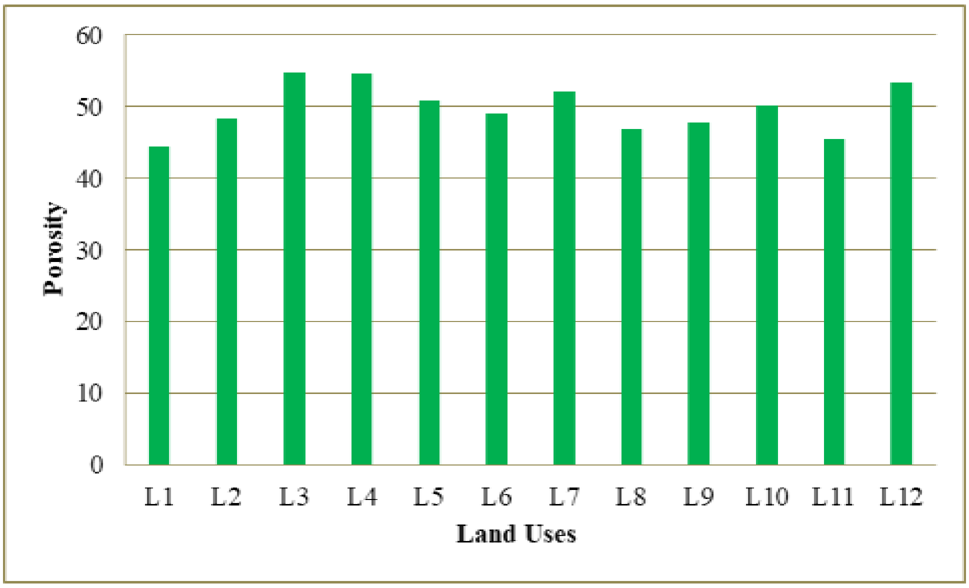
[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 40. Bulk density (Mg m^{-3}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 41. Particle density (Mg m^{-3}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

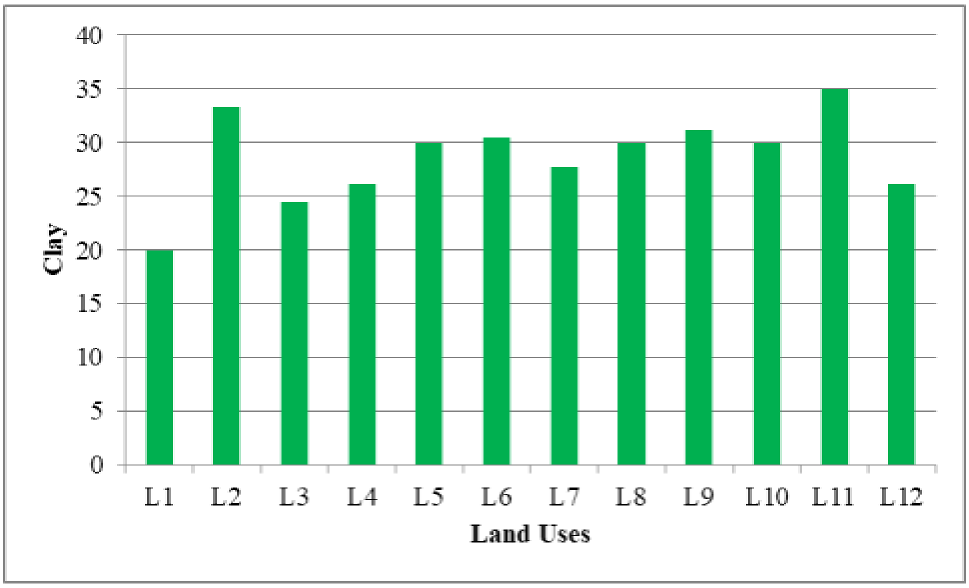


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 42. Porosity (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

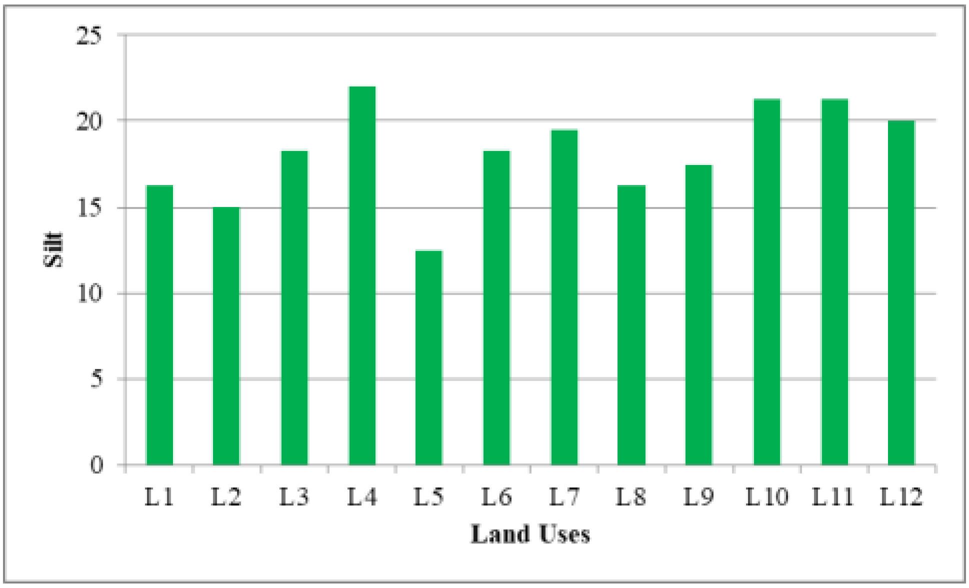
5.6.1.2 Particle size distribution and Soil texture

Varying land uses did not show any significant influence on clay, silt and sand contents in the study area. Post-flood soils in the area under various land uses have experienced deposition of sediments causing variations in soil texture. The most frequent textural class observed under different land uses was sandy clay loam (Table 27, Fig. 43, 44 and 45) except in coconut intercropped with tapioca (sandy clay), coconut alone (clay), vegetables alone (clay loam) and oil palm (clay loam).



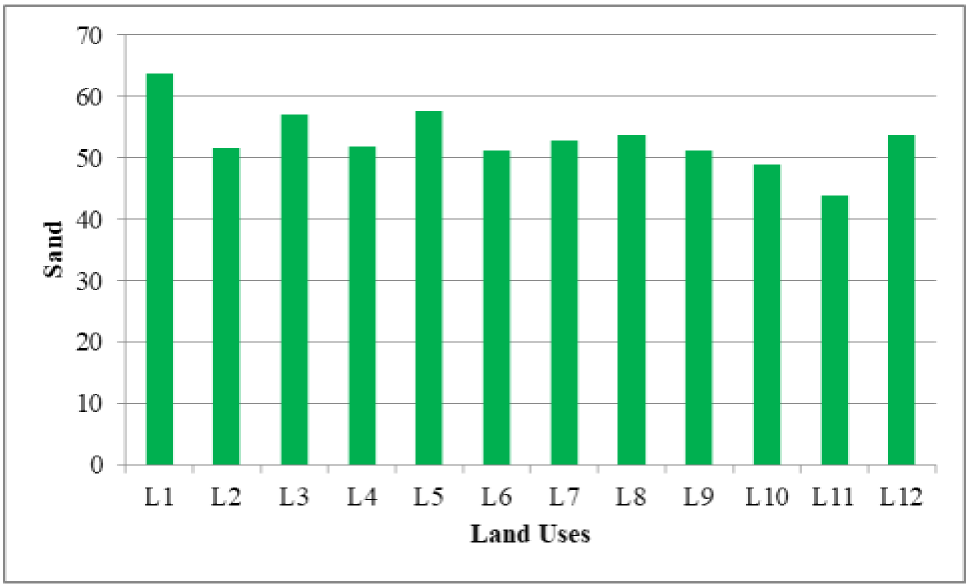
*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6-Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 43. Clay content (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6-Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 44. Silt content (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

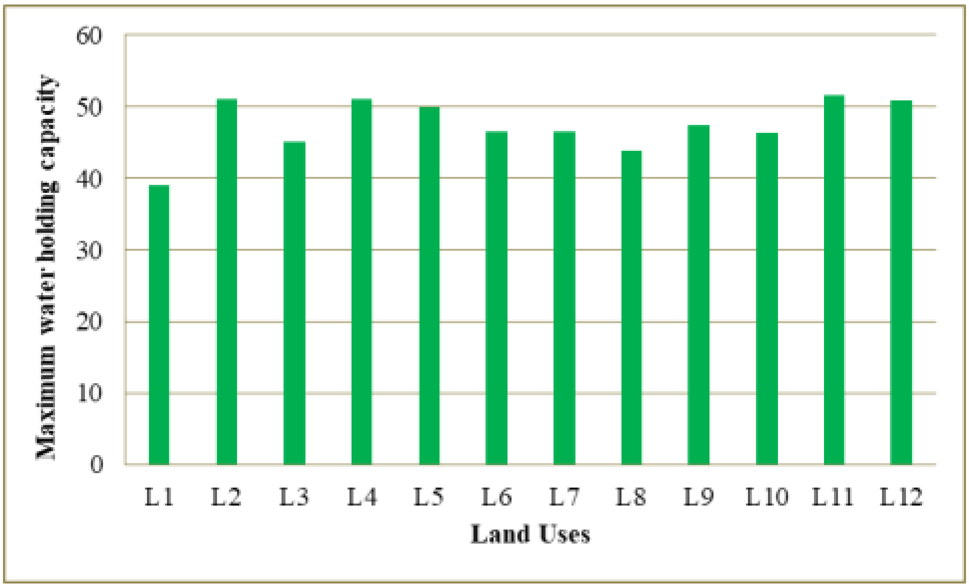


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 45. Sand content (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

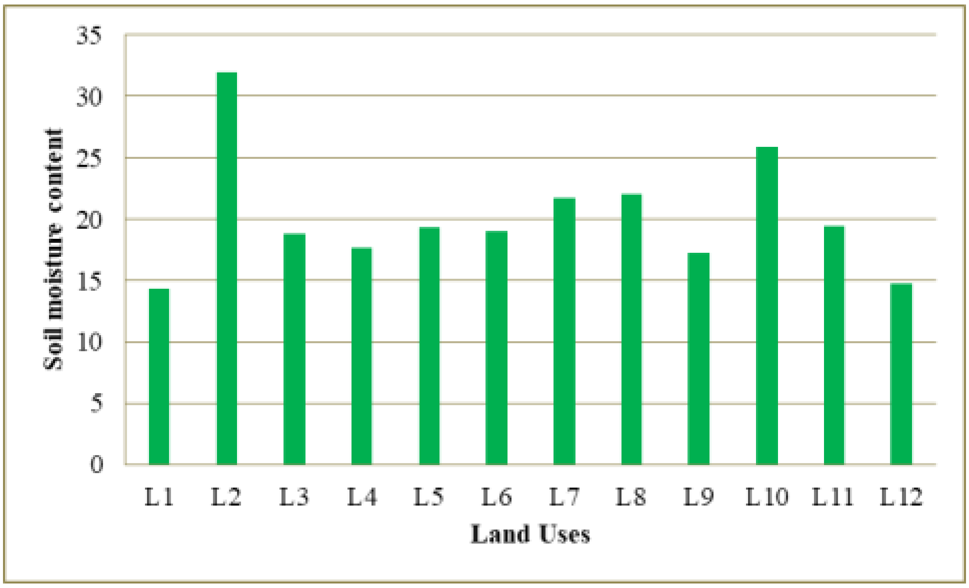
5.6.1.3 Maximum water holding capacity and Soil moisture content

Water holding capacity of soils improves with reduced tillage and regular incorporation of organic manures (Bhriguvanishi, 2008). The maximum water holding capacity was highest under oil palm with higher clay content and less disturbed soils comparatively rich in organic carbon and lowest under banana intercropped with tapioca and vegetables with highest sand content and regular inter cultivation practices. Soil moisture content was also higher under land uses in areas with more clay (Table 28, Fig.46 and 47).



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 46. Maximum water holding capacity (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

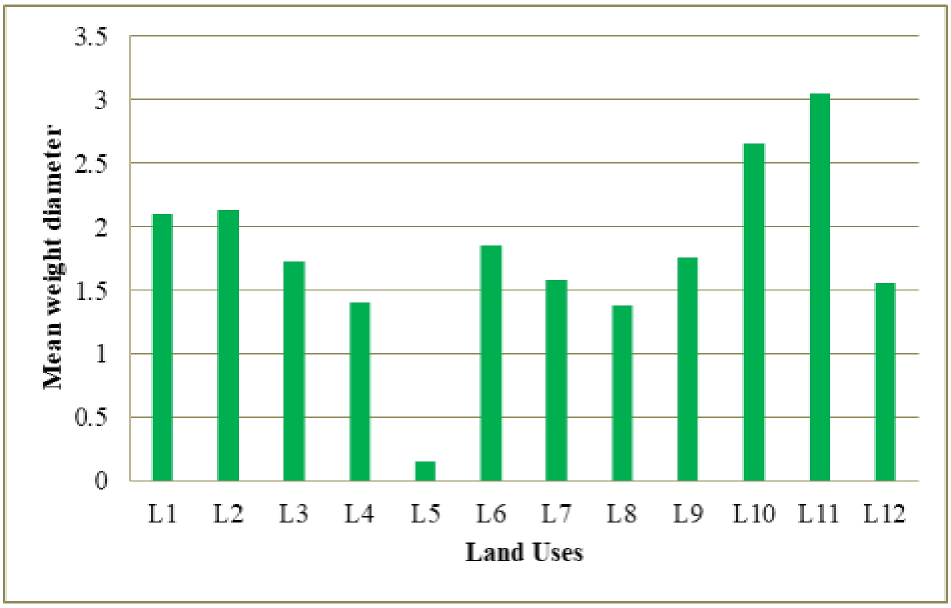


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 47. Soil moisture content (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

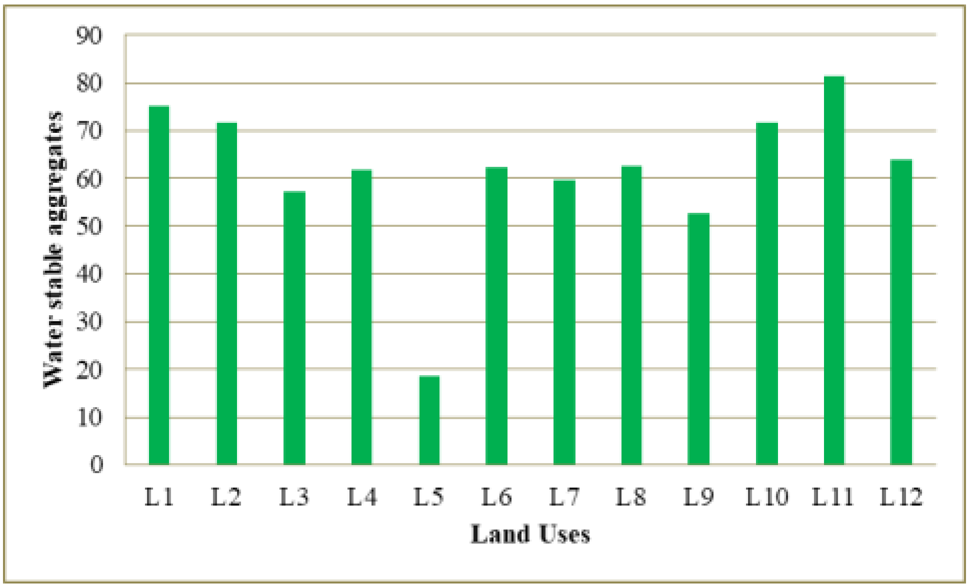
5.6.1.4 Aggregate stability

Mean of MWD and WSA were the highest under oil palm and rubber plantations (Table 29) with less disturbed soils and higher organic carbon (Table 31, Fig. 48 and 49). Absence of regular tillage practices improves aggregate stability and lowers bulk density of soils. The proportion of medium to large sized aggregates (2.0-12.7 mm) tends to increase under long-term no tillage system (Malhi *et al*., 2007). Root exudates also enhance soil aggregate stability as a result of the binding effect of polysaccharides in the exudates (Habib *et al*., 1990). Higher plant cover provides more root exudates and thereby higher aggregate stability. Banana intercropped with tapioca and vegetables and banana with tapioca showed higher aggregate stability compared to banana alone, tapioca alone and vegetables alone (Table 29) indicating the influence of root exudates on aggregate stability.



[*] L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 48. Mean weight diameter (mm) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

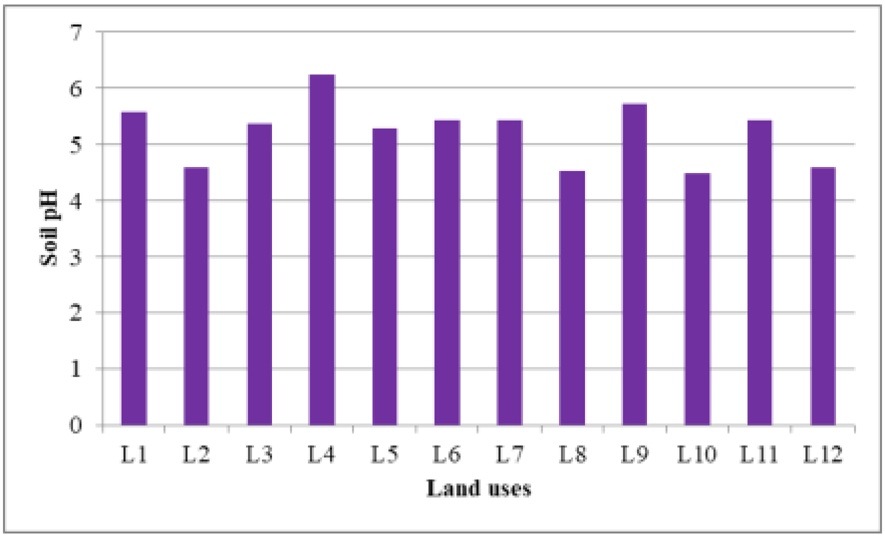
Fig. 49. Water stable aggregates (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.2 Chemical attributes

5.6.2.1 Soil pH and Electrical conductivity

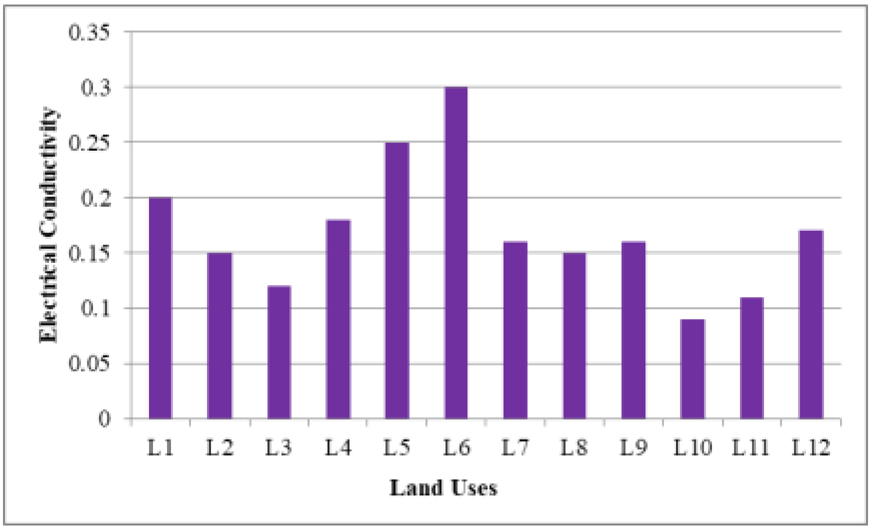
Soil pH showed the highest mean under banana with coconut (6.25) and the lowest under rubber (4.49) (Table 30, Fig. 50). Rubber based land use systems in Kerala are generally low in soil pH (Abraham, 2015). The mean of soil reaction was very strongly acidic under banana intercropped with tapioca, coconut alone, rubber, and other crops; strongly acid under coconut with tapioca, banana alone, tapioca alone, tapioca with vegetables, and oil palm; moderately acid under banana with tapioca and vegetables and vegetables alone, and slightly acid under banana with coconut.

The mean EC was the highest under banana alone (0.30 dS m^{-1}) and lowest under rubber (0.09 dS m^{-1}) (Table 30, Fig. 51). Lower electrical conductivity was observed in rubber plantations in Ultisols by Nithya (2013). Much variation in EC was not observed among different land uses. This might be due to the washing away of soluble salts from the soil profile due to the heavy rainfall received in the study area.



[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 50. pH in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



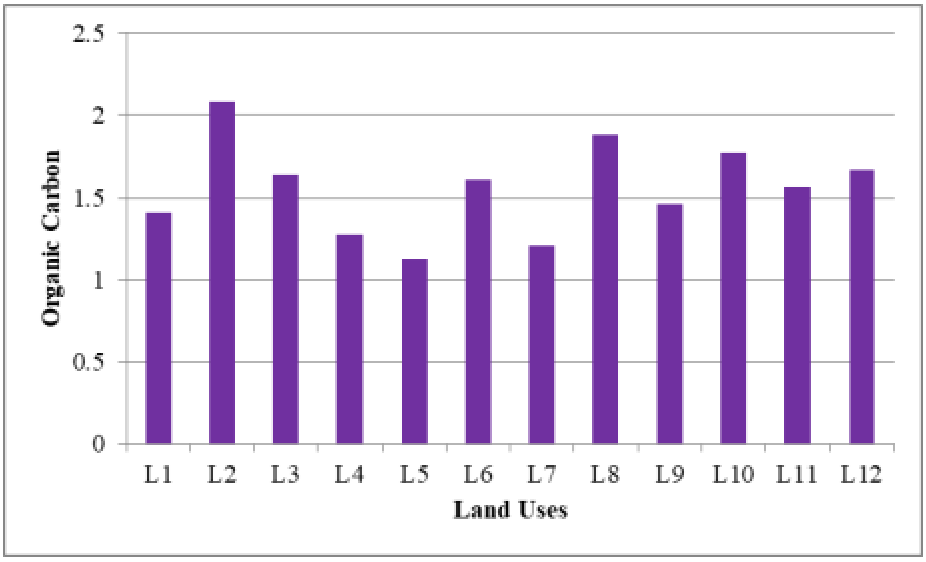
[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 51. EC (dSm^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.2.2 Organic carbon and Available primary nutrients

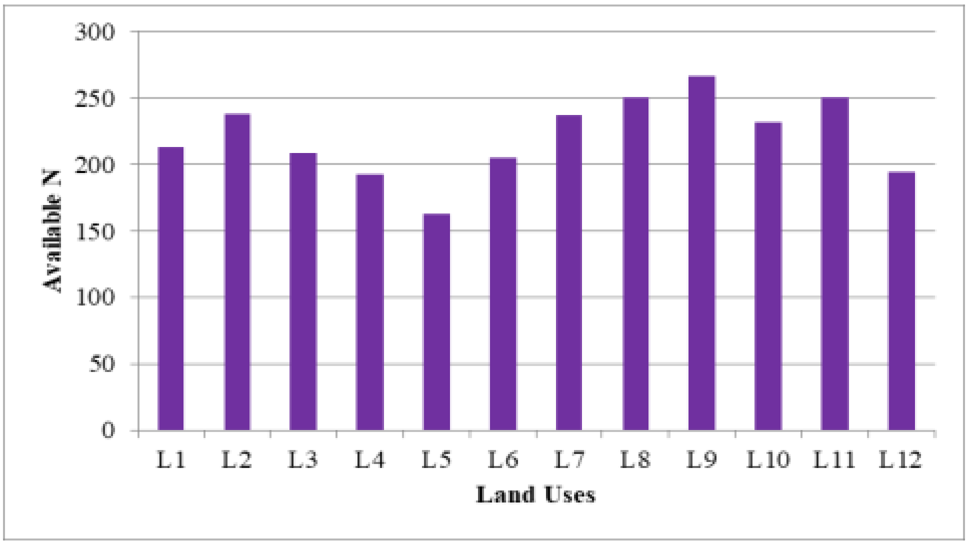
Mean organic carbon was high under many land uses except banana intercropped with tapioca and vegetables, banana with coconut, tapioca with vegetables, tapioca alone and vegetables alone. Comparatively lower organic carbon was observed under land uses with higher rate of inter cultivation practices due to improvement in soil aeration which enhances the breakdown of soil organic matter. In spite of application of organic manures, land use with vegetables alone showed a mean organic carbon in the medium range. This might be due to higher rate of decomposition of organic matter, washing away of organic matter and excessive sediment deposits burying organic matter in many vegetable fields. Even though banana and tapioca are exhaustive crops, the highest mean organic carbon was obtained under banana intercropped with tapioca (Table 31, Fig. 52) since organic nutrient management practices are followed by majority of the farmers in the study area. Moreover, this land use was prevalent in Pramadam, Pathanamthitta and Kalanjoor area with lesser sediment deposits, lower pH and higher organic matter content in soils. Mean organic carbon was also higher under oil palm, rubber and other crops with lesser disturbances to the soil and lower pH hindering the decomposition of organic matter.

Available N was low for all samples under tapioca intercropped with vegetables (Table 31, Fig.53) and banana with tapioca and vegetables, and low to medium under other land uses, which can be attributed to the lower pH which affects mineralisation. Mean available P was high for most of the samples under all land uses (Table 31, Fig. 54). Oil palm showed the lowest mean available P due to the absence of regular application of phosphatic fertilizers. Available K was low to high under all land uses (Table 31, Fig. 55) with the highest value under other crops followed by coconut alone and tapioca alone. Medium to high available K in soils was observed in land uses with application of potassium fertilizers.



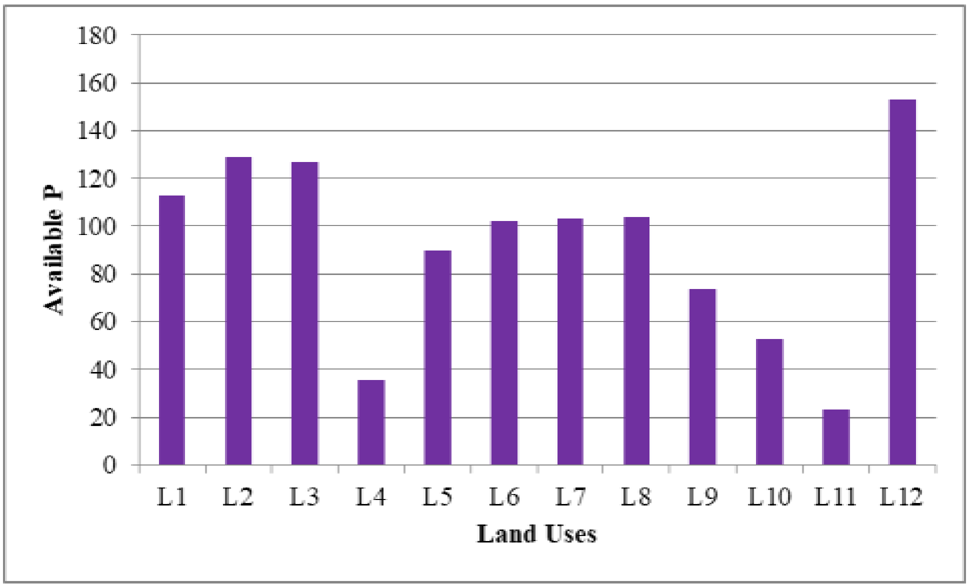
*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 52. Organic carbon (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



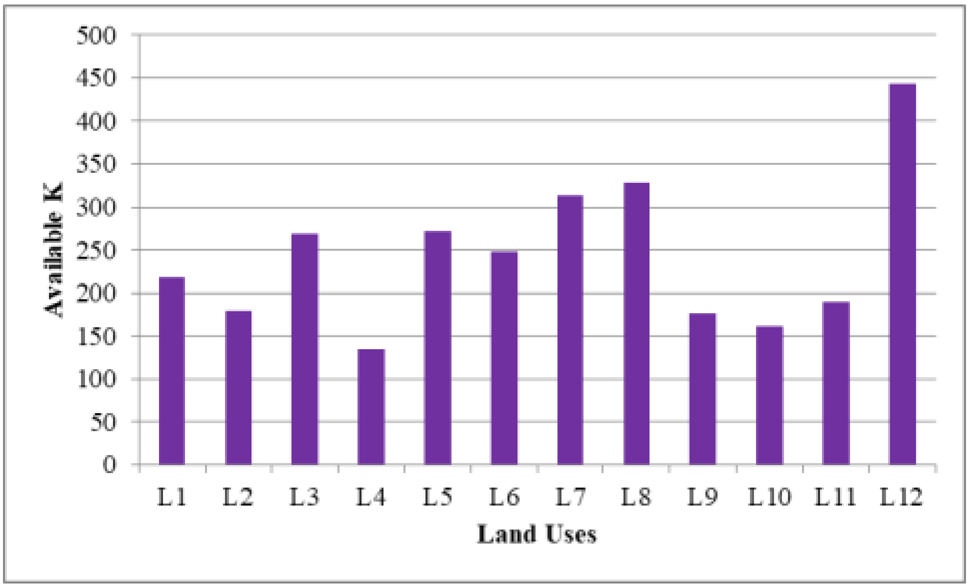
*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 53. Available N (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 54. Available P (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

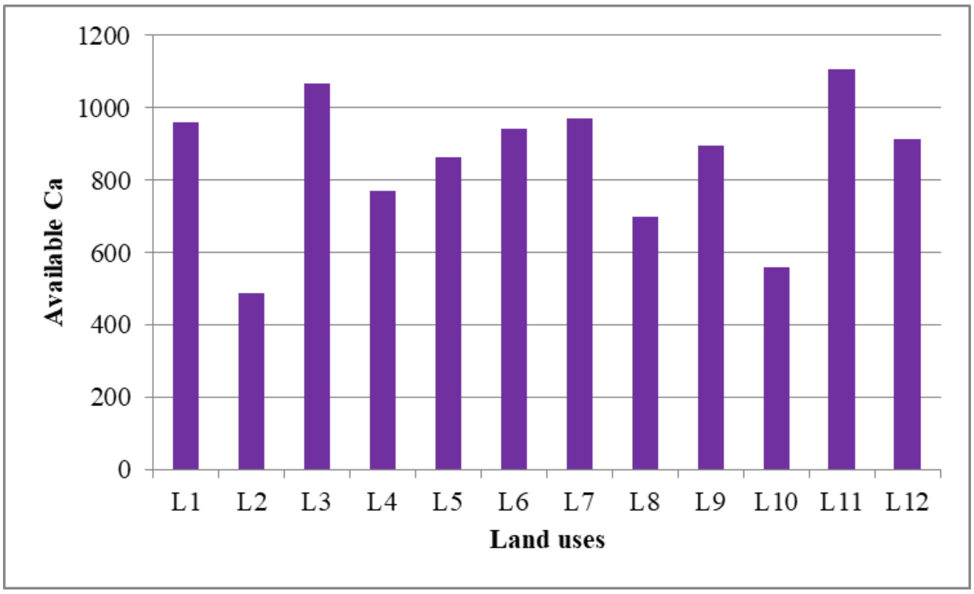


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 55. Available K (kg ha^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.2.3 Available secondary nutrients

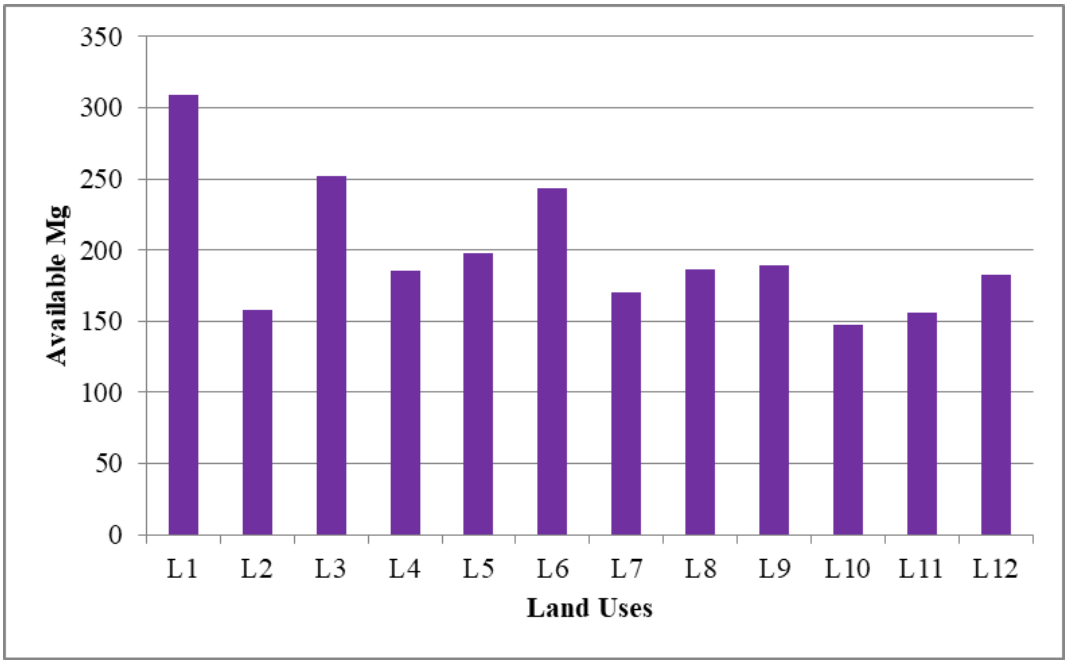
Available Ca was adequate for almost all samples under different land uses with the highest mean under oil palm (Table 32, Fig. 56). Available Ca was observed to be positively correlated with silt content and comparatively higher Ca was observed in crop lands with silt deposition. Available Ca was comparatively lower under land uses with lower pH. Liming of soils cultivated with coconut, rubber, banana and tapioca during the previous years have also contributed to the build up of Ca in soils.



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 56. Available Ca (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

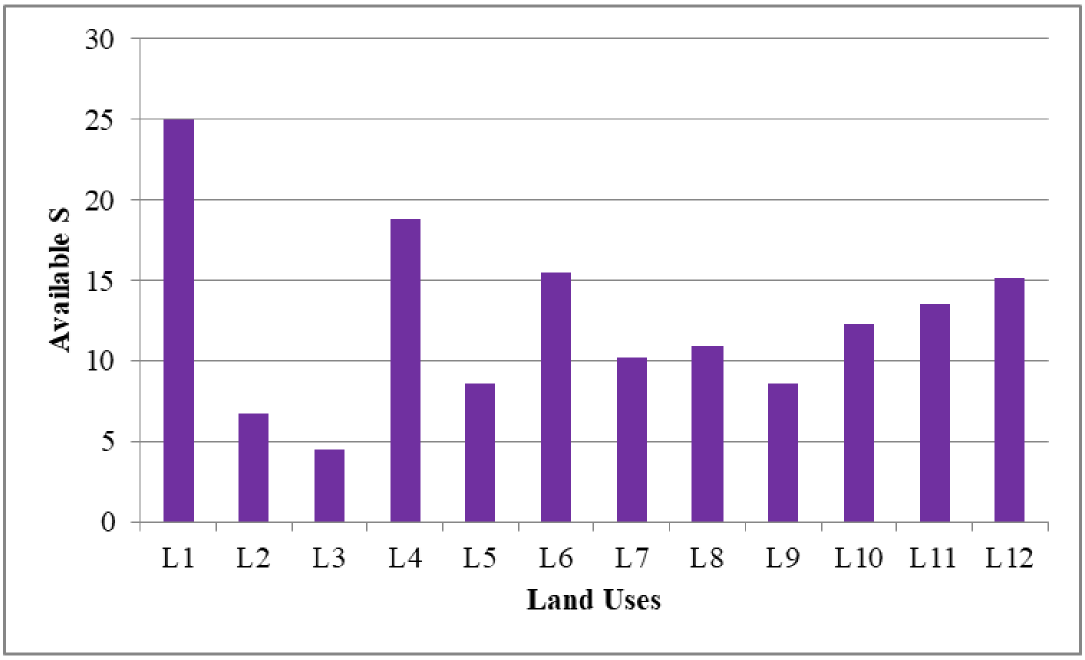
Mean available Mg was in the adequate range for all the land uses (Table 32, Fig. 57). Silt deposition in the crop fields has improved the soil pH and Mg status under different land uses. Mg was comparatively lower under land uses with lesser pH. Available S showed the highest mean under the land use with banana intercropped with tapioca and vegetables and lowest under banana with tapioca (Table 32, Fig. 58).



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6-Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12-Other crops

Fig.57. Available Mg (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

Use of sulphur containing fertilizers like ammonium phosphate sulphate over the previous years has improved the available S in rubber growing soils. Higher pH of soils under banana with tapioca and vegetables, banana with coconut and banana alone along with the application of factamphos over the years has improved the status of available S under these land uses. Available S was generally lower under land uses with organic nutrient management system as in the case of vegetables alone, tapioca with vegetables etc.

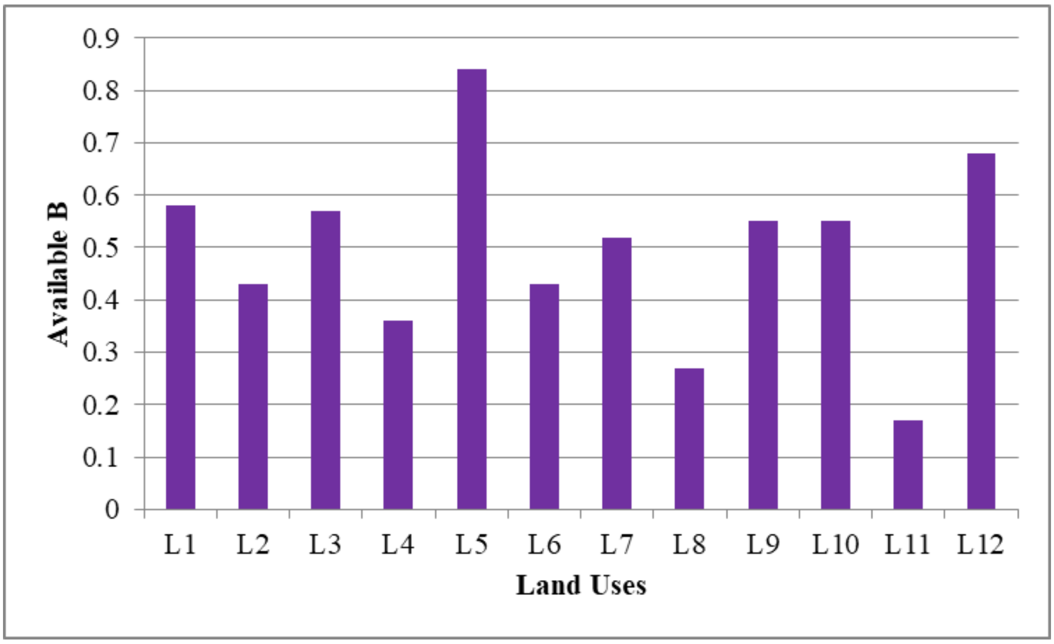


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 58. Available S (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.2.4 Available boron

Available B was deficient to adequate for samples under all the land uses. Mean available B was highest under tapioca intercropped with vegetables and lowest under oil palm (Table 33, Fig. 59). Higher available B might be due to B additions through the deposits during the severe flood. Low available B was observed under oil palm in spite of sediment deposition which can be attributed to the combined effect of higher organic matter, available N and Ca in soils of oil palm plantations. Organic matter tightly binds a large part of B in soils which get released slowly in available forms due to microbial activity (Berger and Pratt, 1963). A negative correlation was observed between available N and B in the study area. Higher Ca in soil may also reduce B availability due to the formation of calcium metaborate (Sillanpaa, 1972).



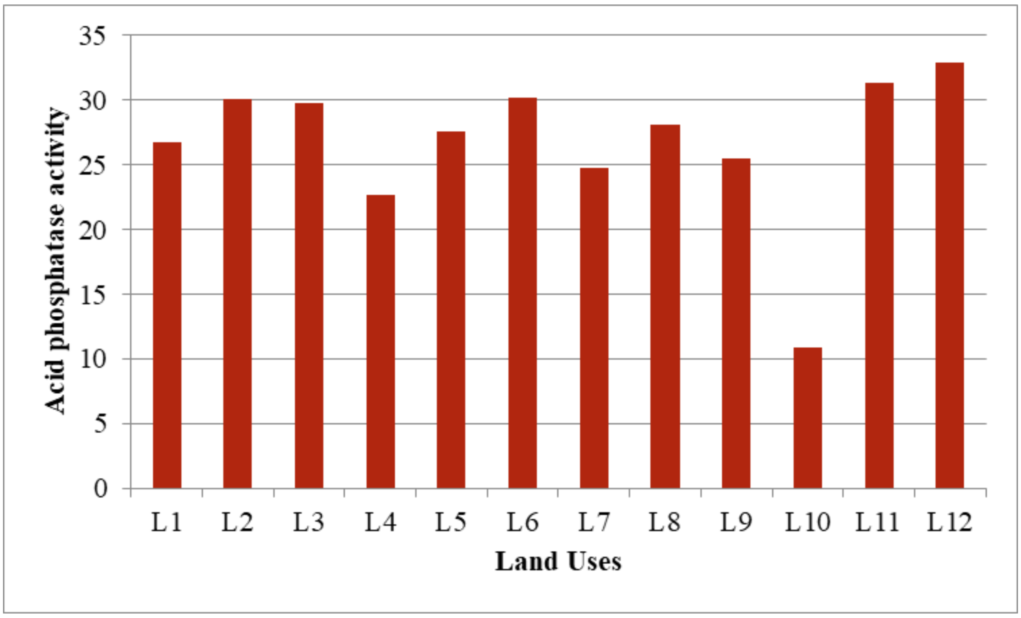
*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 59. Available B (mg kg^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.3 Biological attributes

5.6.3.1 Acid phosphatase activity

Acid phosphatase activity was significantly and positively correlated with soil organic carbon and available K in the study area. The highest mean of acid phosphatase activity was observed in other crops with highest mean of available K and the lowest in rubber (Table 34, Fig. 60). Low acid phosphatase activity in rubber in spite of higher organic carbon can be attributed to continuous application of phosphatic fertilizers during the previous years which increases available P in soil thereby reducing the mineralisation of organic P.

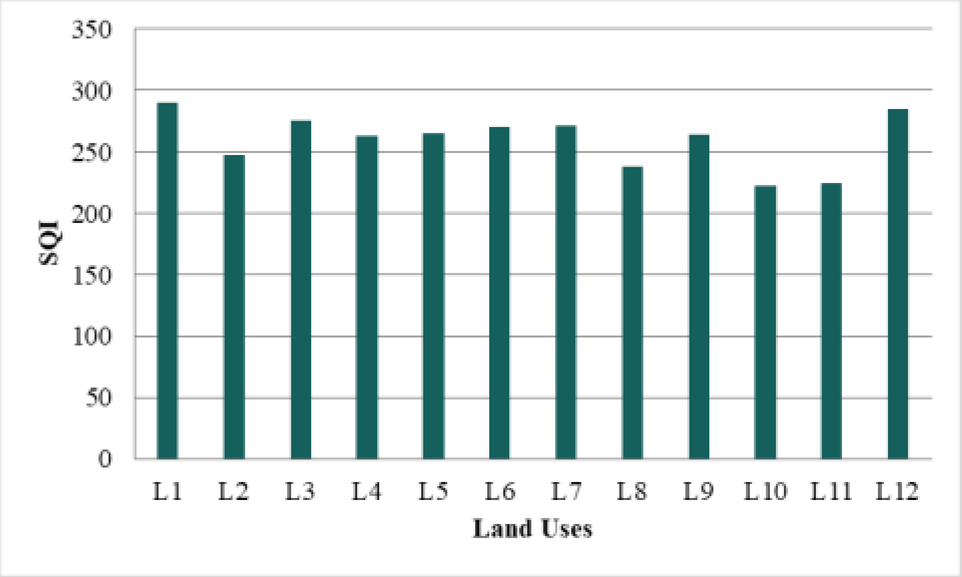


*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 60. Acid phosphatase activity (µg PNP produced g soil^{-1}h^{-1}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

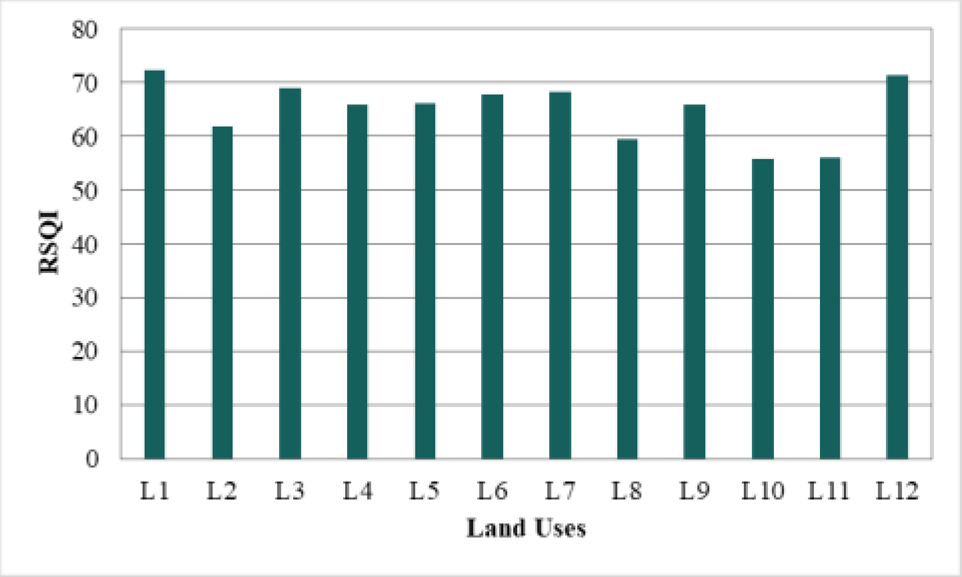
5.6.4 Soil Quality Index

Soil quality index was based on a minimum data set of parameters *viz.* soil pH, available P, K, Mg, B, silt and sand percent, bulk density and acid phosphatase activity. Mean soil quality index and relative soil quality index was the highest under banana with tapioca and vegetables followed by other crops and lowest under rubber (Table 35, Fig. 61 and 62). Low soil quality in rubber plantations was due to very strongly acid pH, comparatively lower P, K, B and acid phosphatase activity.



[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 61. SQI in the post-flood soils of AEU 12 in Pathanamthitta under different land uses



[*]L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

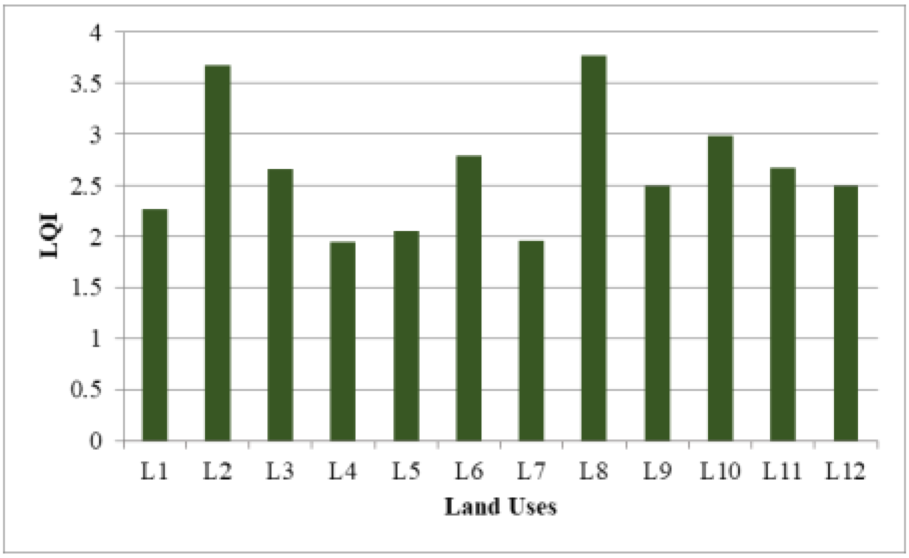
Fig. 62. RSQI (%) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.6.5 Nutrient Index

Nutrient index of organic carbon was high in banana intercropped with tapioca (3.00), rubber alone, (2.75), other crops (2.75), coconut alone (2.50), banana alone (2.33), coconut with tapioca (2.33) and medium in banana with tapioca and vegetables (2.25), vegetables alone (2.25), oil palm (2.25), banana with coconut (2.00), tapioca with vegetables (2.00) and tapioca alone (1.90). Nutrient index of available N was low in all the land uses whereas the nutrient index of available P was high except in rubber and oil palm (medium). Nutrient index of available K was medium in most of the land uses except for other crops, coconut with tapioca, tapioca alone (high) and banana with coconut (low) (Table 36). This is in line with the organic carbon and available primary nutrient statuses under different land uses.

5.6.6 Land Quality Index

Land quality index was calculated based on soil organic carbon. Thus, land uses comparatively rich in organic carbon showed higher land quality (Table 37, Fig. 63). The land quality index was very low under most of the land uses except coconut alone and banana with tapioca (low).



*L1- Banana intercropped with tapioca and vegetables; L2-Banana intercropped with tapioca; L3- Coconut intercropped with tapioca; L4- Coconut intercropped with banana; L5- Tapioca intercropped with vegetables; L6- Banana alone; L7- Tapioca alone; L8- Coconut alone; L9- Vegetables alone; L10- Rubber, L11- Oil palm, L12- Other crops

Fig. 63. LQI (kg m^{-2}) in the post-flood soils of AEU 12 in Pathanamthitta under different land uses

5.7 MANAGEMENT STRATEGIES FOR CROP PRODUCTION IN THE POST-FLOOD SOILS OF PATHANAMTHITTA DISTRICT

Majority of the farmers in the area cultivates banana (53.3%), followed by tapioca (40.0%), vegetables (20.0%) and coconut (20.0%). The other cultivated crops include rubber, cocoa, oil palm, cashew, arecanut, pepper etc. Physicochemical characteristics of the post flood soils have shown significant variations necessitating a revision in the crop production strategies of the area. Soil reaction showed wide variation in the study area. Organic carbon, available N and K status deteriorated whereas available P, Mg and B improved to sufficiency levels in many areas which can be attributed to sediment deposition and application of chemical fertilizers during the previous years.

Soil pH was extremely acidic to strongly acidic in large parts of Kalanjoor, Konni, Pramadam and Pathanamthitta stipulating an elevation in the quantity of liming materials to be applied and a change in the schedule of liming. Soil pH was strongly acid to neutral in Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi indicating lesser lime requirement.

Organic carbon was high in most parts of Ranni-Angadi, Konni, Pramadam, Kalanjoor and Pathanamthitta whereas medium in Ranni-Perunnadu, Vadaserikkara and Naranammoozhi. A reduction in per cent of samples with high organic carbon compared to the pre flood data was also observed. Moreover, very low organic carbon contents were observed in crop lands close to the river with excessive sediment deposition in Vadaserikkara and Naranammoozhi. Aggeregate stability and water holding capacity were also lower in these soils. These observations necessitate an increase in the quantity of organic manure applied to the soils.

Available N was low in 80 per cent of the area indicating a need to increase the dosage of nitrogenous fertilizers and organic manure to the crops. Application of phosphatic fertilizers can be reduced since available P was very high in most of the area. Deterioration in available K status was observed in post-flood soils demanding an incorporation of potassium sources to the soils. Available Ca was adequate for 90 per cent of the area with comparatively higher concentration in soils of Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi. Though available Mg status improved in the post-flood soils, deficiency was observed in 32 per cent of the samples. Use of dolomite for liming can provide Mg and improve the nutrient level. Available S status showed a decline in the post-flood soils mainly due to leaching of soluble sulphates through erosion especially in Konni, Pramadam, Kalanjoor and Pathanamthitta. The nutrient levels were comparatively higher in areas with application of factamphos and also with sediment deposition. Application of nitrogenous fertilizers like ammonium sulphate and complex fertilizers like factamphos can correct S deficiency in soils. Available B was deficient for more than 60 per cent of the area indicating a need to promote the application of B fertilizers like borax and solubor. Adopting such management strategies can improve soil health and crop productivity of the post flood soils of AEU 12 of Pathanamthitta district.

5.7.1 Nutrient recommendation at panchayath levels based on soil test results

Soil test based recommendations for each panchayath are given below (KAU, 2016).

5.7.1.1 Kalanjoor

- The soil reaction was extremely acid to very strongly acid (Fig. 13) with a mean of 4.36 (Table 12). Therefore, lime application @ 850 kg ha^{-1} is recommended.

- Soil organic carbon was high for most of the area (Fig. 16) with a mean of 1.6 per cent (Table 13) which requires the application of organic manures as per POP recommendation and N @ 71per cent of the POP recommendation.

- Available P was very high in the area (Fig. 20) with a mean of 151 kg ha^{-1}(Table 13). Application of P fertilizers can be avoided for three years since the nutrient is abundant. But soil tests should be conducted annually to assess P levels in the soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.

- Available K was medium for most of the area and high in some area (Fig. 22) with a mean of 301 kg ha^{-1} (Table 13). Potassium sources can be applied @ 48 per cent of the POP recommendation.

- Available Ca was adequate for most of the area (Fig. 24) with a mean of 564 mg kg^{-1} (Table 14). Application of lime as per the lime requirement is sufficient.

- Available Mg was adequate for most of the area (Fig. 26) with a mean of 153 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.

- Available S was adequate in most of the area and deficient in few areas (Fig. 28) with a mean of 5.3 mg kg^{-1} (Table 14) demanding an application of S @ 25 kg ha^{-1}.

- Available B was deficient in most of the area and adequate in some area (Fig. 30) with a mean of 0.44 mg kg^{-1} (Table 15). The deficiency can be corrected by the application of borax @ 10 kg ha^{-1} or 0.5 per cent solution of borax as foliar spray.

5.7.1.2 Konni

- Soil reaction was very strongly acid (Fig. 13) for most of the area with a mean of 4.91 (Table 12) which can be ameliorated by applying lime @ 600 kg ha^{-1}.

- Soil organic carbon was high for most of the area and medium in few areas (Fig. 16) with a mean of 1.79 per cent (Table 13). Therefore, application of N fertilizers @ 71 per cent of the POP recommendation is suitable. Organic manure should also be applied as per POP recommendation.

- Mean available P was 81.5 kg ha^{-1} (Table 13) and available P was high for most of the area (Fig. 20) necessitating a reduction in the application of P fertilizers. Application P fertilizers can be avoided for three years as the nutrient is abundant. But soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.

- Available K was medium in most of the area (Fig. 22) with a mean of 183 kg ha^{-1} (Table 13). K fertilizers can be provided @ 83 per cent of the POP recommendation.
- Available Ca adequate for the area (Fig. 24) with a mean of 653 mg kg^{-1} (Table 14). Additional application of Ca is not required as soil gets calcium through liming to ameliorate acidity.
- Available Mg was adequate for most of the area and deficient in some parts (Fig. 26) with a mean of 130 mg kg^{-1} (Table 14). $MgSO_4$ can be applied @ 80 kg ha^{-1}.
- Available S adequate for most of the area and deficient in few areas (Fig. 28) with a mean of 9.68 mg kg^{-1} (Table 14) which can be supplemented through sulphate sources @ 25 kg S per ha.
- Available B was deficient in most of the area and adequate in few parts (Fig. 30) with a mean of 0.5 mg kg^{-1} (Table 15). Therefore, the application of borax @ 10 kg ha^{-1} or 0.5 per cent of borax solution as foliar spray is recommended in areas with deficiency.

5.7.1.3 Pramadam

- Soil reaction was very strongly acid (Fig. 13) for most of the area with a mean of 4.73 (Table 12). Application of lime @ 600 kg ha^{-1} is recommended.
- Organic carbon was high for most of the area and medium in few areas (Fig. 16) with a mean of 2.02 per cent (Table 13) stipulating application of N @ 63 per cent of the POP recommendations and organic manures as per POP recommendation.

- Available P was high for most of the area (Fig. 20) with a mean of 109 kg ha^{-1} (Table 13). Application P fertilizers can be avoided for three years as the nutrient is abundant. But soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.
- Available K medium for most of the area and high in some areas (Fig. 22) with a mean of 254 kg ha^{-1} (Table 13) which requires the provision of K @ 60 per cent of the POP recommendation.
- Available Ca was adequate in the area (Fig. 24) with a mean of 820 mg kg^{-1} (Table 14). Available calcium gets supplemented through liming.
- Available Mg was adequate in the area (Fig. 26) with a mean of 164 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.
- Available S was adequate in most areas and deficient in some parts (Fig. 28) with a mean of 7.50 mg kg^{-1} (Table 14). Provision of S @ 25 kg ha^{-1} is suitable.
- Available B was deficient in most of the area and sufficient in some parts (Fig. 30) with a mean of 0.24 mg kg^{-1} (Table 15). Application of 10 kg borax per ha or 0.5% solution of borax as foliar spray can correct the deficiency.

5.7.1.4 Pathanamthitta Municipality

- Soil reaction was very strongly acid (Fig. 13) for most of the area with a mean of 4.66 (Table 12) creating a lime requirement @ 600 kg ha^{-1}.
- Organic carbon was high in the area (Fig. 16) with a mean of 2.23 per cent (Table 13) requiring the application of organic manures as per POP recommendation and N @ 54 per cent of the POP recommendation.

- Available P was high in the area (Fig. 20) with a mean of 80.6 kg ha^{-1} (Table 13) indicating a need to restrict P application to avoid wastage. Application P fertilizers can be avoided for three years as the nutrient is abundant. But soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.

- Available K was medium in most of the area and high in few parts (Fig. 22) with a mean of 226 kg ha^{-1} (Table 13). Application of K @ 71 per cent of the POP recommendation is recommended.

- Available Ca was adequate in most areas and deficient in few parts (Fig. 24) with a mean of 535 mg kg^{-1} (Table 14). Calcium gets supplemented through liming.

- Available Mg was adequate in most of the area and deficient in some parts (Fig. 26) with a mean of 113 mg kg^{-1} (Table 14). The deficiency can be corrected by the application of $MgSO_4$ @ 80 kg ha^{-1}.

- Available S was adequate in majority of the area and deficient in some locations (Fig. 28) with a mean of 6.44 mg kg^{-1} (Table 14). S @ 25 kg ha^{-1} can be applied.

- Available B was deficient in some parts and adequate in other areas (Fig. 30) with a mean of 0.62 mg kg^{-1} (Table 15). Therefore, application of Borax is not necessary in areas with adequate levels whereas application of borax @ 10 kg ha^{-1} or 0.5% of borax solution as foliar spray is recommended in areas with deficiency.

5.7.1.5 Vadaserikkara

- Soil pH was moderately acid to neutral (Fig. 13) for most of the area with a mean of 5.87 (Table 12). Therefore, the liming @ 250 kg $CaCO_3$ is recommended.

- Organic carbon was medium for most of the area (Fig. 16) with a mean of 0.98 per cent (Table 13) stipulating the application of organic manures at higher rates and N @ 91 per cent of the POP recommendation. Very low organic carbon (0.38%) (Fig. 26) and available N (75.3 kg ha^{-1}) (Fig. 19) were observed in areas close to the river with excessive sedimentation. In such areas, application of organic manures in more quantities and N @ 117 per cent of the POP recommendation is suggested to improve the soil carbon and N status.

- Available P was high in most of the area (Fig. 20) with a mean of 86.8 kg ha^{-1} (Table 13). Application of P fertilizers can be avoided for three years. But soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.

- Available K was medium for most of the area, high in some parts and low in few locations (Fig. 22) with a mean of 206 kg ha^{-1} (Table 13) indicating a requirement of K @ 71 per cent of the POP recommendation.

- Available Ca was adequate for the entire area (Fig. 24) with a mean of 1020 mg kg^{-1} (Table 14). Calcium will get supplemented through liming.

- Available Mg was also adequate for the entire area (Fig. 26) with a mean of 245 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.

- Available S was adequate for most of the area (Fig. 28) with a mean of 16.8 mg kg^{-1} (Table 14). Application of S @ 25 kg ha^{-1} is recommended.

- Available B was deficient in majority of the area and adequate in some (Fig. 30) with a mean of 0.46 mg kg^{-1} (Table 15). Therefore, the application of borax @ 10 kg ha^{-1} or 0.5 per cent of borax solution as foliar spray is recommended in areas with deficiency.

5.7.1.6 Ranni-Angadi

- Soil reaction was strongly acid to slightly acid (Fig. 13) for most of the area with a mean of 5.61 (Table 12). Therefore, application of lime @ 250 kg ha^{-1} is recommended.

- Soil organic carbon was high in most of the area and medium in few areas (Fig. 16) with a mean of 1.83 per cent (Table 13). Application of N @ 71 per cent of the POP recommendation and organic manures as per POP recommendation can be done.

- Available P was high in majority of the area (Fig. 20) with a mean of 63 kg ha^{-1} (Table 13). Therefore, application of P fertilizers can be skipped for three years except in few areas with medium and low levels of available P (Fig. 20). Very low available P was recorded in sampling locations with excessive sedimentation. Such areas require the application of P @ 128 per cent of POP recommendation. Soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed in areas currently high in available P if the available P values get diminished to medium or low levels.

- Available K was medium in most of the area, high in some parts and low in few locations (Fig. 22) with a mean of 269 kg ha^{-1} (Table 13). Application of K @ 60 per cent of the POP recommendation is recommended.

- Available Ca was adequate for most of the area (Fig. 24) with a mean of 1035 mg kg^{-1} (Table 14). Calcium is supplied into the soil through liming.

- Available Mg adequate for majority of the area and deficient in few locations (Fig. 26) with a mean of 259 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.

- Available S adequate in majority of the area and deficient in few locations (Fig. 28) with a mean of 15.1 mg kg^{-1} (Table 14). Application of S @ 25 kg ha^{-1} is recommended.

- Available B deficient in majority of area and sufficient in few locations (Fig. 30) with a mean of 0.29 mg kg^{-1} (Table 15). Therefore, the application of borax @ 10 kg ha^{-1} or 0.5 per cent of borax solution as foliar spray is recommended for areas with deficiency.

5.7.1.7 Ranni-Perunnadu

- Soil pH was moderately acid to neutral for most of the area and strongly acid in some parts (Fig. 13) with a mean of 5.63 (Table 12). Provision of lime @ 250 kg ha^{-1} is recommended.

- Soil organic carbon was medium in most of the area and high in some parts (Fig. 16) with a mean of 1.39 per cent (Table 13). Application of N @ 78 per cent of the POP recommendation and organic manure as per POP recommendation is suitable for this area.

- Available P was high for most of the area (Fig. 20) with a mean of 97.3 kg ha^{-1} (Table 13). Application of P fertilizers can be restricted in the area for three years since available P is high. Soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils gets diminished to medium or low levels.

- Available K was medium for most the area and high in few locations (Fig. 22) with a mean of 218 kg ha^{-1} (Table 13). Available K status in the area stipulates the application of K @ 71 per cent of POP recommendation.

- Available Ca adequate for the entire area (Fig. 24) with a mean of 943 mg kg^{-1} (Table 14). Calcium application is as per the lime requirement provided for amelioration of soil acidity.

- Available Mg was adequate for almost the entire area (Fig. 26) with a mean of 292 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.

- Available S was adequate for the entire area (Fig. 28) with a mean of 29.8 mg kg^{-1} (Table 14). Application of S @ 25 kg ha^{-1} is recommended.

- Available B was adequate in almost half of the area and deficient in rest of the area (Fig. 30) with a mean of 0.63 mg kg^{-1} (Table 15). Application of borax @ 10 kg ha^{-1} or 0.5 per cent solution of borax as foliar spray is recommended for areas with deficiency.

5.7.1.8 Naranammooozhi

- Soil reaction was strongly acid to slightly acid in majority of the area (Fig. 13) with a mean of 5.74 (Table 12) demanding the application of lime @ 250 kg ha^{-1}.

- Soil organic carbon was medium in most of the area, high in few locations and low in some areas (Fig. 16) with a mean of 1.08 per cent (Table 13) stipulating the application of organic manure as per the POP recommendation and N @ 84 per cent of the POP recommendation. Very low organic carbon (0.14%) and available N (25.1 kg ha^{-1}) was observed in the areas close to the river with excessive sedimentation. Such areas require the application of more organic manures and N @ 128 per cent of POP recommendation.

- Available P was high for almost the entire area (Fig. 20) with a mean of 113 kg ha^{-1} (Table 13). Therefore, the application of P fertilizers can be skipped in the area for three years. Soil tests should be conducted annually to assess P levels in soil and application of P as per POP recommendation should be resumed if the available P content in soils get diminished to medium or low levels.

- Available K was high for most of the area and medium in some locations (Fig. 22) with a mean of 304 kg ha^{-1} (Table 13). K @ 48 per cent of the POP recommendation can be applied.
- Available Ca was adequate for the entire area (Fig. 24) with a mean of 1046 mg kg^{-1} (Table 14). Calcium is supplied through liming of soil.
- Available Mg was adequate for most of the area and deficient in few locations (Fig. 26) with a mean of 230 mg kg^{-1} (Table 14). Application of $MgSO_4$ @ 80 kg ha^{-1} is recommended.
- Available S was adequate in most of the area and deficient in a few locations (Fig. 28) with a mean of 13.8 mg kg^{-1} (Table 14). Application of S @ 25 kg ha^{-1} is recommended.
- Available B was adequate for almost half of the area and deficient in the remaining areas (Fig. 30) with a mean of 0.63 mg kg^{-1} (Table 15). Application of borax @ 10 kg ha^{-1} or 0.5 per cent solution of borax as foliar spray is recommended for areas with deficiency.

FUTURE LINE OF WORK

- The study shows that the soil fertility status of AEU 12 in Pathanamthitta district has altered after the severe floods of 2018. Therefore, a revision is required in the nutrient management schedule for different crops cultivated in the area based on the current fertility status of the soils.
- Analysis of soil nutrient status on a yearly basis followed by revision in soil management strategies should be undertaken to attain higher crop productivity and sustainability which can help to mitigate the effect of heavy floods and land slides.

Summary

6. SUMMARY

The study entitled “Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala and generation of GIS maps” was carried out with the objectives to assess the soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district, to develop GIS maps on soil quality and characteristics and to work out a soil quality index. A survey was conducted in the study area based on a pre designed questionnaire during April 2019 and seventy five georeferenced surface soil samples were collected from eight flood affected panchayaths, *viz.* Kalanjoor, Konni, Pramadam, Pathanamthitta, Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi. The samples were analysed for physical (bulk density, particle density, porosity, soil texture, depth of sand/silt/clay deposition, maximum water holding capacity, soil moisture and aggregate analysis), chemical (pH, EC, organic carbon, available N, P, K, Ca, Mg, S and B) and biological (acid phosphatase activity) parameters. The georeferenced data along with analysis results were used for the preparation of GIS based thematic maps of soil characters and quality of the area.

A minimum data set of soil quality indicators was set up using principal component analysis to assess soil quality. Seventeen selected parameters (bulk density, water holding capacity, water stable aggregates, per cent of sand, silt and clay, pH, EC, organic carbon, available N, P, K, Ca, Mg, S, B and acid phosphatase activity) were analysed using principal component analysis yielding a MDS of nine parameters retained from six principal components with eigen value greater than one. The selected indicators were categorised into 4 classes, *viz.*, very poor, poor, good and very good and assigned with scores 1, 2, 3 and 4 respectively. A weighted SQI and a relative soil quality index were developed by combining the scores after assigning appropriate weights to the parameters. The soils were rated as poor, medium or good based on the relative soil quality index. Nutrient indices were computed at panchayath levels for organic carbon and available primary nutrients. A land quality index was also calculated based on soil organic carbon stock. The salient findings of the study are summarised below.

- The major crops cultivated in the area were banana, cassava, coconut, rubber, vegetables, oil palm and cocoa. Banana (53.3%) and cassava (40%) were the crops cultivated by majority of farmers.
- 46.7 per cent of the farmers surveyed followed INM, 33.3 per cent conventional and 20 per cent organic farming practices.
- Most of the holdings were less than 2 ha in size. Homestead farming was prevalent in the area.
- Severe crop loss was reported in AEU 12 during the 2018 flood. The extent of damage was more in Ranni-Angadi, Vadaserikkara and Naranammoozhi.
- In the post-flood soils of Vadaserikkara and Ranni-Angadi (close to Pampa river) with excessive sediment deposition, wilting and N deficiency symptoms were observed in vegetable crops.
- Deposition of sediments in huge quantities was observed in Ranni-Angadi, Vadaserikkara and Naranammoozhi.
- Konni area had the highest mean of bulk density (1.29 Mg m^{-3}) and lowest mean of porosity (44.1%) and available K (183 kg ha^{-1}).
- The highest mean of soil moisture content (34.7%), available P (151 kg ha^{-1}) and the lowest mean of pH (4.36) and S (5.30 mg kg^{-1}) were observed in Kalanjoor.
- The highest mean of MWD (3.16mm), WSA (83.4%), porosity (59.9%), organic carbon (2.23%), available N (271 kg ha^{-1}) and the lowest mean of bulk density (1.0 Mg m^{-3}), EC (0.14 dS m^{-1}), available Ca (535 mg kg^{-1}) and Mg (113 mg kg^{-1}) were observed in Pathanamthitta.
- The lowest mean of available B (0.23 mg kg^{-1}) and the highest mean of EC (0.24 dS m^{-1}) and water holding capacity (58.2%) were recorded in Pramadam.
- Ranni-Angadi recorded the lowest mean of available P (63 kg ha^{-1}) and particle density (2.13 Mg m^{-3}).

- Ranni-Perunnadu recorded the highest mean of particle density (2.51 Mg m^{-3}), available Mg (292 mg kg^{-1}), available S (29.8 mg kg^{-1}) and acid phosphatase activity (35.8 µg PNP produced g $soil^{-1}$ h^{-1}).
- The highest mean of available B (0.63 mg kg^{-1}) was observed in Naranammoozhi and Ranni-Perunnadu.
- Naranammoozhi also showed the highest mean of available K (304 kg ha^{-1}) and Ca (1046 mg kg^{-1}), and the lowest mean of soil moisture content (13.1%), water holding capacity (41.8%) and available N (177 kg ha^{-1}).
- The highest mean of pH (5.87) and lowest mean of MWD (0.47mm), WSA (28.6%), acid phosphatase activity (5.87 µg PNP produced g $soil^{-1}$ h^{-1}) and organic carbon (0.98%) were observed in Vadaserikkara.
- Majority of the samples had a BD <1.2 Mg m^{-3} (65.3%), PD <2.2 Mg m^{-3} (42.7%), porosity between 50 and 70 per cent (56%), soil moisture content between 15 and 25 per cent (34.7%), water holding capacity between 30 and 50 per cent (57.3%), WSA >70 per cent (54.7%) and MWD >2mm (40%).
- Sandy clay loam was the predominant soil textural class observed in the area (57.3 per cent) followed by loam (9.3%), sandy clay (8%), clay loam (8%), clay (6.7%), loamy sand (5.3%) and sandy loam (5.3%).
- Soil pH was very strongly acidic for 25.3 per cent of the samples and extremely acid for 22.7 per cent. EC was less than 1 dS m^{-1} for all the samples. Organic carbon was high for 50.7 per cent of the samples.
- Majority of the samples were low in available N (81.3% samples), high in available P (82.7% samples) and medium in available K (58.7% samples).
- Most of the samples were adequate in available Ca (90.7%), Mg (68%) and S (65.3%) and deficient in available B (62.7%).
- Acid phosphatase activity was between 25 and 50 µg PNP produced g $soil^{-1}$ h^{-1} for 44 per cent of the samples and between 10 and 25 µg PNP produced g $soil^{-1}$ h^{-1} for 42.7 per cent.

- Principal component analysis yielded a MDS consisting of pH, available P, K, Mg, B, sand per cent, silt per cent, bulk density and acid phosphatase activity which were used to compute a weighted SQI.
- The highest mean of SQI was for Naranammoozhi (283), followed closely by Ranni-Perunadu (278), Vadasserikkara (278) and Ranni-Angadi (272). The highest mean value of RSQI was 70.8 per cent obtained for Naranammoozhi and the lowest mean was 58.7 per cent obtained for Kalanjoor.
- Medium soil quality was obtained for 54.67 per cent of the samples and good for 36 per cent. Soil quality was observed to be higher in the panchayaths in Pampa basin with moderately acid to neutral pH and relatively higher available K, Ca, Mg and B.
- Nutrient indices for available N, P and K were low, high and medium respectively for the entire area. Nutrient index for organic carbon was high except for Vadaserikkara, Naranammoozhi and Ranni-Perunnadu (medium). Land quality was very low for 62.7 per cent of the samples and low for 37.3 per cent.
- Comparison with pre flood data of KSPB (2013) shows an increase in per cent of samples with extremely acid pH from 18.4 per cent to 22.7 per cent. Extremely acid pH was mainly observed in Kalanjoor, Konni, Pramadam and Pathanamthitta region which experienced high velocity flow of flood water. The increase in soil acidity indicates leaching of basic cations.
- Soil samples under slightly acid pH range in the area increased from 4 per cent in the pre flood study to 9.33 per cent after the floods. Neutral pH was also observed for 16 per cent of the samples. Moderation in pH was mostly seen in the Ranni-Angadi, Ranni-Perunnadu, Vadaserikkara and Naranammoozhi areas in Pampa basin which experienced sediment deposition.
- Per cent of samples with high levels of available P and adequate levels of available Mg and B was higher after the flood whereas per cent of

samples adequate in available S and high levels of available K declined.

- The major land use systems in the study area were intercropping of banana with tapioca and vegetables, banana with tapioca, coconut with tapioca, coconut with banana, tapioca with vegetables, and sole cropping of banana, tapioca, coconut, vegetables, rubber and oil palm.
- Other crops like cocoa, arecanut, pepper, nutmeg, mangosteen, elephant foot yam also were cultivated in the area.
- The most frequently encountered textural class in the different land uses was sandy clay loam except in coconut intercropped with tapioca (sandy clay), coconut alone (clay), vegetables alone (clay loam) and oil palm (clay loam).
- Banana intercropped with tapioca and vegetables showed the highest mean of available Mg (309 mg kg^{-1}) and S (25.0 mg kg^{-1}) and the lowest mean of porosity (44.4%), water holding capacity (39.0%) and soil moisture content (14.3%).
- The highest mean of soil moisture content (32.0%) and organic carbon (2.08%) and the lowest mean of particle density (2.13 Mg m^{-3}) and available Ca (486 mg kg^{-1}) were obtained for banana intercropped with tapioca.
- Coconut intercropped with tapioca showed the highest mean porosity (54.8%) and lowest mean of available S (4.50 mg kg^{-1}) whereas banana with coconut recorded the highest mean of soil pH (6.25) and the lowest mean of available K (134 kg ha^{-1}).
- Tapioca intercropped with vegetables showed the highest mean particle density (2.56 Mg m^{-3}) and available B (0.84 mg kg^{-1}) and lowest mean of MWD (0.15 mm), WSA (18.6%), organic carbon (1.13%) and available N (163 kg ha^{-1}).
- Sole cropping of banana showed the highest mean EC (0.30 dSm^{-1}) whereas the lowest mean of EC (0.09 dSm^{-1}) was obtained for rubber plantations. Rubber plantations also showed the lowest mean of pH

(4.49), available Mg (147 mg kg^{-1}) and acid phosphatase activity (10.9 µg PNP produced g soil^{-1}h^{-1}).

- The highest mean of bulk density was observed in sole cropping of coconut (1.28 Mg m^{-3}) and the lowest in vegetables alone and other crops (1.01 Mg m^{-3}). Monocropping of vegetables also showed the highest mean of available N (267 kg ha^{-1}) whereas other crops cultivated soils showed the highest mean of available P (153 kg ha^{-1}), K (443 kg ha^{-1}) and acid phosphatase activity (32.9 µg PNP produced g soil^{-1}h^{-1}).
- Oil palm plantations showed the highest mean water holding capacity (51.6%), MWD (3.05 mm), WSA (81.3%) and available Ca (1105 mg kg^{-1}) and the lowest mean of particle density (2.13 Mg m^{-3}), available P (23.2 kg ha^{-1}) and B (0.17 mg kg^{-1}).
- Mean soil quality index was the highest under banana with tapioca and vegetables followed by other crops and lowest under rubber. Low soil quality in rubber plantations was due to very strongly acid pH, comparatively lower P, K, B and acid phosphatase activity.
- NI of organic carbon was high except in banana with tapioca and vegetables, vegetables alone (2.25), oil palm alone (2.25), banana with coconut (2.00), tapioca with vegetables (2.00) and tapioca alone (1.90). Nutrient index of available N was low in all the land uses whereas the nutrient index of available P was high except in rubber and oil palm (medium). Nutrient index of available K was medium in most of the land uses except for other crops, coconut with tapioca, tapioca alone (high) and banana with coconut (low).
- The land quality index was very low under most of the land uses except coconut alone and banana with tapioca (low).

Thus, the study shows that soil conditions have changed in the soils of AEU 12 in Pathanamthitta district after the heavy floods during 2018. Soil acidity declined in areas with sediment deposition and increased in areas which experienced soil erosion. Similarly, variations were observed across the area in organic carbon and soil nutrient status. Soil quality and nutrient status were found to be higher in areas with moderate deposition of sand, silt and clay particles as in Naranammoozhi, Vadaserikkara, Ranni-Perunnadu and Ranni-Angadi. Soil physical, chemical and biological properties also varied under different land uses. Therefore, site specific management of soils based on the current nutrient status, cropping system and quality is essential for achieving higher productivity and sustainability.

References

7. References

Abraham, J. 2015. Soil health in different land use systems in comparison to a virgin forest in a tropical region of Kerala. *Rubber Sci.* 28(1): 8-21.

Akpoveta, V. O., Osakwe, S. A., Ize-Iyamu, O. K., Medjor, W. O., and Egharevba, F. 2014. Post flooding effect on soil quality in Nigeria: the Asaba, Onitsha experience. *Open J. Soil Sci.* 12: 13-19.

Alam, M., Islam, M., Salahin, N., and Hasanuzzaman, M. 2014. Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. *Sci. World J.* 2014: 1-15.

Alkorta, I., Aizpurua, A., Riga, P., Albizu, I., Amézaga, I., and Garbisu, C. 2003. Soil enzyme activities as biological indicators of soil health. *Rev. Environ. Health*, 18(1): 65-73.

Alvarez, R. and Steinbach, H. S. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. *Soil Tillage Res.* 104(1): 1-15.

Amacher, M. C., O'Neil, K. P., and Perry, C. H. 2007. *Soil Vital Signs: A New Soil Quality Index (SQI) for Assessing Forest Soil Health.* US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 12p. Available: http://www.fs.fed.us/rm/pubs/rmrs_rp065.pdf . [07 May 2020].

Andrews, S. S. and Caroll, C. R. 2001. Designing a soil quality assessment tool for sustainable agro ecosystem management. *Ecological Appl.* 11(6): 1573-1585.

Andrews, S. S., Karlen, D. L., and Cambardella, C. A. 2004. The soil management assessment framework: a quantitative soil quality evaluation method. *Soil Sci. Soc. Am. J.* 68(6): 1945-1962.

Andrews, S. S., Mitchell, J. P., Mancinelli, R., Karlen, D. L., Hartz, T. K., Horwarth, W. R., Pettygrove, G. S., Scow, K. M., and Munk, D. S. 2002. On farm assessment of soil quality in California's Central Valley. *Agron. J.* 94: 12-23.

Armenise, E., Redmile-Gordon, M. A., Stellacci, A. M., Ciccarese, A., and Rubino, P. 2013. Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment. *Soil Tillage Res.*130: 91-98.

Arshad, M. A. and Coen, G. M. 1992. Characterization of soil quality: physical and chemical criteria. *Am. J. Altern. Agric*. 1: 25-31.

Arshad and Grossman.1996. Physical tests for monitoring soil quality. *J. Indian Soc. Soil Sci.* 32(3): 234-263.

Arshad, M. A. and Martin, S. 2002. Identifying critical limits for soil quality indicators in agroecosystems. *Agric. Ecosyst. Environ.* 88(2): 153-160.

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47(2): 151-163.

Behara, S. K. and Shukla, A. K. 2014. Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. *Land Degradation Dev.* 26: 71-79.

Berger, K. C. and Pratt, P. F. 1963. Boron determination in soils and plants. In: Mcvickar, M. H., Bridger, G. L., and Nelson, L. B. (eds), *Fertilizer Technology and Usage.* SSSA, Madison, pp. 287-340.

Bhriguvanishi, S. S. 2008. *Soil Fertility and Nutrient Management.* Kalyani Publishers, Ludhiyana, 312p.

Bielders, C. L., DeBacker, L.W., and Delvaux, B. 1990. Particle density of volcanic soils as measured with a gas pycnometer. *Soil Sci. Am. J.* 54(3): 822-826.

Binita, N. K., Dasog, G. S., and Patil, P. L. 2009. Soil fertility mapping in Ghataprabha left bank canal command area of north Karnataka by geographic information system technique. *Karnataka J. Agric. Sci.* 22(1): 73-76.

Bissonnais, Y. 1996. Soil characteristics and aggregate stability. In: Agassi, M. (ed.), *Soil Erosion, Conservation and Rehabilitation,* Marcel Dekker, Inc., New York, pp. 41-50.

Blake, G. R. 1965. Bulk density. In: Black, C. A., Evans, D. D., Ensminger, L. E., White, J. L. and Clark, F. E. (eds), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling.* American Society of Agronomy Inc., Madison, USA, pp. 374-390.

Blanco-Canqui, H., Lal, R., Post, W. M., Izaurralde, R. C., and Shipitalo, M. J. 2006. Organic carbon influences on soil particle density and rheological properties. *Soil Sci. Soc. Am. J.* 70(4): 1407-1414.

Bouma, J. 2000. The land quality concept as a means to improve communication about soils. In: Elmholt, S., Stenberg, B., Gronlund, A. and Nuutinen, V. (eds), *Soil Stresses, Quality and Care.* Proceedings of the NJF Seminar 310, Elmholt, Norway. Danish Institute of Agricultural Sciences, Denmark, pp. 1-14.

Bouyoucos, G. J. 1936. Directions for Making Mechanical Analysis of Soils by Hydrometer Method. *Soil Sci.* 4: 225-228.

Bray, R. H. and Kurtz, I. T. 1945. Determining total, organic and available forms of phosphate in soils. *Soil Sci.* 59: 39-45.

Bredja, J. J., Moorman, T. B., Karlen, D. L., and Dao, T. H. 2001. Identification of regional soil quality factors and indicators: I. Central and southern high plains. *Soil Sci. Soc. Am. J.* 64: 2115-2124.

Burger, J. and Kelting, D. 1998. Soil quality monitoring for assessing sustainable forest management. In: Adams, M. B., Ramakrishna, K., and Davidson, E. (eds), *The Contribution of Soil Science to the Development of and Implementation of Criteria and Indicators of Sustainable Forest Management*. Soil Science Society of America Publication, Madison, USA, pp. 17-52.

Burrough, P. A. 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Oxford, Clarendon Press. 381p.

Carter, M. R. 2002. Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. *Agron. J.* 94(1): 38-47.

Chaudhari, P. R., Ahire, D. V., Ahire, V. D., Chkravarty, M., and Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *Int. J. Sci. Res. Publ.* 3(2): 1-8.

CTCRI [Central Tuber Crops Research Institute]. 2018. *Post-flood loss assessment and rehabilitation of tuber crops in Kerala*. Central Tuber Crops Research Institute (Indian Council of Agricultural Research) Sreekariyam, Thiruvanathapuram. 103p.

Dakshinamurthi, C. and Gupta, R. P. 1968. *Practicals in Soil Science.* I.A.R.I, New Delhi, 210p.

Danielson, R. E. and Sutherland, P. L. 1986. Porosity. In: Klute, A. (ed.), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*. American Society of Agronomy, Madison. pp. 443-461.

Das, S. K. and Varma, A. 2010. Role of enzymes in maintaining soil health. In: Shukla, G. and Varma, A. (eds), *Soil Enzymology*. Springer, Berlin, Heidelberg, pp. 25-42.

DePaulObade. V. and Lal, R. 2013. Assessing land cover and soil quality by remote sensing and geographical information systems (GIS). *Catena*, 104: 77–92.

DePaulObade, V. and Lal, R. 2016. Towards a standard technique for soil quality assessment. *Geoderma*, 265: 96-102.

Dickinson, H. and Calkins, H. W. 1988. The economic evaluation of implementing GIS. *Int. J. Geogr. Inf. Syst.* 2: 307-327.

Doran, J. W. and Parkin, T. B. 1994. Defining and assessing soil quality. *Defining Soil Qual. Sustain. Environ.* 35: 1-21.

Doran, J. W. and Parkin, T. B. 1997. Quantitative indicators of soil quality: a minimum data set. *Methods Assess. Soil Qual.* 49: 25-37.

ESRI [Environmental Systems Research Institute]. 2001. *Using ArcGIS Spatial Analyst.* Environmental Systems Research Institute, USA, 238p.

Ferrnades, J. C., Gamero, C. A., Rodrigues, J. G. L., and Mirás-Avalos, J. M. 2011. Determination of the quality index of a Paleudult under sunflower culture and different management systems. *Soil Tillage Res.* 112(2): 167-174.

Gomez, A. A., Swetekelly, D. E., Seyers, J. K., and Coughlan, K. J. 1996. Measuring sustainability of agricultural systems at the farm level. In: Doran, J. W. and Jones, A. J. (eds), *Methods for Assessing Soil Quality*. Soil Science Society of America, Special Publication 49, Madison, WI, pp. 401–410.

Granatstein, D. and Bezdicek, D. F. 1992. The need for a soil quality index: local and regional perspectives. *Am. J. Altern. Agric.* 1: 12-16.

Gregorich, E. G., Carter, M. R., Angers, D. A., Monreal, C., and Ellert, B. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Can. J. Soil Sci.* 74(4): 367-385.

Gregorich, E. G., Carter, M. R., Doran, J. W., Pankhurst, C. E., and Dwyer, L. M. 1997. Biological attributes of soil quality. *Dev. Soil Sci.* 25: 81-113.

Gupta, U. C. 1972. Effects of boron and limestone on cereal yields and on B and N concentrations of plant tissues. *Commun. Soil Sci. Plant Anal.* 6: 439-450.

Haberern, J. 1992. Viewpoint: a soil health index. *J. Soil Water Conserv.* 47: 6.

Habib, L., Morel, J. L., Guckert, A., Plantureux, S. and Chenu, C. 1990. Influence of root exudates on soil aggregation. *Symbiosis*, 9: 87-91.

He, J., Li, H., Rasaily, R. G., Wang, Q., Cai, G., Su, Y., Qiao, X., and Liu, L. 2011. Soil properties and crop yields after 11 years of no tillage farming in wheat–maize cropping system in North China Plain. *Soil Tillage Res.* 113(1): 48-54.

Hesse, P. R. 1971. *A Textbook of Soil Chemical Analysis.* John Murray Publishers Ltd., London, 520p.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Ltd., New Delhi, pp. 219-221.

Jafari, S. and Narges, Z. 2010. Land suitability analysis using multi attribute decision making approach. *Int. J. Environ. Sci. Dev*. 1: 441–445.

John, K. S., Bharathan, R., Nair, M. M., and Suja, G. 2012. Soil based nutrient management plan for tuber crops in Pathanamthitta district of Kerala. *J. Root Crops,* 38(1): 51-59.

Johnson, D. L., Ambrose, S. H., Bassett, T. J., Bowen, M. L., Crummey, D. E., Isaacson, J. S., Johnson, D. N., Lamb, P., Saul, M., and Winter-Nelson, A. E. 1997. Meanings of environmental terms. *J. Environ. Qual.* 26: 581–589.

Joshua, J. K., Anyanwu, N. C., and Ahmed, A. J. 2013. Land suitability analysis for agricultural planning using GIS and multi criteria decision analysis approach in Greater Karu Urban Area, Nasarawa State, Nigeria. *Afr. J. Agric. Sci. Technol*. 1(1): 14-23.

Karlen, D. L., Andrews, S. S., Weinhold, B. J. and Doran, J. W. 2003. Soil quality: humankind's foundation for survival a research editorial by conservation professionals. *J. Soil Water Conserv.* 58(4): 171-179.

Karlen, D. L., Andrews, S. S., Wienhold, B. J,. and Zobeck, T. M. 2008. Soil quality assessment: past, present and future. *Electr. J. Integrative Biosci.* 6(1): 3-14.

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., and Schuman, G. E. 1997. Soil quality: a concept, definition, and framework for evaluation (a guest editorial). *Soil Sci. Soc. Am. J.* 61(1): 4-10.

Karlen, D. L., Rosek, M. J., Gardner, J. C., Allan, D. L., Alms, M. J., Bezdicek, D. F., Flock, M., Huggins, D. R., Miller, B. S., and Staben, M. L. 1999. Conservation Reserve Program effects on soil quality indicators. *J. Soil Water Conserv.* 54(1): 439-444.

Karlen, D. L. and Stott, D. E., 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., and Stewart, B. A. (eds), *Defining Soil Quality for a Sustainable Environment.* SSSA Special Publication 35, Soil Science Society of America, Madison, WI, pp. 53–72.

Karr, J. R. and Dudley, D. R. 1981. Ecological perspective on water quality goals. *Environ. manag.* 5(1): 55-68.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops* (15th Ed.). Kerala Agricultural University, Thrissur, 360p.

Kay, B. D. and Grand, C. D.1996. Structural aspects of soil quality. In: MacEwan, J. M. and Crater, M. R. (eds), *Advances in Soil Quality for Land Management: Science, Practice and Policies*. Proceedings of an international symposium, University of Ballarat, Victoria, p. 37.

Kerala State Biodiversity Board 2018. *Impact of Flood/Landslides on Biodiversity.* Kerala State Biodiversity Board, Thiruvananthapuram, 250p.

Kerala State Biodiversity Board 2019. *Impact of Flood/Landslides on Biodiversity and Ecosystem of Pathanamthitta District and Tribal Livelihood in Idukki and Pathanamthitta Districts.* Centre for management and development, Thiruvanathapuram, 453p.

Kozlowski, T. T. 1984. Extent, causes and impact of flooding. In: Kozlowski, T. T. (ed.), *Flooding and Plant growth*. Academic press, Harcout Brace Jovanovich Publishers, pp.1-5.

KSPB [Kerala State Planning Board]. 2013. *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board, Thiruvanathapuram. 514p.

Kumar, T. and Jhariya, D. C. 2015. Land quality index assessment for agricultural purpose using multi-criteria decision analysis (MCDA). *Geocarto Int.* 30(7): 822-841.

Kundu, S., Coumar, M. V., Saha, J. K., Rajendiran, S., Hati, K. M., Biswas, A. K., Reddy, K. S., and Rao, A. S. 2012. Assessing soil health of Vertisol of AESR 10.1 using selected physical, chemical and biological attributes of soils. *J. Indian Soc. Soil Sci.* 60(4): 281-287.

Lal, R. 1976. No-tillage effects on soil properties under different crops in Western Nigeria. *Soil Sci. Soc. Am. J.* 40(5): 762-768.

Larsen, W. E. and Pierce, F. J. 1991. Conservation and enhancement of soil quality. In: Lai, R. and Pierce, F.J. (eds), *Evaluation for Sustainable Land Management in the Developing World.* Proceedings of the international workshop on evaluation for sustainable land management in the developing world, Chiang Rai, Thailand. International Board for Soil Research and Management, Bangkok, Thailand, pp. 38-46.

Larsen, W. E. and Pierce, F. J. 1994. The dynamics of soil quality as a measure of sustainable management. In: Doran, J. W., Coleman, D. C., Bezdicek, D. F., and Stewart, B. A. (eds), *Defining Soil Quality for a Sustainable Environment,* Vol. 35, SSSA, pp. 37-51.

Liaghat, S. and Balasundram, S. K. 2010. A review: The role of remote sensing in precision agriculture. *Am. J. Agric. Biol. Sci.* 5(1): 50-55.

Lima, A. C. R., Brussaard, L., Totola, M. R., Hoogmoed, W.B., and De Goede, R. G. M. 2013. A functional evaluation of three indicator sets for assessing soil quality. *Appl. Soil Ecol.* 64: 194-200.

Maheswarappa, H. P., Kumari, P. A., Kamalakshiamma, P. G., and Shanavas, M. 2005. Influence of integrated nutrient management and high density multi-species cropping system on soil properties, plant nutrition and yield in root (wilt) affected coconut palms. *Coconut Res. Dev. J.* 21(02): 34-34.

Malczewski, J. 2006. GIS-based multicriteria decision analysis: a survey of the literature. *Int. J. Geogr. Inf. Sci.* 20(7): 703-726.

Malhi, S. S., Moulin, A. P., Johnston, A. M., and Kutcher, H. R. 2007. Short-term and long-term effects of tillage and crop rotation on soil physical properties, organic C and N in a black chernozem in northeastern Saskatchewan. *Can. J. Soil Sci.* 88: 273-282.

Mandal, D. K., Mandal, C., and Velayutham, M. 2001. Development of a land quality index for sorghum in Indian semi-arid tropics (SAT). *Agric. Syst.* 70(1): 335-350.

Massoumi, A. and Cornfield, A. H. 1963. A rapid method for determining sulphate in water extracts of soils. *Analyst*, 88(1045): 321-322.

Mishra, A., Pattnaik, T., Das, D., and Das, M. 2014. Soil fertility maps preparation using GPS and GIS in Dhenkanal District, Odisha, India. *Int. J. Plant Soil Sci.* 3(8): 986-994.

Mukherjee, A. and Lal, R. 2014. Comparison of soil quality index using three methods. *PloS one*, 9(8): 105981.

Murugan, S. S. 2013. *Ground Water Information Booklet of Pathanamthitta District, Kerala.* Technical reports series D, Central Ground Water Board, Ministry of Water Resources, Thrivanathapuram, 30p.

Nakajima, T., Lal, R., and Jiang, S. 2015. Soil quality index of a crosby silt loam in central Ohio. *Soil Tillage Res. 146*: 323-328.

Navas, M., Benito, M., Rodríguez, I., and Masaguer, A. 2011. Effect of five forage legume covers on soil quality at the Eastern plains of Venezuela. *Appl. Soil ecol.* 49:242-249.

Nithya, A. M. 2013. Long term effect of field management on soil quality in Ultisol. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 160p.

Ogbozige, F. J., Adie, D. B., and Abubakar, U. A. 2018. Water quality assessment and mapping using inverse distance weighted interpolation: a case of river Kaduna, Nigeria. *Nigerian J. Technol.* 37(1): 249-261.

Pankhurst, C. E., Doube, B., and Gupta, V. V. S. R. 1997. *Biological Indicators of Soil Health*. CAB International. Oxon, UK, 346p.

Papendick, R. I., Hornick, S. B., and Parr, J. F.1991. Soil quality: The foundation of a sustainable agriculture. *Proc. Int. Conf. Kyusei Nat. Farming*, 2: 7-11.

Parker, F. W., Nelson, W. L., Winter, E., and Miller, L. E. 1951. The broad interpretation of soil test informations. *Agron. J.* 43: 105·1 12.

Parr, J. F., Papendick, R. I., Hornick, S. B., and Meyer, R. E. 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture. *Am. J. Altern. Agric.* 1: 5-11.

Pearson, E. S. 1931. The test of significance for the correlation coefficient. *J. Am. Statistical Assoc.* 26: 128-134.

Pedrazzini, F. R. and McKee, K. L. 1984. Effect of flooding on activities of soil dehydrogenases and alcohol dehydrogenase in rice (Oryza sativa L.) roots. *Soil Sci. Plant Nutr.* 30(3): 359-366.

Ponnamperuma, F. N. 1984. Effects of flooding on soils. In:Kozlowski, T. T. (ed.), *Flooding and Plant growth.* Academic press, Harcout Brace Jovanovich Publishers, pp. 9-45.

Powers, R. F., Tiarks, A. E., and Boyle, J. R. 1998. Assessing soil quality: practicable standards for sustainable forest productivity in the United States. In: Davidson, E.A., Adams, M.B., and Ramakrishna, K. (eds), *The Contribution of Soil Science to the Development and Implementation of Criteria and Indicators of Sustainable Forest Management*. SSSA Special Publication No. 53, SSSA, Madison, WI, pp. 53-80.

Rajasekharan, P., Nair, K. M., John, K. S., Kumar, P. S., Kutty, M. N., and Nair, A. R. 2014. Soil fertility related constraints to crop production in Kerala. *Indian J. Fertil.* 10(11): 56-62.

Ramamurthy, B. and Bajaj, J. C. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. *Fert. News,* 14:25-36.

Rezaei, S. A., Gilkes, R. J., and Andrews, S. S. 2006. A minimum data set for assessing soil quality in rangelands. *Geoderma*, 136(1-2): 229-234.

Roming, D. E., Garlynd, M. J., Harris, R. F., and McSweeney, K. 1995. How farmers assess soil health and quality. *J. Soil Water Conserv*. 50: 229–236.

Sah, R. N. and Mikkelson, D. S. 1989. Phosphorus behaviour in flooded drained soils. *Soil Sci. Soc. Am. J.* 53(6): 1718-1722.

Sahu, N., Reddy, G. P., Kumar, N., and Nagaraju, M. S. S. 2015. High resolution remote sensing, GPS and GIS in soil resource mapping and characterization-A Review. *Agric. Rev.* 36(1): 14-25.

Schoenholtz, S. H., VanMiegroet, H., and Burger, J. A. 2000. A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *For. Ecol. Manag.* 138(1-3): 335-356.

Seybold, C. A., Herrick, J. E., and Brejda, J. J. 1999. Soil resilience: a fundamental component of soil quality. *Soil Sci.* 164(4): 224-234.

Shakhila, S. S. and Mohan, K. 2014. Study of heavy metal contamination on soil and water in major vegetable tracts of Pathanamthitta district, Kerala, India. *Int. J. Eng. Sci. Invent*. 3(12): 34-39.

Shalimadevi, G. M. and Anil Kumar, K. S. 2006. Characteristics of coffee growing soils and their organic carbon stocks in Karnataka state. *Agropedol.* 19(1): 6-14.

Sharma, K. L. and Mandal, B. 2009. Soil quality and its relevance in sustainable agriculture, *J. Indian Soc. Soil Sci.* 57(4): 572-586.

Sharma, K. L., Mandal, B., and Venkateswarlu, B. 2012. Improvement and assessment of soil quality under long-term conservation agricultural practices in hot, arid tropical Aridisol. *Commun. Soil Sci. Plant Anal.* 44: 1033-1055.

Shi, W. 2011. Agricultural and ecological significance of soil enzymes: soil carbon sequestration and nutrient cycling. In: Shukla, G. and Varma, A. (eds), *Soil Enzymology* . Springer, Berlin/Hindelberg, Germany, chapter 3, pp. 43-60.

Shrestha, R. P. 2006. Relating soil electrical conductivity to remote sensing and other soil properties for assessing soil salinity in northeast Thailand. *Land degradation dev.* 17(6): 677-689.

Shukla, M. K., Lal, R. and Ebinger, M. 2006. Determining soil quality indicators by factor analysis. *Soil Tillage Res.* 87(2): 194-204.

Sillanpaa, M. 1972. *Trace Elements in Soils and Agriculture: Vol. 17.* FAO, Rome, 67p.

Singer, M. J. and Ewing, S. 2000. Soil quality. In: Sumner (ed.), *Handbook of Soil Science*. CRC press, Boca Raton, F. L, pp. 271-298.

Singh, A. K., Mazumdar, A. R., Saha, A. R., and Kundu, D. K. 2017. Soil quality changes resulting from long-term fertilizer application under intensive cropping system in alluvial soils. *Commun. Soil Sci. Plant Anal.* 48(13): 1503-1510.

Star, J. L., Estes, J. E., McGwire, K. C., Arvidson, R. E., and Rycroft, M. J. 1997. *Integration of Geographic Information Systems and Remote Sensing*: *Vol. 5*. Cambridge University Press.

Stepniewski, W., Glinski, J., and Ball, B. C. 1994. Effects of compaction on soil aeration properties. *Elsevier Sci.* 1: 167-189.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* 25: 259-260.

Sudha, B. and George, A. 2011. Tillage and residue management for organic carbon sequestration in coconut (Cocos nucifera)-based cropping systems. *Indian J. Agron.* 56(3): 223-227.

Tabatabai, M. A. and Bremner, J. M. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil biol. biochem.* 1(4): 301-307.

Unger, I. M., Motavalli, P. P., and Muzika, R. M. 2009a. Changes in soil chemical properties with flooding: a field laboratory approach. *Agric. Ecosyst. Environ.* 131(1-2): 105-110.

Unger, I. M., Kennedy, A. C. and Muzika, R. M. 2009b. Flooding effects on soil microbial communities. *Appl. Soil Ecol.* 42(1): 1-8.

USDA [United States Department of Agriculture]. 2008. Soil Quality Physical Indicators: Selecting Dynamic Soil Properties to Assess Soil Function [on line]. Soil Quality Technical Note No. 10, soil quality technical notes, Natural Resources Conservation Services, USDA. Available: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050948.pdf. [07 May 2020].

USDA [United States Department of Agriculture]. 2006. Soil bulk density/moisture/aeration [on line]. Soil Quality Kit – Guides for Educators, Natural Resources Conservation Services, USDA. Available: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf [17 July 2020].

Utobo, E. B. and Tewari, L. 2015. Soil enzymes as bioindicators of soil ecosystem status. *Appl. Ecol. Environ Res.* 13(1): 147-169.

Vadyunina, A. F. and Korchagina, Z. A. 1986. Methods of studying the physical properties of soils. *Moscow: Agropromizdat*, 416p.

Valpassos, M. A. R., Cavalcante, E. G. S., Cassiolato, A. M. R., and Alves, M. C. 2001. Effects of soil management systems on soil microbial activity, bulk density and chemical properties. *Pesquisa Agropecuária Brasileira,* 36(12): 1539-1545.

Vasu, D., Singh, S. K., Ray, S. K., Duraisami, V. P., Tiwary, P., Chandran, P., Nimkar, A. M., and Anantwar, S. G. 2016. Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India. *Geoderma,* 282: 70-79.

Vaughan, B. and Howe, J. 1994. Evaluation of boron chelates in extracting soil boron. *Commun. Soil Sci. Plant Anal.* 25: 1071-1084.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.* 31: 29-38.

Wander, M. M. and Bollero, G. A. 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Sci. Soc. Am. J.* 63(4): 961-971.

Wang, S., Li, Z., and Fan, G. 2012. Soil quality and microbes in organic and conventional farming systems. *Afr. J. Microbiol. Res.* 6(24): 5077-5085.

Wang, X. J. and Gong, Z. T. 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma,* 81: 339-355.

Warkentin, B. P. 1995. The changing concept of soil quality. *J. Soil Water conserv.* 50(3): 226-228.

Wymore, A. W. 1993. *Model-Based Systems Engineering. An Introduction to the Mathematical Theory of Discrete Systems and to the Tricotyledon Theory of System Design*. CRC, Boca Raton, FL. 386p.

Yoder, R. E. 1936. A direct method of aggregate analysis and study of the physical nature of erosion losses. *J. Am. Soc. Agron.* 28: 337-351.

Yu, J., Chean, Y., and Wu, J. P. 2009. Cellular automata and GIS based land use suitability simulation for irrigated agriculture. In*: 18th world IMACS/MODSIM Congress*, 13-17 July 2009, Cairns, Australia [On-line]. Available: http://mssanz.org.au/modsim09 [07 May 2020]

Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X., and Liu, S. 2009. The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat–maize cropping system. *Eur. J. Agron.* 31(1): .36-42.

ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 12 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS.

by

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ABSTRACT

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ABSTRACT

The study entitled “Assessment of soil quality in the post-flood scenario of AEU 12 in Pathanamthitta district of Kerala and generation of GIS maps” was undertaken with the objectives of evaluating soil quality in the post-flood area of AEU 12, formulation of soil quality index and generation of GIS maps of soil characters and quality. A survey was conducted during April 2019 in the study area and seventy five georeferenced surface soil samples were collected from eight flood affected panchayaths *viz.,* Kalanjoor, Pramadom, Konni, Pathanamthitta municipality, Ranni-Angadi, Vadaserikkara, Ranni-Perunadu and Naranammoozhi. The major land use systems in the study area were intercropping of banana with tapioca and vegetables, banana with tapioca, coconut with tapioca, coconut with banana, tapioca with vegetables, and sole cropping of banana, tapioca, coconut, vegetables, rubber and oil palm and other crops like cocoa, arecanut, pepper, nutmeg, mangosteen elephant foot yam etc. Most of the farmers apply lime and chemical fertilizers in coconut, banana, cassava and rubber. Vegetable cultivation is mostly organic using indigenous nutrient sources.

The samples were characterized for selected physical, chemical and biological attributes. A minimum data set (MDS) of indicators to assess soil quality was set up using Principal component analysis (PCA). PCA yielded six principal components with eigen value >1 from which highly weighted parameters were selected for the MDS. The MDS consisted of nine parameters *viz.,* sand and silt per cent, bulk density, soil pH, available P, available K, available B, available Mg and acid phosphatase activity. A weighted soil quality index was formulated using the MDS following standard procedures. Land quality index and nutrient indices for organic carbon and available primary nutrients were also worked out. Spatial variability in soil characters, SQI, LQI and NI were mapped using GIS techniques. Status of soil properties and soil quality under different land uses were also assessed and correlations between the analysed parameters were computed.

Deposition of sediments was observed in Ranni-Angadi, Naranammoozhi, Vadaserikkara and Ranni-Perunnadu in the area close to the Pampa river. Majority of the area had a BD <1.2 Mg m^{-3} (65.3%), PD <2.2 Mg m^{-3} (42.7%), porosity between

50 and 70 per cent (56%), soil moisture content between 15% and 25% (36.0%), water holding capacity between 30 and 50 per cent (57.33%), WSA (%) >70 per cent (54.7%) and MWD >2mm (40.0%). The predominant soil textural class in the study area was sandy clay loam. Soil pH was very strongly acidic for 25.3 per cent of the area and extremely acidic for 22.7 per cent. EC was <1 dS m $^{-1}$ for the entire area. Organic carbon was high for 50.7 per cent of the area. Available N was low and available P was high for more than 80 per cent of the area. Available K was in the medium range for 58.7 per cent of the area. Available Ca, Mg and S were adequate and available B deficient for most of the area. Acid phosphatase activity was between 25 and 50 µg PNP produced g soil^{-1} h^{-1} for 44 per cent and between 10 and 25 µg PNP produced g soil^{-1} h^{-1} for 42.7 per cent of the area.

Medium soil quality was obtained for 54.7 per cent of the area and good for 36 per cent. The highest mean was for Naranammoozhi (283), followed by Ranni-Perunadu (278), Vadasserikkara (278) and Ranni-Angadi (272). Land quality was very low for more than 60 per cent of the area. Nutrient indices for available N, P and K were low, high and medium respectively for the entire area. Nutrient index for organic carbon was high except for Vadaserikkara, Naranammoozhi and Ranni-Perunnadu (medium). Soil quality index was found to be the highest for the land use involving intercropping of banana with tapioca and vegetables.

Comparison with the pre flood data of KSPB (2013) showed an increase in the percent of samples with extremely acid, slightly acid and neutral pH, a decline in the percent of area with high organic carbon and available K. Per cent of area with adequate levels of available Ca were similar in the pre flood and post flood study whereas percent of area with adequate available Mg and S declined. Area with adequate available B and high available P showed an increase in the post flood study.

Thus, the present study shows that site specific soil management based on current nutrient status, cropping system and periodic interventions for quality assessment will help in achieving higher productivity and sustainability. Increase in soil acidity in areas which experienced erosion and moderation of pH in areas of deposition and variations in the status of organic carbon, available P, K, Mg, S and B compared to pre flood study necessitate a revision in soil management practices.

Appendices

Appendix I

Post-flood survey questionnaire

Name of the panchayath :

Name and address of the farmer :

Size of holding :

Survey No :

Geocoordinates of the sample :

Crops cultivated :

Nutrient management practices :

Depth of sand/silt/clay deposition after floods :

Appendix II

Area and crop management of sampled locations

Panchayathh/ Municipality	Sample No.	Size of holding	Crops	Nutrient management
Pramadam	1.	20 cent	Tapioca, banana	Conventional
	2.	30 cent	Tapioca	INM
	3.	1 acre	Banana	INM
	4.	50 cent	Cocoa, elephant foot yam and arecanut	INM
	5.	30 cent	Tapioca, banana	INM
	6.	2 acre	Tapioca, Mangosteen	INM
	7.	25 cent	Banana	Conventional
	8.	20 cent	Banana, Taro	INM
	9.	3 acre	Banana, coconut and tapioca	INM
Kalanjoor	10.	10 cent	Tapioca and banana	Organic
	11.	20 cent	Tapioca, banana	INM
	12.	30 cent	Coconut	Conventional
	13.	40 cent	Banana	Conventional
	14.		Tapioca, banana	Organic
Ranni-Angadi	15.	1 acre	Size of holding	INM
	16.	20 cent	Banana and vegetables	Organic
	17.	15 cent	Vegetables	Organic
	18.	25 cent	Banana	INM
	19.	2 acre	Vegetables	Organic
	20.	15 cent	Banana	INM
	21.	5 acre	Nutmeg, pepper, oilpalm and mangosteen	Conventional
	22.	30 cents	Oilpalm	Conventional
	23.	25 cent	Coconut and tapioca	INM
	24.	1 acre	Oilpalm	INM
	25.	3 acre	Banana, coconut, cocoa and pepper	INM
	26.	30 cent	Coconut, banana and Tapioca	Conventional
	27.	1 acre	Banana	INM
Pathanamthitta	28.	15 cent	Vegetables	Organic
	29.	25 cent	Banana and vegetables	INM
	30.	20 cent	Tapioca	INM
	31.	20 cent	Coconut and banana	INM
	32.	35 cent	banana, tapioca and coconut	Conventional
	33.	1 acre	Rubber	Conventional
	34.	1.5 acre	Banana and Tapioca	Organic
	35.	1 acre	Tapioca	Conventional

Panchayathh/ Municipality	Sample No.	Size of holding	Crops	Nutrient management
Ranni-Perunnadu	36.	1.5 acre	Rubber	Conventional
	37.	20 cent	Banana	INM
	38.	35 cent	Banana	INM
	39.	6 acre	Rubber, Banana, coconut, arecanut, pepper and cocoa	Conventional
	40.	30 cent	Banana and tapioca Vegetables	Conventional
	41.	35 cent	Arecanut, banana, coconut and vegetables	INM
Vadaserikkara	42.	30 cent	Tapioca and Vegetables	Organic
	43.	15 cent	Banana	INM
	44.	35 cent	Vegetables, banana and tapioca	INM
	45.	5.5 acre	Nutmeg, cocoa, coconut, banana	Conventional
	46.	35 cent	Banana and tapioca Vegetables	Organic
	47.	25 cent	Banana, tapioca and Vegetables	INM
	48.	6 acre	Tapioca and vegetables	INM
	49.	25 cent	Tapioca and vegetables	Organic
	50.	30 cent	Tapioca and vegetables	Organic
	51.	25 cent	Banana	Conventional
Naranammoozhi	52.	30 cent	Vegetables	Organic
	53.	5 acre	Tapioca	Conventional
	54.	1.5 acre	Pepper, coconut, cocoa and tapioca	Conventional
	55.	20 cent	Banana	INM
	56.	30 cent	Tapioca	Conventional
	57.	20 cent	Tapioca	Conventional
	58.	1 acre	Banana	Conventional
	59.	20 cent	Tapioca	INM
	60.	1 acre	Coconut	INM
	61.	20 cent	Elephant foot yam and taro	Conventional
	62.	40 cent	Cashew	Conventional
	63.	2 acres	Banana and coconut	INM
	64.	1.5 acre	Tapioca	Conventional
Konni	65.	50 cent	Rubber	Conventional
	66.	20 cent	Banana and tapioca	Organic
	67.	1 acre	Rubber	INM
	68.	30 cent	Banana	INM
	69.	25 cent	Coconut	INM
	70.	25 cent	Banana	INM
	71.	30 cent	Oil palm	Conventional
	72.	25 cent	Banana	INM
	73.	40 cent	Coconut	Organic
	74.	20 cent	Banana	INM
	75.	1 acre	Tapioca	Organic

Appendix III

ANALYSIS RESULTS (for individual samples)

A. Results of physical parameters (for individual samples)

Panchayath/ Municipality	Sample No.	PD (Mg m^{-3})	BD (Mg m^{-3})	Porosity (%)	SMC (%)	Max.WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Pramadom	1	2.00	1.16	42.00	28.56	52.77	0.287	19.9	46.2	20	33.8	Clay
	2	2.26	1.08	52.21	25.63	64.74	1.202	65.92	36.2	20	43.8	Clay loam
	3	2.17	1.26	41.94	18.92	60.39	1.342	65.18	31.2	15	53.8	Sandy clay loam
	4	2.13	1.00	53.15	24.86	54.71	2.075	78.26	31.2	10	58.8	Sandy clay loam
	5	2.13	1.01	52.58	36.29	58.95	1.691	76.4	26.2	20	53.8	Sandy clay loam
	6	2.15	1.16	46.05	21	52.77	1.488	71.62	36.2	15	48.8	Sandy clay
	7	2.15	1.00	53.58	25.63	64.74	1.202	65.92	46.2	20	33.8	Sandy clay loam
	8	2.17	1.01	53.46	18.92	60.39	1.342	65.18	36.2	20	43.8	Sandy clay loam
	9	2.26	1.08	52.21	24.86	54.71	0.287	19.9	26.2	20	53.8	Sandy clay
Kalanjoor	10	2.30	1.32	42.61	45.4	63.09	2.89	80.7	36.2	15	48.8	Sandy clay
	11	2.44	1.39	43.03	26.81	53.44	1.61	75.3	36.2	10	53.8	Sandy clay
	12	2.32	1.18	49.14	23.13	55.07	1.441	73.52	41.2	15	43.8	Clay
	13	2.57	1.20	53.31	36.11	40.77	1.877	72.48	31.2	10	58.8	Sandy clay loam
	14	2.61	1.24	52.49	41.94	41.5	3.397	88.36	31.2	10	58.8	Sandy clay loam
Ranni-Angadi	15	2.14	1.00	53.32	16.98	51.46	1.742	69.96	31.2	20	48.8	Sandy clay loam
	16	2.00	1.44	43.00	12.7	49.62	1.506	73.6	26.2	30	43.8	Loam
	17	1.80	1.34	25.56	16.65	44.98	2.54	77.6	31.2	30	38.8	Clay loam
	18	1.80	1.33	34.16	12.16	49.35	0.706	33.84	26.2	30	43.8	Loam
	19	2.33	1.10	52.96	20.92	57.79	1.502	39.3	31.2	25	43.8	Clay loam
	20	2.05	0.97	52.68	11.08	54.45	2.19	70.68	26.2	40	33.8	Loam
	21	2.05	0.97	52.68	11.08	54.45	1.904	84.2	31.2	20	48.8	Sandy clay loam
	22	2.34	0.99	57.69	39.5	60.29	4.628	86.78	46.2	20	33.8	Clay

Panchayath/ Municipality	Sample No.	PD (Mg m^{-3})	BD (Mg m^{-3})	Porosity (%)	SMC (%)	Max.WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Ranni-Angadi	23	2.81	1.07	61.92	23.64	44.68	3.242	88.14	31.2	10	58.8	Sandy clay loam
	24	2.02	1.34	33.66	12.16	49.35	1.742	69.96	31.2	20	48.8	Loam
	25	2.05	0.97	52.68	20.92	57.79	1.506	73.6	26.2	30	43.8	Sandy clay loam
	26	2.34	0.99	57.69	39.5	60.29	4.628	86.78	46.2	20	33.8	Sandy clay loam
	27	2.00	1.07	46.50	23.64	44.68	3.242	88.14	31.2	10	58.8	Clay
Pathanamthitta	28	2.31	1.12	51.52	21.62	42.52	2.634	77.54	31.2	10	58.8	Sandy clay loam
	29	2.51	1.06	57.77	20.55	45.17	3.266	84.32	31.2	10	58.8	Sandy clay loam
	30	2.41	0.95	60.58	26.47	67.09	3.002	96.8	21.2	25	53.8	Sandy clay loam
	31	2.48	0.97	60.89	19.09	62.36	2.613	87.96	31.2	20	48.8	Sandy clay loam
	32	2.52	1.12	55.56	10.3	40.24	3.07	92.14	26.2	10	63.8	Sandy clay loam
	33	2.64	0.86	67.42	43.37	37.38	4.024	75.4	21.2	15	63.8	Sandy clay loam
	34	2.51	1.06	57.77	20.55	45.17	2.634	77.54	31.2	10	58.8	Sandy clay loam
	35	2.64	0.86	67.42	43.37	37.38	4.024	75.4	21.2	15	63.8	Sandy clay loam
Ranni-Perunnadu	36	2.46	1.11	54.88	27.9	55.93	2.34	84.9	31.2	15	53.8	Sandy clay loam
	37	2.6	1.21	53.46	16.78	45.07	2.047	79.68	31.2	25	43.8	Clay loam
	38	2.46	1.36	44.72	30.55	37.44	1.599	79.46	36.2	15	48.8	Sandy clay
	39	2.60	1.17	55.00	19.72	52.05	1.506	73.6	31.2	15	53.8	Sandy clay loam
	40	2.56	1.27	50.39	23.13	41.25	2.88	81.06	31.2	20	48.8	Sandy clay loam
	41	2.35	1.01	57.02	16.45	55.66	1.97	81.6	26.2	15	58.8	Sandy clay loam

Panchayath/ Municipality	Sample No.	PD (Mg m^{-3})	BD (Mg m^{-3})	Porosity (%)	SMC (%)	Max.WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Vadaserikkara	42	2.61	1.44	44.83	12.7	44.41	0.119	11.8	31.2	10	58.8	Sandy clay loam
	43	2.39	1.17	51.05	16.52	40.84	0.022	1.68	46.2	15	38.8	Sandy clay loam
	44	2.59	1.45	44.02	14.72	40.79	0.339	49	26.2	20	53.8	Clay
	45	2.50	1.08	56.80	14.02	43.29	0.109	11.2	26.2	20	53.8	Sandy clay loam
	46	1.80	1.2	33.33	8.62	29.62	1.464	63.02	11.2	15	73.8	Loamy sand
	47	1.80	1.14	36.67	9.11	29.62	2.083	75.28	11.2	15	73.8	Loamy sand
	48	2.50	1.08	56.80	12.7	56.29	0.119	11.8	31.2	10	58.8	Sandy clay loam
	49	2.50	1.08	56.80	42.81	68.04	0.022	1.68	46.2	15	38.8	Sandy clay loam
	50	2.61	1.44	44.83	9.11	30.79	0.339	49	11.2	15	73.8	Loamy sand
	51	2.10	1.17	44.29	9.52	35.73	0.109	11.2	26.2	20	53.8	Loamy sand
Naranammoozhi	52	2.19	0.84	61.64	9.56	44.41	0.37	16.46	31.2	5	63.8	Sandy clay loam
	53	2.39	1.15	51.88	12.73	36.02	0.425	37.24	26.2	20	53.8	Sandy clay loam
	54	2.19	1.09	50.23	7.85	36.08	1.663	63.54	16.2	25	58.8	Sandy loam
	55	1.80	0.93	55.71	26.79	56.29	0.694	33.8	16.2	25	58.8	Sandy loam
	56	1.80	1.11	47.14	28.62	50.59	1.496	62.04	21.2	35	43.8	Loam
	57	2.40	1.26	47.50	14.96	38.26	1.279	63.2	21.2	10	68.8	Sandy clay loam
	58	2.39	0.84	64.85	9.56	35.73	0.37	16.46	31.2	5	63.8	Sandy clay loam
	59	2.19	1.15	47.49	12.73	36.02	0.425	37.24	26.2	20	53.8	Sandy clay loam
	60	2.19	1.09	50.23	26.79	36.08	1.663	63.54	16.2	25	58.8	Sandy loam
	61	1.80	0.93	55.71	7.85	42.04	0.694	33.8	21.2	35	43.8	Sandy loam
	62	2.10	1.11	47.14	9.52	50.59	1.496	62.04	26.2	20	53.8	Loam
	63	2.40	1.26	47.50	14.96	39.87	1.279	63.2	16.2	25	58.8	Sandy clay loam
	64	2.40	1.26	47.50	7.85	42.04	0.37	16.46	26.2	20	53.8	Sandy clay loam

Panchayath/ Municipality	Sample No.	PD (Mg m^{-3})	BD (Mg m^{-3}	Porosity (%)	SMC (%)	Max. WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Konni	65	2.11	1.18	44.08	18.03	48.31	3.928	84.06	36.2	30	33.8	Clay loam
	66	2.38	1.25	47.48	24.42	42.36	2.409	83.14	26.2	20	53.8	Sandy clay loam
	67	2.11	1.38	34.60	14.49	44	0.309	42.3	31.2	25	43.8	Sandy clay loam
	68	2.38	1.18	50.42	18.03	38.26	4.759	97.74	21.2	10	68.8	Sandy clay loam
	69	2.78	1.43	48.56	24.07	50.37	2.103	71.12	41.2	15	43.8	Clay
	70	2.29	1.25	45.41	13.97	37.25	2.811	88.98	21.2	10	68.8	Sandy clay loam
	71	2.11	1.31	37.91	14.72	42.36	3.928	84.06	31.2	25	43.8	Clay loam
	72	2.02	1.25	38.12	24.42	48.31	2.409	83.14	36.2	30	33.8	Loam
	73	2.38	1.43	39.92	14.49	34	0.309	42.3	21.2	10	68.8	Sandy clay loam
	74	2.29	1.25	45.41	12.81	38.26	4.759	97.74	21.2	10	68.8	Sandy clay loam
	75	2.78	1.31	52.88	24.07	40.37	2.103	71.12	41.2	15	43.8	Sandy clay loam

B. Results of chemical and biological parameters (for individual samples)

Panchayath/ Municipality	Sample No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase activity (µg PNP g soil^{-1}h^{-1})
Pramadam	1	5.19	0.18	2.82	226	113.2	242	680	108	19.00	0.01	25.36
	2	4.46	0.18	1.50	226	52.8	376	1120	168	4.50	1.12	19.72
	3	5.53	0.27	2.55	326	176.2	123	660	156	9.00	0.01	35.45
	4	4.75	0.14	1.65	276	15.8	349	1460	156	10.50	0.03	45.27
	5	4.4	0.13	3.15	289	46.1	146	640	264	0.50	0.02	24.09
	6	5.78	0.11	1.74	213	60.2	376	720	168	2.00	0.01	20.54
	7	4.36	0.36	1.50	213	160.0	269	320	120	4.00	0.01	26.99
	8	3.83	0.70	1.95	314	232.7	269	800	120	10.50	0.65	29.63
	9	4.31	0.13	1.32	276	131.1	134	980	216	7.50	0.30	11.09
Kalanjoor	10	4.13	0.44	1.98	226	214.4	392	400	108	9.00	0.51	20.18
	11	4.61	0.07	1.62	263	264.2	78	400	120	0.50	0.87	27.63
	12	4.68	0.15	1.31	238	129.2	699	1340	312	14.00	0.31	23.54
	13	4.13	0.22	1.53	263	89.2	168	440	48	2.00	0.48	14.09
	14	4.25	0.06	1.55	176	57.4	168	240	180	1.00	0.05	15.45

Panchayath/ Municipality	Sample No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase activity (µg PNP g soil^{-1}h^{-1})
Ranni-Angadi	15	4.52	0.47	1.31	439	52.8	202	860	348	9.00	0.54	22.9
	16	6.28	0.24	2.48	100	99.6	381	1380	240	2.50	0.62	30.27
	17	4.99	0.11	2.13	326	15.5	235	1120	96	7.50	0.02	37.27
	18	6.35	0.31	2.36	163	110.5	392	1620	624	78.50	0.11	60.9
	19	6.82	0.37	0.32	151	139.2	101	1280	444	19.00	0.03	16.36
	20	6.54	0.68	2.12	151	47.7	538	1360	468	30.50	0.60	15.18
	21	5.83	0.14	1.43	289	47.7	403	1020	264	11.50	0.03	41.27
	22	6.45	0.16	1.49	201	30.6	235	1960	312	17.50	0.26	28.72
	23	5.8	0.08	1.35	125	151.0	370	1100	216	2.50	1.18	38.54
	24	4.71	0.09	2.01	314	9.3	67	540	36	6.00	0.04	46.99
	25	5.37	0.1	2.72	314	0.7	123	620	72	4.50	0.02	37.54
	26	5.12	0.13	2.24	226	61.1	190	120	144	3.50	0.26	14.45
	27	4.1	0.12	1.83	251	53.5	258	480	84	4.00	0.02	35.09
Pathanamthitta	28	5.48	0.008	2.25	351	25.9	157	400	108	0.50	1.27	27.27
	29	5.33	0.14	3.08	213	51.4	202	600	156	14.00	0.34	26.18
	30	4.15	0.09	1.62	251	200.8	215	420	96	0.50	0.88	28.27
	31	4.72	0.34	1.97	339	25.0	190	300	120	3.50	0.02	30.18
	32	4.62	0.17	1.98	238	98.2	280	1240	72	8.50	0.09	43.45
	33	4.21	0.08	2.57	176	117.9	146	260	132	7.50	1.33	14.73
	34	4.05	0.13	1.79	238	86.6	56	200	156	1.00	0.42	56.27
	35	4.75	0.19	2.61	364	38.7	560	860	60	16.00	0.62	30.54

Panchayath/ Municipality	Sample No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase activity (µg PNP g soil^{-1}h^{-1})
Ranni-Perunnadu	36	4.62	0.10	1.05	188	6.71	168	680	108	21.50	0.38	4.27
	37	4.95	0.15	2.70	163	125.3	358	820	180	13.00	0.62	96.89
	38	5.07	0.10	1.39	201	140.3	146	700	240	10.00	0.36	24.09
	39	6.92	0.26	1.17	213	65.1	190	1180	324	50.50	0.23	22.18
	40	6.85	0.27	1.01	201	43.1	190	1480	732	58.50	1.30	31.45
	41	5.35	0.11	1.05	226	203.3	258	800	168	25.00	0.96	36.18
Vadaserikkara	42	6.47	0.17	0.38	113	72.7	67	860	216	18.00	1.06	8.45
	43	6.69	0.14	0.47	100	19.5	202	1420	132	38.00	0.01	16.36
	44	6.6	0.16	0.42	88	134.5	146	1260	444	49.00	0.86	14.089
	45	7.05	0.08	0.38	75	25.9	67	680	144	13.00	0.02	9.91
	46	6.48	0.13	1.44	213	69.2	202	1200	192	9.00	0.05	28.72
	47	3.62	0.3	2.15	213	137.1	224	360	144	7.50	0.01	10.45
	48	4.14	0.25	1.5	188	83.4	213	440	168	2.50	0.26	19.54
	49	5.38	0.1	1.29	100	11.4	168	940	156	8.00	1.40	25.45
	50	5.14	0.47	1.35	251	192.0	638	1220	252	6.00	0.62	56.9
	51	7.11	0.27	0.39	113	122.0	134	1820	600	7.50	0.34	31.45
Naranammoozhi	52	5.6	0.16	1.13	238	113.7	213	780	108	7.50	0.90	20.91
	53	5.25	0.09	0.74	238	114.9	213	700	156	10.50	0.48	35.81
	54	5.99	0.14	2.25	226	99.8	302	1120	324	3.50	0.24	39.81
	55	6.92	0.53	0.65	125	17.4	269	1960	732	26.00	1.11	15.09
	56	5.57	0.12	0.66	314	75.3	269	880	300	6.50	0.04	24.72
	57	5.83	0.06	1.11	125	7.2	190	840	168	2.00	0.22	22.82
	58	6.53	0.01	1.38	100	24.5	157	1080	48	15.50	0.29	19.99
	59	6.02	0.26	0.71	263	283.4	571	1460	24	7.00	0.38	16.45
	60	4.97	0.12	1.01	213	165.6	336	660	240	2.00	0.21	23.54
	61	4.14	0.26	2.43	88	362.0	515	800	240	1.50	1.09	16.36
	62	4.13	0.16	1.53	188	31.0	650	600	168	23.50	0.62	33.91
	63	7.44	0.1	0.14	25	62.1	101	1080	264	22.50	1.59	13.54
	64	7.06	0.23	0.36	151	107.2	168	1960	324	51.00	1.06	11.91

Panchayath/ Municipality	Sample No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase activity (µg PNP g soil^{-1}h^{-1})
Konni	65	6.17	0.1	1.52	314	76.0	258	620	228	2.00	0.38	8.27
	66	5.52	0.01	1.64	251	117.9	168	840	168	16.00	1.14	41.27
	67	4.58	0.06	2.01	251	9.5	78	680	120	18.00	0.12	16.27
	68	4.56	0.06	1.35	238	145.2	213	820	180	5.00	0.28	32.91
	69	4.18	0.1	2.46	226	109.1	67	260	24	18.00	0.53	22.18
	70	4.98	0.15	2.31	201	288.3	336	540	108	10.00	1.36	33.99
	71	4.72	0.04	1.35	201	5.3	56	900	12	19.00	0.35	8.09
	72	4.66	0.7	0.84	188	10.0	134	300	108	2.00	0.47	8.27
	73	4.29	0.24	2.73	326	13.7	213	540	168	9.45	0.01	43.18
	74	5.35	0.12	2.39	138	27.8	291	940	72	5.00	0.48	24.36
	75	4.95	0.27	1.08	226	94.2	202	740	240	2.00	0.39	37.26

C. SQI and LQI (for individual samples)

Panchayath/Municipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Pramadom	1	222	55.5	49.1	4.91
	2	286	71.5	24.3	2.43
	3	278	69.5	48.2	4.82
	4	266	66.5	24.7	2.47
	5	242	60.5	47.7	4.77
	6	274	68.5	30.3	3.03
	7	234	58.5	22.5	2.25
	8	244	61.0	29.5	2.95
	9	217	54.3	21.4	2.14
Kalanjoor	10	250	62.5	39.2	3.92
	11	224	56.0	33.8	3.38
	12	264	66.0	23.2	2.32
	13	188	47.0	27.5	2.75
	14	248	62.0	28.8	2.88
Ranni-Angadi	15	264	66.0	19.6	1.96
	16	347	86.8	53.6	5.36
	17	243	60.8	42.8	4.28
	18	350	87.5	47.1	4.71
	19	293	73.3	5.30	0.53
	20	351	87.8	30.8	3.08
	21	296	74.0	20.8	2.08
	22	279	69.8	22.1	2.21
	23	316	79.0	21.7	2.17
	24	174	43.5	40.4	4.04
	25	182	45.5	39.6	3.96
	26	232	58.0	33.3	3.33
	27	209	52.3	29.4	2.94
Pathanamthitta	28	245	61.3	37.8	3.78
	29	264	66.0	49.0	4.90
	30	254	63.5	23.1	2.31
	31	232	58.0	28.7	2.87
	32	227	56.8	33.3	3.33
	33	252	63.0	33.2	3.32
	34	250	62.5	28.5	2.85
	35	246	61.5	33.7	3.37
Ranni-Perunnadu	36	195	48.8	17.5	1.75
	37	302	75.5	49.0	4.90
	38	246	61.5	28.4	2.84
	39	305	76.3	20.5	2.05
	40	338	84.5	19.1	1.91
	41	284	71.0	15.9	1.59
Vadaserikkara	42	286	71.5	8.20	0.82
	43	307	76.8	8.20	0.82
	44	303	75.8	9.10	0.91
	45	280	70.0	6.20	0.62
	46	285	71.3	25.9	2.59
	47	232	58.0	36.8	3.68
	48	254	63.5	24.3	2.43
	49	242	60.5	20.9	2.09
	50	277	69.3	29.2	2.92
	51	310	77.5	6.80	0.68

Panchayath/Municipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Naranammoozhi	52	274	68.5	14.2	1.42
	53	277	69.3	12.8	1.28
	54	296	74.0	36.8	3.68
	55	324	81.0	9.10	0.91
	56	292	73.0	11.0	1.10
	57	238	59.5	21.0	2.10
	58	232	58.0	17.4	1.74
	59	259	64.8	12.2	1.22
	60	266	66.5	16.4	1.64
	61	286	71.5	33.9	3.39
	62	304	76.0	25.5	2.55
	63	316	79.0	2.60	0.26
	64	318	79.5	6.80	0.68
Konni	65	257	64.3	26.9	2.69
	66	298	74.5	30.8	3.08
	67	189	47.3	41.6	4.16
	68	307	76.8	26.5	2.65
	69	171	42.8	52.8	5.28
	70	282	70.5	43.3	4.33
	71	149	37.3	23.9	2.39
	72	213	53.3	15.8	1.58
	73	250	62.5	58.6	5.86
	74	242	60.5	44.8	4.48
	75	283	70.8	21.2	2.12

Appendix IV

Soil pH, organic carbon, available primary and secondary nutrients , available B and soil texture in the pre flood soils of AEU 12 of Pathanamthitta district*

Parameters	Fertility class	Pre flood
		Per cent of samples
pH	Extremely acid	18.4%
	Very strongly acid	37.6%
	Strongly acid	28.1%
	Moderately acid	11.9%
	Slightly acid	4.00%
	Neutral	-
Organic carbon	Low	4.38%
	Medium	30.4%
	High	65.3%
Available P	Low	18.0%
	Medium	19.1%
	High	62.8%
Available K	Low	5.38%
	Medium	31.9%
	High	62.8%
Available Ca	Adequate	90.6%
	Deficient	9.37%
Available Mg	Adequate	62.5%
	Deficient	37.5%
Available S	Adequate	83.4%
	Deficient	17.6%
Available B	Adequate	27.5%
	Deficient	72.5%
Soil texture		Clayey and loamy

* Kerala State Planning Board (2013)

Soil pH, organic carbon, available primary and secondary nutrients , available B and soil texture in the pre flood soils of selected panchayathhs in AEU 12 of Pathanamthitta district*

Parameters	Fertility class	Pre flood							
		Kalanjoor	Konni	Pramadam	Pathanamthitta Municipality	Ranni-Angadi	Ranni-Perunnadu	Vadaserikkara	Naranammoozhi
pH	Extremely acid	38.0%	12.0%	16.0%	20.0%	16.0%	27.0%	31.0%	25.0%
	Very strongly acid	43.0%	50.0%	32.0%	36.0%	35.0%	29.0%	27.0%	54.0%
	Strongly acid	-	24.0%	20.0%	28.0%	30.0%	29.0%	22.0%	21.0%
	Moderately acid	19.0%	14.0%	11.0%	16.0%	19.0%	15.0%	20.0%	-
	Slightly acid	-	-	13.0%	-	-	-	-	-
	Neutral	-	-	-	-	-	-	-	-
Organic carbon (%)	Low	10.0%	2.0%	2.0%	11.0%	4.0%	4.0%	1.0%	1.0%
	Medium	37.0%	28.0%	22.0%	58.0%	24.0%	40.0%	23.0%	11.0%
	High	53.0%	70.0%	76.0%	31.0%	72.0%	56.0%	76.0%	88.0%
Available P	Low	16.0%	26.0%	4.0%	17.0%	14.0%	18.0%	23.0%	27.0%
	Medium	8.0%	18.0%	9.0%	15.0%	16.0%	31.0%	32.0%	24.0%
	High	76.0%	56.0%	87.0%	68.0%	70.0%	51.0%	45.0%	49.0%
Available K	Low	1.0%	5.0%	4.0%	-	6.0%	-	3.0%	24.0%
	Medium	58.0%	47.0%	33.0%	30.0%	43.0%	-	16.0%	28.0%
	High	41.0%	48.0%	63.0%	70.0%	51.0%	100%	81.0%	48.0%

Parameters	Fertility class	Pre flood							
		Kalanjoor	Konni	Pramadam	Pathanamthitta Municipality	Ranni-Angadi	Ranni-Perunnadu	Vadaserikkara	Naranammoozhi
Available Ca	Adequate	32.0%	100%	93.0%	100%	100%	100%	100%	100%
	Deficient	68.0%	-	7.0%	-	-	-	-	-
Available Mg	Adequate	-	100%	-	-	100%	100%	100%	100%
	Deficient	100%	-	100%	100%	-	-	-	-
Available S	Adequate	-	100%	59.0%	100%	100%	100%	100%	100%
	Deficient	100%	-	41.0%	-	-	-	-	-
Available B	Adequate	64.0%	-	16.0%	32.0%	43.0%	20.0%	21.0%	21.0%
	Deficient	36.0%	97.0%	84.0%	68.0%	57.0%	80.0%	79.0%	79.0%

[*] Kerala State Planning Board, 2013

Appendix V

Descriptive Statistics

Descriptive statistics of chemical and biological parameters in the post-flood soils of AEU 12 in Pathanamthitta district

Descriptive statistics	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg PNP produced g soil^{-1} h^{-1})
Mean	5.28	0.19	1.60	216	93.6	246	865	204	12.9	0.47	27.1
Standard Error	0.11	0.02	0.08	8.94	8.76	16.8	50.3	17.41	1.68	0.05	1.69
Median	5.12	0.14	1.52	226	76.0	213	800	168.0	8.50	0.36	24.7
Mode	4.13	0.10	1.50	226	52.8	168	680	108.0	2.00	0.01	16.4
Standard Deviation	0.97	0.15	0.73	77.5	75.9	145	436	151	14.5	0.44	14.6
Sample Variance	0.95	0.02	0.53	5998	5758	21056	189733	22730	212	0.19	213
Kurtosis	-0.90	3.49	-0.64	0.14	1.59	1.50	0.08	4.41	6.53	-0.49	6.1
Skewness	0.45	1.82	0.02	0.06	1.21	1.29	0.66	1.94	2.38	0.79	1.74
Range	3.82	0.69	3.01	414	361	643	1840	768	78.0	1.49	92.6
Minimum	3.62	0.01	0.14	25.1	0.69	56.0	120	12.0	0.50	0.01	4.27
Maximum	7.20	0.70	3.15	439	362	699	1960	780	78.5	1.50	96.9
Sum	396	14.4	119.7	16244	7018	18431	64900	15264	964.5	35.2	2029
Count	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
Largest(1)	7.20	0.70	3.15	439	362	699	1960	780	78.5	1.50	96.9
Smallest(1)	3.62	0.01	0.14	25.1	0.69	56.0	120	12.0	0.50	0.01	4.27

Descriptive statistics of physical parameters in the post-flood soils of AEU 12 in Pathanamthitta district

Descriptive statistics	PD ($Mg\ m^{-3}$)	BD ($Mg\ m^{-3}$)	Porosity (%)	SMC (%)	WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)
Mean	2.29	1.15	49.3	20.5	47.3	1.83	62.8	29.3	18.3	52.4
Standard Error	0.03	0.02	0.93	1.12	1.10	0.15	3.00	0.96	0.85	1.21
Median	2.32	1.14	51.0	18.9	45.1	1.66	71.6	31.2	20	53.8
Mode	2.1	1.08	52.7	12.7	38.3	1.51	73.6	31.2	20	53.8
Standard Deviation	0.25	0.16	7.91	9.71	9.54	1.27	26.0	8.29	7.37	10.5
Sample Variance	0.05	0.02	65.2	94.4	91.2	1.61	675	68.8	54.4	110
Kurtosis	-0.53	-0.58	0.48	0.24	-0.81	-0.32	-0.23	0.13	0.12	-0.55
Skewness	0.00	0.10	-0.39	0.91	0.26	0.54	-0.95	0.09	0.60	0.01
Range	1.01	0.61	41.9	37.6	38.4	4.74	96.1	35.0	35.0	40
Minimum	1.8	0.84	25.6	7.85	29.6	0.02	1.68	11.2	5.00	33.8
Maximum	2.81	1.45	67.4	45.4	68.0	4.76	97.7	46.2	40.0	73.8
Sum	172.8	86.0	3735	1542	3549	138	4709	2200	1370	3930
Count	75.0	75.0	75.0	75.0	75.0	75	75	75.0	75.0	75
Largest(1)	2.81	1.45	67.4	45.4	68.0	4.76	97.7	46.2	40.0	73.8
Smallest(1)	1.8	0.84	25.6	7.85	29.6	0.02	1.68	11.2	5.00	33.8