ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS

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DECLARATION

I, hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 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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Certified that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a record of research work done independently by Ms. Shafna S H, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, or fellowship to her.

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Shafna S H

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LIST OF ABBREVIATIONS

%	Percent
ºC	degree Celsius
µg	Microgram
AEU	Agro-ecologicalUnit
B	Boron
BD	Bulk density
Ca	Calcium
cm	Centimeter
c mol g^{-1}	centi mol per gram
dS m^{-1}	deci Siemen per meter
EC	Electrical Conductivity
et al.	and others
Ex. Acidity	Exchangeable acidity
Fig.	Figure
g	Gram
GIS	Geographic Information System
GOK	Government of Kerala
GPS	Global Positioning System
h	Hour

ha	Hectare
INM	Integrated Nutrient Management
K	Potassium
KAU	Kerala Agricultural University
$kgha^{-1}$	kilogram per hectare
$kg\ m^{-2}$	kilogram per square metre
KSPB	Kerala State Planning Board
LQI	Land Quality Index
m	Metre
MDS	Minimum Data Set
Mg	Magnesium
$Mgha^{-1}$	Mega gram per hectare
$mgkg^{-1}$	milligram per kilogram
Mgm^{-3}	Mega gram per cubic metre
mm	Millimeter
Max.	Maximum
Min.	Minimum
Mn	Manganese
MWD	Mean Weight Diameter
N	Nitrogen

NBSS&LUP	National Bureau of Soil Science and Land Use Planning
NI	Nutrient Index
No.	Number
OC	Organic carbon
P	Phosphorus
PC	Principal component
PCA	Principal Component Analysis
PD	Particle density
PNP	*p*-nitrophenyl
r	correlation coefficient
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
Zn	Zinc

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Introduction

1. INTRODUCTION

Kerala state is the "gateway of summer monsoon" over India. It is located between $8^0 15^' N$ and $12^0 50^' N$ latitude and between $74^0 50^' E$ and $77^0 30^' E$ longitude. Which is presented in north south direction with Arabian sea at west and western ghats and nilgiri hills at east. The state is divided into three natural regions, eastern high land, hilly midlands and western low lands (Krishnakumar *et al*., 2008)

Kerala state has mainly two rainy seasons, the south west monsoon that reaches at the end of may or early june and north east monsoon that reaches at mid of october. Monsoon rain was part of Kerala state every year. Yet the south west monsoon of 2018 had a different impact which resulted in a disastrous flood. In a period of 30 days 339 human were died, thousands of houses collapsed, over a million and half people were replaced to relief camps, large stretches of roads got washed away and bridges got collapsed. Uninterrupted rain affected most areas of the state from 8^{th} to 18^{th} of August 2018 which resulted in wide spread damage to the major sectors of the state.

The state gained an excess of 96 percent rain from 1^{st} to 30^{th} August 2018 and 33 percent during the entire monsoon period till the end of August. In Pathanamthitta district, normal rainfall for 1st to 30^{th} August was 352.7 mm, but the actual rainfall received during this period was 764.9 mm. The heavy rain that created the extreme flood in Kerala happened between 8^{th} to 17^{th} August 2018. Sporadic events of intense rainfall in the catchment of western ghats leads to reservoirs to arrive full capacity and resulted in the release of excess water into flood gates. The discharge of excess water overwhelm the parts of Pathanamthitta, Alappuzha, Kottayam, Idukki, Ernakulam, Thrissur and Wayanad districts (Vishnu *et al*.,2019).

The entire Kuttanad region lying in the Alappuzha, Kottayam and Pathanamthitta districts was submerged in the flood water for weeks. This heavy rainfall resulted in huge overland flow causing to complete saturation of topsoil, leads to deep seated landslides, debris flow and substantial sheet erosion resulted in the rivers exceeding the embankment areas and leads to destruction of life and property.

The Indian Government declared it as a level 3 calamity or "calamity of a severe nature".

The unprecedented heavy rain caused exorbitant damage to the agricultural sector. Besides affecting cash crops such as pepper, rubber, coffee etc., the devastating flood washed away vegetable crops, medicinal plants and horticulture crops and hactares of paddy. The primary analysis of the state agricultural department showed that around 56,844.44 ha of cropped area has been affected by floods causing a loss of Rs.1355.68 crore to 3.14 lakh farmers. Among the major crops paddy and banana were the worst flood affected crops with 26,106 and 6,348 ha of crops damaged, respectively.

Soil is the most important natural resource which supports productivity of any region. The knowledge of impact of flood on soil characteristics is highly essential to maintain sustainable ecosystem balance. Soil erosion due to excessive run off and silt deposition during floods will result in decline in the qualitative and quantitative characteristics of soil. Due to high intensity rainfall, soil erosion is severe in hilly terrain and flood plains of Kerala. The high intensity rainfall eroded the surface and subsurface soils from hilly terrain and rivers transported the sediment into faraway places and deposited in the plains and valleys. The severe erosion and deposition changes the physical, chemical and biological characteristics of the soil. In addition to this leaching of nutrients, surface crusting, surface cracking of soils and destruction of fauna such as earthworms have occurred due to the flood. The devastating impact of flood on soils and deterioration in soil quality has necessitated the present study.

Pathanamthitta district is located on the south western part of Kerala and extend over an area of 2,65,277 ha. The district lies between 9^{0} 16’ north latitude and 76^{0} 47’ east longitude. Major physiographic divisions of the districts are lowland, midlands, mid-uplands, uplands and highland. The district is mainly drained by Pampa, Achenkovil and Manimala rivers.

The AEU 9 (south central laterites) in Pathanamthitta includes Mallappally, Koipram, Elanthoor, Parakkode, and Panthalam blocks and Adoor municipality. The soils of the south central laterites (AEU 9) exhibit spatial variability in their properties. These soils are strongly acidic, gravelly, contains lateritic clay and is underlined by plinthite. Parts of Manimala, Pamba and Achankovil rivers passes through AEU 9. The devastating flood heavily impacted the agricultural sector in the south central laterite area of Pathanamthitta district. Farmers should be made well aware about the changes that has occurred to the soil due to the flood and management strategies to be adopted for the effective implementation of post-flood management activities in agriculture sector. A detailed study on soil quality of post-flood soils of AEU 9 covering predominant cropping systems will help in formulating sustainable crop management strategies in these flood affected areas. Hence the present study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Pathanamthitta district of Kerala and generation of GIS maps" has been undertaken with the objectives :

- To assess the soil quality of post-flood soils of AEU 9 in Pathanamthitta district
- To develop maps on soil characters and quality using GIS techniques
- To workout soil quality index.

Review of Literature

2. REVIEW OF LITERATURE

The study entitled "Assessment of soil quality in post flood scenario of AEU 9 of Pathanamthitta district of Kerala" is conducted to determine the impact of flood on the soil quality and to help the farmers by providing post flood soil management. Review of literature that related to the study are presented under this chapter.

2.1 EFFECT OF FLOOD IN PATHANAMTHITTA DISTRICT

Pathanamthitta district was severely affected by flood and landslide which occurred in August 2018. Out of 53 panchayats, 18 were totally flood affected and 27 panchayat were partially affected. The total estimated loss was Rs 1810 crores of which 66.03 crore was in the agricultural sector and 16.89 crore in animal husbandry sector. Three persons were killed in natural calamity and 1,15,519 people were evacuated to relief camps. The unprecedented rainfall which occurred in the district from 12^{th} to 17^{th} August lead to the opening of Kakki , Kochupampa and Anathode dams to let out ragging water to Pampa and Manimala rivers which increases the water level up to 15 feet height. Water stagnation continued for 5 to 6 days in the entire flooded area with thick deposition of silt and sand. The district also experienced severe landslide in some panchayats resulting in loss of agriculture and human life (Department of soil survey and soil conservation, 2018).

2.3 AGRO ECOLOGICAL UNIT 9: SOUTH CENTRAL LATERITE

The AEU 9 (south central laterites) in Pathanamthitta includes Mallappally, Koipram, Elanthoor, Parakkode, and Panthalam blocks and Adoor municipality. The unit covers 67,223 ha (25.34%) in the district. The south central laterites agroecological unit represent the midland laterite terrain with typical laterite soil and short dry periods. The climate is tropical humid monsoon type having mean annual temperature of $26.5\,^{0}C$ and rainfall 2810 mm. These soils are strongly acidic, gravelly, contains lateritic clay and underlined by plinthite. The overall nutrient status of Pathanamthitta soils are medium in content of organic carbon and available potassium, high content of available phosphorus, exchangeable calcium and sulphur, deficit levels of magnesium and boron and sufficiency with respect to iron, copper, manganese and zinc (Kerala State Planning Board, 2013).

Major crops includes rubber, coconut, banana, tapioca, paddy and vegetables such as amaranth, brinjal, bhindi, cowpea, cucumber, bottlegourd, snakegourd, ashgourd, chilli and tomato (Kerala State Land Use Board, 2015). Parts of Manimala, Pamba and Achankovil rivers passes through AEU 9. The flood affected panchayaths of AEU 9 are Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally.

2.3 EFFECT OF FLOODING ON SOIL PROPERTIES

Flooded or submerged soil undergoes a series of physical, chemical and biological processes that changes the quality of the soil. The nature of these changes depends upon the type of soil and duration of submergence.

2.3.1 Effect of flooding on physical properties of soil

Flooding lead to decrease in gaseous pore space in soil which affect oxygen diffusion. Within few hours of flooding, microorganisms and root use up the oxygen present in the soil and leave submerged soil devoid of oxygen. Consequently the oxygen supply of the soil stops and gases formed by soil metabolism accumulates. Drastic restriction of gas exchange between flooded soil and the atmosphere leads to accumulation of nitrogen, carbon dioxide, methane and hydrogen gases. The gases build up pressure and escape as bubbles. Analysis of such bubbles from flooded rice fields shows the presence of nitrogen 10-95 per cent, methane 15-75 per cent, carbon dioxide 1-20 per cent and hydrogen 0-10 per cent (Kozlowski, 1984).

Increase in water content darkens the soil and lowers the albedo values of soils. Flooding destroys soil structure and alters soil consistency. Flooded soils show lower shear strength and they are beyond the liquid limit (Ponnamperuma,1984). Submergence causes depletion of oxygen in soil and consequently soil aggregation. Flooding resulted in rupture of large soil aggregates which causes the filling of pores with dispersed clay and there by decreases the soil permeability (Kirk *et al.,* 2013).

Temperature of flooded soils is $6^0 C$ lower than well drained soils. The temperature of flooded soil affect velocity and pattern of chemical and electrochemical changes initiated by flooding, release of nutrients, production of toxins, and plant growth.

Another effect of flooding is the swelling of soil colloids. The extent of swelling depends on the clay content, type of clay mineral and nature of exchangeable cations. As the soil moisture increased, cohesion of water film around soil particles causes them to stick together rendering the soil plastic. At higher water content as in flooded soil, cohesion decreases rapidly due to increase in the thickness of water film between soil particles. When flooded soil is drained and dried, cohesion increases and the soil shrinks and cracks. Flooding resulted in destruction of soil structure due to break down of aggregates resulted by reduction in cohesion with increase in water content, deflocculation of clay as a result of dilution of soil solution, pressure of entrapped air, stresses caused by uneven swelling and destruction of cementing agents (Ponnamperuma,1984). Sodic soil show marked breakdown of aggregates on flooding, whereas soil high in iron and aluminium oxides or organic matter undergo little aggregate destruction.

2.3.2 Effect of flooding on chemical properties of soil

Flooding resulted in the instantaneous dilution of soil solution. This results in the increase in pH, decrease in electrical conductance and alters the diffuse double layer of colloidal particles. But these are insignificant compared with the drastic changes in the redox potential, pH, electrical conductance, ionic strength, ion exchange, sorption and desorption caused by soil reduction. The flooded soil shows low redox potential ranging from 0.2 to 0.4 V. Redox potential falls rapidly after flooding reaches a minimum within a few days, rises rapidly to a maximum, and then decreases asymptoticaly with time. Flooding resulted in increase in pH of acid soil and decrease in pH of sodic soil. The increase in pH of acid soil is due to reduction of Fe^{3+} and Fe^{2+} ions and the decrease in pH of sodic soil and check in pH of acid soils are due to CO_2 accumulation (Ponnamperuma, 1984).

The specific conductance of interstitial solutions of flooded soil increases during the first few weeks after flooding reaches a peak and decline to a fairly stable value. The peak increase is 1-2 dsm^{-1}. Another chemical transformation includes disappearance of O_2, accumulation of CO_2 and anaerobic decomposition of organic matter. Flooding increases the concentration of NH_3 and HCO_3, converts Mn^{4+} and Fe^{3+} compounds to Mn^{2+} and Fe^{2+} forms, which are much soluble in water. These processes increases the ionic strength. The frequent flooding results in deposition of fine sediments leads to development of weak alluvial soils. Sedimentological and pedological analysis combined with radiocarbon and Pb^{210} dating is useful in the determination of floodplain sedimentation rates (Saint-Laurent *et al.,* 2010).

The analysis of soil total nitrogen and soil organic carbon on different areas of frequent flood zones, moderate flood zones and no flood zones shows that alluvial soils subject to frequent flooding have a lower concentration in soil total nitrogen and soil organic carbon than soils in non flood zones. A lower concentration of nutrients was observed in flood affected soils. Higher soil acidity noted in the non flood zones. The soil textural matrices are relatively similar among the three zones under study, also the textures are generally coarser in the soils outside the flood zones (Saint-Laurent *et al.*, 2014).

Effect of flood on soil heavy metals and nutrient levels studied by Hafeez *et al.* (2019) reported that flood events increased the heavy metal cadmium while lowered lead concentration. Meanwhile, flooding did not affect the status of cromium in soil. Soil nitrates and phosphorous were declined after flood. Correlation analyses of soil physicochemical properties with soil nutrients and heavy metals showed that after flood, soil texture and organic carbon content are the major factors that lead to the changes in soil heavy metals and nutrient concentration.

2.3.3 Effect of flooding on biological properties of soil

Mace *et al.* (2016) reported that flooding resulted in the alteration of soil enzyme activity by changing nutrient availability, oxygen concentration and microbial population. The activity of lignin and cellulose degrading enzymes increases with flooding. Intermittent flooding leads to increase in the population of aerobic microbes compared to other microorganisms. 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 condition (Unger *et al*., 2009).

Pedrazzini and Mckee (1984) reported that submergence of soils resulted in increased level of dehydrogenase activity coupled with a reduction in redox potential. Increased dehydrogenase activity indicated a shift in soil microflora from aerobic to anaerobic. Enzymes in flooded soil show temporal peak activity during the first week after flood. It indicates that available carbon is utilized rapidly by the microorganisms. Later on, there is a decline in enzyme activity rate due to the limitation of substrates in the flooded soil **(**Burns and Ryder, 2001).

2.4 CONCEPT OF SOIL QUALITY

Doran and Parkin (1994) defined soil quality as the capacity of a soil to function within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health. Soil quality indicators refers to measurable soil attributes that influence the capacity of soil to perform crop production or environmental function (Arshad and Martin, 2002).

The concept of soil quality includes assessment of soil properties and processes as they relate to the ability of soil to function effectively as a component of a healthy ecosystem (Schoenholtz *et al*., 2000). Parr *et al.* (1992) reported that different chemical, physical, and biological properties of a soil interact with each other and determine its potential fitness or capacity to produce healthy and nutritious crops. The combination of these properties and resulting level of productivity is referred as soil quality.

Soil indicators are interdependent as they interact with each other and one parameter is affected by others. Different chemical, physical and biological properties of soil integrate and interact with each other resulting in a particular level of productivity referred to as soil quality. This interconnection is prominent between chemical and biological indicators of soil quality (Doran and Parkin, 1994).

Soil quality depends on climate, landform and mostly on people, because human decisions and actions that ultimately determines the sustainability of agricultural production system on a given soil (Arshad and Coen, 1992). The quality and health of soil indicates the agricultural sustainability and environmental quality, which jointly determine plant, animal and human health (Haberern, 1992). The significance of soil quality lies in attaining sustainable land use and management system, to balance productivity and environmental protection (De la Rosa and Sobral, 2008).

Organic farming is a measure to attain the higher soil quality with good microbiological activity than conventional farming, it is mainly by the crop rotations, reduced application of synthetic nutrients, and the absence of pesticides (Hansen *et al.,* 2001). Thus the soil quality concept differ from conventional agricultural approach by giving more attention towards the soil productivity and by understanding various roles played by soil in the agroecosystems and natural environment (Karlen *et al*., 1999).

Soil Quality comprises of two distinct but related parts namely innate and dynamic qualities. Innate refers to inherent soil quality results from natural and soil forming processes and includes properties like particle size distribution. Dynamic soil quality encompasses those soil properties that changes over short periods of time due to human use and management (Carter,2002).

2.4.1 Soil Quality Indicators

Soil quality is broadly defined as the capacity of a soil to function and can be assessed using a wide variety of biological, physical and chemical indicators (Karlen *et al*., 1997). Soil quality measured from the changes in attributes of the ecosystem, referred to as indicators. Most desirable indicators are the attributes that are most sensitive to management. The changes in soil quality indicators determine whether the soil quality is improving, declining or maintaining stability (Bredja *et al*.,2001).

Arshad and Martin (2002) reported that soil quality indicators are the measurable soil parameters that influence the capacity of soil to perform crop production or environmental functions. It is important to adopt different physical, chemical and biological indicators to develop soil quality. Soil organic carbon and pH are the most widely used indicators. All the indicators are integrated to develop a soil quality index (SQI). It helps to develop information on soil processes and information (Zornoza *et al.,* 2015).

Soil organic carbon was the important soil attribute. Other key soil attributes for the 0-10 cm depth of soil were field water capacity, pH, air-filled porosity and soil bulk density. Mean weight diameter of aggregates and total nitrogen are the major attributes for the 10–20 depth. Therefore, soil organic carbon plays an important role for assessing soil quality (Shukla *et al*., 2006).

Granatstein (1990) reported that good soil quality indicates increased infiltration, aggregate stability and size, macropores, soil aeration and organic matter and decreased soil resistance to tillage, root penetration and decreased runoff and erosion. Sharma and Mandal (2009) suggested that water logging, salinity, alkalinity and formation of acid sulphate soil indicates land degradation and development of poor soil quality.

The important soil quality indicators at micro and macro farm scale are classified into three groups, such as physical indicators, chemical indicators and biological indicators. The physical indicators are passage of air, structural stability, bulk density, particle size distribution, color, consistency, hydraulic conductivity, soil tilth, infiltration, 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. Important chemical indicators are CEC, base saturation, pH, EC, plant nutrient availability, SAR, plant nutrient content, ESP, contaminant presence and nutrient cycling rates. Biological indicators include organic carbon, microbial biomass carbon, total biomass, oxidizable carbon, potentially mineralizable nitrogen, soil respiration, soil enzymes, total organic carbon, microbial community finger printing, substrate utilization, fatty acid and nucleic acid analysis (Singer and Ewing, 2000).

2.4.1.1 Physical indicators

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, 2006). Soil texture, structure, hydraulic conductivity, infiltration, bulk density, porosity and aggregate stability are used as physical soil quality indicators. Physical properties plays an important role in determining the soil erodibility and soil- plant-water-atmosphere relationships (More, 2010).

Physical properties such as penetration resistance and effective porosity were not affected by management practices, whereas aeration pores and saturated hydraulic conductivity were varied. Small water-stable aggregates (0.25-2 mm), bulk density, available water capacity and air-filled pores at field capacity are the most important indicators for evaluation and monitoring of soil physical quality (Moebius *et al*., 2007).

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 Grant,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.

2.4.1.2 Chemical indicators

Chemical indicators of soil quality include soil pH, soil nutrients and soil organic matter (Karlen *et al*., 2008). Chemical attributes like pH, EC, organic nitrogen, mineralizable nitrogen, mineral phosphorus, exchangeable potassium and organic carbon are basic chemical indicators of soil quality (Doran and Parkin, 1994).

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).

Chemical indicators are controlled by management and natural disturbances, which include irrigation water, crops cultivated and fertilizer application. Reactions and processes taking place in the soil are affected by soil chemical components. pH can control mobility and availability of micro, macro nutrients and heavy metals. (USDA, 2006).

2.4.1.3 Biological indicators

Biological indicators affected by both natural and human induced changes and it includes many soil components and processes related to organic matter cycling, such as total organic carbon and nitrogen, microbial biomass, mineralizable carbon and nitrogen, enzyme activities and soil fauna and flora (Gregorich *et al*., 1997).

Soil dehydrogenase activity and soil basal respiration were the important soil biological properties commonly evaluated (Filelatch *et al*., 2007). In addition to chemical and physical soil quality indicators, soil enzymes such as dehydrogenase and phenol oxidase activities were positively correlated with several soil quality indicators (Veum *et al*., 2014)

Soil microbiological and biochemical indicators can be used to assess soil quality. Bacteria and fungi are key drivers of biogeochemical processes in soil and microbial enzymes are proximate drivers of organic matter transformation and decomposition. Biological indicators typically include microbial biomass carbon and microbial enzyme activities (Karlen *et al*. 1997).

Gil-Sotres *et al.* (2005) stated that microbial biomass carbon and activity of enzymes like dehydrogenase, phosphatase, urease and glucosidases are the biochemical properties used to determine soil quality. They observed that the dehydrogenase activity in rhizosphere soils is considered as a measure of microbial activity and also used as an index of soil microbial biomass.

2.5 CONCEPT OF MINIMUM DATASET

The minimum data set (MDS) formation involves selection of small subset of attributes. Many of the attributes are related to each other and they were used to estimate other attributes using pedotransfer functions (Larson and Pierce, 1991). The data sets are tool to get the whole picture of soil quality and the components within the data set varies depending on the type of picture which indicates that the data set is dynamic and flexible. The minimum data set involves small subset of attributes that help the assessment of specific character (Gregorich *et al.*, 1994).

The set of physical, chemical and biological indicators which shows at least 70 percent of variability in the total data set at each sampling site is termed as MDS for determining soil quality (Rezaei *et al.,* 2006). Effective utilisation of minimum data set depends on how the relevance of these indicators were interpreted in agricultural system (Doran and Parkin, 1994).

A minimum soil quality dataset established for a long-term tillage, residue management and rotation trial for wheat and maize production systems includes physical indicators such as aggregate stability, permanent wilting point, time-to-pond and top soil penetration resistance and chemical indicators were soil carbon, nitrogen, potassium and zinc concentrations in the 0–5 cm top soil and carbon, nitrogren concentration in 5–20 cm depth (Govaerts *et al*., 2006).

Principle component analysis is used as a data reduction tool which helps to select most appropriate indicators for data selection. Principal component with eigen value >1 is selected for MDS. Within each principal component indicator receiving weighted loading within 10 percent of highest weighted value were selected for MDS. If there is more than one variable within a principle component, then correlation sum were calculated to identify which component is redundant. Highly weighted variables were highly correlated (Razaei *et al*, 2006).

The first step in the development of a MDS is the selection of appropriate soil quality indicators that effectively reflect the soil functions based on the goals for which the soil quality assessment is carried out (Sharma and Mandal, 2009).

Researchers developed different methods to identify MDS as indicators to determine soil quality. Principal component analysis (PCA) (Andrews and Carroll, 2001), expert opinion (Andrews *et al*. 2002), factor analysis (Shukla *et al*., 2006) and pedotransfer functions, linear and multiple regression, decision trees (Moncada *et al*., 2014) are some of the commonly used methods.

2.6 SOIL QUALITY INDEX

Soil quality index (SQI) can be calculated using three methods. Simple additive SQI method in which soil parameters were assigned threshold values based on the literature review and expert opinion of the authors. The individual index values are then summed up to obtain a total SQI. The second method is weighted additive SQI approach in which each soil parameter was first assigned unitless score ranging from 0 to 1 by employing linear scoring functions. Finally the statistically modelled SQI method in which statistics-based model was used to obtain SQI using principal component analysis. The advantage of first method is that the soil quality could be assessed after measuring any number (low to high) of soil parameters and this method is relatively easier compared to other methods. The disadvantage of first method is that it is subjective and relies mainly on researcher's point of view. Advantage of second method is that it includes weightage based on the design of the study. And the disadvantage of second method is that it requires multiple numbers of soil parameters under different soil functional systems and which is expensive and time consuming. The third method has ability to predict soil quality based on a reduced dataset with low number of soil parameters. This method is mostly objective and the statistical procedure would select a low number of soil parameters needed to calculate SQI based on the variances present in the whole dataset (Mukherjee and Lal, 2014).

Various methods like principle component analysis, multiple correlation, factor analysis, cluster analysis and star plots are used to calculate soil quality index (Bachmann and Kinzel, 1992). Parr *et al*. (1992) explained soil quality index by the expression

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

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 management inputs.

Soil quality index calculation include 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).

2.7 NUTRIENT INDEX

Singh *et al.* (2017) stated that nutrient index (NI) value is the measure of nutrient supplying capacity of soil to plants which helps to compare the levels of soil fertility of one area with those of another.

Parker's nutrient index is three tier system which is used to evaluate the fertility status of soils based on the percentage of samples in each of the three classes which includes low, medium and high and is multiplied by 1, 2 and 3 respectively. The sum of the figures thus obtained is divided by 100 to give the index or weighted average, nutrient index = {(1 x A) + (2 X B) + (3 X C)}/ TNS where A = number of samples in low category; B = number of samples in medium category; C = number of samples in high category and TNS = total number of samples.

Nutrient index ratings were <1.5 as low, 1.5 - 2.5 medium and >2.5 high (Parker *et al.,* 1951). The modified NI ratings were less than 1.67 for low fertility status, 1.67-2.33 for medium and greater than 2.33 for high (Ramamurthy and Bajaj, 1969).

2.8 LAND QUALITY INDEX

Dumanski and Pieri (2000) explained that indicators of land quality are being developed to co-ordinate actions on land related issues, such as land degradation and that land quality refers to the condition of land relative to the requirement of land use, including crop production, forestry, conservation and environmental management. The need for development of a land quality index (LQI) with reference to type of land use was emphasized by Karlen *et al*. (1997).

Kumar and Jhariya (2015) used remote sensing and geographic information system to evaluate the land quality for agriculture purpose using analytic hierarchy process technique. Different thematic layers such as organic matter content, soil texture, soil depth, soil pH, soil phosphorus, soil potassium, geomorphology, run-off potential, slope and land use or land cover are used to obtain the LQI of the area for the agriculture purpose which were generated in the remote sensing and geographic information system. The study area was divided into four zones namely high quality, moderately quality, marginally and low quality according to their suitability of land quality for agriculture purpose.

Mandal *et al.* (2001) generated a crop specific land quality index 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 as climatic requirements varies with crops. From the yield correlation, the LQI class has been fixed as LQI value <1.0 rated as high, 1–1.5 as moderate and >1.5 as low.

2.9 REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEM (GIS) AND SOIL MAPPING

The GIS and remote sensing (RS) are the powerful tools, which could be utilised to study the dynamic behaviour of waterlogged areas. Application of remote sensing technology in mapping and monitoring degraded lands has shown great promise of enhanced speed, accuracy and cost effectiveness (Dwivedi and Sreenivas, 1998).

In agriculture, geographic positioning system (GPS) and GIS technologies have been used for better management of land and other resources for sustainable crop production. Obtaining spatial data in GIS platform and remote sensing (RS) plays a major role in information management systems. Remote sensing is an accurate, efficient, economical and reliable technique to develop a complete inventory of the natural resources of an area. (Palaniswami *et al.*, 2011).

The information technology accelerates our ability to obtain large volumes of spatial data. It is widely adopted that key technologies helping modern precision agriculture are yield monitors, remote and proximal sensing, GPS and GIS. Remote sensing and photogrammetric techniques supply 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 huge amounts of data (Sahu *et al*., 2015).

Geographic information system is used for development of soil fertility map of an area and formulating balanced fertilizer recommendation to understand the status of soil fertility spatially and temporally (Binita *et al.,* 2009). GIS combines spatially referenced datasets for the purposes of modeling and informative decision making. It is an innovative method for assessing land quality (Jafari and Narges, 2010).

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

The high resolution satellite imagery, relief and land-use maps, hydraulic characteristics of river channels and flood-plain surveys, and probable water levels can be used for predictive flood hazard mapping. The flood risk evaluation has two-stage procedure. First stage is the calculation of statistical probabilities of stage discharge characteristics of river sections to determine the over-bank flow and the river sections at which the flow exceeds the carrying capacity of the river. Second stage is to evaluate the inhabited areas falling in the greater or lesser flood risk zone based on the relief map and high resolution remote sensing imagery (Sheng *et al*., 2010).

GIS based land use suitability of soils can be assessed by soil survey based on georeferencing and laboratory analysis of location. It is helpful for land managers and farmers to identify the problems / constraints in an area. Land quality parameters like soil texture, depth, slope, flooding etc. can be evaluated and mapped. (Abdel Rehman *et al*., 2018).

A thematic map is designed to visualise a particular data or information effectively. Representation of laboratory analysed data of soil quality can be done by Arc GIS tool. Development of soil quality map includes various steps such as GPS based soil sample collection, laboratory physio- chemical analysis of soil, soil quality index calculation and Arc GIS maping. The map will provide scientific knowledge on quality of soil in that particular area. (Mishra *et al.,* 2014).

Materials and Methods

3. MATERIALS AND METHODS

A study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Pathanamthitta district of Kerala and generation of GIS maps" was carried out to determine the changes in physical, chemical and biological properties of soil after flood during 2018 and to generate thematic maps.

The investigation includes:

1. Survey, collection and characterisation of soil
2. Setting up of Minimum Data Set (MDS) for assessment of soil quality
3. Formulation of SQI, LQI and NI
4. Generation of GIS maps.
5. Statistical analysis.

3.1. SURVEY AND COLLECTION OF SOIL

3.1.1. Details of the study area

The flood affected panchayats of AEU 9 (south central laterites) in Pathanamthitta were Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally. All these panchayats selected for study were severely affected by flood havoc and submergence that occurred in Manimala, Pamba and Achankovil rivers during August 2018.

The south central laterites agroecological unit represent the midland laterite terrain with typical laterite soil and short dry periods. The AEU 9 have tropical humid monsoon climate with mean annual temperature $26.5\,^{0}C$ and rainfall 2810 mm. Soils of these regions are strongly acidic, gravelly, contains lateritic clay and underlained by plinthite (Kerala State Land Use Board, 2015). Major crops includes rubber, coconut, banana, tapioca, paddy and vegetables (KAU, 2016).

3.1.2. Details of survey

A survey was conducted in the flood affected areas of AEU 9 to identify the flood affected areas, the basic details of the farmers, details of crop grown, nutrient management practices and the observable soil changes due to flooding were collected using a pre designed questionnaire(Appendix 1).

3.1.3. Collection of soil samples

A total of seventy five samples (Table 1) were collected from flood affected panchayats of AEU 9 in Pathanamthitta district for analysing the physical chemical and biological attributes. Soil samples were collected from a depth of 0-20 cm from each sampling sites using V notch method. From which representative samples were collected by quartering. Core samples were also collected from each site for examining the physical parameters. GPS was used to note the coordinates of each sampling sites and is given in Table 1. The soil sampling site of AEU 9 of Pathanamthitta district is also depicted in the georeferenced location map of study area (Fig 1).

Table 1. Details of soil sampling locations in AEU 9 of Pathanamthitta district.

Sl. No.	Panchayat/ Municipality	No. of Samples	Sampling Points	N Latitude	E Longitude
1	Aranmula	7	1	9.326295	76.677602
			2	9.322525	76.685429
			3	9.325092	76.695788
			4	9.320413	76.699140
			5	9.318844	76.704375
			6	9.329478	76.694573
			7	9.323300	76.686414
2	Mallapally	8	8	9.428211	76.659503
			9	9.431933	76.663349
			10	9.427276	76.670421
			11	9.438181	76.668303
			12	9.439593	76.659809
			13	9.447197	76.656306
			14	9.444996	76.663455
			15	9.441974	76.647336
3	Kallupara	7	16	9.393792	76.632497
			17	9.402974	76.637004
			18	9.410911	76.642195
			19	9.406517	76.638193
			20	9.408423	76.645182
			21	9.408261	76.652332
			22	9.418828	76.646621

Table1. Details of soil sampling locations (continued)

Sl. No.	Panchayat/ Municipality	No. of Samples	Sampling Points	N Latitude	E Longitude
4	Kulanada	8	23	9.241403	76.665402
			24	9.240844	76.668343
			25	9.237311	76.670258
			26	9.235037	76.671251
			27	9.236579	76.676139
			28	9.238698	76.674797
			29	9.234078	76.681730
			30	9.232619	76.685882
5	Kaviyur	7	31	9.386764	76.609052
			32	9.390534	76.615836
			33	9.387271	76.622708
			34	9.394753	76.62612
			35	9.399338	76.61568
			36	9.403756	76.621583
			37	9.398441	76.613251
6	Panthalam	8	38	9.230532	76.673368
			39	9.234405	76.674214
			40	9.231655	76.677424
			41	9.230047	76.680173
			42	9.228059	76.682617
			43	9.227849	76.685831
			44	9.218522	76.670218
			45	9.213510	76.675104
7	Thumbamon	7	46	9.231253	76.688890
			47	9.229223	76.692619
			48	9.224186	76.692665
			49	9.225651	76.698857
			50	9.221671	76.698131
			51	9.223664	76.703487
			52	9.223326	76.712326

Table1. Details on soil sampling locations (continued).

Sl. No.	Panchayat/ Municipality	No. of Samples	Sampling Points	N Latitude	E Longitude
8	Mezhuveli	8	53	9.228817	76.700556
			54	9.228222	76.704931
			55	9.232195	76.705047
			56	9.2764 05	76.685404
			57	9.279459	76.686690
			58	9.277463	76.679019
			59	9.280108	76.681397
			60	9.278056	76.687333
9	Kozhanchery	7	61	9.344967	76.707798
			62	9.350003	76.707026
			63	9.347633	76.711826
			64	9.345390	76.713240
			65	9.353769	76.715426
			66	9.354615	76.718640
			67	9.344101	76.715323
10	Thottapuzhassery	8	68	9.335070	76.678113
			69	9.340082	76.679910
			70	9.337787	76.687476
			71	9.336176	76.689365
			72	9.344342	76.700133
			73	9.349888	76.693687
			74	9.356978	76.696359
			75	9.355459	76.709354

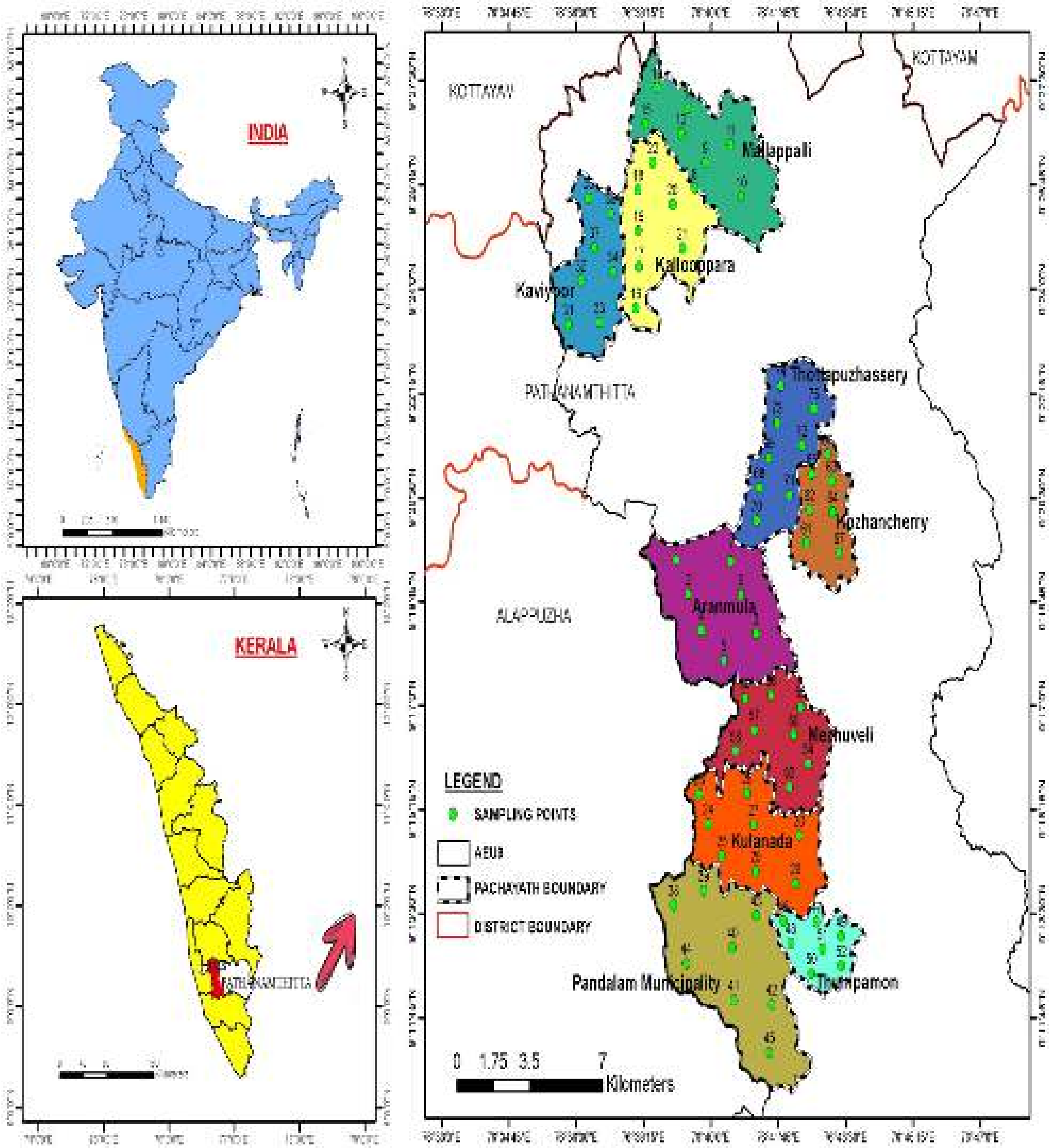

Fig.1 Location map of samples in AEU 9 of Pathanamthitta district.

3.1.3. Processing of soil samples

The collected soil samples were shade dried, powdered using wooden pestle and mortar, sieved through 2 mm sieve and stored in labelled containers. A portion of unprocessed soil samples and core samples were stored for the determination of aggregate stability and bulk density respectively. A portion of fresh sample also stored in refrigerator for biological analysis.

3.1.4. 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 RARS, Kayamkulam. The monthly mean of maximum temperature, minimum temperature, relative humidity, rainfall and no. of rainy days are represented in fig 2. The deviation in rainfall and number of rainy days in the year during 2018 from the average over last ten years (2008-2017) is presented in Table 2 and Fig 3.

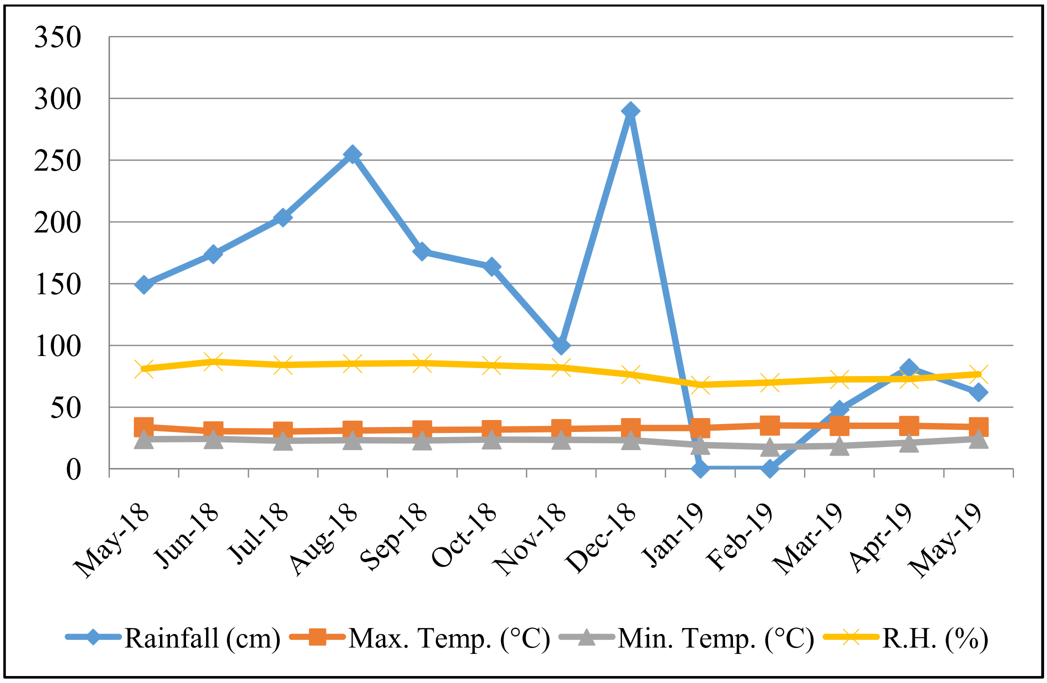

Fig. 2 Monthly mean of weather parameters in AEU 9(May 2018 to May 2019)

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

Month	Average rainfall (cm) (2008 – 2017)	Rainfall (cm) during 2018	Deviation in rainfall (mm)	Average no. of rainy days (2008 – 2017)	No. of rainy days during 2018	Deviation in no. of rainy days
January	107.0	34.0	-73.0	1	1	0
February	118.0	47.0	-71.0	2	2	0
March	136.0	97.7	-38.3	4	5	+1
April	132.4	118.9	-13.5	8	8	0
May	173.0	149.2	-23.8	11	18	+7
June	198.9	173.9	-25	21	27	+6
July	163.4	203.6	+40.2	20	22	+2
August	122.0	254.8	+132.8	15	21	+6
September	137.6	176.0	+38.4	15	4	-11
October	190.3	163.8	-26.5	12	13	+1
November	126.0	99.9	-26.1	10	11	+1
December	150.2	29.0	-121.2	4	3	-1

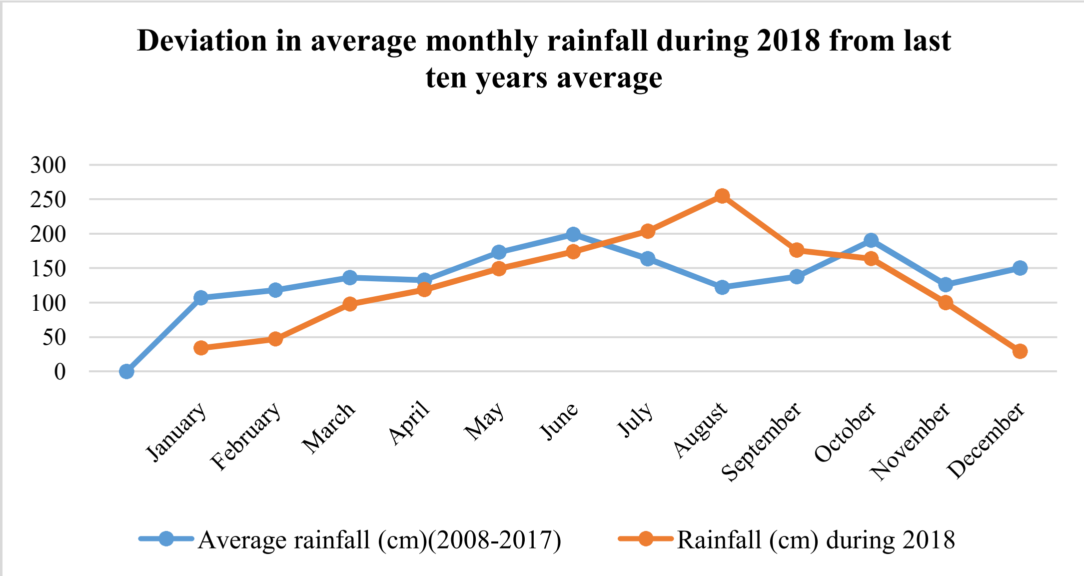

Fig. 3 Deviation in average monthly rainfall during 2018 from the average of last ten years

3.2 CHARACTERISATION OF SOIL

Soil samples collected from flood affected areas of AEU 9 of Pathanamthitta district were characterised for physical, chemical and biological parameters using the standard procedures.

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	Effective CEC	$BaCl_2$ compulsive exchange method	Gillman and Sumpter (1986)
10	Exchangeable acidity	1N KCl extraction and standard alkali titration	Sarma *et al*. (1987)
11	Organic carbon	Walkley and Black method	Walkley and Black (1934)
12	Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
13	Available phosphorus	Extraction using Bray No. 1 and estimation using spectrophotometer	Bray and Kurtz (1945)
14	Available potassium	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
15	Available calcium and magnesium	Versanate titration method	Hesse (1971)

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

Sl. No.	Attribute	Method	Reference
16	Available sulphur	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield(1963)
17	Available Boron	Hot water extraction and estimation in spectrophotometer (Azomethane H reagent method)	Gupta (1972)
18.	Available Fe, Mn, Zn and Cu	0.1 N HCl extraction and estimation using atomic absorption spectroscopy	Sims and Johnson (1991)
19.	Available heavy metals (Pb, Cd, Ni, Cr)	0.1 N HCl extraction and estimation using atomic absorption spectroscopy	Jackson (1973)
20.	Acid phosphatase activity	Colorimetric estimation of PNP released	Tabatabai and Bremner (1969)
21.	Dehydrogenase activity	Colorimetric estimation of TPF hydrolysed	Casida *et al.* (1977)

3.3 SETTING UP OF MINIMUM DATA SET (MDS) FOR ASSESSMENT OF SOIL QUALITY (SQ)

Principal component analysis method was used to determine the minimum data set. The data were analysed to prioritise the indicators and the principal component with high Eigen value ≥ 1 were taken into consideration. Each variable under a principal component give a factor loading which represent contribution of that variable to the principal component. Only the highly weighted variable which were having highest observed factor loading within 10 percent were retained in each principal component. When more than one variable comes under a principal component, linear correlation between the variables were used to check redundancy. Those variable with high correlation coefficient (correlation coefficient > 0.6) was taken redundant and considered for MDS. If they were not correlated (correlation coefficient<0.6), then each was considered important and retained in MDS (Andrews *et al*.,2002).

3.4 FORMULATION OF SOIL QUALITY INDEX

3.4.1 Soil quality index (SQI)

Soil quality index calculated as per the procedure given by Larsen and Pierce (1994). The attributes selected for MDS were assigned appropriate weight based on existing soil conditions, cropping system and agroclimatic conditions. Each attributes were classified into 4 classes, class I, class II, class III, class IV. Class I the most suitable for plant growth, class II suitable to plant growth but with slight limitation. Class III with serious limitation than class II, Class IV with severe limitation for plant growth. Scores of 4,3,2 and I were assigned to class I, class II, class III, class IV respectively (Kundu *et al*.,2012; Mukherjee and lal, 2014) with slight modifications based on soil fertility ratings for Kerala soils.

SQI was represented by equation,

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

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

3.4.2 Relative soil quality index

Relative soil quality index (RSQI) was the measurement of changes in soil quality. It was calculated using the formula suggested by Karlen and Slott (1994). The sampling location were rated based on RSQI value (Kundu *et al*., 2012).

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

Where SQI was the calculated SQI and SQI_m was the theoretical maximum.

\

Table 4. Relative soil quality index ratings

Sl	RSQI Rating	RQI Values (%)
1	Poor	<50
2	Medium	50-70
3	Good	>70

3.5 SOIL NUTRIENT INDEX

Soil fertility status of study area was obtained by using nutrient index rating. Nutrient index for soil organic carbon, available nitrogen, phosphorus, and potassium in soil were calculated by the formula given by Parker *et al*. (1951).

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

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

The sloils were rated based on the nutrient index value as suggested by Ramamurthy and Bajaj (1969).

Table 5. Nutrient index ratings

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

3.6 LAND QUALITY INDEX

Land quality index was calculated using the soil organic carbon stock (kg ha^{-1}) as per the criteria given by Shalimadevi (2006).

Soil organic carbon was estimated the method suggested by Batjes (1996) and expressed in Mg ha^{-1}.

Soil organic carbon stock (Mg ha^{-1}) = Soil organic carbon (%) x Bulk density (Mgm^3) x Soil depth (m) x 100

Table 6. 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

3.6 GENERATION OF GIS MAPS

GIS based thematic maps were prepared for parameters like soil texture, pH, organic carbon, available macronutrients, micronutrients, SQI, LQI and NI using Arc GIS 10.5.1 software through interpolation.

Inverse distance weighted (IDW) method is the interpolation tool used, which is a spatial analyst tool in Arc GIS software. Principle underlying IDW interpolation is the first law of Geography formulated by Tobler (1970) which state that everything is related to everything else, but near things are more related than distant things. It assumes that the nearer a sample point is to the cell whose value is to be estimated, more closely the cell's value will resemble the sample point's value. The visualization of nutrient status data in spatial environment is done by the procedure depicted below.

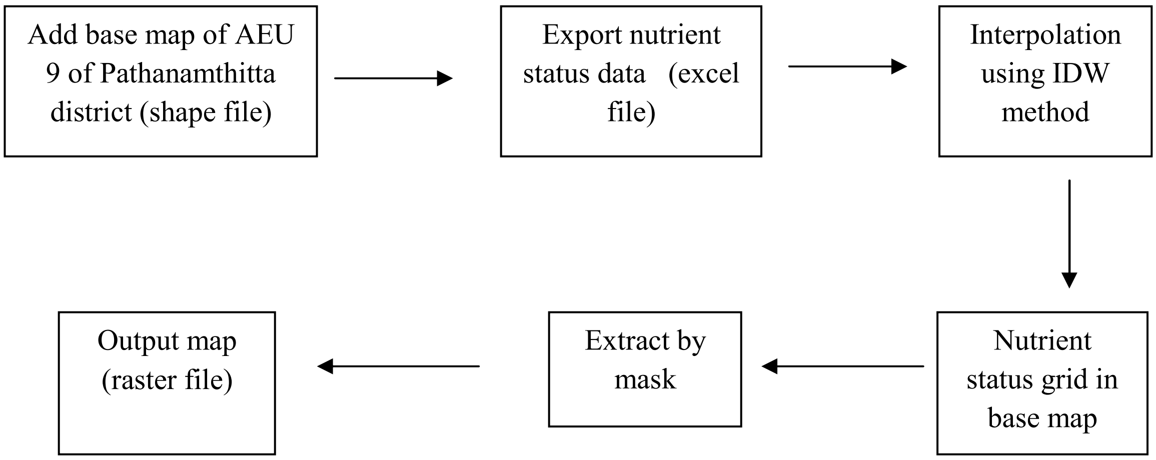

Fig.4. Flow chart of ArcGIS mapping using IDW method.

3.8 STATISTICAL ANALYSIS

Correlations between physical, chemical and biological properties were calculated in terms of Pearson's correlation coefficient (Pearson, 1931) using OPSTAT software.

Results

4. RESULTS

The soil quality in AEU 9 of Pathanamthitta district was evaluated through the present investigation entitled “Assessment of soil quality in the post-flood scenario of AEU 9 in Pathanamthitta district of Kerala and generation of GIS maps”. A survey was conducted and georeferenced surface soil samples were collected from the selected panchayats in AEU 9 of Pathanamthitta district affected by the flood during August 2018. Soil samples collected were analyzed for physical, chemical and biological properties. Minimum data set was formulated with the most sensitive soil parameters and soil quality index was worked out. Nutrient index and land quality index were also calculated and GIS maps were generated. The results obtained during the course of the investigation are presented in this chapter.

4.1 SURVEY OF FLOOD AFFECTED AREA IN AEU 9 OF PATHANAMTHITTA DISTRICT

The major rivers Achankovil, Pampa and Manimala draining through AEU 9 of Pathanamthitta district were overflowed and left the area flooded for almost a week. The panchayats affected by the flood were Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally. Most of the areas in these panchayats were under water stagnation for four to five days. Large quantity of sand and silt deposits of about 5-10 cm height was observed in Aranmula, Panthalam and Thumbamon panchayats

High rainfall and rise in water level in rivers caused widespread crop damage in these areas. The details on crops, nutrient management practices and size of holdings are provided in Table 7. Among the major crops, paddy and banana were the most affected. Other crops affected by flood includes tuber crops, rubber, coconut and vegetables. Banana and vegetable crops showed withering after flood. Nendran variety was the most affected banana variety. Incidence of root wilt disease in coconut increased after flood. Farmers reported incidence of fungal and bacterial infection, severe weed growth and pest infestation immediately after the flood.

Most of the area is under coconut based cropping system(26.6%) followed by banana (20.1 %) and vegetables (20.3 %). More than 77 per cent of farmers are marginal farmers (< 1ha) and others are small farmers (1 -2 ha). Integrated nutrient management practices was followed by majority of the farmers (46.6%). Farmers apply urea, factomphos, rock phosphate and muriate of potash in two splits in the coconut gardens. In situ green leaf manuring with cow pea is also practised. Conventional system of nutrient management is followed by banana farmers by applying fertilizers like factomphos, rajphos and muriate of potash in split doses. Majority of the vegetable farmers rely on organic nutrient sources like cowdung, vermicompost, biogas slurry and green manure for crop nutrition. Liming is done once in a year for coconut and banana. Most of the farmers practising INM use urea, factomphos, rock phosphate and MOP along with organic manures.

Table 7. Details of field survey conducted in AEU 9 of Pathanamthitta district

Particulars	No. of farmers	Percentage
Crops		
1.Coconut	20	26.6%
2.Paddy	10	13.3%
3.Banana	15	20.1%
4.Cassava	10	13.2%
5.Vegetables	15	20.3%
6. Rubber	5	6.50%
Nutrient management		
1.INM	35	46.6%
2.Organic	15	20.0%
3.Conventional	25	33.3%
Size of holdings		
1.<1 ha	58	77.3%
2.>1 ha	17	22.6%

4.2. CHARACTERISATION OF SOIL

Soil quality was assessed by determining physical, chemical and biological properties of soils collected from flood affected areas of AEU 9 of Pathanamthitta district and the results are given below.

4.2.1 Physical attributes

The soil samples were analysed for physical parameters *viz.* bulk density, particle density, porosity, soil texture, aggregate stability, moisture content, maximum water holding capacity and depth of sand/silt/clay deposition. The results are presented below.

4.2.1.1. Bulk density, particle density and porosity

Bulk density varied between 0.87 to 1.76 Mg m^{-3} with a mean of 1.30 Mg m^{-3}. The lowest and the highest mean values were observed for Kaviyur panchayat (1.07 Mg m^{-3}) and Kalloopara panchayat (1.54 Mg m^{-3}), respectively (Table 8).

Particle density ranged between 2.07 to 2.45 Mg m^{-3} in the post- flood soils with a mean value of 2.21 Mg m^{-3}.The lowest mean at panchayat level were observed for Aranmula and Kaviyur panchayat (2.15Mg $m^{-3)}$ and the highest mean at Kalloopara panchayat (2.33 Mg m^{-3}), respectively (Table 8).

Porosity ranged from 25.4 percent to 58.4 percent with a mean of 41.5 percent. The highest and lowest mean were recorded in Kaviyur panchayat (50.3%) and Kalloopara panchayat (33.83%), respectively (Table 8).

Table 8. Bulk density, particle density and porosity in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Bulk Density (Mg m^{-3})		Particle Density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Aranmula	1.37±0.04	1.31-1.42	2.15 ± 0.05	2.07-2.21	36.4±1.92	33.8-38.8
Mallapalli	1.26±0.07	1.19-1.37	2.16±0.08	2.07-2.29	41.5±3.89	33.8-46.7
Kalloopara	1.54±0.21	1.31-1.76	2.33±0.07	2.21-2.41	33.8±7.78	25.4-43.7
Kulanada	1.39±0.18	1.22-1.71	2.19±0.10	2.11-2.41	36.6±6.87	28.4-45.1
Kaviyur	1.07±0.13	0.87-1.22	2.15±0.05	2.09-2.22	50.3±5.17	45.1-58.4
Panthalam	1.21±0.07	1.14-1.33	2.17±0.04	2.12-2.22	43.9±3.44	38.7-48.7
Thumbamon	1.21 ±0.08	1.12-1.31	2.18 ±0.07	2.12-2.31	44.6 ±3.74	41.0-50.7
Mezhuveli	1.21±0.08	1.12-1.31	2.18±0.07	2.12-2.31	44.6±3.74	41.0-50.7
Kozhanchery	1.37 ±0.04	1.33-1.42	2.30 ±0.08	2.23-2.45	40.4 ±1.45	38.1-42.0
Thottapuzhassery	1.23±0.08	1.13-1.32	2.22±0.07	2.11-2.34	44.7±2.16	41.9-47.5
AEU 9	1.30±0.16	0.87-1.76	2.21±0.09	2.07-2.45	41.5±6.25	25.4-58.4

4.2.1.2 Soil texture

The results of soil textural analysis are given in table 9. The results indicated that the predominant textural class of flood affected soils of AEU 9 was loam which was observed in Aranmula, Mallapalli, Kaviyur, Thumbamon, Mezhuvely, Kozhanchery and Thottapuzhassery panchayat. Clay loam texture was observed in Kulanada and Panthalam panchayat. Sandy loam texture was observed in Kalloopara panchayat. Sand content varied between 34.9 and 56.2 percent with highest and the lowest mean values in Kalloopara (51.4%) and Kulanada (39.3%), respectively. Silt content varied between 26.5 and 42.5 percent and the lowest and highest mean values were obtained in Kalloopara (30.0%) and Mallapalli (39.2%), respectively. Clay content in the soils ranged from 16.9 to 31.2 percent. The highest and lowest mean values were recorded for Panthalam (27.6%) and Kalloopara (18.6%), respectively.

Table 9. Soil texture in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Sand (%)		Silt (%)		Clay (%)		Textural class
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Aranmula	41.8±5.85	35.7-51.2	33.9±4.71	27.1-41.7	24.3±2.87	19.1-27.6	Loam
Mallapalli	39.1±3.41	35.4-44.4	39.2±2.15	35.6-42.0	21.7±2.38	17.9-24.1	Loam
Kalloopara	51.4±3.66	46.4-56.2	30.0±1.98	26.9-32.7	18.6±2.24	16.9-22.2	Sandy loam
Kulanada	39.3±1.83	36.4-41.4	34.2±1.82	30.4-36.1	26.6±3.08	23.1-31.2	Clay loam
Kaviyur	42.0±5.36	35.7-51.2	34.8±4.87	26.5-40.2	23.2±3.71	18.1-28.4	Loam
Panthalam	42.2±1.98	39.3-44.2	30.2±1.59	27.6-32.2	27.6±2.39	24.9-31.1	Clay loam
Thumbamon	42.2 ±2.13	39.2-45.1	32.8 ±1.36	31.6-35.3	25.0 ±2.14	22.9-28.0	Loam
Mezhuveli	42.2±2.13	39.2-45.1	32.8±1.36	31.6-35.3	25.0±2.14	22.9-28.0	Loam
Kozhanchery	43.7±3.51	40.8-51.2	32.9 ±2.78	29.6-36.1	23.4 ±2.42	19.1-27.1	Loam
Thottapuzhassery	44.5±1.62	42.2-47.1	30.4±1.00	28.6-31.5	25.2±2.06	22.2-28.3	Loam
AEU 9	42.3±4.74	34.9-56.2	33.6±3.97	26.5-42.5	24.1±3.43	16.9-31.2	

4.2.1.3 Depth of sand, silt and clay deposits

Deposition of sediments with varying depth and texture were observed in Aranmula, Mallapalli, Kalloopara, Kulanada, Kaviyur, Panthalam, Thumbamon, Mezhuvely, Kozhanchery and Thottapuzhassery (Table 10). Maximum deposits were observed in Aranmula and Kalloopara with sand and silt deposits up to 10 to 15 cm, followed by Mallapalli, Thumbamon, Thottapuzhassery and Kozhanchery where silt and sand deposited up to 5 to 10 cm height. Sand and silt deposits of less than 1 cm depth was observed in Mezhuvely panchayat. Sand and clay deposits of less than 1-5cm was observed in Kulanada, Panthalam and Kaviyur.

Table 10. Depth of silt/sand/clay deposition in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Depth of deposition	Nature of deposits
Aranmula	10-15cm	Sand, silt
Mallapalli	5-10cm	Sand, silt
Kalloopara	10-15cm	Sand, silt
Kulanada	1-5cm	Sand, clay
Kaviyur	1-5cm	Sand, clay
Panthalam	1-5cm	Sand, clay
Thumbamon	5-10cm	Sand, silt
Mezhuveli	<1cm	Sand, silt
Kozhanchery	5-10cm	Sand, silt
Thottapuzhassery	5-10cm	Sand, silt

4.2.1.4. Soil moisture content and water holding capacity

The highest mean value for soil moisture content was observed in Kaviyur (44.0%) followed by Kalloopara (29.0%) and the lowest in Kozhanchery (20.5%). Soil moisture content varied between 15.2 to 50.8 percent in the post-flood area of AEU 9 in Pathanamthitta district with a mean of 26.2 percent (Table 11)

The water holding capacity was the highest (51.0%) in Panthalam, followed by Thottapuzhassery (48.6%) and the lowest value was observed in Kalloopara (29.7 %). The results showed that the water holding capacity ranged between 25.4 and 62.4 percent in the post-flood soils of AEU 9 with a mean of 42.8 percent (Table 11).

Table 11. Soil moisture content and water holding capacity of post-flood soils of AEU 9 in Pathanamthitta district.

Panchayat/ Municipality	Moisture Content (%)		WHC (%)	
	Mean ± SD	Range	Mean ± SD	Range
Aranmula	26.24±1.69	24.1-28.3	37.0±2.82	33.5-40.4
Mallapalli	24.5±1.82	20.2-26.1	42.3±5.58	25.0-49.9
Kalloopara	29.0±2.02	26.4-32.1	29.7±4.35	25.4-38.1
Kulanada	24.0±4.51	20.4-31.1	41.5±11.3	31.7-62.2
Kaviyur	44.0±4.22	40.7-50.8	44.21±2.56	39.1-46.6
Panthalam	27.6±3.31	22.4-31.0	51.0±4.33	44.3-55.5
Thumbamon	21.5 ±3.01	15.2-24.6	48.04 ±4.95	40.5-54.1
Mezhuveli	21.5±3.01	15.2-24.6	48.1±4.95	40.5-54.1
Kozhanchery	20.5 ±1.46	18.4-22.4	42.8 ±4.78	35.1-47.9
Thottapuzhassery	23.0±3.65	16.1-28.4	48.6±6.11	44.2-62.4
AEU 9	26.2±6.84	15.2-50.8	42.8±7.99	25.4-62.4

4.2.1.5. Aggregate stability

Aggregate stability was measured by calculating mean weight diameter (mm) and percentage of water stable aggregates. The data on MWD and percentage of water stable aggregates in the post-flood area in AEU 9 are presented in Table 12. MWD ranged between 0.47 to 2.41 mm with a mean of 1.62 mm. The highest and the lowest mean values of MWD were obtained for Kaviyur (2.22 mm) and Kozhanchery (0.69 mm) respectively. Percentage of water stable aggregates varied between 38.6 to 68.5 percent in the post-flood soils of AEU 9 in Pathanamthitta district with a mean of 53.5 percent. The highest and the lowest mean values were recorded in Kaviyur (64.1%) and Kozhanchery (40.9%), respectively,

Table 12. Mean weight diameter and water stable aggregates in the post-flood soils of AEU 9 in Pathanamthitta district.

Panchayat/ Municipality	MWD (mm)		WSA (%)	
	Mean ± SD	Range	Mean ± SD	Range
Aranmula	1.37±0.15	1.12-1.53	42.1±2.18	39.6-45.2
Mallapalli	2.21±0.37	1.90-2.41	60.9±2.89	55.5-66.2
Kalloopara	2.01±0.18	1.78-2.23	63.8±2.92	57.9-66.2
Kulanada	1.56±0.10	1.43-1.71	50.9±2.44	46.8-54.0
Kaviyur	2.22±0.46	1.83-2.32	64.1±3.74	60.1-68.5
Panthalam	1.55±0.09	1.42-1.71	52.5±1.48	50.1-54.4
Thumbamon	1.02 ±0.30	0.62-1.32	41.5 ±1.56	39.4-43.3
Mezhuveli	0.71±0.14	0.47-0.84	41.5±1.56	39.4-43.3
Kozhanchery	0.69 ±0.14	0.47-0.80	40.9±1.79	38.6-44.4
Thottapuzhassery	1.36±0.11	1.22-1.53	56.1±2.52	52.9-60.1
AEU 9	1.62±0.55	0.47-2.41	53.5±9.15	38.6-68.5

4.2.2 Chemical attributes

The soil samples were analyzed in the laboratory for chemical parameters viz. pH, electrical conductivity, exchangeable acidity, effective CEC, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron, iron, manganese, zinc, copper and heavy metals and the results obtained are given below.

4.2.2.1 pH, exchangeable acidity, effective cation exchange capacity and electrical conductivity

The results obtained with respect to pH, electrical conductivity and exchangeable acidity of soils in AEU 9 are presented in Table 13. The soil pH ranged between 4.60 to 5.60 with a mean of 5.16. The lowest and the highest mean value of pH was observed in Mallapalli (4.77) and Thumbamon (5.57), respectively. The exchangeable acidity of post-flood soils of AEU 9 in Pathanamthitta district was in the range of 0.7 to 2.90 c mol g^{-1} with a mean of 1.75 c mol g^{-1}. The highest mean value was obtained in Kaviyur (2.73 c mol g^{-1}), followed by Aranmula (2.27 c mol g^{-1}) and the lowest in Mezhuveli (1.18 c mol g^{-1}).

The ECEC ranged between 2.80 to 5.50 meq/100g in the post-flood soils of AEU 9 in Pathanamthitta district with a mean of 3.96 meq $100g^{-1}$. The lowest mean value of 3.24 meq/100g was obtained in Mallapalli and the highest mean value was obtained in Thumbamon (4.54 meq $100g^{-1}$).

EC ranged between 0.05 to 0.40 dS m^{-1} in the post-flood soils of AEU 9 in Pathanamthitta district with a mean of 0.13 dS m^{-1}. The lowest mean value of 0.06 dS m^{-1} was obtained in Thumbamon followed by Kalloopara and Kaviyur (0.09 dS m^{-1}) and the highest mean value was obtained in Aranmula (0.21 ds m^{-1})

Table 13. pH, electrical conductivity, exchangeable acidity and ECEC in the post-flood soils of AEU 9 in Pathanamthitta district.

Panchayat/ Municipality	pH		Ex.Acidity (cmolg^{-1})		ECEC (meq/100g)		EC (dsm^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Aranmula	5.36±0.42	5.31-5.41	2.27±0.35	1.90-2.90	4.27±0.35	3.90-4.90	0.21±0.14	0.12-0.41
Mallapalli	4.77±0.12	4.64-4.96	1.23±0.21	0.90-1.50	3.24±0.29	2.80-3.70	0.11±0.01	0.10-0.12
Kalloopara	4.83±0.16	4.60-4.95	2.46±0.48	1.80-2.90	3.93±0.65	3.00-4.60	0.09±0.03	0.05-0.12
Kulanada	5.31±0.07	5.24-5.40	1.61±0.30	1.30-2.20	4.09±0.38	3.80-4.70	0.16±0.04	0.12-0.21
Kaviyur	4.78±0.15	4.60-4.95	2.73±0.13	2.50-2.90	4.50±0.53	3.90-5.50	0.09±0.02	0.06-0.11
Panthalam	5.19±0.05	5.12-5.25	1.46±0.23	1.20-1.80	4.23±0.34	3.80-4.70	0.18±0.04	0.12-0.21
Thumbamon	5.57±0.04	5.51-5.60	1.64±0.35	1.30-2.20	4.54±0.70	3.40-5.40	0.06±0.01	0.05-0.07
Mezhuveli	5.16±0.05	5.10-5.25	1.18±0.27	0.80-1.40	3.53±0.44	2.80-4.30	0.13±0.03	0.11-0.20
Kozhanchery	5.34±0.04	5.31-5.40	1.24±0.30	0.70-1.50	3.47±0.43	2.90-4.10	0.14±0.03	0.12-0.21
Thottapuzhassery	5.33±0.03	5.31-5.40	1.58±0.30	1.30-2.10	3.90±0.46	3.30-4.60	0.13±0.02	0.11-0.16
AEU 9	5.16±0.27	4.60-5.60	1.75±0.66	0.70-2.90	3.96±0.61	2.80-5.50	0.13±0.06	0.05-0.40

4.2.2.2 Organic carbon

The organic carbon content of post-flood soils of AEU 9 is presented in Table 14. Organic carbon content varied from 0.40 to 3.50% with a mean value of 1.63 percent. It was the highest in Kaviyur (2.53%) followed by Aranmula (2.43%) and the lowest soil organic carbon was observed in Kozhanchery (0.66%).

4.2.2.3 Available nitrogen, phosphorous and potassium

The results of available nitrogen(N) in post flood soils of AEU 9 in Pathanamthitta district revealed that the values varied from 201 to 464 kg ha^{-1} with a mean of 289 kg ha^{-1} (Table 14). The highest available nitrogen status of 358 kg ha^{-1} was recorded in Kalloopara followed by Panthalam (310 kg ha^{-1}) and the lowest in Mallapalli (245 kg ha^{-1}).

Available phosphorus (P) content varied between 8.10 to 104 kg ha^{-1} with a mean of 31.9 kg ha^{-1} (Table 14). The highest available P of 57.8 kg ha^{-1} was obtained in Mallapalli, which was followed by Mezhuveli (51.4 kg ha^{-1}). The lowest P availability of 14.3 kg ha^{-1} was observed in Thottapuzhassery.

Available potassium (K) in the post-flood area of AEU 9 in Pathanamthitta district varied between 78.7 and 493 kg ha^{-1} with a mean of 246 kg ha^{-1} (Table 14). The availability of K in soil was found to be highest in Kulanada (356 kg ha^{-1}), followed by Mezhuveli (327 kg ha^{-1}). The lowest value was observed in Kaviyur (105 kg ha^{-1}).

Table 14. Organic carbon and available N, P, K in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	OC %		N_2 (Kg ha^{-1})		P (Kg ha^{-1})		K (Kg ha^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Aranmula	2.43±0.68	1.80-3.40	291±22.2	257-326	26.4±4.80	23.1-36.8	254±74.5	190-381
Mallapalli	1.49±0.15	1.30-1.80	245±15.34	222-268	57.8±24.4	36.8-104	313±19.4	280-336
Kalloopara	2.33±0.33	2.00-3.00	358±50.1	321-464	15.0±3.32	9.50-19.1	154±30.3	124-213
Kulanada	1.83±0.80	1.00-3.50	300±13.0	284-314	44.5±4.89	36.7-50.0	356±78.9	280-493
Kaviyur	2.53±0.51	2.10-3.40	292±30.3	252-320	21.1±7.45	14.1-35.7	105±19.0	78.7-135
Panthalam	1.43±0.18	1.10-1.60	310±19.8	289-351	22.6±8.12	13.9-35.7	194±20.2	166-220
Thumbamon	1.19±0.28	0.90-1.70	298±54.7	261-414	25.5±11.0	15.2-45.1	162±25.8	132-212
Mezhuveli	1.25±0.23	0.80-1.50	258±49.6	201-326	51.4±9.42	42.3-65.5	327±59.9	255-460
Kozhanchery	0.66±0.26	0.40-1.20	263±30.8	209-311	35.9±11.6	25.4-55.5	318±43.4	250-375
Thottapuzhassery	1.35±0.19	1.10-1.60	279±21.2	250-313	14.3±6.40	8.10-25.8	246±30.3	191-281
AEU 9	1.63±0.69	0.40-3.50	289±43.3	201-464	31.9±18.0	8.10-104	246±92.2	78.7-493

4.2.2.4 Available calcium (Ca), magnesium (Mg) and sulphur (S)

The results with respect to availability of secondary nutrients viz. calcium, magnesium and sulphur are given in Table 15. Available Ca ranged between 151 to 521 mg kg^{-1}in the post-flood area with a mean of 326 mg kg^{-1}. The highest available Ca was recorded in Thumbamon (449 mg kg^{-1}) and the lowest in Kaviyur (213 mg kg^{-1}).

Available Mg in soil varied between 30.4 to 210 mg kg^{-1} and the mean value was 106 mg kg^{-1}. It was the highest in Panthalam (142 mg kg^{-1}) followed by Thottapuzhassery (141 mg kg^{-1}) and the lowest in Kalloopara (55 mg kg^{-1}).

Available S varied between 0.5 and 87.5 mg kg^{-1} with mean value of 21.4 mg kg^{-1}. The highest and the lowest mean value for available S in soil were observed in Kozhanchery (51.2 mg kg^{-1}) and Kulanada (3.71mg kg^{-1}), respectively.

4.2.2.5 Available boron (B)

The available B in the post flood soil of AEU 9 in Pathanamthitta district varied between 0.01 mg kg^{-1} to 0.45 mg kg^{-1} with mean of 0.13 mg kg^{-1}. (Table 15). Aranmula recorded the highest available B of 0.23 mg kg^{-1} followed by Thumbamon (0.18 mg kg^{-1}). Thottapuzhassery and mallapally recorded the lowest available B of 0.05 mg kg^{-1} .

Table 15. Available Ca, Mg, S and B in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Ca (mg Kg^{-1})		Mg (mg Kg^{-1})		S (mg Kg^{-1})		B (mg Kg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Aranmula	258±39.3	181-310	110±21.2	90.1-151	7.06±0.75	6.30-8.50	0.23±0.12	0.01-0.41
Mallapalli	289±32.6	251-330	94.5±11.6	78.5-109	7.10±3.79	0.50-13.1	0.05±0.03	0.01-0.08
Kalloopara	220±28.4	180-251	55.0±18.8	30.4-78.7	7.90±2.11	6.00-12.0	0.08±0.02	0.05-0.10
Kulanada	370.±29.4	330-410	107±15.1	78.5-120	3.71±2.30	0.80-8.10	0.13±0.08	0.06-0.31
Kaviyur	213±46.0	151-300	69.4±9.33	54.5-84.8	14.0±4.76	8.90-22.5	0.16±0.05	0.09-0.21
Panthalam	416±22.7	381-441	142±25.6	90.8-174	37.9±22.2	18.9-87.5	0.14±0.07	0.07-0.25
Thumbamon	449±89.0	320-521	137±33.6	90.5-176	30.9±11.4	21.2-54.5	0.18±0.14	0.01-0.45
Mezhuveli	368±61.8	320-481	91.4±33.4	51.6-161	12.3±7.38	0.50-25.4	0.17±0.13	0.05-0.41
Kozhanchery	326±50.6	240-410	108±14.5	90.8-132	51.2±24.0	31.1-86.0	0.12±0.09	0.02-0.26
Thottapuzhassery	327±38.1	281-400	141-44.1	90.3-210	42.8±20.0	27.1-84.3	0.05±0.02	0.02-0.09
AEU 9	326±86.5	151-521	106±36.6	30.4-210	21.4±20.7	0.50-87.5	0.13±0.10	0.01-0.45

4.2.2.6 Available iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu)

The results with respect to availability of micro nutrients viz. *iron, manganese, zinc and copper* are given in table 16. Available Fe ranged from 18.8 to 155 mg kg^{-1}in the post-flood area with a mean of 108 mg kg^{-1}. The highest available Fe was recorded in Thottapuzhassery (151 mg kg^{-1}) followed by Kaviyur (140 mg kg^{-1}) and the lowest in Kulanada (31.4 mg kg^{-1}).

Available Mn in soil varied between 10.3 and 125 mg kg^{-1} and the mean value was 85.6 mg kg^{-1}. It was highest in Thottapuzhassery (120 mg kg^{-1}) followed by Thumbamon (119 mg kg^{-1}) and the lowest in Mezhuveli (22.5 mg kg^{-1}).

Available zinc varied between 0.31 to 3.64 mg kg^{-1} with mean value of 1.48 mg kg^{-1}. The highest and lowest mean value for available zinc in soil were observed in Thottapuzhassery (3.24 mg kg^{-1}) and Mallapalli (0.46 mg kg^{-1}) respectively.

Available Cu varied between 1.11 to 6.60 mg kg^{-1} with mean value of 5.19 mg kg^{-1}. The highest and lowest mean value for available copper in soil were observed in Thottapuzhassery (5.91 mg kg^{-1}) and Mezhuveli (1.71mg kg^{-1}) respectively.

Table 16. Available Fe, Mn, Zn and copper in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Fe ($mg\ kg^{-1}$)		Mn ($mg\ kg^{-1}$)		Zn ($mg\ kg^{-1}$)		Cu ($mg\ kg^{-1}$)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Aranmula	78.0±30.1	47.5-121	26.1±3.14	20.7-29.0	2.69±0.57	2.09-3.64	3.90±0.98	2.13-4.81
Mallapalli	96.7±97.3	32.6-144	52.9±33.8	34.3-136	0.46±0.21	0.31-0.93	4.29±0.84	2.69-5.12
Kalloopara	76.8±2.41	73.4-79.9	23.8±7.29	10.3-32.7	1.08±0.16	0.93-1.31	4.83±0.32	4.33-5.23
Kulanada	31.4±1.80	28.9-34.4	84.1±17.1	72.2-125	1.17±0.33	0.94-2.96	5.68±1.37	3.63-8.55
Kaviyur	140±21.3	92.5-152	49.3±22.0	35.5-98.5	1.09±0.26	0.59-1.34	5.28±0.44	4.70-6.10
Panthalam	124±6.56	119-136	95.0±13.3	82.2-125	1.31±0.16	1.11-1.50	4.31±0.24	3.92-4.63
Thumbamon	92.3±35.4	18.8-136	119±10.4	107-138	1.34±0.11	1.21-1.52	4.44±0.31	4.12-5.08
Mezhuveli	68.0±19.0	25.7-84.2	22.5±11.7	15.4-50.6	0.77±0.13	0.49-0.87	1.71±0.70	1.11-3.34
Kozhanchery	125±13.7	115-154	95.2±16.9	59.9-112	1.68±0.40	0.87-2.10	4.72±1.12	2.60-5.47
Thottapuzhassery	151±6.06	120-155	110±9.96	98-125	3.24±0.62	2.91-3.54	5.91±0.62	4.5-6.60
AEU 9	108±66.2	18.8-155	85.6±74.7	10.3-125	1.48±0.87	0.31-3.64	5.19±2.81	1.11-6.60

4.2.2.7 Heavy metals

The soil sample collected from AEU 9 of Pathanamthitta district were analysed for the presence of heavy metals lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr). Cd, Ni and Cr were not detected anywhere in the flood affected panchayaths. Pb was the only detected heavy metal (table 17). Pb content varied between 0.012 and 0.412 mg kg^{-1} and average was 0.154 mg kg^{-1}. It was highest in Kozhanchery (0.403 mg kg^{-1}) and lowest in Thottapuzhassery (0.022 mg kg^{-1}).

Table 17. Heavy metals in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Pb (mg Kg^{-1})		Cd (mg Kg^{-1})		Ni (mg Kg^{-1})		Cr (mg Kg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Aranmula	0.038±0.138	0.032-0.044	ND	ND	ND	ND	ND	ND
Mallapalli	0.109±0.172	0.106-0.113	ND	ND	ND	ND	ND	ND
Kalloopara	0.164±0.082	0.154-0.178	ND	ND	ND	ND	ND	ND
Kulanada	0.135.±0.134	0.130-0.141	ND	ND	ND	ND	ND	ND
Kaviyur	0.024±0.155	0.012-0.033	ND	ND	ND	ND	ND	ND
Panthalam	0.325±0.123	0.312-0.354	ND	ND	ND	ND	ND	ND
Thumbamon	0.110±0.054	0.107-0.118	ND	ND	ND	ND	ND	ND
Mezhuveli	0.165±0.156	0.150-0.184	ND	ND	ND	ND	ND	ND
Kozhanchery	0.408±0.145	0.403-0.412	ND	ND	ND	ND	ND	ND
Thottapuzhassery	0.022±0.134	0.015-0.043	ND	ND	ND	ND	ND	ND
AEU 9	0.154±0.122	0.012-0.412	ND	ND	ND	ND	ND	ND

4.2.3 Biological attributes

The soil samples were analysed in the laboratory for biological parameters like acid phosphatase and dehydrogenase activity and the results obtained are presented below.

4.2.3.1 Acid phosphatase activity

The results of acid phosphatase activity of flood affected soils of AEU 9 presented in Table 18 revealed that the acid phosphatase activity ranged between 15.5 and 57.8 µg PNP produced g^{-1} h^{-1} with a mean of 27.9 µg PNP produced g^{-1} h^{-1}. The highest and lowest activity was observed in Panthalam (31.7 µg PNP produced $g^{-1}h^{-1}$) and Thottapuzhassery (23.3µg PNP produced g^{-1} h^{-1}), respectively.

4.2.3.2 Dehydrogenase activity

Dehydrogenase activity varied between 17.1 and 27.7 µg TPF hydrolysed g^{-1}soil 24 hr^{-1}) with a mean value of 24.4 µg TPF hydrolysed g^{-1} soil 24 hr^{-1} (Table 18). The highest mean value was observed in Panthalam (25.6 µg TPF hydrolysed g^{-1} soil 24 hr^{-1}) and the lowest in Thottapuzhassery (23.0 µg TPF hydrolysed g^{-1} soil 24 hr^{-1})

Table 18. Acid phosphatase and dehydrogenase activity in the post-flood soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	Acid phosphatase activity(µg p-nitrophenol released g^{-1} soil hr^{-1})		Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})	
	Mean±SD	Range	Mean±SD	Range
Aranmula	28.0±6.00	21.0-34.5	24.4±2.60	18.8-27.1
Mallapalli	29.5±3.25	24.8-33.7	23.9±2.70	18.2-26.3
Kalloopara	26.5±5.05	20.0-33.5	23.6±2.50	19.9-26.1
Kulanada	30.5±4.70	19.1-33.8	24.3±1.22	21.8-25.5
Kaviyur	27.5±7.50	18.1-36.7	24.5±1.79	20.9-26.1
Panthalam	31.7±5.70	19.1-37.8	25.6±1.77	22.8-27.7
Thumbamon	26.0±7.04	15.5-34.4	24.7±2.33	19.8-27.1
Mezhuveli	31.0±13.9	15.5-57.8	25.3±0.58	24.7-26.2
Kozhanchery	24.1±5.16	16.3-30.5	24.7±2.61	18.9-26.3
Thottapuzhassery	23.3±5.06	16.0-28.9	23.0±3.67	17.1-25.8
AEU 9	27.9±7.10	15.5-57.8	24.4±2.30	17.1-27.7

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

Principal Component Analysis (PCA) was used for setting up of the minimum data set. The soil parameters used in PCA were bulk density, particle density, soil moisture content, water holding capacity, mean weight diameter, water stable aggregates, sand , silt and clay per cent , pH, EC, exchangeable acidity, ECEC, organic carbon, available primary and secondary nutrients, available B, available micronutrients, acid phosphatase and dehydrogenase activity. The PCA resulted in seven principal components with eigen value greater than 1, which were selected for the MDS. These seven principle components explained 26.3, 18.5, 11.9, 9.7, 5.8 and 5.4 percent variance, respectively (Table 19).

The factor loadings of variables under a particular PC denote the contribution of that variable to the PC. Only highly weighted variables within 10 percent of the highest factor loading were retained in the 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 significantly correlated (r>0.6), then the variable with the highest factor loading was retained for the MDS and the remaining excluded. On the other hand, all the non-correlated highly weighted variables under a PC were considered important and retained (Andrews and Carroll, 2001).

Table 19. Result of principal component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	5.001	3.518	2.252	1.846	1.108	1.032
% variance	26.3	18.5	11.9	9.7	5.8	5.4
Cumulative variance	26.3	44.8	56.7	66.4	72.2	77.7
Eigen vectors						
Bulk density ((Mgm^{-3})	0.097	0.113	**-0.438**	-0.248	0.368	0.012
Particle density (Mgm^{-3})	0.019	0.117	-0.392	**-0.387**	-0.105	-0.099
Soil moisture content (%)	-0.106	-0.143	0.258	-0.278	-0.204	0.018
Water holding capacity (%)	-0.195	-0.338	0.238	-0.129	0.004	-0.103
Mean weight diameter (mm)	0.302	0.103	0.207	-0.135	-0.014	0.162
Water stable aggregates (%)	0.158	0.295	-0.078	-0.179	0.322	0.371
Sand (%)	-0.065	**0.419**	-0.263	-0.065	-0.097	-0.004
Silt (%)	0.231	-0.255	0.250	-0.174	-0.004	-0.144
Clay(%)	-0.178	-0.284	0.074	0.291	0.139	0.173
pH	-0.304	-0.199	-0.268	0.138	0.158	-0.114
EC (dSm^{-1})	-0.041	-0.093	-0.144	-0.306	-0.171	-0.145
OC (%)	0.166	0.247	0.175	0.345	**0.384**	0.098
N ($kgha^{-1}$)	-0.011	0.291	-0.181	0.264	0.093	0.433
P ($kgha^{-1}$)	0.213	-0.347	0.029	-0.214	0.139	0.123
K ($kgha^{-1}$)	0.038	-0.328	-0.100	-0.304	**0.409**	-0.019
Ca($mgkg^{-1}$)	-0.192	-0.326	-0.195	0.097	-0.162	**0.390**
Mg ($mgkg^{-1}$)	-0.295	-0.199	-0.019	0.054	0.063	0.198
S ($mgkg^{-1}$)	-0.306	-0.027	-0.018	-0.144	**-0.422**	-0.010
B ($mgkg^{-1}$)	0.040	-0.125	-0.141	**0.419**	-0.065	**-0.613**
Fe ($mgkg^{-1}$)	-0.267	0.120	0.345	-0.179	-0.122	-0.101
Mn($mgkg^{-1}$)	**-0.388**	0.043	0.162	-0.188	0.084	0.059

Table 19. Result of principal component analysis (continued)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Zn ($mgkg^{-1}$)	-0.329	0.115	0.086	-0.017	0.397	-0.323
Cu ($mgkg^{-1}$)	-0.306	0.189	0.256	-0.171	0.256	0.040
Ex. Acidity	0.132	-0.324	-0.069	-0.245	0.161	-0.113
Acid phosphatase	-0.131	-0.318	-0.144	0.224	0.189	0.374
Dehydrogenase	0.242	-0.057	0.101	-0.438	0.174	-0.074

In the first principal component, manganese had the highest factor loading and hence was selected. Sand percent was the highly weighted variable in the second PC.

Bulk density was selected from third PC and available B was retained from the fourth principal component. In the fifth PC available S, available K and organic carbon percent were highly weighted variable, which were found to be non correlated hence retained. In the sixth PC, again available B was retained. The minimum data set selected thus consisted of eight parameters (Table 20).

Table 20. Minimum Data Set (MDS) selected from PCA

PC1	PC2	PC3	PC4	PC5	PC6
Mn	Sand%	Bulk density	Available B	Available S	Available B
				Available K	
				Organic carbon%	

4.4 FORMULATION OF SOIL QUALITY INDEX

4.4.1 Scoring of soil parameters

To formulate the soil quality index, the parameters in the MDS were assigned appropriate weights and each class with suitable scores (Larsen and Pierce, 1991). Scoring was done following the method suggested by Kundu *et al*. (2012) and Mukherjee and Lal (2014) with slight modifications based on soil fertility ratings for Kerala soils. Organic carbon had the highest weightage of 25 followed by bulk density with weightage of 20. Texture and available K were assigned the weightage of 15 each. Available S, available B and available Mn were assigned weightage of 10, 9, and 6, respectively. All these parameters were also categorized into four classes with scores ranging from 4 to 1 (Table 21).

Table 21. Scoring of soil quality indicators

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})	20	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 %)	15	Loam	Clay loam/ Sandy loam	Sand/Clay	Grit
Organic carbon%	25	>1	1-0.75	0.75-0.5	<0.5
Available K (kg ha^{-1})	15	>280	280-200	200-120	<120
Available S (mg kg^{-1})	10	>15	15– 10	10-5	<5
Available B (mg kg^{-1})	9	>1.5	1.5-0.7	0.7-0.5	<0.5
Available Mn (mg kg^{-1})	6	>5.0	5.0-2.0	2.0-1.0	<1.0

4.4.2 Computation of Soil quality index and Relative soil quality index (RSQI)

After scoring of soil quality indicators, a weighted SQI was computed. A relative soil quality index was also computed to study the change in soil quality and samples were rated based on RSQI value.

Soil quality index (SQI) of flood affected soils in AEU 9 ranged from 248 to 384 with a mean value of 316.2 (Table 22). The relative soil quality index (RSQI) ranged from 62 to 96 per cent with a mean of 79 per cent. The highest mean value of relative soil quality index was observed in Aranmula and Mezhuveli (84.2 %), and the lowest in Kaviyur (71.1%).

Table 22. SQI and RSQI of flood affected soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	SQI		RSQI	
	Range	Mean	Range	Mean
Aranmula	318-384	336.7±22.3	79.5-96	84.2±5.6
Mallapalli	314-353	335±13.1	78.5-88.3	83.8±3.3
Kalloopara	248-328	284.4±31.6	62-82	71.1±7.9
Kulanada	268-333	310.5±19.8	67-83.3	77.6±5
Kaviyur	263-303	278±14.1	67-75.7	69.5±3.5
Panthalam	288-358	318±21.3	72-89.5	79.5±5.3
Thumbamon	278-343	310.7±22.5	69.5-85.7	77.7±5.6
Mezhuveli	293-373	336.8±22.2	73.2-93.2	84.2±7.8
Kozhanchery	283-373	312.3±31.1	72-93.2	78.1±7.8
Thottapuzhassery	343-373	331.8±21.3	75.7-93.2	82.9±5.0
AEU 9	248-384	316.2±28.9	62-96	79.0±7.2

4.5 NUTRIENT INDEX

Nutrient indices were calculated for organic carbon, available N, P and K and presented in Table 23. Nutrient indices for organic carbon was medium for Mallapally, Panthalam, Thumbamon, Mezhuveli, Kozhanchery and Thottapuzhassery and high for Aranmula, Kalloopara, Kulanada and Kaviyur panchayats. Nutrient indices for available N were low for Mallapally, Kaviyur, Thubamon, Mezhuvely, Kozhanchery and Thottapuzhassery and medium for Aramula, Kalloopara, Kulanada and Panthalam.. Nutrient indices for available P medium for Kalloopara and Thottapuzhassery low for other panchayats. Nutrient indices for available K were low for Kaviyur and high for Mallapally, Kulanada, Mezhuvely and Kozhanchery and medium for remaining panchayats.

Table 23. Nutrient index of post-flood soils of AEU 9 of Pathanamthitta district

Panchayat/ Municipality	Nutrient Index (NI)							
	Organic carbon		Available N		Available P		Available K	
	NI	Rating	NI	Rating	NI	Rating	NI	Rating
Aranmula	3.0	High	1.8	Medium	3.0	High	2.3	Medium
Mallapalli	2.1	Medium	1	Low	3.0	High	3.0	High
Kalloopara	3.0	High	2	Medium	1.8	Medium	2.0	Medium
Kulanada	2.4	High	2	Medium	3.0	High	3.0	High
Kaviyur	3.0	High	1.5	Low	2.5	High	1.2	Low
Panthalam	2.3	Medium	2	Medium	2.5	High	2.0	Medium
Thumbamon	2.1	Medium	1.2	Low	2.4	High	2.0	Medium
Mezhuveli	2.0	Medium	1.3	Low	3.0	High	2.8	High
Kozhanchery	1.9	Medium	1.1	Low	3.0	High	2.7	High
Thottapuzhassery	2.1	Medium	1.3	Low	1.8	Medium	2.2	Medium

4.6 LAND QUALITY INDEX

Soil organic carbon stock ranged between 0.8 to 7.19 kgm^{-2} in the study area with a mean of 3.18 kg m^{-2}. The lowest and highest values were observed in Kozhanchery (1.35 kg m^{-2}) and Kalloopara (5.32 kg m^{-2}), respectively. LQI was found to be low in Aranmula, Kalloopara and Kaviyur and very low in rest of the panchayats.

Table 24. Soil Organic Carbon stock and Land Quality Index in the flood affected soils of AEU 9 in Pathanamthitta district

Panchayat/ Municipality	SOC stock (Mg ha $^{-1}$)	SOC Stock (Kg m^{-2})		LQI
		Range	Mean ± SD	
Aranmula	35.4-71.9	3.54-7.19	4.98±1.41	Low
Mallapalli	24.1-33.5	2.41-3.35	2.81±0.29	very low
Kalloopara	47.6-58.9	4.76-5.89	5.32±0.47	Low
Kulanada	18.3-70.4	1.83-7.04	3.83±1.75	very low
Kaviyur	28.7-55.6	2.87-5.56	4.08±1.05	Low
Panthalam	20.1-31.9	2.01-3.19	2.59±0.15	very low
Thumbamon	15.3-23.9	1.53-2.39	2.14±0.26	very low
Mezhuveli	17.0-28.7	1.70-2.87	2.45±0.21	very low
Kozhanchery	8.04-24.8	0.80-2.48	1.35±0.30	very low
Thottapuzhassery	20.9-29.7	2.09-2.97	2.47±0.09	very low
AEU 9	8.04-71.9	0.80-7.19	3.18±1.45	

4.7 GENERATION OF GIS MAPS

Spatial variability of soil pH, organic carbon, available N, P, K, Ca and S in flood affected panchayats of AEU 9 of Pathanamthitta district were mapped. Soil quality index, land quality index and nutrient index of organic carbon, nitrogen, phosphorus and potassium were also mapped using ArcGIS software.

4.8 CORRELATION STUDIES

Correlation between analyzed parameters were worked out in terms of Pearson's correlation coefficient.

4.8.1 Correlation between organic carbon and physical parameters

Correlation analysis was done to determine the relationship between soil physical parameters and organic carbon (Table 25).

Organic carbon showed a positive correlation with mean weight diameter (0.372^{**}) and moisture content (0.502^{**}) and a significant negative correlation with particle density (-0.235^{*}). Particle density showed negative correlation with porosity (-0.264^{*}), water holding capacity (-0.391^{**}), clay (-0.277^{*}) and positive correlation with water stable aggregates (0.235^{*}) and sand (0.320^{**}). Bulk density showed negative correlation with water holding capacity(-0.548^{**}), porosity(-0.945^{**}), soil moisture content (-0.340^{**}) and clay(-0.264^{*}) and positive correlation with particle density (0.562^{**}) and sand (0.311^{**}).

Porosity showed negative correlation with sand (-0.229^{*}) and positive correlation with soil moisture content (0.342^{**}) and water holding capacity (0.483^{**}). Soil moisture content showed a positive correlation with mean weight diameter (0.431^{**}) and water stable aggregates (0.321^{**}). A positive correlation was observed between water holding capacity and clay (0.491^{**}) but was negatively correlated with sand (-0.280^{*}). Mean weight diameter showed positive correlation with water stable aggregates (0.687^{**}) and silt (0.325^{**}). Water stable aggregate showed positive correlation with silt (0.355^{**}) and sand (0.227^{*}). Sand negatively correlated with silt (-0.704^{**}) and clay (-0.567^{**}).

4.8.2 Correlation between physical and chemical parameters

Correlation data presented in table 26 revealed that the soil pH had significant negative correlation with soil moisture content (-0.540^{**}), water stable aggregates (-0.775^{**}) and mean weight diameter (-0.788^{**}). Exchangeable acidity showed negative correlation with water holding capacity (-0.284^{*}). Electrical conductivity showed positive correlation with porosity (0.270^{*}). Effective CEC positively correlated with moisture content (0.334^{**}) and clay (0.238^{*}).

Organic carbon was positively correlated with moisture content (0.502^{**}), mean weight diameter (0.372^{**}) and negatively correlated with particle density (-0.235^{*}). Nitrogen had positive correlation with sand (0.436^{**}). Positive correlation was observed between available P and water stable aggregates (0.345^{**}), mean weight diameter (0.257^{*}) and negative correlation with sand (-0.480^{**}). Potassium showed negative correlation with moisture content (-0.520^{**}) and sand (-0.356^{**}). Calcium showed positive correlation with maximum water holding capacity (0.444^{**}), percentage of clay (0.492^{**}). Magnesium showed positive correlation with water holding capacity (0.504^{**}) and percentage of clay (0.415^{**}).

Available S showed positive correlation with silt (0.246^{*}). Available Fe showed negative correlation with bulk density (-0.300^{**}) and positive correlation with porosity (0.316^{**}) and water holding capacity (0.280^{*}). Mn showed negative correlation with bulk density (-0.237^{*}) and moisture content (-0.259^{*}) and positive correlation with porosity (0.250^{*}) and water holding capacity (0.434^{**}).

4.8.3 Correlation between chemical and biological parameters

Organic carbon showed positive correlation with B (0.310^{**}), acid phosphatase (0.366^{**}) and dehydrogenase (0.564^{**}) Potassium showed positive correlation with Mg (0.324^{**}) and S (0.345^{**}). Acid phosphatase negatively correlated with pH (-0.282^{*}), Mn (-0.345^{**}) and Ca (-0.252^{*}) and positively correlated with K (0.308^{**}). Dehydrogenase negatively correlated with the B (-0.271^{*}) (table 27).

Table 25. Correlation between organic carbon and physical parameters

	Organic carbon	Bulk density	particle density	Porosity	SMC	WHC	Mean weight diameter	Water stable aggregates	Sand	Silt	Clay
Organic carbon	1.000										
Bulk density	0.035	1.000									
Particle density	-0.235*	0.562**	1.000								
Porosity	-0.120	-0.945**	-0.264*	1.000							
SMC	0.502**	-0.340**	-0.189	0.342**	1.000						
WHC	-0.129	-0.548**	-0.391**	0.483**	-0.062	1.000					
Mean weight diameter	0.372**	-0.044	-0.045	0.043	0.431**	0.048	1.000				
Water stable aggregates	0.119	0.110	0.235*	-0.027	0.321**	0.109	0.687**	1.000			
Sand	0.086	0.311**	0.320**	-0.229*	0.099	-0.280*	-0.074	0.011	1.000		

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

Table 25. Correlation between organic carbon and physical parameters (continued)

Silt	-0.007	-0.144	-0.143	0.108	-0.030	-0.091	0.325**	0.355**	-0.704**	1.000	
Clay	-0.110	-0.264*	-0.277*	0.191	-0.103	0.491**	0.175	0.227*	-0.567**	-0.186	1.000

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

Table 26. Correlation between physical and chemical parameters

	Bulk Density	Particle Density	Porosity	Moisture content	WHC	MWD	WSA	Sand	Silt	Clay
pH	-0.023	0.016	0.018	-0.540**	0.178	-0.788**	-0.775**	-0.083	-0.173	0.131
Ex. Acidity	0.043	-0.004	-0.030	0.109	-0.284*	0.185	0.050	0.234*	-0.115	-0.190
ECEC	-0.066	-0.074	0.060	0.334**	0.105	0.142	0.161	0.019	0.128	0.238*
EC	0.191	-0.091	0.270*	-0.112	0.049	-0.084	-0.183	-0.071	-0.075	0.185
OC	0.035	-0.235*	-0.120	0.502**	0.129	0.372**	0.119	0.086	-0.007	-0.110
N	0.166	-0.001	-0.181	0.232*	-0.104	-0.070	-0.025	0.436**	-0.294*	-0.146
P	0.076	-0.128	-0.150	-0.257*	-0.026	0.253*	0.345**	-0.480**	0.244*	0.033
K	0.184	0.062	-0.209	-0.520**	0.032	0.003	0.049	-0.356**	0.286*	0.160
Ca	-0.123	-0.041	0.114	-0.258*	0.444**	-0.268*	-0.168	-0.278*	-0.093	0.492**
Mg	-0.163	-0.147	0.119	-0.296*	0.504**	-0.135	-0.284*	-0.120	-0.216	0.415**
S	-0.194	0.091	0.156	-0.239*	0.233	-0.167	-0.198	0.068	0.246*	0.192
B	-0.097	-0.153	0.053	0.172	0.009	-0.181	-0.144	-0.091	-0.041	0.173
Fe	-0.300**	-0.089	0.316**	0.018	0.280*	-0.024	-0.148	0.089	-0.200	0.109
Mn	-0.237*	-0.060	0.250*	-0.259*	0.434**	-0.109	-0.180	0.131	-0.143	0.217
Zn	-0.046	-0.058	0.027	-0.170	0.111	-0.165	-0.125	0.151	-0.118	0.161
Cu	-0.166	-0.083	0.164	-0.050	0.203	-0.183	-0.159	0.136	-0.143	0.071

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

Table 27. Correlation between chemical and biological parameters

	pH	Ex. Acidity	ECEC	EC	OC	N	P	K	Ca	Mg	S	B	Fe	Mn	Zn
pH	1.000														
Ex. acidity	0.171	1.000													
ECEC	-0.083	0.192	1.000												
EC	-0.187	0.192	0.140	1.000											
OC	0.075	0.188	-0.066	0.174	1.000										
N	-0.099	-0.168	-0.109	0.136	0.148	1.000									
P	-0.208	-0.165	0.023	0.121	-0.072	0.132	1.000								
K	-0.195	-0.180	-0.142	-0.185	-0.303	0.133	0.116	1.000							
Ca	-0.137	-0.020	-0.203	0.015	0.163	0.192	-0.069	0.163	1.000						
Mg	-0.087	-0.032	-0.197	0.107	-0.065	-0.204	-0.295*	0.324**	0.104	1.000					
S	-0.203	-0.112	-0.221	-0.085	-0.220	-0.077	0.099	0.345**	-0.082	0.123	1.000				
B	-0.094	-0.176	-0.050	-0.046	0.310**	0.109	-0.048	-0.144	-0.112	0.286*	0.177	1.000			
Fe	0.053	-0.052	-0.207	-0.119	-0.137	-0.081	-0.215	-0.079	0.045	0.130	-0.048	0.158	1.000		
Mn	0.160	-0.110	-0.098	-0.102	-0.075	-0.081	-0.199	-0.171	-0.103	-0.124	-0.275*	0.100	0.178	1.000	

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

Table 27. Correlation between chemical and biological parameters (continued)

	pH	Ex. acidity	ECEC	EC	OC	N	P	K	Ca	Mg	S	B	Fe	Mn	Zn
Zn	-0.018	-0.185	0.101	-0.053	-0.225	0.137	-0.226	-0.036	-0.240*	-0.036	0.129	0.164	-0.052	0.160	1.000
Cu	0.106	0.150	0.178	-0.192	-0.104	0.115	-0.135	-0.116	-0.129	-0.174	-0.065	-0.118	-0.281*	0.153	0.179
Acid phosphotase	-0.282*	0.186	-0.060	0.103	0.366**	-0.100	-0.213	0.308**	-0.252*	-0.054	-0.207	-0.072	0.103	-0.345**	-0.048
Dehydrogenase	0.193	0.130	0.125	0.152	0.564**	-0.195	-0.161	0.173	-0.072	-0.097	0.136	-0.271*	-0.041	-0.093	-0.175

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

Table 27. Correlation between chemical and biological parameters (continued)

	Cu	Acid phosphatase	Dehydrogenase
Cu	1.000		
Acid phosphotase	0.100	1.000	
Dehydrogenase	0.110	0.221	1.000

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

Discussion

5. DISCUSSION

A study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Pathanamthitta district of Kerala" was undertaken during 2018-20 to understand the influence of flood on soil characteristics and quality. The results related 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 with the help of available literature.

5.1 CHARACTERISATION OF SOIL SAMPLES

The results of physical, chemical and biological parameters of soil were discussed below

5.1.1 Physical attributes

The physical attributes of soil quality are bulk density, particle density, porosity, texture, moisture content, water holding capacity and aggregate stability were analysed and the results are discussed below.

5.1.1.1 Bulk density

Bulk density is the dynamic soil character which varies with soil structure, differences in hydrology, cultivation practices and organic addition (Morales – Olmedo *et al.,* 2015) and is mostly affected by the organic matter content, texture, constituent minerals and porosity (Chaudhari *et al.,* 2013).

The bulk density of soil varied between 0.87 and 1.76 Mg m^{-3} with a mean of 1.30 Mg m^{-3}. The frequency distribution of bulk density in the study area depicted in Fig. 1 revealed that the bulk density of 58.7 percent of soils lies in the range of 1.2 - 1.4 Mg m^{-3}, 24 percent in < 1.2 Mg m^{-3} and 17.3 % in >1.4 Mg m^{-3} range. High bulk density was observed in soils of Kalloopara panchayat (1.54 Mg m^{-3}) where the highest sand content (51.4 %) and lowest clay (18.6 %) were recorded. Low bulk density was observed in soils of Kaviyur panchayat (1.07 Mg m^{-3}) where high organic carbon content (2.53 %) was noticed. Organic matter present in soil help in aggregation of soil particles which resulted in reduction of soil bulk density, thus bulk density reduced with increase in organic matter content. These results are in accordance with findings of Njoku and Okoro (2015) who observed that bulk density reduced after flood as a result of sediment and organic matter accumulation. There exist a significant negative correlation of clay content with bulk density, whereas a positive correlation was observed between bulk density and sand content. Similar results were recorded by Prevost (2004), Federer *et al.,* (1993), Sakin (2012) and Mestdagh *et al.,* (2006).

5.1.1.2 Particle density

Particle density ranged between 2.07 and 2.45 Mg m^{-3} in the post- flood soils with a mean value of 2.21 Mg m^{-3}. The lowest mean was observed for Aranmula and Kaviyur panchayat (2.15Mg m^{-3}) and the highest mean at Kalloopara panchayat (2.33 Mg m^{-3}) where high sand content, low clay and silt content were reported. The highest organic matter content was observed at Aranmula and Kaviyur. The above result is supported by the findings of Joerg *et al*., (2006) who reported that the particle density tends to decrease, when there is an increase in organic matter in soil. Ball *et al*., (2000) also recorded a significant negative correlation between particle density and soil organic matter. Particle density of 49.3 per cent of the soils lie between 2.2-2.4 Mg m^{-3}, 46.7 per cent of the soil were < 2.2 Mg m^{-3} and 4 percent between 2.4- 2.6 Mg m^{-3} (Fig. 6). The particle density of a typical mineral soil ranges between 2.65 and 2.75 Mg m^{-3} and in the post flood soils of AEU 9 of Pathanamthitta district the particle density is much lower than this average value. If the soil contains high organic matter then the particle density falls below 2.5.

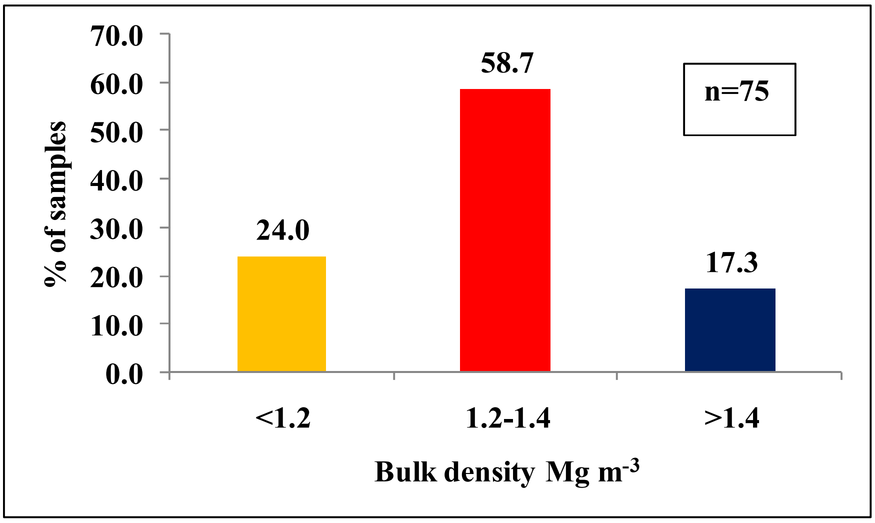

Fig 5. Frequency distribution of bulk density in the post-flood soils of AEU 9 in Pathanamthiitta district

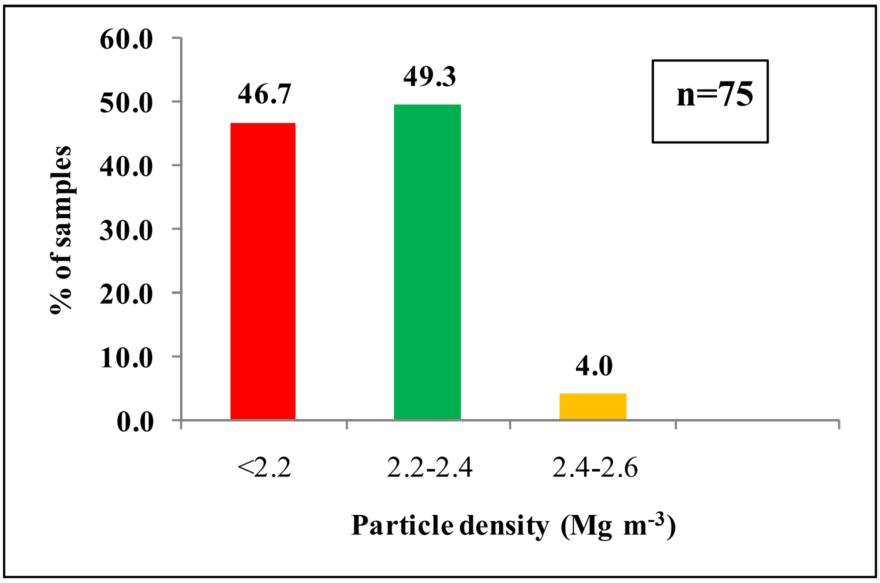

Fig 6. Frequency distribution of particle density in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.1.3 Porosity

Porosity ranged from 25.4 to 58.4 percent with a mean of 41.5 per cent. The highest and lowest mean were recorded in Kaviyur panchayat (50.3%) and Kalloopara panchayat (33.83%) respectively. High organic matter content recorded at kaviyur (2.53 %) might have contributed to high porosity. 89.3 per cent of sample showed porosity between 30-50 percent. Bulk density is the important soil parameter influencing porosity. Porosity is negatively correlated with bulk density. Li and Shao (2006) reported that bulk density and porosity showed inverse relation with each other. Fahmi *et al* (2014) also reported similar findings.

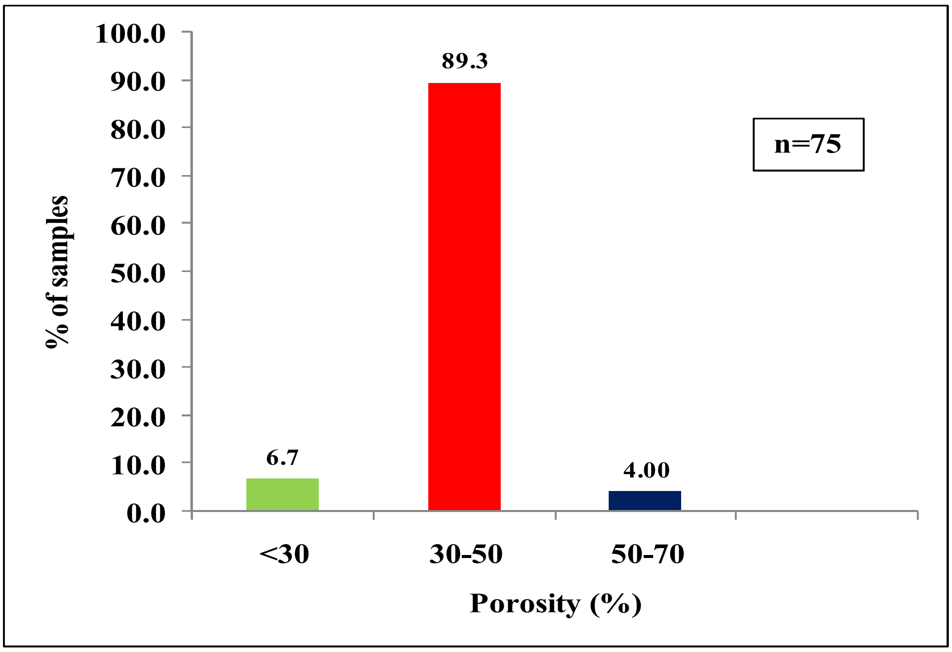

Fig. 7 Frequency distribution of porosity (%) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.1.4 Soil texture

The proportion of sand, silt and clay indicates the texture of soil. Sand, silt and clay content exhibited wide variations in the soils of AEU 9. Clay content varied between 16.9 and 31.2 percent, silt between 26.5 and 42.5 percent and sand between 34.9 and 56.2 percent. Loam was the predominant textural class observed in 62.7 percent of soils in AEU 9 of Pathanamthitta district (Fig 8), followed by clay loam

(21.3 %), sandy loam (13.3%) and sandy clay loam (2.7 %).

Sandy loam texture was observed in Kalloopara where high amount of sand and silt were deposited. Clay loam texture was exhibited by Kulanada and Panthalam where deposition of sand and clay occurred. All other soils are loamy in texture. In post-flood soils a slight shift from sandy clay to loam texture was noticed in majority of surface soil which can be attributed to the sediment deposition of sand and silt due to flood. The spatial distribution of soil texture is shown in Fig 9.

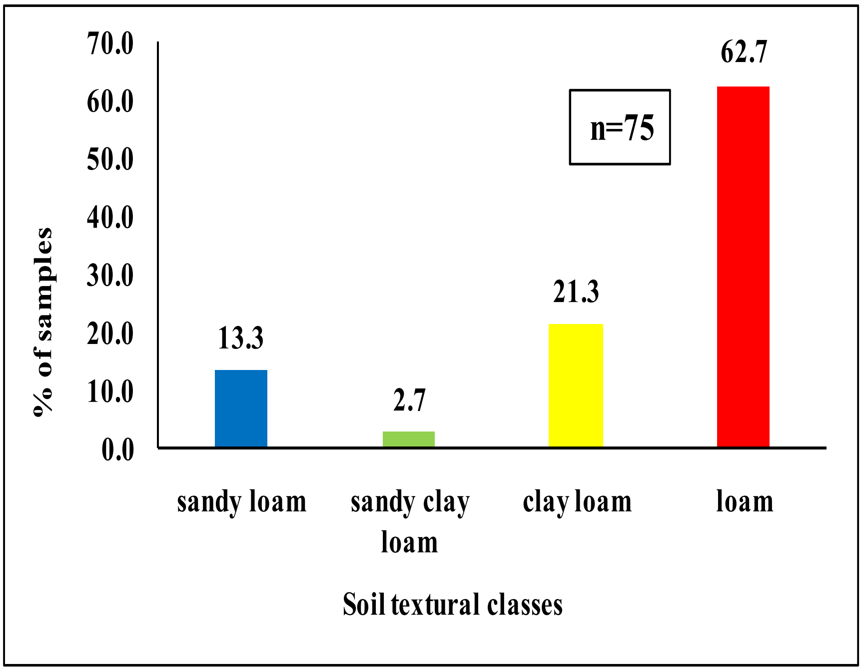

Fig 8. Frequency distribution of soil textural classes in the post-flood soils of AEU 9 in Pathanamthitta district

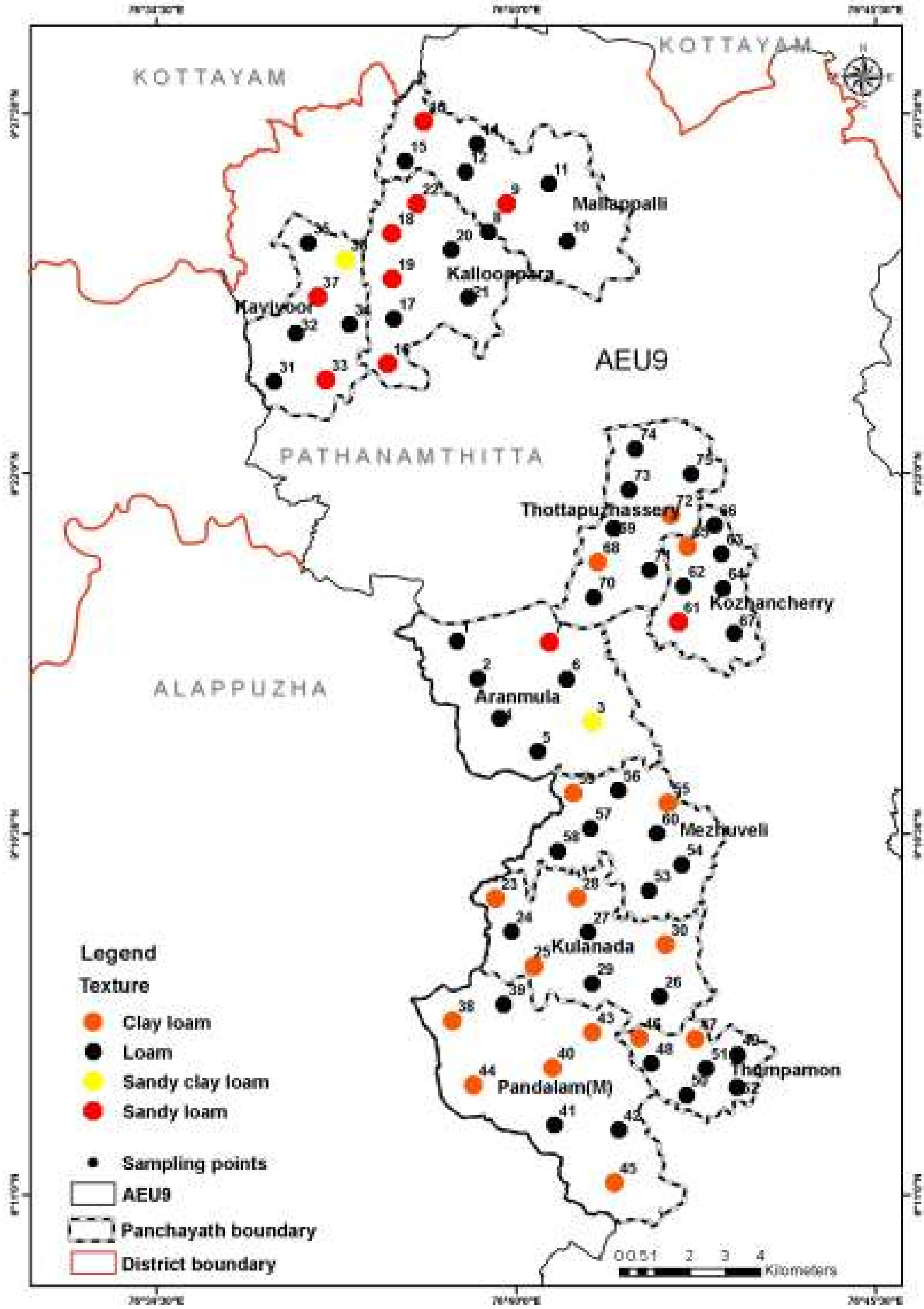

Fig 9. Spatial distribution of textural classes in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.1.5 Depth of sand/silt/clay deposition

Sediment deposition of sand, silt and clay were found in the flood affected area of AEU 9 of Pathanamthitta district on the banks of river Pamba, Manimala and Achankovil contributing to the textural changes in the surface soil. The rise in water level in these rivers during 2018 flood overflowed to the surrounding villages of AEU 9 for more than a week. This flood water carried sediment materials and deposited indiscriminately resulted in build up of these sediments at various places of AEU 9.

Maximum deposits were observed in Aranmula and Kalloopara with sand and silt deposits up to 10 to 15 cm, followed by Mallapalli, Thumbamon, Thottapuzhassery and Kozhanchery where silt and sand deposited up to 5 to 10 cm height. Sand and silt deposits of less than 1 cm depth was observed in Mezhuvely panchayat. Sand and clay deposits of less than 1-5cm was observed in Kulanada, Panthalam and Kaviyur. The sediments brought by the rivers from upstream would have deposited in these areas due to the flood water stagnation for more than a week.

5.1.1.6 Maximum water holding capacity

The maximum water holding capacity of soil ranged from 25.4 and 62.4 per cent with a mean value of 42.8 per cent. Majority of soils (73.3%) had WHC between 30 and 50 per cent, 6.7 per cent of sample below 30 per cent and 20 per cent of soils in between 50 and 70 per cent (Fig 10).

The water holding capacity was the highest (51.0%) in Panthalam where high clay content was observed and soil texture was clay loam and the lowest value was observed in Kalloopara (29.7 %) where the highest sand content with sandy loam texture was observed. This corroborates with the findings of Stepniewski *et al.* (1994). Hudson (1994) also reported that one percent increase in soil organic matter increases the water holding capacity by 3.7 per cent. The lowest water holding capacity was noticed in soils with sandy loam texture. Also in the present study the water holding capacity was found to be significantly and positively correlated with clay content but negatively correlated with sand content of soil.

5.1.1.7 Soil moisture content

The moisture content of soils of AEU 9 varied between 15.2 and 50.8 per cent with a mean value of 26.2 percent. The highest mean value for soil moisture content was observed in Kaviyur (44.0%) where high organic carbon content and clay deposit were noticed. The lowest moisture content was in Kozhanchery (20.5%) where relatively low organic carbon content was observed. Moisture content of soil is influenced by the clay and organic matter content of the soil. Majority (54.7%) of soils registered moisture content between 15 and 25 percent and 47.3 per cent exhibited more than 25 per cent of moisture content (Fig 11). Njoku and Okoro (2015) also reported a similar increase in moisture content after flood as a result of accumulation of clay particles and organic matter that were brought to soil by the flood.

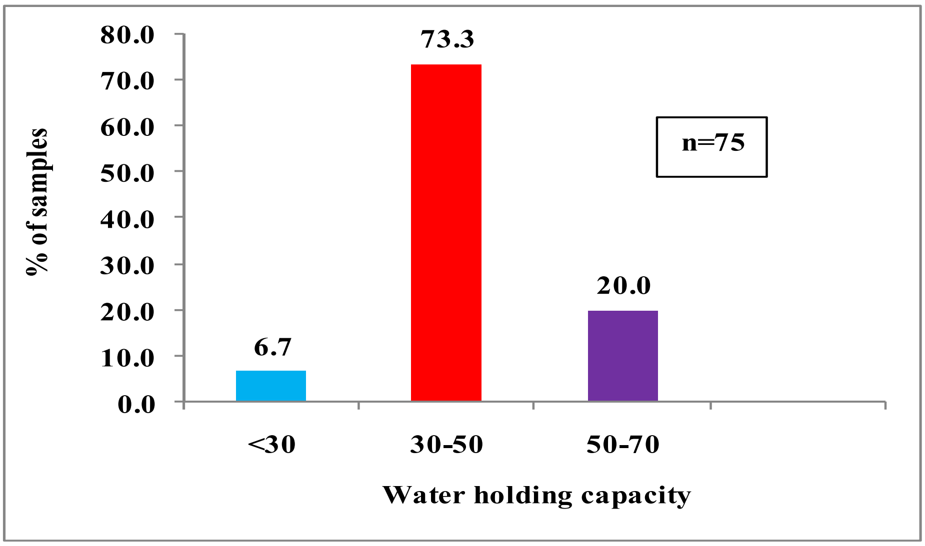

Fig 10. Frequency distribution of maximum water holding capacity (%) in the post-flood soils of AEU 9 in Pathanamthitta district

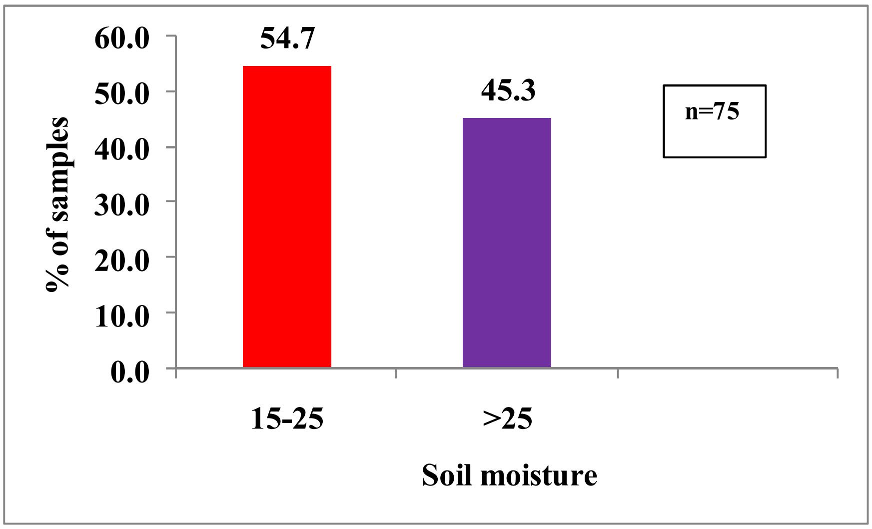

Fig 11. Frequency distribution of soil moisture content (%) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.1.8 Aggregate stability

Soil aggregation and aggregate stability are the most important soil quality indicators that are affected by texture and organic matter. Water stable aggregates are high in soils rich in organic carbon and clay content. The mean weight diameter is a measure of aggregate stability of soil which ranged from 0.47 and 2.41 mm with a mean of 1.62 mm. Per cent of water stable aggregates varied between 38.6 and 68.5 per cent with a mean of 53.5 per cent. Mean weight diameter of 37.3 per cent soils were 1.5 to 2.0 mm (Fig.12), 22.7 per cent samples were more than 2 mm and 26.7 per cent samples were 1 to 1.5 mm. Frequency distribution of water stable aggregates is given in Fig.13.

Highest mean weight diameter and water stable aggregates were observed for Kaviyur panchayat where organic carbon content was high. Soil aggregate stability is affected by the organic matter content and texture. Increased organic matter content of soil leads to aggregation of particles through it's binding property (Bissonnais, 1996). Similar findings were reported by Kirk *et al*. (2013) and Njoku *et al.* (2011).

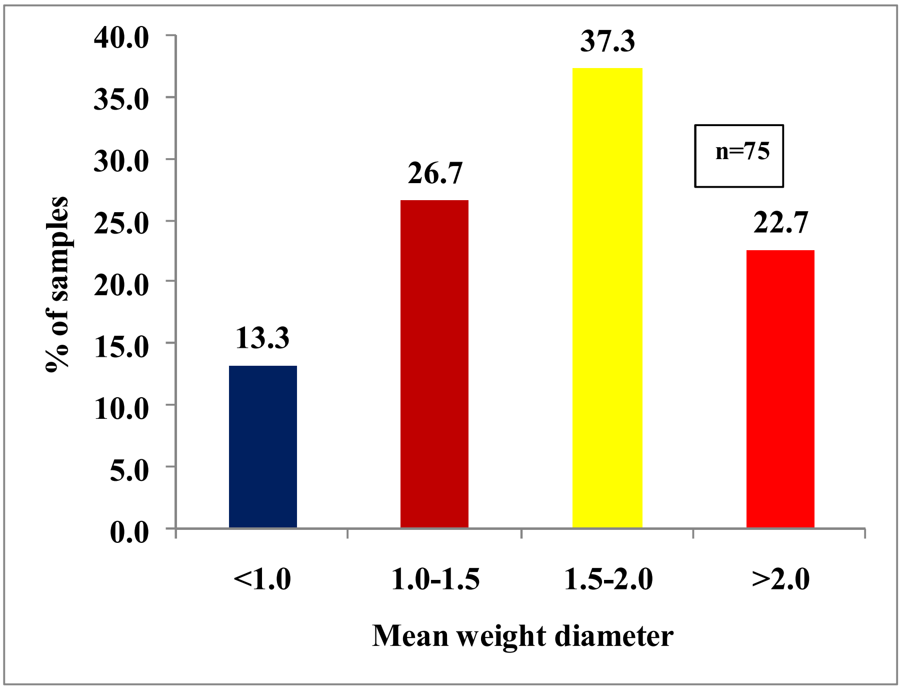

Fig 12. Frequency distribution of mean weight diameter (mm) in the post-flood soils of AEU 9 in Pathanamthitta district

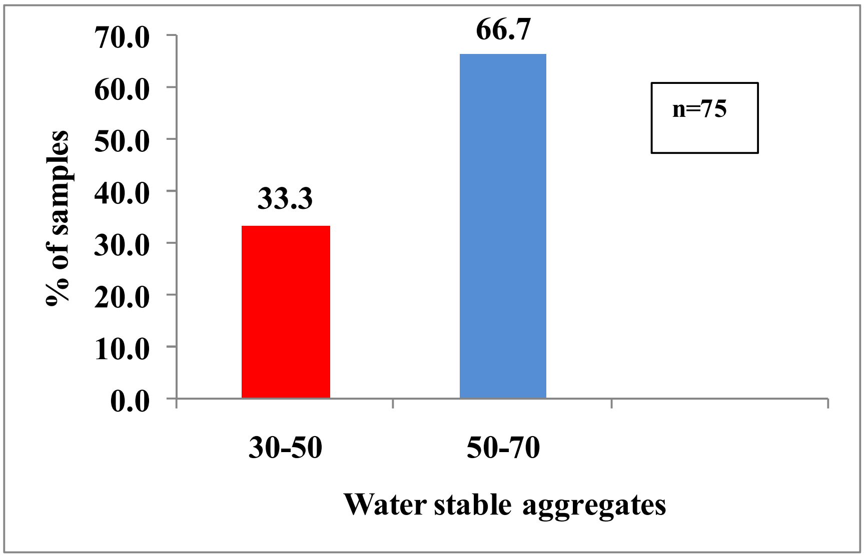

Fig 13. Frequency distribution of water stable aggregates (%) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2 Chemical attributes

The results of chemical parameters *viz.* pH, electrical conductivity, exchangeable acidity, effective CEC, organic carbon and available nutrient status in the post-flood soils of AEU 9 of Pathanamthitta district are interpreted and discussed here under.

5.1.2.1 Soil pH

The present investigation revealed that soil pH ranged between 4.60 and 5.60 with a mean of 5.16. Chandran *et al.,* (2005) indicated that the soils of Kerala were mostly laterites and basically acidic in reaction. The thematic map of soil pH is depicted in Fig.14. Majority of soils (90.6 %) were in the range of very strongly acidic to strongly acidic category (Fig 14). Leaching of basic cations from the soil might have led to increased acidity. Soil acidity was observed to be lower in areas with sediment deposits where concentration of basic cation, Ca was found to be higher. Acidity falls into very strongly acidic, strongly acidic and moderately acidic categories after flood. Extremely acidic and slightly acidic categories vanished after flood (Appendix IV). Leaching of basic cations from the soil might have led to increased acidity and also the soil acidity lowered in regions where sediment deposits with high basic cations occurred. Similar results were reported by Akpovete *et al.,* (2014).

5.1.2.2 Exchangeable acidity

Exchangeable acidity of soils ranged from 0.7 and 2.9 c mol g^{-1} with a mean of 1.75 c mol g^{-1} and majority of soils (68 %) lies in the 1.00 - 2.00 c mol g^{-1} range, 26.7 per cent in 2.00 - 3.00 c mol g^{-1} range and 5.3 per cent lies <1 c mol g^{-1} (Fig.15).

The low pH of the soils might have resulted in increased exchangeable acidity. Thus soil pH was inversely related with exchangeable acidity. Similar results were reported by Shalimadevi and Anilkumar (2009).

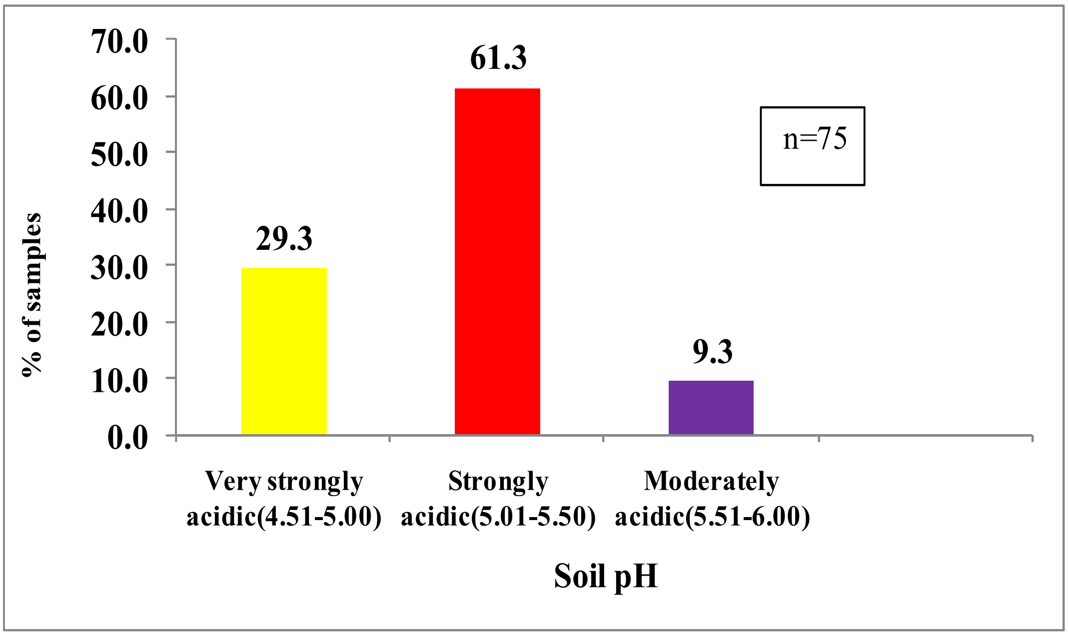

Fig 14. Frequency distribution of soil pH in the post-flood soils of AEU 9 in Pathanamthitta district

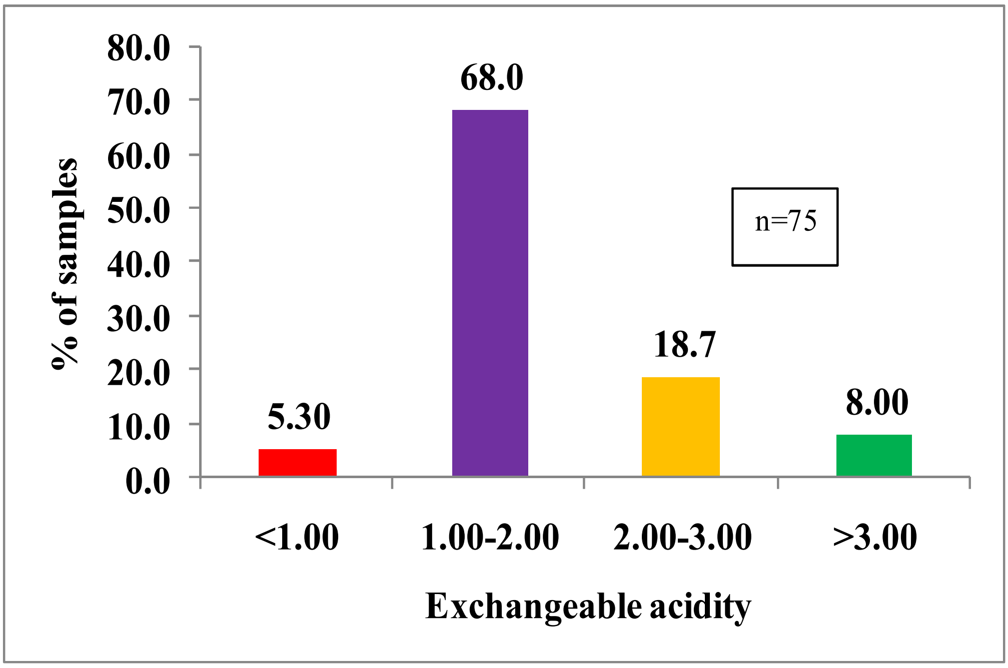

Fig 15. Frequency distribution of exchangeable acidity (c mol g^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

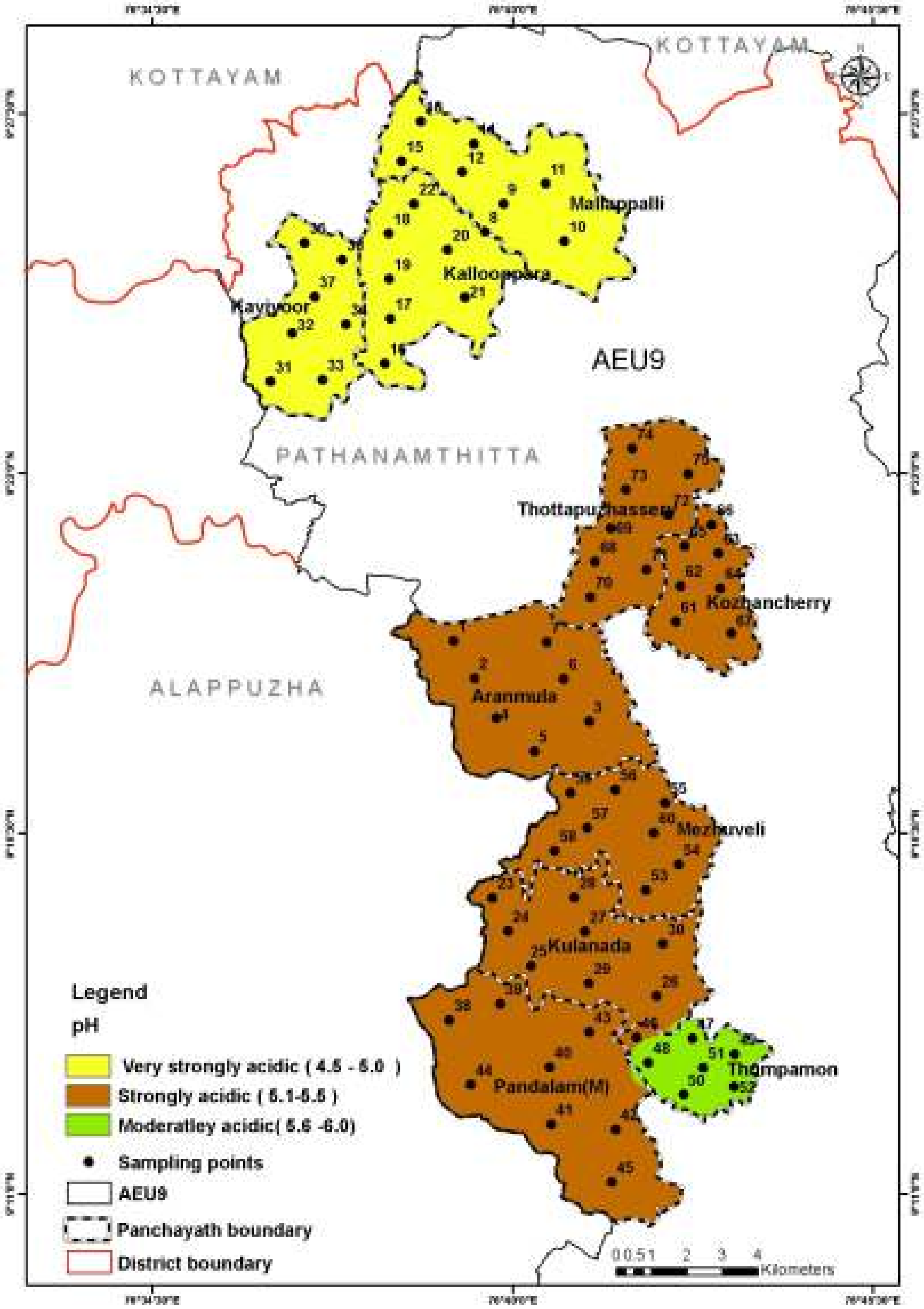

Fig 16. Spatial distribution of soil pH in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.3 Electrical Conductivity

Electrical conductivity of soils in the study area varied between 0.05 and 0.40 dSm^{-1} with a mean of 0.13 dSm^{-1}. EC was found to be less than 1 dSm^{-1} in all the soils which is considered as normal range having low salinity hazards (Fig.16). This can be attributed to the removal of soluble salts by the flowing flood water. Ponnamperuma (1984) reported that flooding increased the dilution of soil, thereby decreasing electrical conductance indicating the absence of soluble ions at the soil surface. A negative correlation was reported between soil pH and electrical conductivity in the present study. Mohd-aizat *et al.* (2014) also reported similar result.

5.1.2.4 Effective cation exchange capacity (ECEC)

The ECEC ranged between 2.80 and 5.50 meq $100g^{-i}$ in the post-flood soils of AEU 9 in Pathanamthitta district with a mean of 3.96 meq $100g^{-1}$. The highest mean value was obtained in Thumbamon where comparatively high clay content was reported. Majority of sample (92 %) falls under category of 3 to 15 meq 100 g^{-1}.

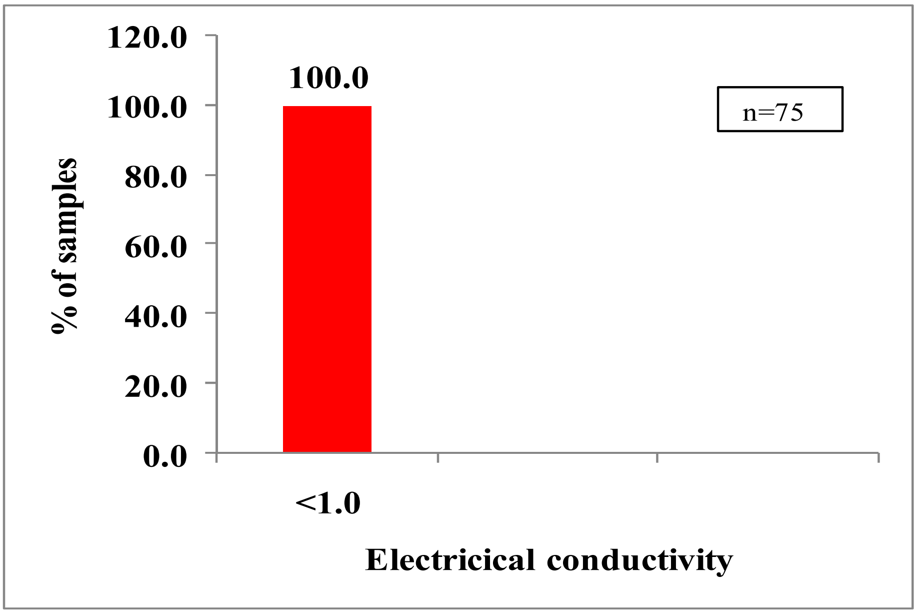

Fig 17. Frequency distribution of electrical conductivity (dSm^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

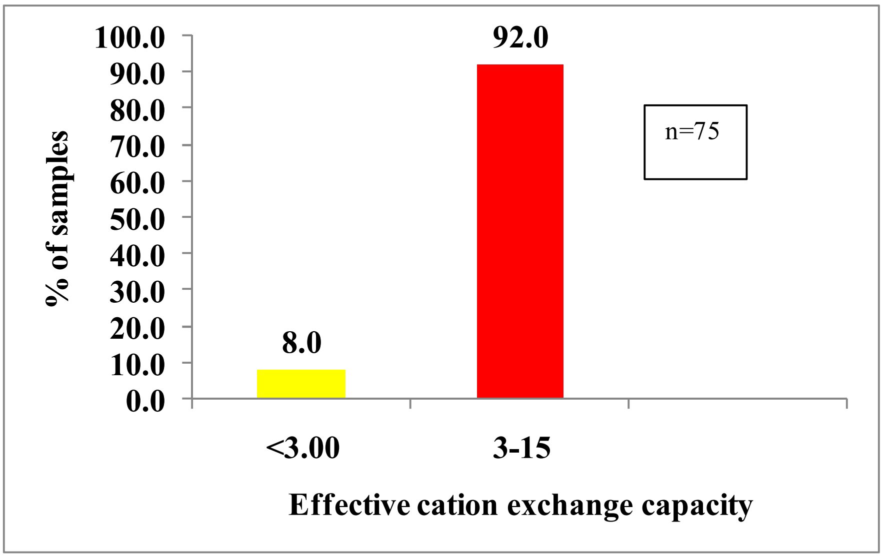

Fig 18. Frequency distribution of effective cation exchange capacity (meq $100g^{-1}$) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.5 Organic carbon

Organic carbon content varied from 0.40 to 3.50 per cent with a mean value of 1.63 per cent. Majority (57.3%) of the post flood soils are having medium organic carbon status followed by 38.7% soils with high status (Fig 19). Spatial variability of organic carbon in the post-flood area of AEU 9 is given in Fig 21. Most of the sample (96 %) falls under medium and high status after flood. Percent of sample low in organic carbon status decreased after flood compared to pre flood soil (appendix IV). Organic carbon was high in Kaviyur (2.53%) followed by Aranmula (2.43%). This can be due to the deposition of sediments rich in organic matter under the inflow of flood water and is in compliance with the findings of Kalshetty *et al.* (2012). Organic carbon showed a significant positive correlation with mean weight diameter and moisture content. Similar findings were obtained by Hoyle *et al.,* (2011).

5.1.2.6 Available nitrogen

The available nitrogen content of soil varied between 201 to 464 kg ha^{-1} with a mean of 289 kg ha^{-1}. Available N was medium in 54.7 percent samples and low in 46.7 percent of the post flood soils (Fig.20). The thematic map of available nitrogen is depicted in Fig.22. Available nitrogen was found to be medium in Pandalam, Kulanada, Kalloopara, Aranmula and some areas of Kaviyur and Thumbamon panchayats and low in other panchayats. The reason for low available N observed in some panchayats eventhough they showed medium to high organic carbon status may be attributed to low mineralization of organic matter as the soils are highly acidic. These results are in confirmation with those of Usha and Jose (1983) in laterite soils.

The low availability of N in soil might also be due to leaching of nitrate nitrogen present in soil in the study area which received high amount of rainfall and also under the anaerobic conditions N loss would have occurred due to nitrate reduction and denitrification (Unger *et al.,* 2009). Slow decomposition rate of organic matter also added to the decreased N availability. Increasing soil acidity obstructs mineralization of organic matter and decreased the availability of N in soil under submerged condition (Liji, 1987).

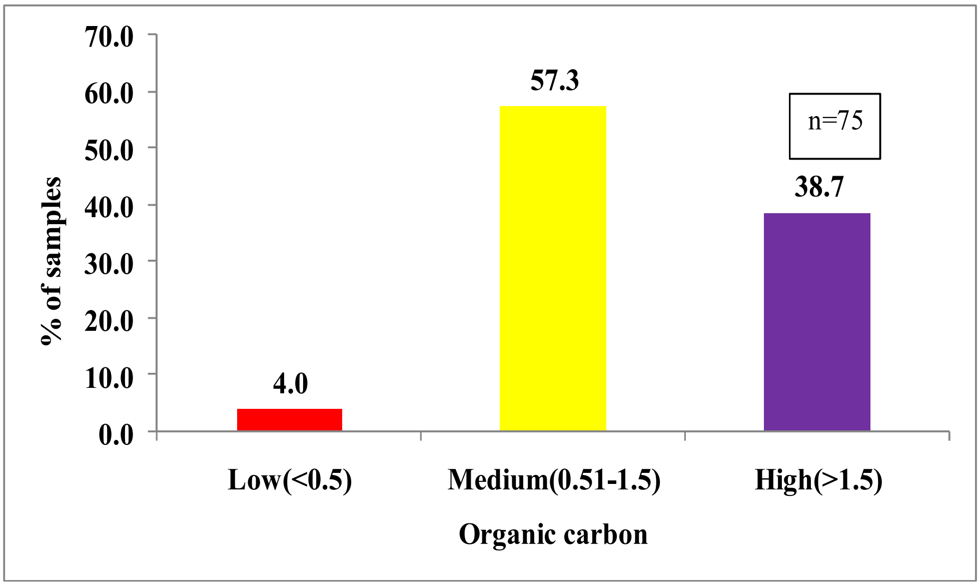

Fig 19. Frequency distribution of organic carbon % in the post-flood soils of AEU 9 in Pathanamthitta district

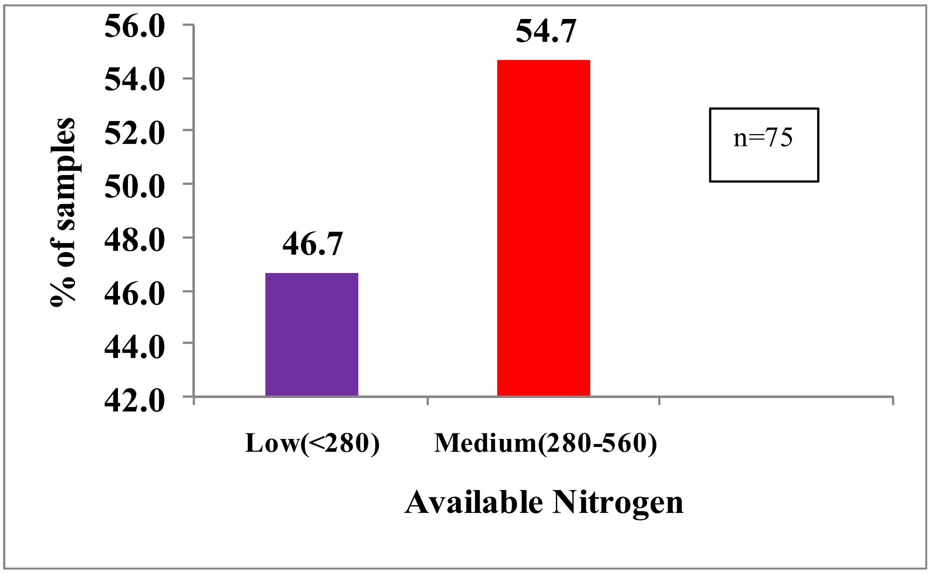

Fig 20. Frequency distribution of available nitrogen (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

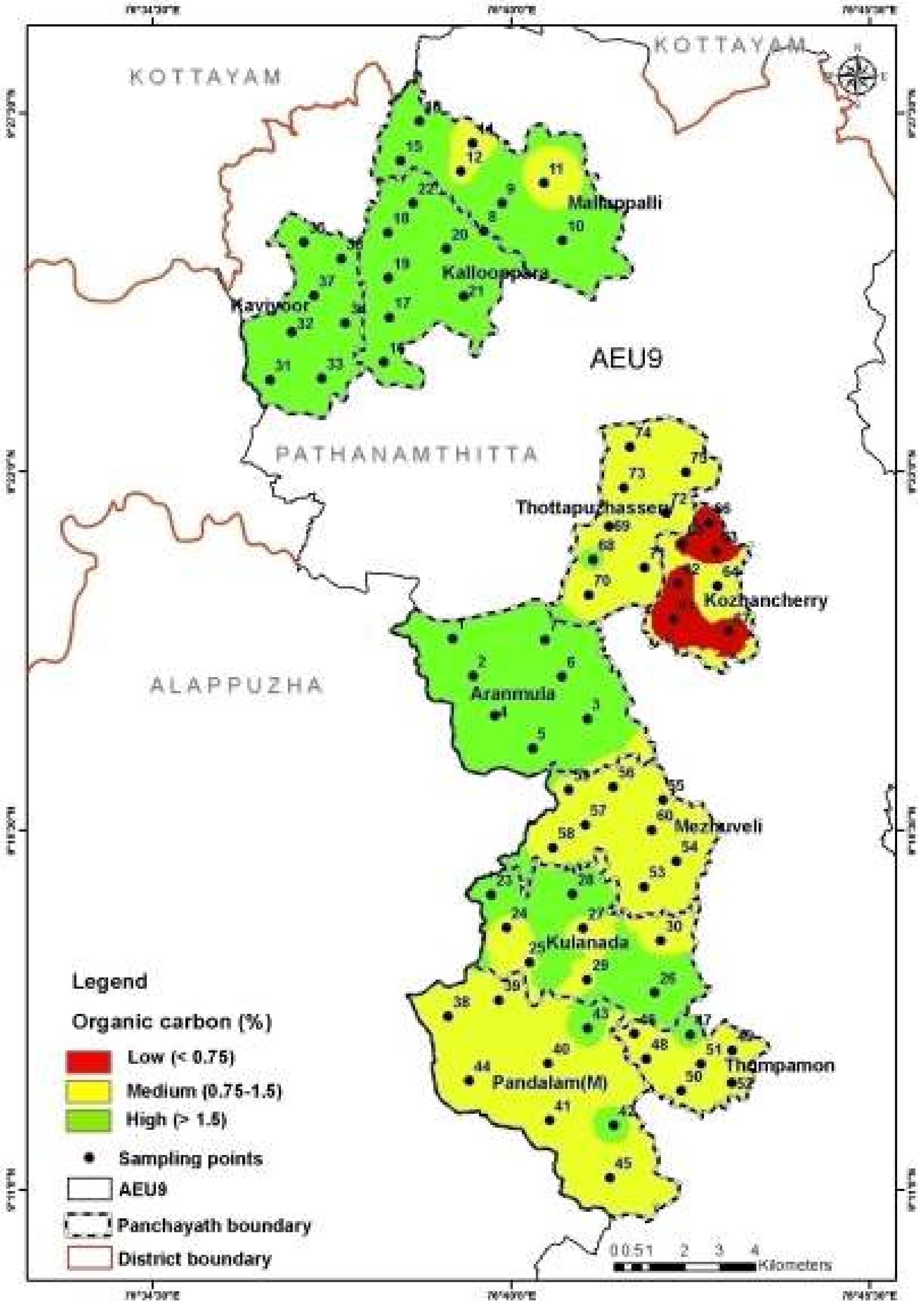

Fig 21. Spatial distribution of organic carbon % in the post-flood soils of AEU 9 in Pathanamthitta district

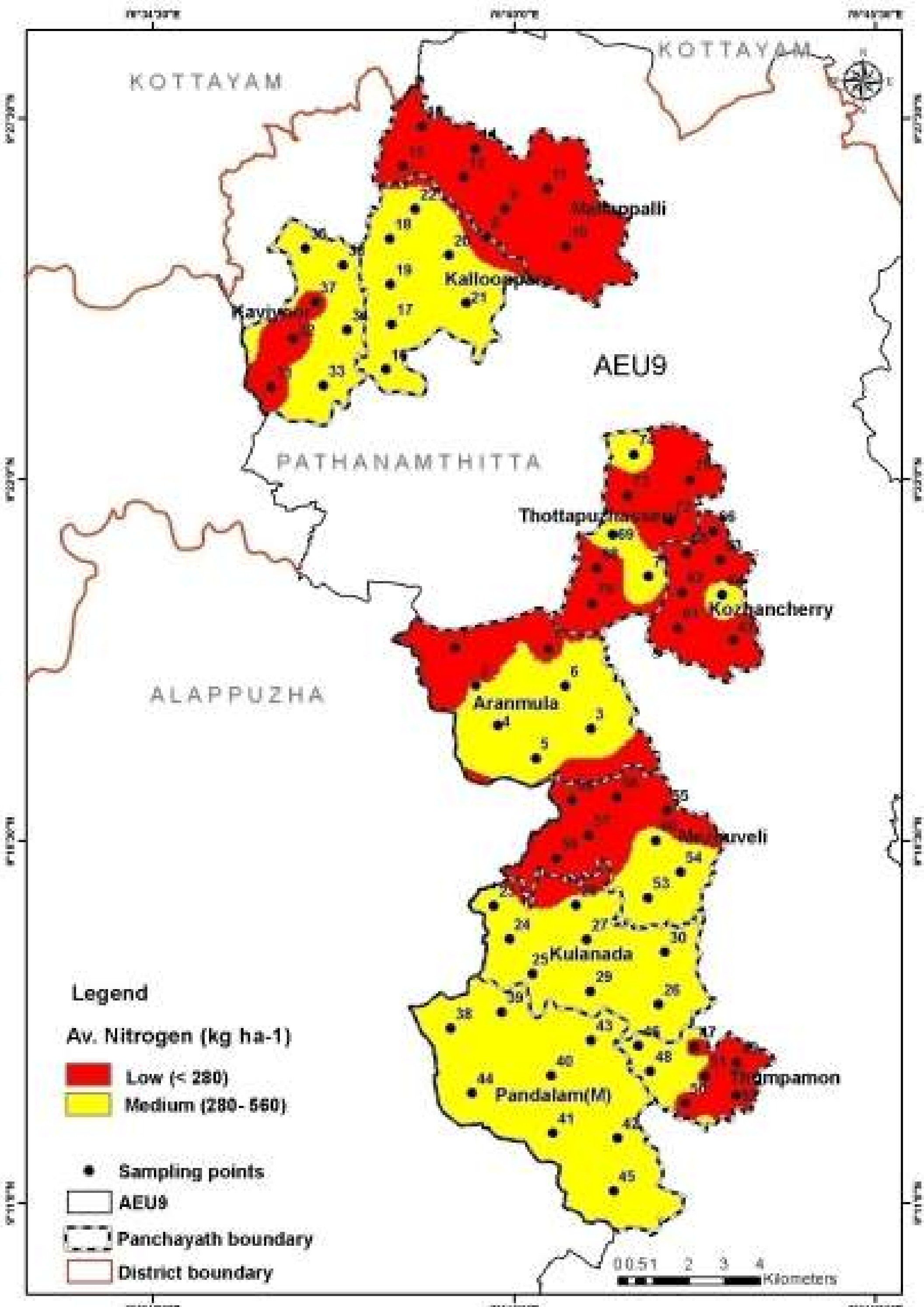

Fig 22. Spatial distribution of available nitrogen (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.7 Available phosphorus

Soil reaction is one of the important factors that have profound effect on availability of P in soils. High variability in status of plant available phosphorous was observed in highly weathered acid soils. As acidity increases the increase in H^+ ions accompanied by increase in Fe^{2+} and Al^{3+} ions lead to fixation of soluble inorganic P rendering it unavailable (Yadav *et al.,* 2019).

The available P content of soil varied from 8.10 and 104 kg ha^{-1} with a mean of 31.9 kg ha^{-1} and was found to be medium in 37.3 percent of the soils, high in 58.7 percent and low in 4 percent soils (Fig 23). Soils with medium status of available phosphorous increased in post-flood (37.3) compared to pre-flood (17%) whereas high phosphorous soils decreased from 65 to 58.7 percent. (Appendix IV).

The P availability in these soils have reduced after flood which can be attributed to change in soil pH. The P availability is highly dependent on soil pH and P availability will be maximum at a pH of 6.5. Most of the sample falls under very strongly acidic to strongly acidic category after flood and there is no slightly acidic category after flood. Organic matter deposition in the soils may have also contributed to phosphate sorption and reduction in P availability. This agree with the findings of Sah and Mikkelsen (1989) who reported that flood induced P deficiency in soil is caused by high P sorptivity. Spatial distribution map of available P presented in Fig.25 revealed that available phosphorous was low in some locations of Thottapuzhassery and it was high in Mallapally, Mezhuvely, Kulanada, Aranmula and Kozhenchery.

5.1.2.8 Available potassium

The available K content in soil ranged between 78.7 and 493 kg ha^{-1} with a mean of 246 kg ha^{-1}. Majority (50.7%) of the soils were medium in available K, 44.0 percent were high and 6.7 percent low (Fig 24). Available K status in soil increased in post-flood soils compared to pre-flood soils. About 96.7 % samples became medium and high in K status earlier it was 92 %. Soils low in potassium status were reduced compare to pre flood soil. Similar findings were reported by Kalshetty *et al.* (2012).

Clay deposition after the flood might have contributed to this increase in the potassium status. Low activity clays such as kaolinite and iron and aluminium oxides and hydroxides are predominant in laterite soils. These tropical soils can store K even without a large content of high activity clays and avoid leaching losses (Rosolem and Steiner, 2017). Hence it may be inferred that the low activity clay minerals in these soils were efficient in holding the exchangeable potassium to a considerable extent which might have contributed to increased availability of potassium. High organic carbon content and low pH may also have added to the increase in potassium status. These agree with the findings of Nair *et al*. (2013).

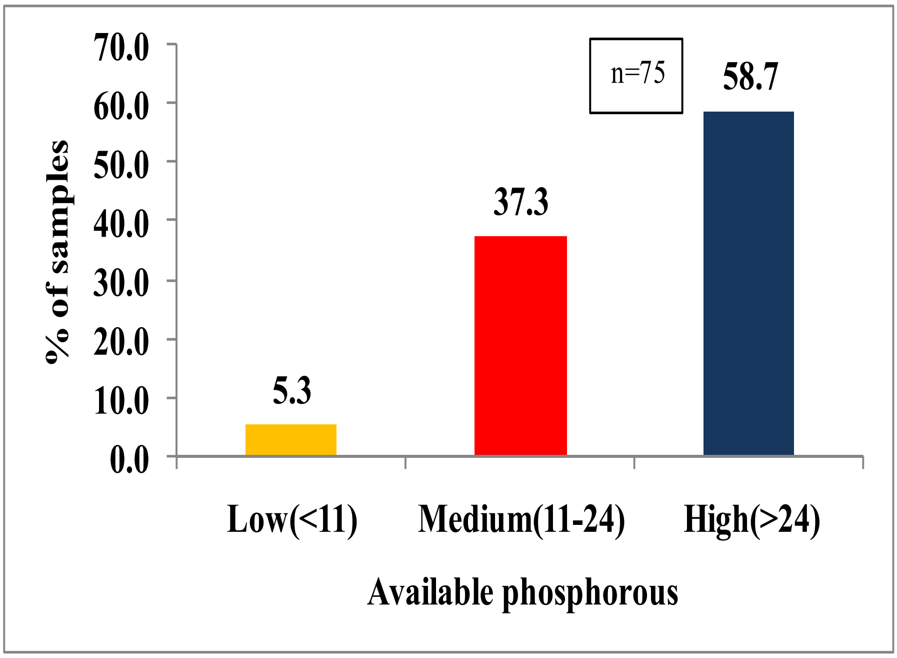

Fig 23. Frequency distribution of available phosphorus (kg h^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

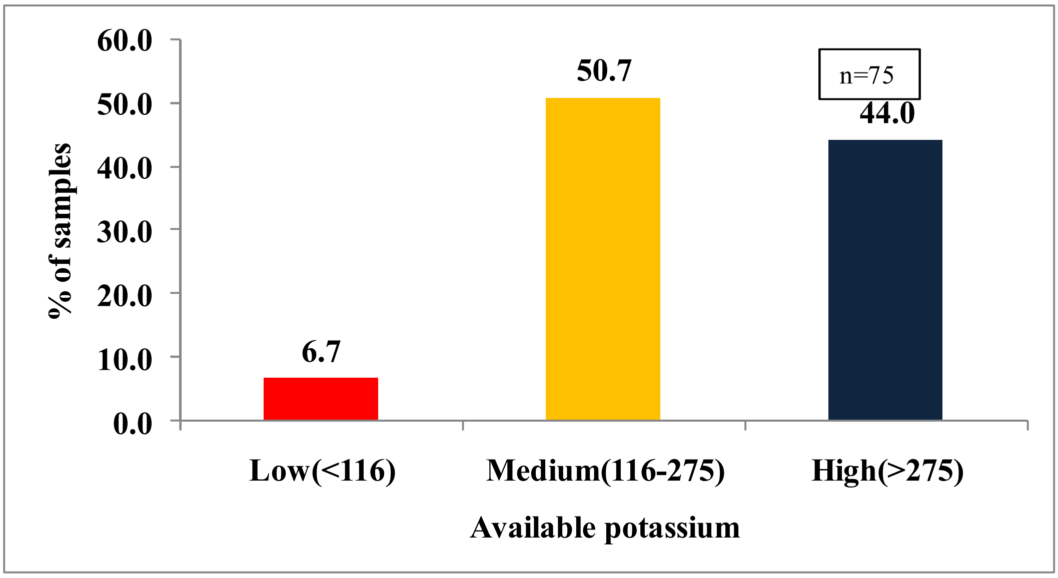

Fig 24. Frequency distribution of available potassium (kg h^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

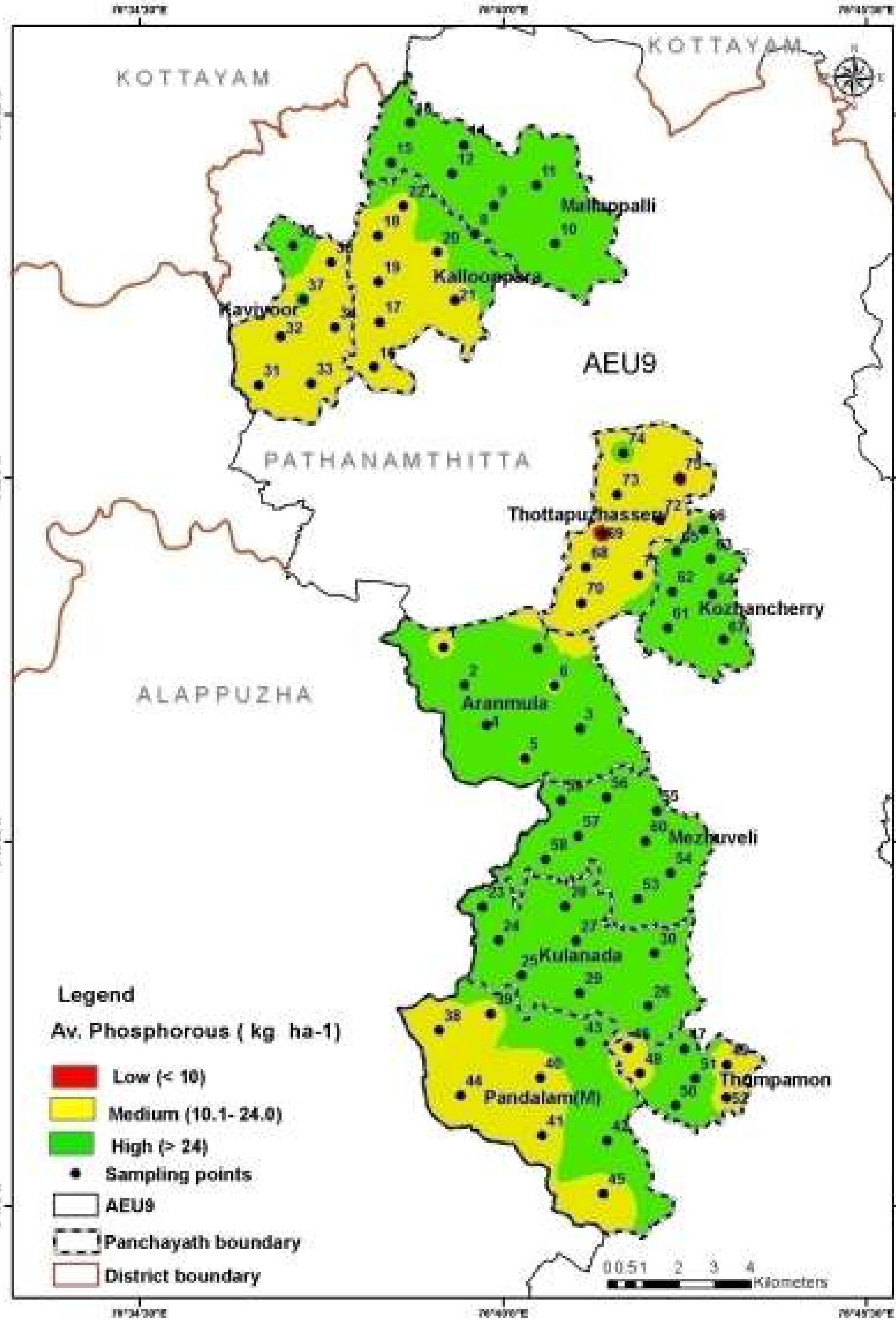

Fig 25. Spatial distribution of available phosphorus (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

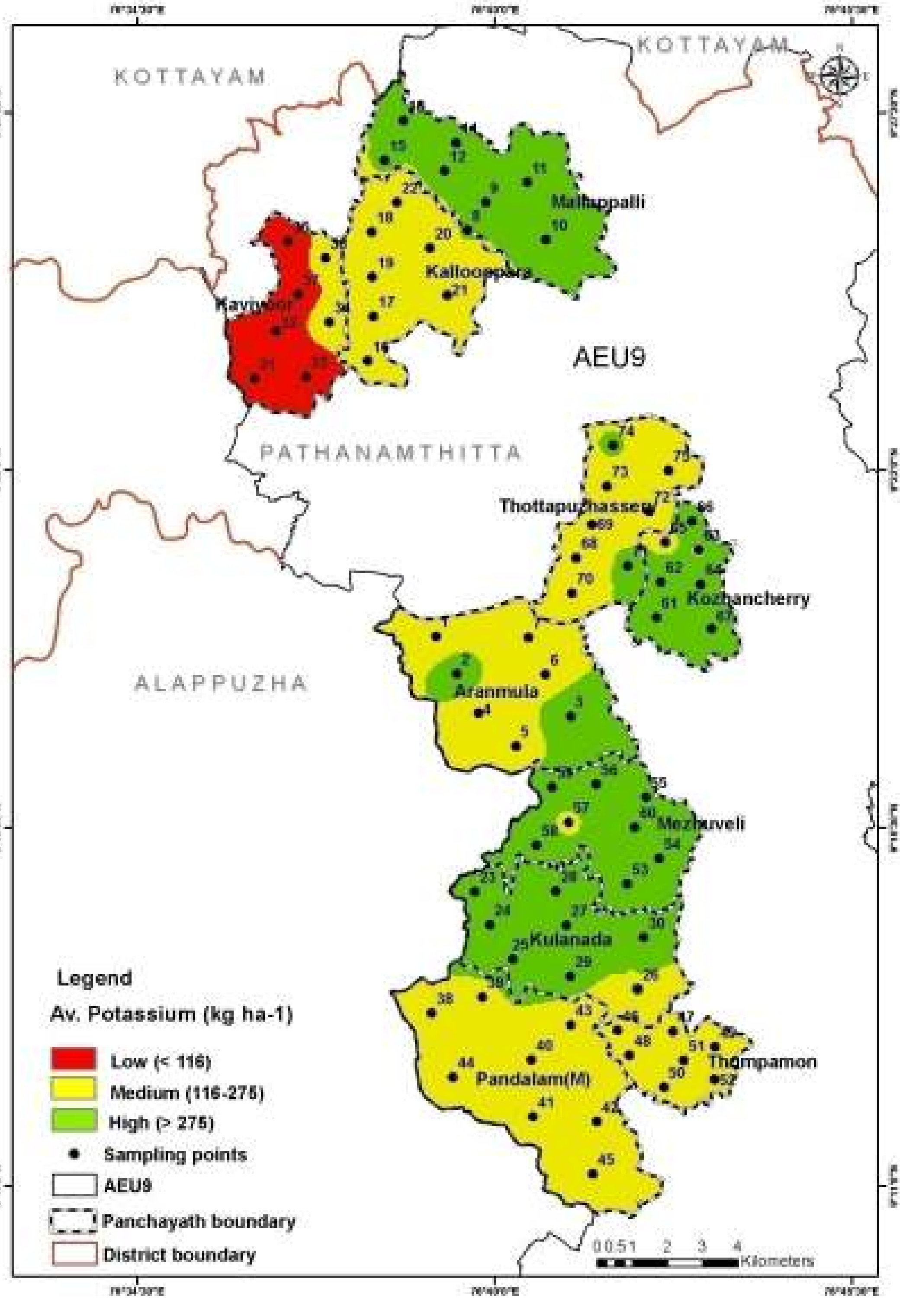

Fig 26. Spatial distribution of available potassium (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.9 Available calcium

Available Ca ranged between 151 and 521 mg kg^{-1}in the post-flood area with a mean of 326 mg kg^{-1}. Available Ca was deficient in 36 percent of post-flood soils and adequate in 65.3 percent but in pre flood soils 30 percent were deficient and 70 percent adequate in calcium. Decrease in calcium content after flood was due to the leaching of basic cations in flood water. These findings were in accordance with those reported by Leno *et al.* (2013) and Mengel *et al.* (2011). Spatial distribution of available calcium shown in Fig 26 revealed that almost the entire area in Aranmula, Kalloopara, Mallapally and Kaviyur were found to be deficient in Ca and other areas were adequate in Ca. The present study showed significant positive correlation of Ca with clay content.

5.1.2.10 Available magnesium

Available Mg varied between 30.4 and 210 mg kg^{-1} and the mean value was 106 mg kg^{-1}. There was a decline in available magnesium in soil due to the flood. Available magnesium was found to be deficient in 68 percent of the post flood soils (Fig.28). Percent of sample deficient in Mg reduced (68%) compared to pre-flood soils (74 %). This reduction in Mg deficiency is due to the deposition of sediments.

Most of the samples are deficient in Mg in both pre and post flood conditions. Mg being a weak competitor of exchange sites with aluminium and Ca, appears to accumulate in soil solution and is subject to leaching loss in acid soils (Edmeades *et al.,* 1985) which might be the reason for lower magnesium levels in soils despite the high Ca content observed in the same areas. Similar findings were also reported by Natarajan *et al*. (2013).

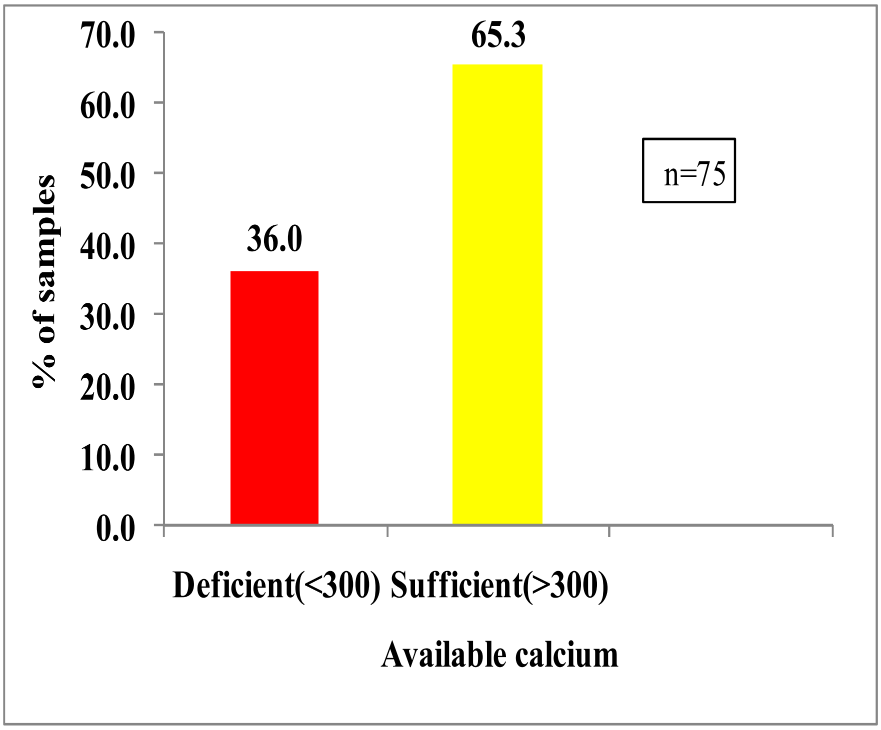

Fig 27. Frequency distribution of available calcium (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

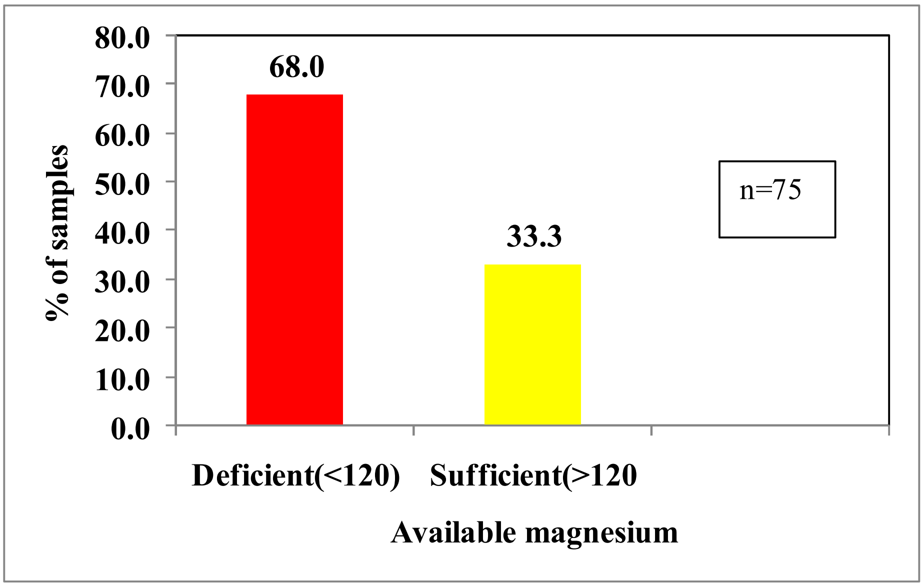

Fig 28. Frequency distribution of available magnesium (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

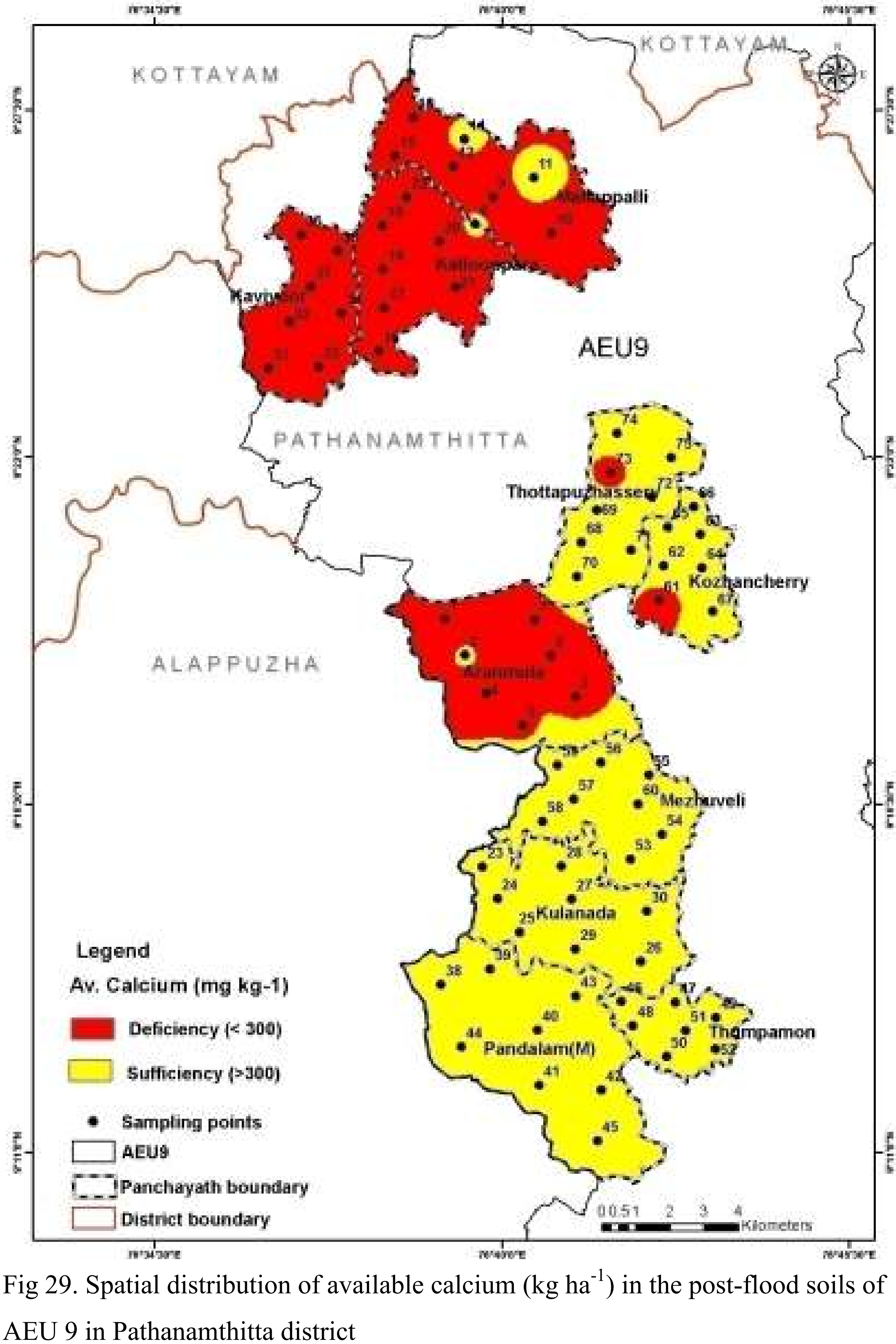

Fig 29. Spatial distribution of available calcium (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.11 Available sulphur

Available S content in soil varied between 0.5 and 87.5 mg kg^{-1} with mean value of 21.4 mg $kg^{-1}$and was found to be adequate in 92.0 % soils (Fig.30). The higher levels of available S might be due to the accumulation of organic matter and sediments in these soils. Available S was significantly and positively correlated with silt content. Similar results were reported by Kalshetty *et al.* (2012). The combined effects of decreased adsorption, increased mineralisation and accumulation of sulphur bearing minerals from sediments would have increased in available S levels in soil.

5.1.2.12 Available boron

Available B in soil ranged between 0.01 to0.45 mg kg^{-1} with mean of 0.13 mg kg^{-1}. Available B became deficient in all the soils of AEU 9 after the flood earlier deficientcy was 59 % (appendix IV). This can be attributed to the higher mobility of boron in soils and also leaching losses which led to B deficiency in these soils. High intensity rainfall will lead to loss of soluble forms of B by leaching (Mengel *et al.,* 2011).

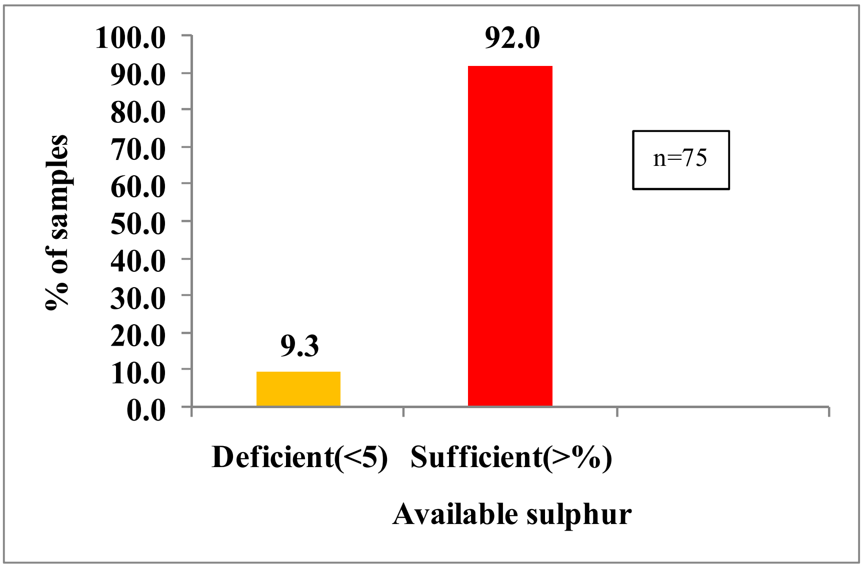

Fig 30. Frequency distribution of available sulphur (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

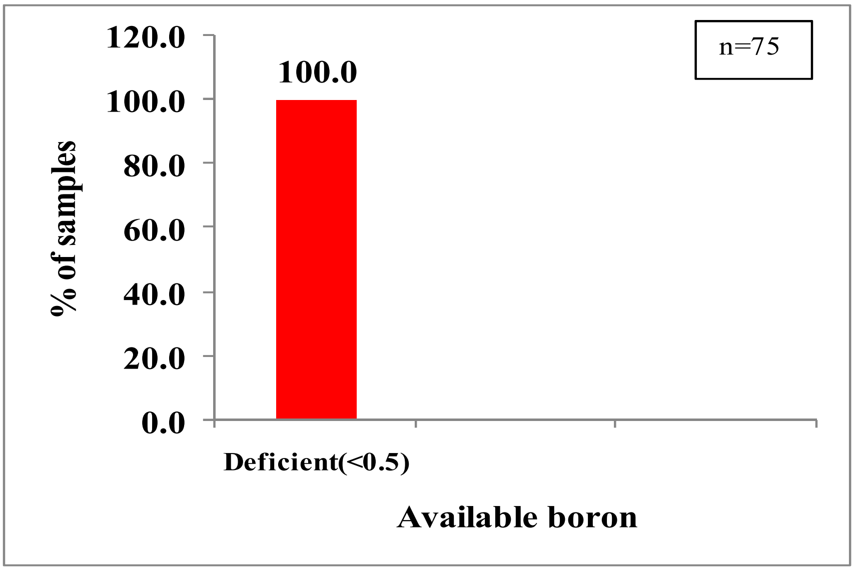

Fig 31. Frequency distribution of available boron (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

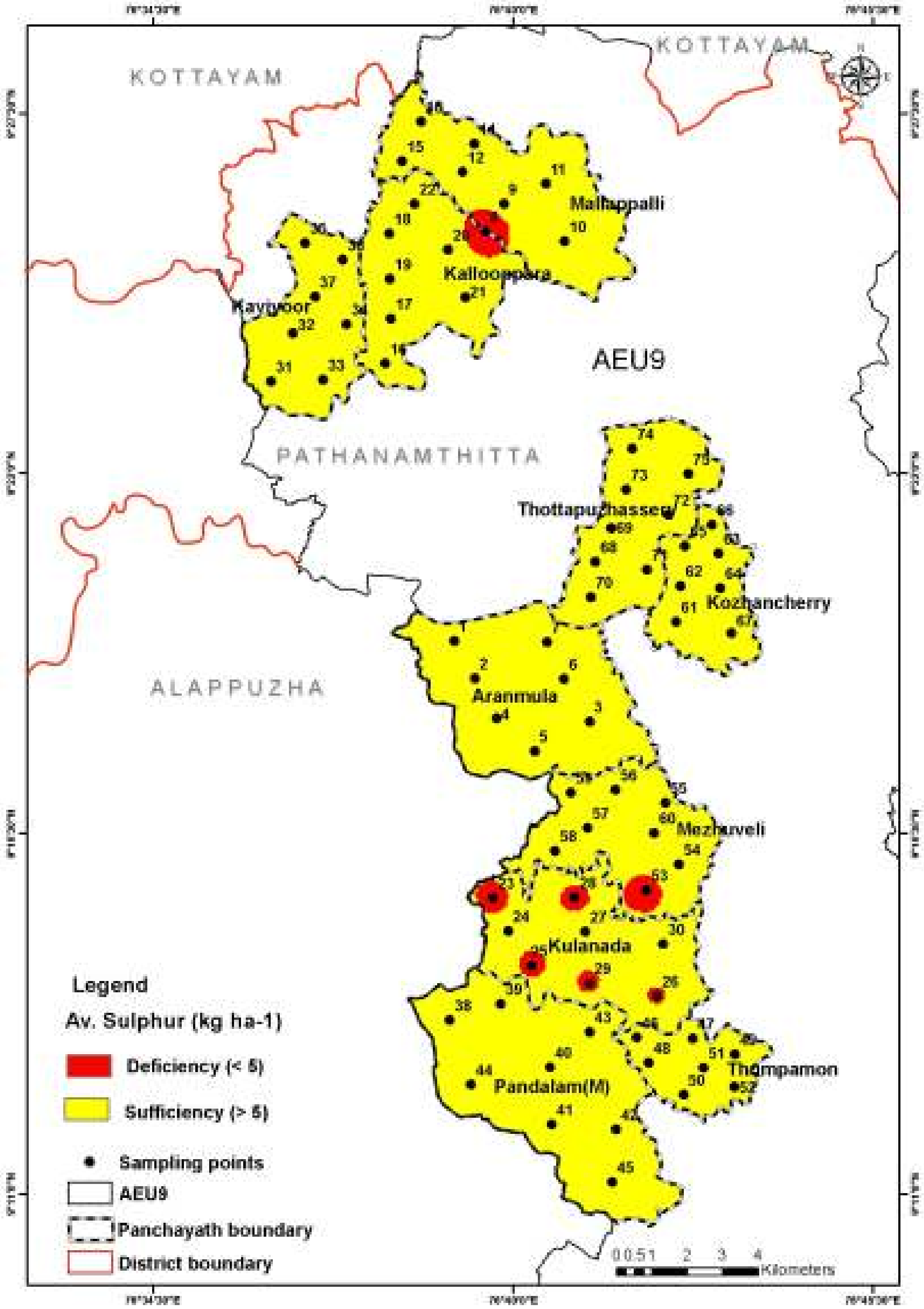

Fig 32. Spatial distribution of available sulphur (kg ha^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.13 Available iron

Available iron content was adequate in all the soil samples (Fig.33). The sufficiency of available iron in the post flood soil might be due to the reason that insoluble form of Fe is reduced to more soluble form (Fe^{2+}) under submerged condition (Fageria *et al.,* 2011). Presence of iron rich parent material and leaching of basic materials from the surface layers of the soils might also lead to the high available iron.

5.1.2.14 Available manganese

Available manganese content was adequate in 100% of samples (Fig.34). Manganese content remained high in the study area in both pre and post flood period. The sufficiency of available Mn in the post flood soil might be due to the reason that insoluble form of Mn is reduced to more soluble form (Mn^{2+}) under submerged condition (Fageria *et al.,* 2011)

5.1.2.15 Available zinc

Available zinc content was adequate in 66.7% and deficient in 33.3% of samples (Fig.35). Deficiency of Zn increased after flood (33.3%) compare to pre flood condition (10 %) (KSPB, 2013). This deficiency may be due to leaching losses occurred during flood. Similar reduction in availability of Zn reported by Fageria *et al.* (2011) in submerged soils.

5.1.2.16 Available copper

Available copper content was adequate in all the samples which was deficient in 13 percent samples of pre flood soil. This may be due to accumulation of organic matter and sediments after flood.

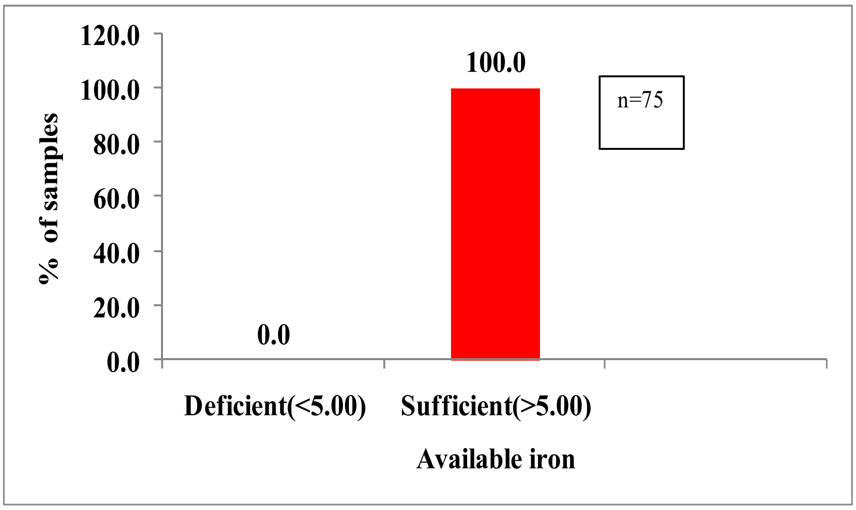

Fig 33. Frequency distribution of available iron (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

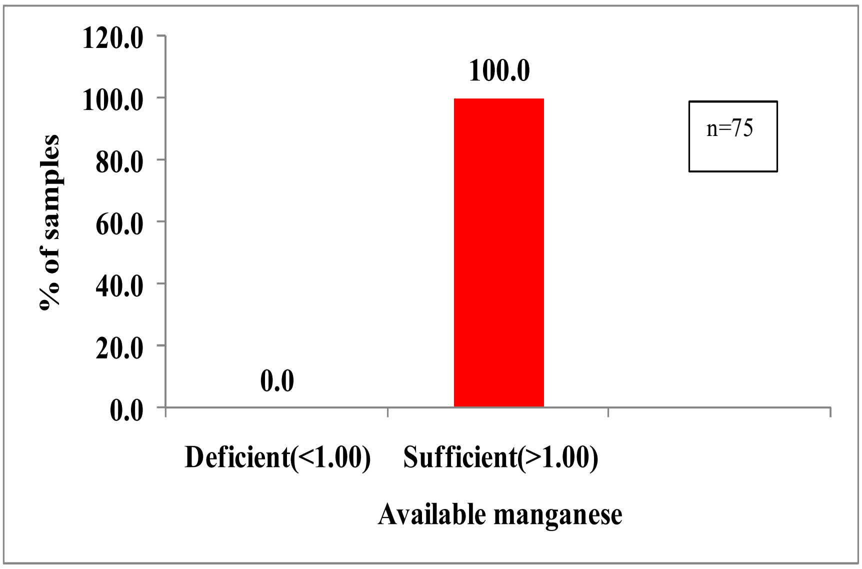

Fig 34. Frequency distribution of available manganese (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

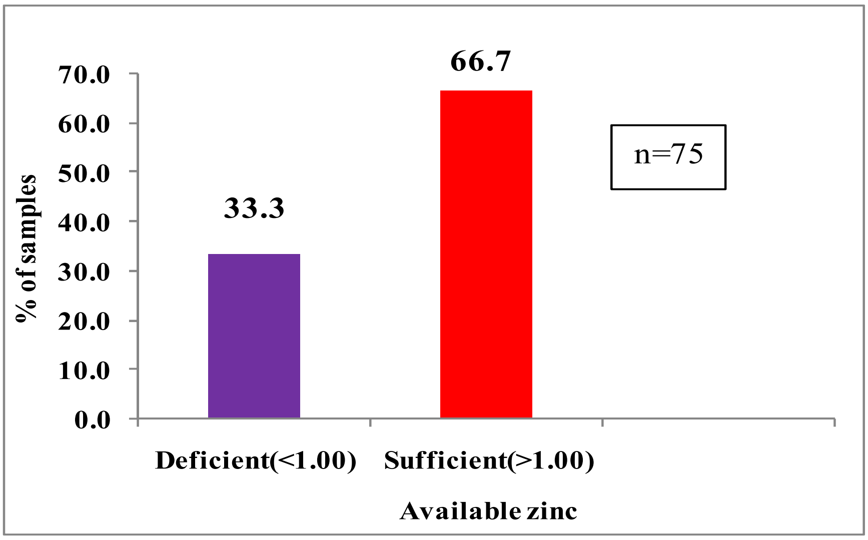

Fig 35. Frequency distribution of available zinc (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

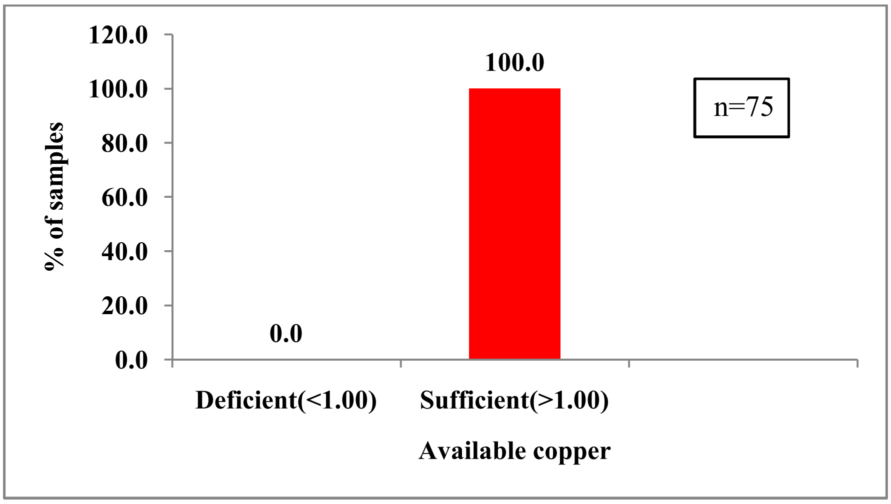

Fig 36. Frequency distribution of available copper (mg kg^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.1.2.17 Heavy metals

The soil collected from flood affected areas of AEU 9 of Pathanamthitta district showed the presence of only heavy metal the lead. Other heavy metals viz., nickel, cadmium and chromium were found to be in non detectable level in all the samples. Hafeez *et al*. (2019) also found that flood had no effect on the concentration of heavy metals such as Cd and Cr.

5.1.3 Biological attributes

The results of biological parameters in the post flood soils of AEU 9 of Pathanamthitta district are discussed below.

5.1.3.1 Acid phosphatase activity

Acid phosphatase activity in soil ranged between 15.5 and 57.8 µg PNP produced g $soil^{-1}hr^{-1}$. Majority (68 percent) of soils recorded an acid phosphatase activity between 25 and 50 µg PNP produced g $soil^{-1}h^{-1}$ (Fig 37). The improved organic matter in soils can enhance microbial and enzyme activity. Increased enzyme activity observed might be attributed to the improved organic matter status in the soils which is in accordance with the findings of Shi (2011). The optimum pH of soil for the activity of acid phosphatase is 4.0-6.5. The soils of the study area are within the pH range of 4.6-5.60 which was found favourable for phosphatase enzyme activity.

5.1.3.2 Dehydrogenase activity

Dehydrogenase activity in soil varied between 17.1 and 27.7 µg TPF hydrolysed g^{-1}soil 24 hr^{-1} in the post-flood area of AEU 9. Majority (60 percent) of soils registered dehydrogenase activity between 25 and 50 µg PNP produced g $soil^{-1}h^{-1}$ (Fig 38).

Increased dehydrogenase activity indicated a shift in microflora from aerobic to anaerobic. Pedrazzini and Mckee (1984) also reported increased levels of dehydrogenase activity in submerged soils. The increased soil moisture content (15.2-

50.8%) after the flood might have increased the dehydrogenase activity in these soils.

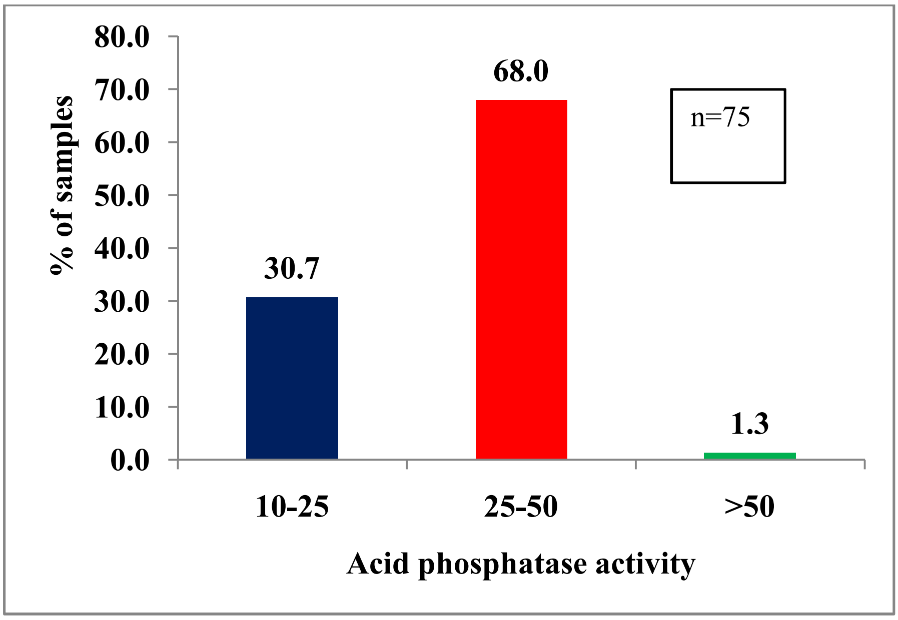

Fig 37. Frequency distribution of acid phosphatase (µg PNP produced g $soil^{-1}h^{-1}$) in the post-flood soils of AEU 9 in Pathanamthitta district

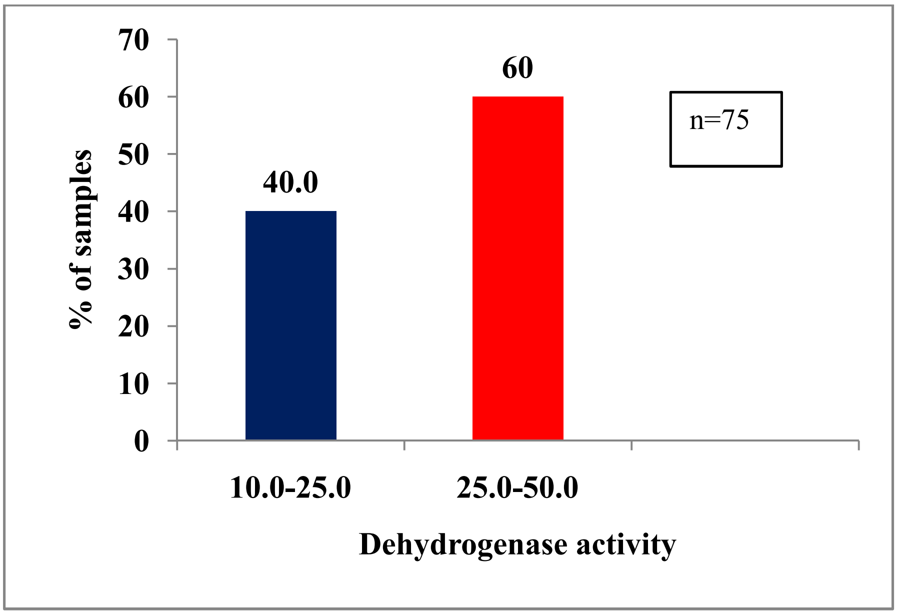

Fig 38. Frequency distribution of dehydrogenase (µg TPF hydrolysed g^{-1}soil 24 hr^{-1}) in the post-flood soils of AEU 9 in Pathanamthitta district

5.2 SOIL QUALITY INDEX

Soil quality index of the post-flood soils of AEU 9 of Pathanamthitta was calculated from eight parameters of minimum data set viz., *organic carbon percent, bulk density, available K, available B, available S, sand percent and manganese*. Relative soil quality index of the soil ranged between 62 and 96 percent. Majority of the soils (86.7 %) had high soil quality while 13.3 percent of soils had medium soil quality (Fig.39). Soil quality was observed to be maximum in Aranmula and Mezhuveli where organic carbon, available potassium, available boron and available sulphur were found to be high and sediment depositions were observed. Spatial distribution of soil quality is presented in Fig 40. The contribution of organic carbon and available nutrient status to soil quality is substantial as the important indicators of soil quality index.

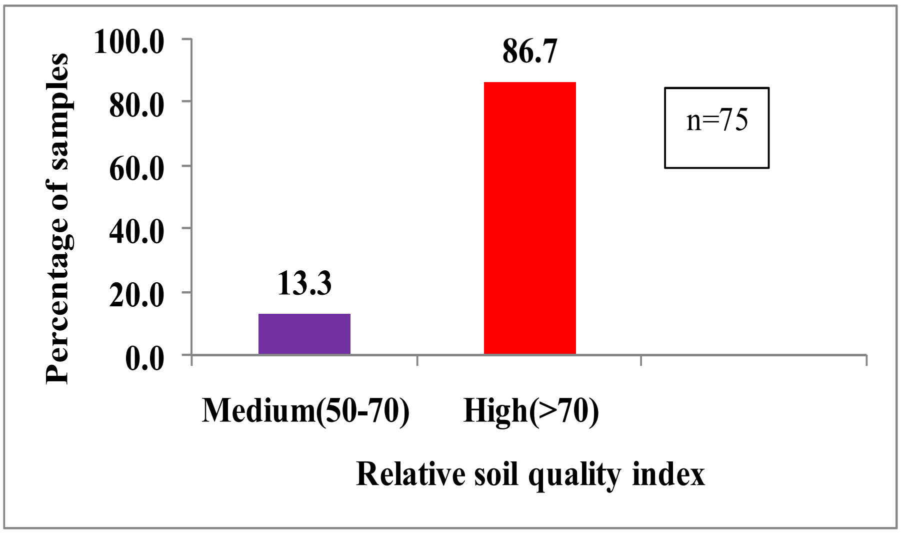

Fig 39. Frequency distribution of relative soil quality index (%) in the post-flood soils of AEU 9 in Pathanamthitta district

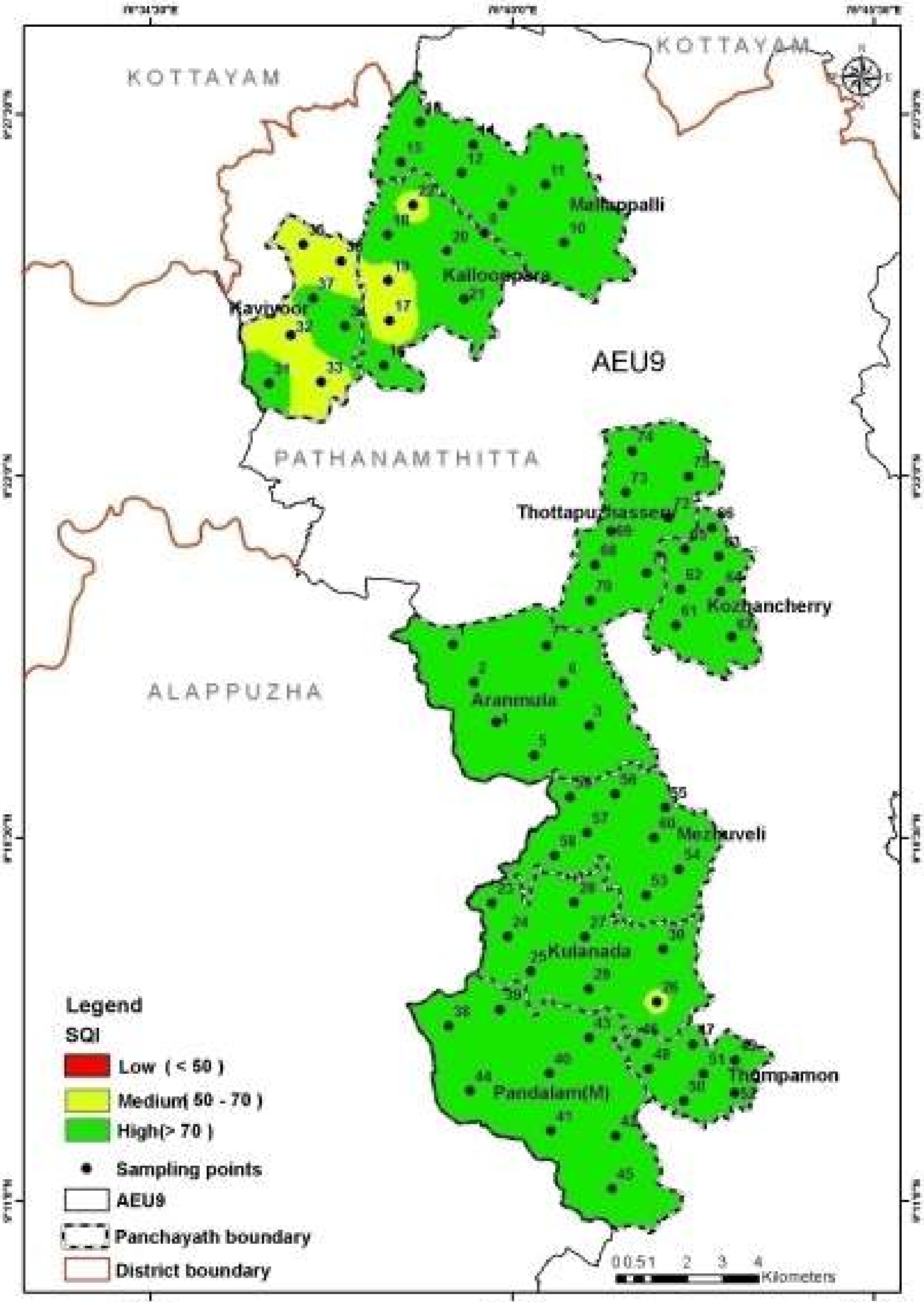

Fig 40. Spacial distribution of soil quality index in the post-flood soils of AEU 9 in Pathanamthitta district

5.3 NUTRIENT INDEX

Nutrient Index was worked out for organic carbon, available nitrogen, phosphorous and potassium contents in soil. Nutrient indices for organic carbon was medium for Mallapally, Panthalam, Thumbamon, Mezhuveli, Kozhanchery and Thottapuzhassery and high for Aranmula, Kalloopara, Kulanada and Kaviyur panchayats. (Fig.41). This can be attributed to the deposition of sediments rich in organic matter under the inflow of flood water. The results are in line with the findings of Grybos *et al.* (2009). Nutrient indices for available nitrogen were low for Mallapally, Kaviyur, Thumbamon, Mezhuvely, Kozhanchery and Thottapuzhassery and medium for Aramula, Kalloopara, Kulanada and Panthalam (Fig.42). This can be attributed to the losses of nitrogen that has occurred and also the low mineralization of organic matter in highly acidic soil which requires replenishment for sustaining soil productivity (Liji,1987). Nutrient indices for available phosphorous was medium for Kalloopara and Thottapuzhassery and was low for other panchayats. (Fig.43). This is attributed to low pH, phosphate sorption and also fixation of soluble inorganic P in the soils as reported by Sah and Mikkelsen (1989). Nutrient indices for available potassium were low for Kaviyur and high for Mallapally, Kulanada, Mezhuvely and Kozhanchery and medium for remaining panchayats.

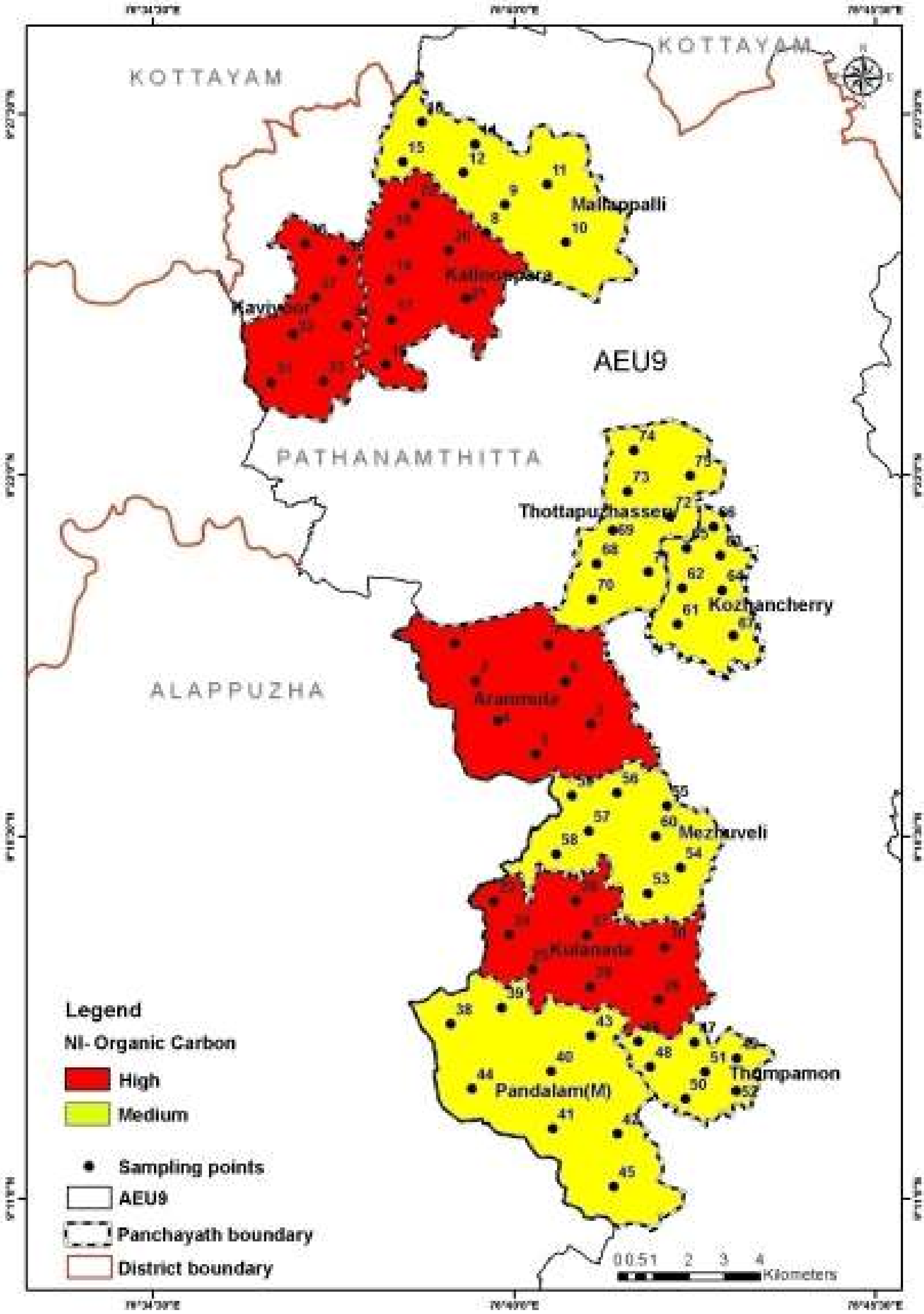

Fig 41. Spatial distribution of nutrient index for organic carbon in the post-flood soils of AEU 9 in Pathanamthitta district

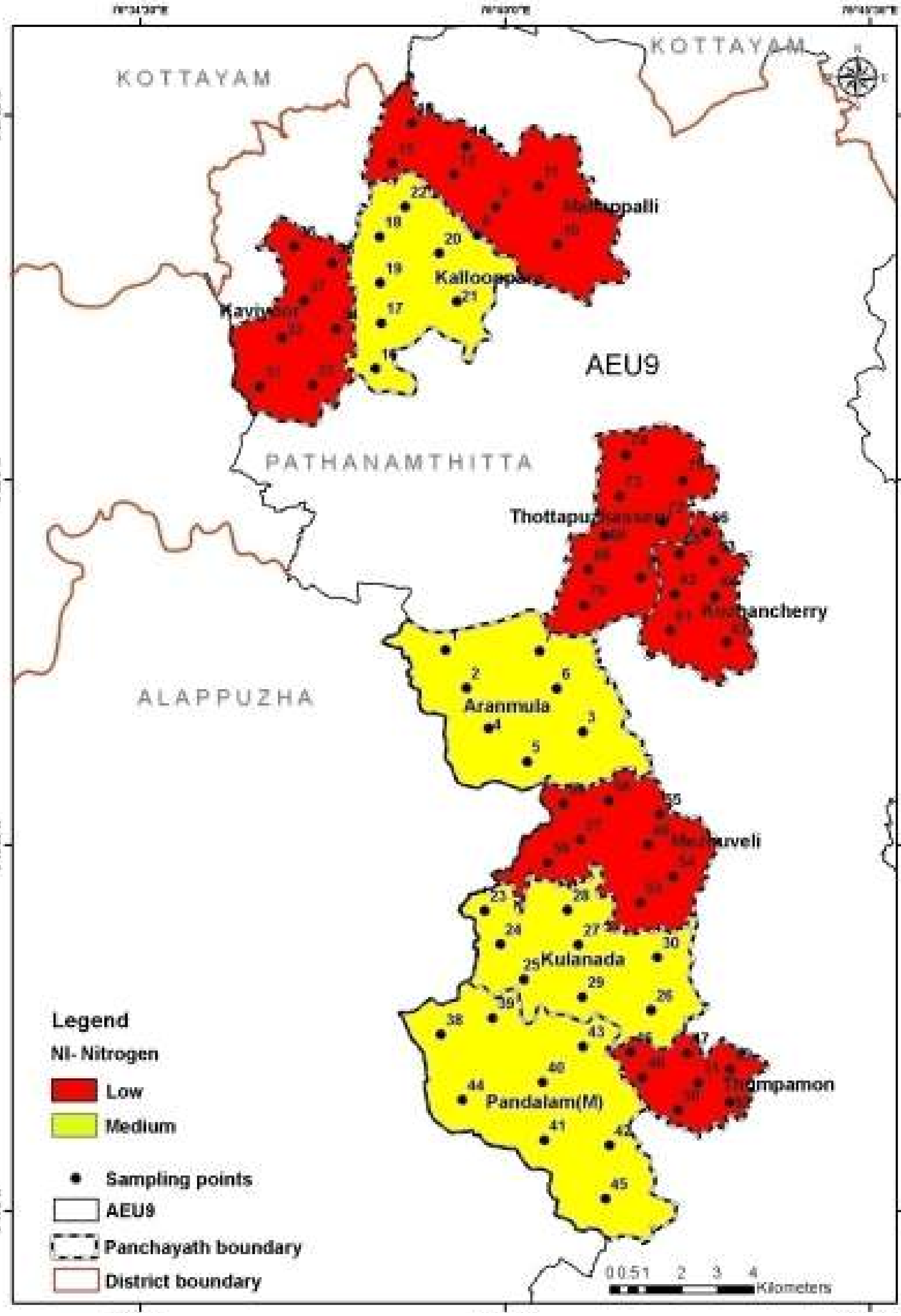

Fig 42. Spatial distribution of nutrient index for nitrogen in the post-flood soils of AEU 9 in Pathanamthitta district

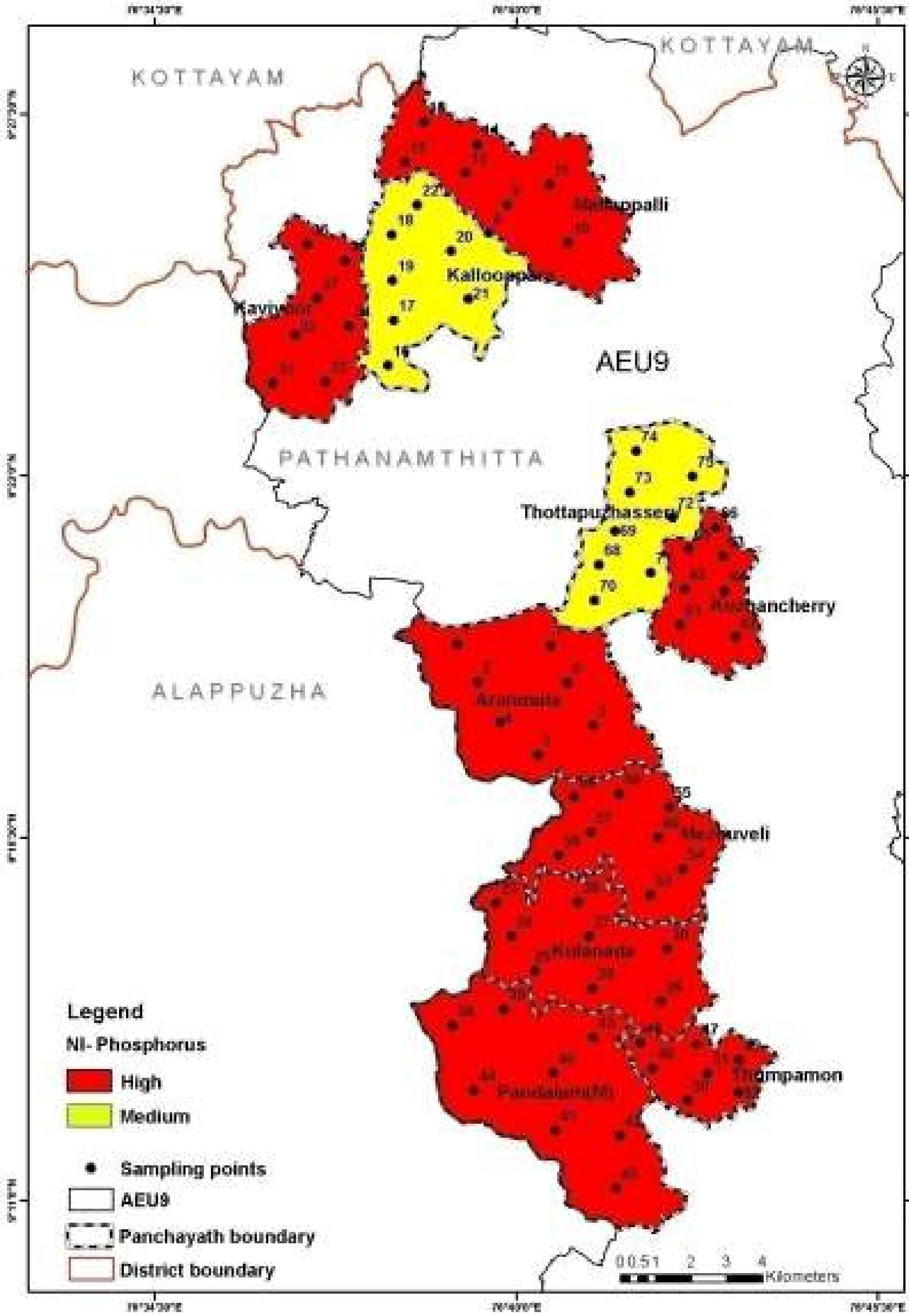

Fig 43. Spatial distribution of nutrient index for phosphorus in the post-flood soils of AEU 9 in Pathanamthitta district

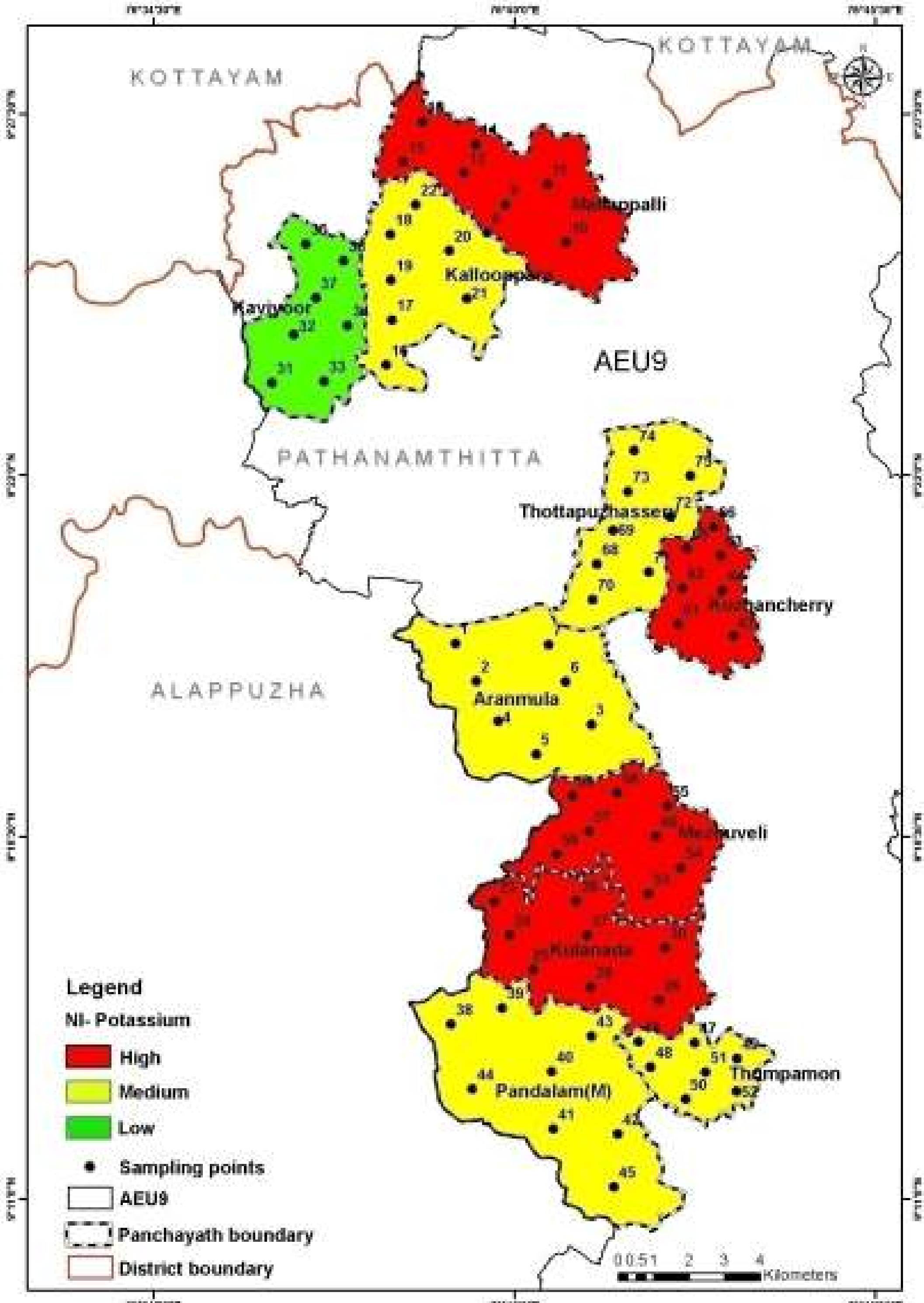

Fig 44. Spatial distribution of nutrient index for potassium in the post-flood soils of AEU 9 in Pathanamthitta district

5.4 LAND QUALITY INDEX

Land quality index was computed based on soil organic carbon stock in kg m^{-2}. LQI was very low (< 3 kg m^{-2}) in 64 % of soils, low (3-6 kg m^{-2}) in 32 % and medium (6-9 kg m^{-2}) in 4 % of soils (Fig 45). Spatial variability of LQI in flood affected soils of AEU 9 is depicted in Fig 46. The soil organic carbon stock varied between 0.8 kg m^{-2} and 7.19 kg m^{-2}. Land quality index was found to be low in Aranmula, Kalloopara and Kaviyur and very low in rest of the panchayats. The very low and low LQI implies depletion of soil organic carbon stock in the surface soils. Even though organic carbon status of soil was medium to high, it has not reflected in LQI which might be due to low carbon storage in surface soil (0- 15 cm) and also due to the low bulk density of the soil (Shalimadevi, 2006).

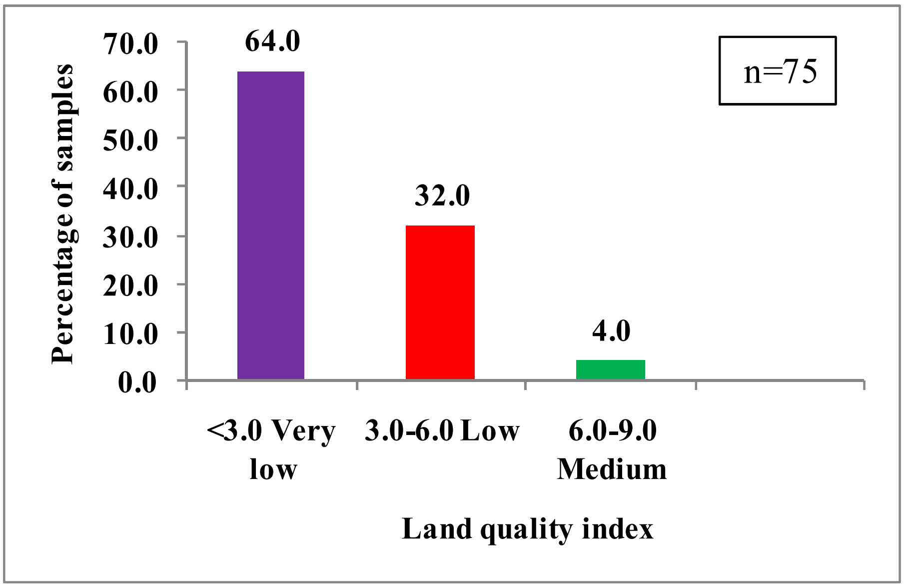

Fig 45. Frequency distribution of land quality index in the post-flood soils of AEU 9 in Pathanamthitta district

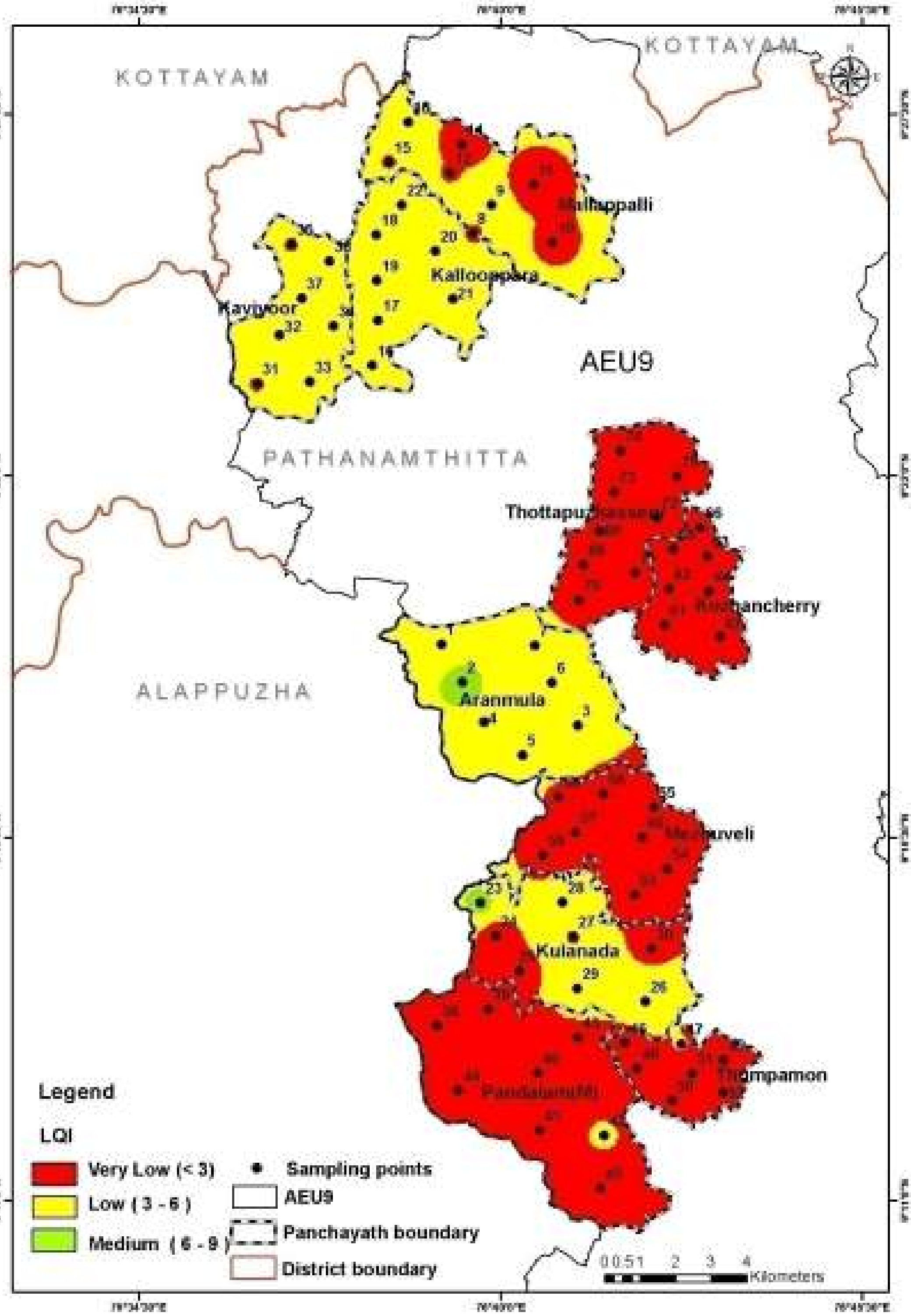

Fig 46. Spatial distribution of land quality index in the post-flood soils of AEU 9 in Pathanamthitta district

5.5 COMPARISON OF PRE AND POST- FLOOD SOILS OF AEU 9 OF PATHANAMTHITTA DISTRICT

Agro ecological unit 9 in Pathanamthitta district was severely affected by the devastating flood which occurred in August, 2018. The panchayats affected by the flood were Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally. Large quantity of sediment deposition was observed in this area after flooding. The flood did not cause much alteration in the soil texture of AEU 9 of Pathanamthitta. The dominant textural class was loam.

Soil acidity falls into very strongly, strongly and moderately acidic categories after flood. Extremely acidic and slightly acidic categories vanished after flood. Most of the samples come under strongly acidic category after flood. Leaching of basic cations from the soil might have led to increased acidity and also the soil acidity lowered in regions where sediment deposits with high basic cations occurred (Table 28).

Majority (57.3%) of the post flood soils are having medium organic carbon status followed by 38.7% soils with high status (Fig 17). Pre-flood samples (90 %) were also medium and high in organic carbon status. Percent of sample low in organic carbon status decreased after flood compared to pre flood soil. This can be attributed to the deposition of sediments rich in organic matter under the inflow of flood water.

The phosphorus availability in these soils have reduced after flood which can be attributed to change in soil pH. The phosphorus availability is highly dependent on soil pH and P availability will be maximum at a pH of 6.5. Soils with medium status of available phosphorous increased in post-flood (37.3) compared to pre-flood (17%) whereas high phosphorous soils decreased from 65 to 58.7 per cent. Organic matter deposition in the soils may have also contributed to phosphate sorption and reduction in phosphorous availability. Available K status in soil increased in post-flood soils compared to pre-flood soils. About 96.7 per cent samples became medium and high in

K status earlier it was 92 per cent. Samples low in potassium status were reduced compare to pre flood soil.

Available Ca was deficient in 36 per cent of post-flood soils and adequate in 65.3 per cent but in pre flood soils 30 per cent were deficient and 70 per cent adequate in calcium. Decrease in calcium content after flood was due to the leaching of basic cations in flood water. Most of the samples are deficient in Mg in both pre and post flood conditions. Magnesium being a weak competitor of exchange sites with aluminium and calcium, appears to accumulate in soil solution and is subject to leaching loss in acid soils.

Sulphur content increased in post flood soil (adequate in 92%) compared to pre flood soil (adequate in 76%).The higher levels of available sulphur might be due to the accumulation of organic matter and sediments in these soils. Available B became 100 per cent deficient in the soils of AEU 9 after the flood earlier deficientcy was 59 per cent (Fig.31). This can be attributed to the higher mobility of boron in soils and also leaching losses which led to B deficiency in these soils.

Manganese content remained high in the study area in both pre and post flood period. Deficiency of Zn increased after flood (33.3%) compare to pre flood condition (10 %). The deficiency of Zn might be due to leaching losses occurred during flood. Available copper content became adequate in 100 per cent of samples which was deficient in 13 per cent samples of pre flood soil. This may be due to accumulation of organic matter and sediments after flood.

Table 28. Comparison of parameters of pre and post-flood soils of AEU 9 of Pathanamthitta district

Parameters	Fertility class	Percent of samples	
		Pre flood (KSPB, 2013)	Post flood
pH	Extremely acidic	15	_
	Very strongly acidic	34	29.3
	Strongly acidic	24	61.3
	Moderately acidic	16	9.3
	Slightly acidic	11	-
OC (%)	Low	10	4
	Medium	42	57.3
	High	48	38.7
Available P (kg ha^{-1})	Low	18.0	5.3
	Medium	17.0	37.3
	High	65.0	58.7
Available K (kg ha^{-1})	Low	8	6.7
	Medium	39	50.7
	High	53	44
Available Ca (mg kg^{-1})	Deficient	30	36.0
	Sufficient	70	65.3
Available Mg (mg kg^{-1})	Deficient	74	68
	Sufficient	26	33.3
Available S (mg kg^{-1})	Deficient	24	9.3
	Adequate	76	92

Table 28. Comparison of parameters of pre and post-flood soils of AEU 9 of Pathanamthitta district (continued)

Parameters	Fertility class	Percent of samples	
		Pre flood (KSPB, 2013)	Post flood
Available B (mg kg^{-1})	Deficient	59	100.0
	Sufficient	41	--
Cu (mg kg^{-1})	Deficient	13	
	Sufficient	87	100
Zn (mg kg^{-1})	Deficient	10	33.3
	Sufficient	90	66.7

5.6 SUGGESTED INTERVENTIONS IN AEU 9 OF PATHANAMTHITTA DISTRICT

Flood caused various changes in soil properties which directly affected the agriculture in this region. The major land uses in AEU 9 are coconut, banana, paddy, tapioca, vegetables and rubber. Successful crop production can be obtained only by adopting changes in nutrient management practises according to the fertility status of soil after the flood.

Flood resulted in the sediment deposition on most of the crop lands near river banks in Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Panthalam, Kozhanchery, Aranmula, and Mallapally panchayaths. Major sediment material deposited on crop land was sand fractions which should be removed wherever possible to make the land suitable for future cultivation. Soil acidity should be managed since soil pH of most of the areas declined after the flood. It is essential to apply lime to these areas based on soil test results. Lime application will also meet the calcium requirement of crops as the soils are deficient in available calcium. Majority of soils are medium in organic carbon status, so it is important to apply organic manures to maintain the soil life.

Available nitrogen content in flood affected soils are low in status which necessitating the application of nitrogenous fertilizers as per package of practices recommendations of KAU (2016). The available P and K content of the soils in flood affected area is in medium and high status, so application of phosphorus and potassium fertilizers can be reduced based on the current soil test results. Magnesium and boron are deficient in most of the areas. Magnesium deficiency can be corrected by application of magnesium sulphate or dolomite. Boron deficiency can be corrected by application of borax either as soil or foliar application.

Summary

SUMMARY

The study entitled "Assessment of soil quality in the post flood scenario of AEU 9 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 soils of AEU 9 in Pathanamthitta district, to develop maps on soil characters and quality using GIS techniques and to work out the Soil Quality Index.

A survey was conducted in the study area during April 2019 and seventy five geo referenced soil samples were collected from flood affected panchayats *viz.* Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally

The soil samples were analysed for different physical (bulk density, particle density, porosity, texture, maximum water holding capacity, soil moisture content and aggregate stability), chemical (pH, electrical conductivity, exchangeable acidity, effective CEC, organic carbon, available N, P, K, Ca, Mg, S, B, Fe, Mn, Zn, Cu and heavy metals) and biological (acid phosphatase and dehydrogenase activity) parameters for evaluating soil quality. GIS based thematic maps of soil quality was also made.

A minimum data set (MDS) of parameters for assessing soil quality was set up using principal component analysis (PCA). Twenty eight soil parameters (bulk density, particle density, silt, clay, sand, maximum water holding capacity, soil moisture content, water stable aggregates, mean weight diameter, pH, electrical conductivity, exchangeable acidity, effective CEC, organic carbon, available N, P, K, Ca, Mg, S, B, Fe, Mn, Zn, Cu, acid phosphatase and dehydrogenase activity) were analysed using PCA and a MDS of seven parameters (sand, organic carbon, available K, B, S, Mn and bulk density) yielded from six principal components (PC1 to PC 6) with eigen values greater than one were retained .The selected soil quality indicators were categorized into four classes *viz.* very poor, poor, good and very good and assigned with scores 1, 2, 3 and 4 respectively. Soil quality index was computed by combining the scores after assigning appropriate weights to each parameter. Based on relative soil quality index, soils were rated as poor, medium or good. Nutrient indices were computed for organic carbon and available primary nutrients (N, P and K).

Land quality index was also calculated based on soil organic carbon stock. Thematic maps were generated in ArcGIS software for soil texture, pH, organic carbon, available N, P, K, Ca, S, soil quality index, land quality index and nutrient index for organic carbon, available N, P and K. Correlation between physical, chemical and biological parameters were worked out. Post flood soil data of AEU 9 was compared with the pre flood data of Kerala State Planning Board (2013) and interpreted. The salient findings of the study is summarized below.

- The flood affected panchayats in AEU 9 of Pathanamthitta district are Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally.
- Most of the area in AEU 9 is under coconut based cropping system (26.6%) followed by banana (20.1 %), vegetables(20.3 %), paddy (13.3%), cassava (13.2%) and rubber (6.5%). High rainfall and rise in water level in rivers during flood caused widespread crop damage in these areas. Among the major crops paddy and banana were the most affected. Other crops affected by flood includes tuber crops, rubber, coconut and vegetables.
- Integrated nutrient management practices were adopted by majority of the farmers (46.6%) followed by organic (20.0%) and conventional (33.3%) practices. More than 77 per cent of farmers are marginal farmers (< 1ha) and others are small farmers (1 -2 ha).
- Sediment deposition of sand, silt and clay to a depth of 0-15 cm were observed in Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally.
- The lowest and highest bulk density values were observed in Kaviyur panchayat (1.07 Mg m^{-3}) and Kalloopara panchayat (1.54 Mg m^{-3}) respectively, while lowest particle density observed for Aranmula and Kaviyur panchayat (2.15Mg $m^{-3)}$ and highest at Kalloopara panchayat (2.33 Mg m^{-3}).
- The highest and lowest values for porosity were recorded in Kaviyur panchayat (50.3%) and Kalloopara panchayat (33.83%) respectively
- Loam was the predominant soil texture observed in 62.7per cent of the flood

affected soils of AEU 9 followed by clay loam (21.3%), sandy loam (13.3%) and sandy clay texture(2.7%).

- The soil moisture content varied between 15.2 and 50.8per cent with the highest content in Kaviyur and lowest in Kozhanchery. The highest water holding capacity of 51.0 per cent was recorded in Panthalam, and lowest of 29.7 per cent in Kalloopara.
- Soils of Kaviyur panchayat showed the highest MWD (2.22 mm) and WSA (64.1%) whereas Kozhanchery showed lowest MWD (0.69 mm) and WSA (40.9%).
- Majority of soils showed bulk density between 1.2 and 1.4 Mg m^{-3} (58.7%), particle density between 2.2 and 2.4 Mg m^{-3} (49.3%), porosity between 30-50% (89.3%), maximum water holding capacity between 30-50% (73.3%), soil moisture content between 15-25 percent (54.7%), MWD between 1.5- 2 mm (37.3%) and WSA between 50-70 percent (66.7%).
- Soil pH varied between 4.60 and 5.60 with a mean of 5.16. About 61.3% of the soils were strongly acidic (5.0-5.5), 29.3% very strongly acidic (4.5-5.0) and 9.3 % moderately acidic (5.5-6.0). Electrical conductivity was less than 1 dSm^{-1} in all the soils. Majority (68 percent) of the soils reported exchangeable acidity between 1.0-2.0 $meq100g^{-1}$ and effective CEC of majority of soil (92 %) were between 3-15 $meq100g^{-1}$.
- The organic carbon content was highest in Kaviyur (2.53%) followed by Aranmula (2.43%) and lowest in Kozhanchery (0.66%). Organic carbon was rated medium for 57.3% and high for 38.7% of the soils.
- The highest available N (358 kg ha^{-1}) was recorded in Kalloopara, available P in Mallapalli (57.8 kg ha^{-1}) and available K in Kulanada (356 kg ha^{-1}). About 54.7% of the soils were low in available N status, 58.7% high in available P and 50.7% medium in available K content.
- Soils of Thumbamon recorded the highest available calcium (449 mg kg^{-1}), Panthalam registered the highest available magnesium (142 mg kg^{-1}), Kozhanchery recorded highest available sulphur (51.2 mg kg^{-1}) and Aranmula recorded the highest available boron of 0.23 mg kg^{-1}.Calcium (36.0%), magnesium (68%) and boron (100%) were deficient and sulphur (92%) was sufficient in

majority of soils.

- Availability of micro nutrients viz. iron, manganese, zinc and copper were highest at Thottapuzhassery. Iron, manganese and copper were sufficient in 100 % soil and zinc was deficient in 33.3 % soils.
- The only heavy metal detected in the soil was lead. Other heavy metal like nickel, cadmium and chromium were found to be non detectable in all the samples. Highest Pb content (0.403 mg kg^{-1}) was recorded in Kozhanchery .
- Majority (68%) of soils registered acid phosphate activity in the range of 25 to 50 µgm PNP produced/gram soil/hr. Dehydrogenase activity was in the range of 25 to 50 µg TPF/gram soil/24hr in 60per cent of the soils.
- Relative soil quality index ranged from 62 to 96 per cent with a mean of 79 per cent. Soil quality was observed to be higher in Aranmula and Mezhuveli which also registered relatively higher organic carbon, available potassium, sulphur and boron. About 86.7per cent of soils were rated high and 13.3per cent were medium in soil quality.
- Nutrient index for organic carbon was medium in Mallapally, Panthalam, Thumbamon, Mezhuveli, Kozhanchery and Thottapuzhassery and high in Aranmula, Kalloopara, Kulanada and Kaviyur panchayats.
- Nutrient index for available nitrogen were low for Mallapally, Kaviyur, Thubamon, Mezhuvely, Kozhanchery and Thottapuzhassery and medium for Aramula, Kalloopara, Kulanada and Panthalam.
- Nutrient index for available phosphorous was medium for Kalloopara and Thottapuzhassery where as low for other panchayats. Nutrient indices for available potassium were low for Kaviyur and high for Mallapally, Kulanada, Mezhuvely and Kozhanchery and medium for remaining panchayats.
- Soil organic carbon stock ranged between 0.8 and 7.19 kg m^{-2} in the study area. The highest value was observed in Kozhanchery (1.35 kg m^{-2}). LQI was very low (<3 kg m^{-2}) in 64%, low (3- 6 kg m^{-2}) in 32per cent and medium (6-9 kg m^{-2}) in 4 % of the soils.

Comparison with pre flood data of KSPB (2013) showed that soil acidity falls into very strongly, strongly and moderately acidic categories after flood. Extremely acidic and slightly acidic categories vanished after flood. Leaching of basic cations from the soil might have led to increased acidity and also the soil acidity lowered in regions where sediment deposits with high basic cations occurred

Most of the sample (96 %) falls under medium and high status in organic cabon content after flood. The phosphorus availability in these soils have reduced after flood. Samples low in potassium status were reduced compare to pre flood soil. Calcium content showed decreasing trend after flood. Most of the samples are deficient in Mg both in pre and post flood conditions. But sulphur content higher in pre flood soil compared to post flood soil. Available B became 100 per cent deficient in the soils of AEU 9 after the flood earlier deficiency was reported in 59 per cent soils. Iron and manganese content remained high in the study area in both pre and post flood period. Deficiency of Zn increased after flood. Available copper content became adequate in 100 per cent of samples which was deficient in 13 per cent samples of pre flood soil.

From the study it is concluded that soil condition and nutrient status were slightly altered in the soils of AEU 9 in Pathanamthitta district after the 2018 flood. Most of the samples become strongly acidic after flood due to the leaching of basic cations and erosion by flowing flood water. Organic carbon status, available K and S were increased after the floods in the areas with sediment deposits. The phosphorus availability in these soils reduced after flood which can be attributed to change in soil pH. The results outline the need for regular liming to control soil acidity and to alleviate Ca deficiency. The soils should be supplemented with Mg and B in addition to recommended dose of N, P and K fertilizers.

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Abstract

ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 IN PATHANAMTHITTA DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

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ABSTRACT

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ABSTRACT

A study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Pathanamthitta district of Kerala and generation of GIS maps" was carried out during 2018-20 with the objective to evaluate the soil quality in the flood affected areas of AEU 9 of Pathanamthitta district, to work out the soil quality index and to generate maps of various soil attributes and quality indices using GIS techniques.

Survey conducted to identify the flood affected areas in AEU 9 of Pathanamthitta district revealed that the flood affected panchayats includes Kaviyur, Thumbamon, Kulanada, Thottapuzhassery, Kallupara, Mezhuvely, Panthalam, Kozhanchery, Aranmula, and Mallapally. All these panchayats were severely affected by flood havoc and submergence that occurred in Manimala, Pamba and Achankovil rivers during August 2018.

A total of seventy five geo referenced surface soil samples were collected from the flood affected panchayats and analyzed for various physical, chemical and biological attributes. Minimum data set of soil indicators for computing soil quality was selected using principal component analysis. The selected parameters were sand content, bulk density, available B, available S, available K, available Mn and organic carbon. Scores and weights were assigned to each selected indicator, and computed the soil quality index. GIS techniques were used to generate thematic maps of various soil attributes and soil quality indices.

Sediment deposition was observed in all panchayats, while highest deposition of sand and silt were observed in Aranmula and Thumbamon panchayats. The flood did not cause much alteration in the soil texture of AEU 9 of pathanamthitta. The dominant textural class was loam. The particle density and bulk density of soil ranged from 2.07 to 2.45 and 0.87 to 1.76 Mg m^{-3} respectively. More than 89 per cent of the soils showed porosity in the range of 50 to 80 per cent. The soil moisture content ranged between 15.2 to 50.8 per cent. The water holding capacity and water stable aggregates ranged from 25.4 to 62.4 per cent and 38.6 to 68.5 per cent respectively.

The electrical conductivity of soil ranged between 0.05 and 0.40 dS m^{-1}. Post flood soil showed an increase in the organic carbon status of the soil. Majority (95 %) of soil comes under medium and high organic carbon status after flood. About 54.7 per cent of the soils are medium in available N content. Available phosphorus content varied between 8.10 and 104 kg ha^{-1} with a mean of 31.9 kg ha^{-1} and available potassium varied between 78.7 and 493 kg ha^{-1} with a mean of 246 $kgha^{-1}$. The post flood soils are adequate in available sulphur (92 %) and deficient in boron status (100 %).

The soil quality analysis revealed that majority of soils had high soil quality index (86.7%). Land quality index was very low in 64 % of soils while 32 % samples showed low land quality index. Nutrient index for nitrogen was low in most of the panchayats, medium and high for phosphorus, potassium and organic carbon.

The results of the study revealed that most of the soil became strongly acidic after flood. Organic carbon, potassium, phosphorus and sulphur are high and medium status while nitrogen is low in most of the panchayats. Deficiency of calcium and magnesium increases after flood. The entire study area showed deficiency of boron. The results outline the need for regular liming to control soil acidity and alleviate calcium deficiency. It is also suggested to supplement magnesium and boron to improve soil quality.

Appendices

Appendix I

Performa of survey questionnaire

1. Name of the panchayath :

2. Name of the farmer :

3. Address :

4. Size of holding :

5. Survey no. :

6. Geo cordinates of the sample :

7. Crops cultivated :

8. Nutrient management practices :

9. Depth of sand/silt/clay deposition :

Appendix II

Area and crop management of sampled locations

Panchayath/ Muncipality	Sample No.	Size of holding	Crops	Nutrient management
Aranmula	1	50 cent	Paddy	Organic
	2	40 cent	Paddy	INM
	3	1 ha	Banana	INM
	4	60 cent	Vegetables	Organic
	5	20 cent	Paddy	INM
	6	10 cent	Vegetables	INM
	7	1.3 ha	Paddy	INM
Mallappally	8	10 cent	Vegetables	Conventional
	9	30 cent	Rubber	INM
	10	1 ha	Vegetables	Organic
	11	50 cent	Coconut	INM
	12	25 cent	Banana	INM
	13	1 ha	Banana	Organic
	14	30 cent	Vegetables	Conventional
	15	1.2 ha	Banana	INM
Kalloopara	16	35 cent	Coconut	Conventional
	17	15 cent	Vegetables	INM
	18	20 cent	Paddy	INM
	19	1.5 ha	Coconut	INM
	20	10 cent	Cassava	Organic
	21	40 cent	Coconut	Conventional
	22	29 cent	Vegetables	Organic
Kulanada	23	40 cent	Banana	INM
	24	16 cent	Cassava	Conventional
	25	28 cent	Banana	Organic
	26	1.3 ha	Banana	Conventional
	27	34 cent	Cassava	Conventional
	28	50 cent	Vegetables	INM
	29	15 cent	Vegetables	INM
	30	1 ha	Coconut	Conventional
Kaviyur	31	30 cent	Paddy	INM
	32	40 cent	Paddy	INM
	33	15 cent	Banana	INM
	34	60 cent	Coconut	Conventional
	35	25 cent	Paddy	INM
	36	30 cent	Coconut	Conventional
	37	35 cent	Coconut	Conventional

Appendix II (Continued)

Panchayath/ Muncipality	Sample No.	Size of holding	Crops	Nutrient management
Panthalam	38	30 cent	Cassava	Organic
	39	40 cent	Banana	INM
	40	1.1 ha	Coconut	Conventional
	41	15 cent	Coconut	Organic
	42	40 cent	Banana	INM
	43	30 cent	Banana	INM
	44	30 cent	Coconut	Conventional
	45	20 cent	Banana	Conventional
Thumbamon	46	25 cent	Coconut	Conventional
	47	30 cent	Vegetables	INM
	48	1 ha	Vegetables	INM
	49	30 cent	Coconut	Conventional
	50	20 cent	Cassava	Conventional
	51	1 ha	Coconut	Conventional
	52	15 cent	Banana	INM
Mezhuveli	53	40 cent	Cassava	Organic
	54	30 cent	Cassava	Organic
	55	1.2 ha	Banana	Conventional
	56	15 cent	Coconut	Conventional
	57	25 cent	Cassava	Conventional
	58	1 ha	Vegetables	INM
	59	18 cent	Vegetables	Organic
	60	1 ha	Coconut	INM
Kozhanchery	61	15 cent	Paddy	INM
	62	25 cent	Paddy	INM
	63	20 cent	Cassava	Organic
	64	1 ha	Rubber	Conventional
	65	30 cent	Coconut	INM
	66	10 cent	Rubber	INM
	67	15 cent	Coconut	Conventional
Thottapuzhassery	68	25 cent	Rubber	INM
	69	20 cent	Cassava	Conventional
	70	1.3 ha	Banana	INM
	71	35 cent	Coconut	Conventional
	72	30 cent	Rubber	Organic
	73	10 cent	Vegetables	INM
	74	15 cent	Vegetables	Organic
	75	1 ha	Coconut	INM

Appendix III

Results of soil physical parameters

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Aranmula											
1	1.38	2.21	37.6	28.3	35.1	1.32	41.6	41.1	33.6	25.3	Loam
2	1.41	2.13	33.8	26.3	37.7	1.45	39.6	36.9	35.5	27.6	Loam
3	1.42	2.19	35.2	26.2	34.1	1.33	40.5	47.4	27.1	25.5	sandy clay loam
4	1.35	2.07	34.8	24.2	40.4	1.53	40.3	43.2	33.4	23.4	Loam
5	1.31	2.14	38.8	26.3	33.5	1.29	44.4	35.7	41.7	22.6	Loam
6	1.33	2.16	38.4	24.1	40.3	1.53	43.3	37.1	36.3	26.6	Loam
7	1.37	2.15	36.3	28.3	37.7	1.12	45.2	51.2	29.7	19.1	sandy loam
Mallapalli											
1	1.22	2.29	46.7	25.1	44.8	2.61	65.1	35.4	42	22.6	Loam
2	1.24	2.14	42.1	24.2	35	2.44	68.5	42.8	39.3	17.9	sandy loam
3	1.21	2.15	43.7	25.3	49.9	2.14	60.6	36.1	41.3	22.6	Loam
4	1.24	2.08	40.4	24.4	47	1.9	60.1	39.1	37.6	23.3	Loam
5	1.37	2.07	33.8	20.2	38.1	3.1	67.1	35.7	40.2	24.1	Loam
6	1.35	2.26	40.3	26.1	35	2.22	63.3	44.4	37.5	18.1	sandy loam
7	1.19	2.15	44.7	25.3	44.2	2.12	63.6	41.2	35.6	23.2	Loam
8	1.29	2.16	40.3	25.2	44.4	2.54	64.3	38.2	40.1	21.7	Loam

Appendix III (Continued)

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Kalloopara											Kalloopara
1	1.31	2.21	40.7	32.1	38.1	1.81	66.2	54.1	28.6	17.3	sandy loam
2	1.65	2.36	30.1	28.4	29.1	1.98	57.9	49.1	32.7	18.2	Loam
3	1.32	2.24	41.1	26.7	25.4	2.22	64.4	53.3	29.6	17.1	sandy loam
4	1.75	2.35	25.5	30.1	28.8	2.23	62.6	52.9	29.8	17.3	sandy loam
5	1.76	2.36	25.4	30.1	31.8	1.78	66.2	46.4	32.1	21.5	Loam
6	1.34	2.38	43.7	28.9	25.4	2.12	63.8	47.7	30.1	22.2	loam
7	1.68	2.41	30.3	26.4	29.1	1.94	65.5	56.2	26.9	16.9	sandy loam
Kulanada											
1	1.34	2.14	37.4	20.8	31.88	1.56	52.9	39.3	33.6	27.1	clay loam
2	1.22	2.22	45.0	20.4	48.9	1.68	51.6	39.4	36.1	24.5	loam
3	1.24	2.13	41.8	31.1	62.2	1.71	54	37.2	33.5	29.3	clay loam
4	1.71	2.41	29.0	22.4	31.8	1.56	53.3	41.1	35	23.9	loam
5	1.51	2.11	28.4	23.1	43.6	1.52	49.3	41.4	34.4	24.2	loam
6	1.34	2.22	39.6	22.6	48.9	1.56	46.8	38.4	30.4	31.2	clay loam
7	1.52	2.13	28.6	20.4	33.2	1.43	49.5	40.8	36.1	23.1	loam
8	1.23	2.14	42.5	31.1	31.7	1.45	50.1	36.4	34.2	29.4	clay loam

Appendix III (Continued)

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Kaviyur											
1	0.92	2.12	56.6	40.7	45.4	3.18	57.9	41.7	35.7	22.6	loam
2	1.09	2.13	48.8	41.5	43.5	2.21	64.4	37.1	36.3	26.6	loam
3	1.12	2.21	49.3	50.8	46.6	2.32	62.6	51.2	29.7	19.1	sandy loam
4	1.13	2.11	46.4	43.7	43.5	1.99	66.2	39.1	37.6	23.3	loam
5	0.87	2.09	58.4	49.1	45.2	2.14	60.6	35.7	40.2	24.1	loam
6	1.13	2.14	47.2	41.5	46.2	1.83	55.5	45.1	26.5	28.4	sandy clay loam
7	1.22	2.22	45.0	40.7	39.1	1.89	59.4	44.4	37.5	18.1	sandy loam
Panthalam											
1	1.22	2.15	43.3	31	44.6	1.42	52.9	41.2	30.4	28.4	clay loam
2	1.14	2.14	46.7	26.7	52.7	1.65	51.6	44.2	30.9	24.9	loam
3	1.23	2.12	42.0	31	55.5	1.56	54	41.3	28.4	30.3	clay lom
4	1.14	2.18	47.7	26.4	44.3	1.52	53.3	43.1	31.8	25.1	loam
5	1.33	2.17	38.7	22.4	51.3	1.55	54.4	44.2	30.6	25.2	loam
6	1.22	2.13	42.7	28.1	52.6	1.71	50.1	44.2	27.6	28.2	clay loam
7	1.29	2.21	41.6	24.1	55.4	1.46	51.1	39.3	29.6	31.1	clay loam
8	1.14	2.22	48.6	31	51.2	1.52	52.2	40.1	32.2	27.7	clay loam

Appendix III (Continued)

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
	Thumbamon										
1	1.13	2.14	47.2	15.2	54.1	0.821	43.3	39.2	32.8	28	clay loam
2	1.22	2.14	43.0	24.6	44.4	0.648	42.7	40.2	31.9	27.9	clay loam
3	1.31	2.22	41.0	22.1	40.5	0.822	41.1	45.1	31.7	23.2	loam
4	1.14	2.31	50.6	20.9	52.3	0.631	40.2	44.1	31.6	24.3	loam
5	1.12	2.12	47.2	22.2	50.3	0.466	39.4	43.2	33.9	22.9	loam
6	1.23	2.13	42.3	22.1	50.2	0.843	43.2	41.1	35.3	23.6	loam
7	1.31	2.22	41.0	23.4	44.5	0.613	40.6	42.5	32.4	25.1	loam
Mezhuveli											
1	1.35	2.31	41.6	23.9	50.9	1.81	63.3	39.1	38.1	22.8	loam
2	1.14	2.28	50.0	25.2	37.6	2.32	61.1	39.1	37.6	23.3	loam
3	1.42	2.26	37.2	23.4	37.3	2.12	59.3	38.1	33.6	28.3	clay loam
4	1.35	2.32	41.8	18.4	42.1	1.54	59.4	34.9	42.5	22.6	loam
5	1.37	2.24	38.8	23.9	50.4	1.87	60.7	37.1	36.3	26.6	loam
6	1.14	2.24	49.1	24.2	38.1	1.63	64.3	36.1	41.3	22.6	loam
7	1.34	2.28	41.2	23.2	37.3	2.13	60.8	41.1	31.7	27.2	clay loam
8	1.42	2.32	38.8	23.9	37.1	1.93	62.6	41.1	35.3	23.6	loam

Appendix III (Continued)

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Kozhanchery											
1	1.34	2.24	40.2	20.8	42.7	1.21	56.3	51.2	29.7	19.1	sandy loam
2	1.36	2.33	41.6	20.4	38.3	0.638	58.4	40.8	36.1	23.1	loam
3	1.42	2.45	42.0	22.1	35.1	1.31	54.4	44.2	30.9	24.9	loam
4	1.38	2.23	38.1	18.4	47.1	1.32	54.2	41.1	35.3	23.6	loam
5	1.33	2.27	41.4	20.1	46.4	0.912	56.4	43.3	29.6	27.1	clay loam
6	1.34	2.26	40.7	22.4	47.9	0.621	60.1	43.2	33.5	23.3	loam
7	1.41	2.31	39.0	19.1	42.4	1.13	52.9	42.3	35.1	22.6	loam
Thottapuzhassery											
1	1.13	2.14	47.2	24.4	49.3	1.31	40.2	42.2	29.7	28.1	clay loam
2	1.21	2.22	45.5	24.7	44.4	1.42	41.6	43.7	31.5	24.8	loam
3	1.27	2.23	43.0	20.2	49	1.53	39.6	44.5	31.2	24.3	loam
4	1.14	2.11	46.0	16.1	62.4	1.34	40.5	46.4	29.4	24.2	loam
5	1.31	2.34	44.0	28.4	50.1	1.35	40.3	43.1	28.6	28.3	clay loam
6	1.14	2.17	47.5	22.1	44.3	1.23	44.4	47.1	30.7	22.2	loam
7	1.32	2.27	41.9	24.3	44.2	1.22	42.2	44.2	30.9	24.9	loam
8	1.29	2.24	42.4	24.1	45.1	1.44	38.6	44.8	30.8	24.4	loam

Appendix III

Soil chemical and biological parameters

Sl. No.	pH	Ex.Acidity ($cmolg^{-1}$)	ECEC (meq/100g)	EC (dsm^{-1})	OC %	N2 (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	S ($mgKg^{-1}$)	Acid Phosphatase*	Dehydrogenase*
Aranmula													
1	5.41	2.3	4.5	0.12	1.9	256.7	23.1	198.1	180.8	90.1	7	34.5	25.3
2	5.33	2.5	4.2	0.41	3.4	281	36.8	338.4	310.3	150.5	8.5	21	25.1
3	5.39	2.1	4.2	0.15	2	326.1	25.9	380.8	260.6	110.1	7.3	32.5	18.8
4	5.31	1.9	3.9	0.12	3	294.7	26.4	224	260.3	96.6	6.5	22.1	24.8
5	5.32	2.9	4.9	0.15	1.8	307.6	23.1	190.3	280.3	90.9	6.3	22	24.3
6	5.4	1.9	3.9	0.13	3	290.2	23.6	220	250.5	120.2	7.3	31.5	25.1
7	5.33	2.3	4.3	0.41	1.9	278.4	25.7	225	260.6	110.1	6.5	32.6	27.1
Mallapalli													
1	4.96	1.5	3.7	0.11	1.5	222.1	54.2	280.4	320.2	108.8	0.5	25.8	22.3
2	4.65	1.2	3.1	0.11	1.8	250	36.8	310	270.7	96.6	5.5	24.8	25.4
3	4.78	1.1	3.1	0.1	1.5	263.4	44.6	330.7	280.6	90.3	13.1	32.1	25.4
4	4.64	1.3	3.5	0.12	1.3	240.5	103.8	336.4	330.4	78.5	7.2	28.1	26.2
5	4.77	0.9	2.8	0.11	1.4	235.7	86.5	324.8	250.7	108.1	6.8	30.5	24.2
6	4.81	1.5	3.4	0.1	1.5	255.7	36.9	320	260.4	98.9	5.5	28.1	23.3
7	4.88	1.2	3.3	0.11	1.4	268.3	54.8	310.5	330.4	78.5	7.1	33.7	18.2
8	4.65	1.1	3	0.12	1.5	240	44.8	290.3	270.7	96.6	11.1	32.5	26.3

*Acid phosphatase activity(µg p-nitrophenol released g^{-1} soil hr^{-1})
*Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})

Appendix III (Continued)

Sl. No.	pH	Ex.Acidity ($cmolg^{-1}$)	ECEC (meq/100g)	EC (dsm^{-1})	OC %	N2 (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	S ($mgKg^{-1}$)	Acid Phosphatase*	Dehydrogenase*
Kalloopara													
1	4.95	2.5	3.9	0.11	3	464.1	13.1	123.7	230.3	30.4	6.5	31.5	20.7
2	4.6	2.8	4.5	0.09	2	321.4	9.5	132.4	250.9	78.7	6	24.7	25.1
3	4.88	1.8	3	0.05	2.4	330.4	15.2	160	180.3	62	12	20	26.1
4	4.6	2.8	4.5	0.06	2.1	350.2	18.7	138.2	230.1	51.3	8.1	21.2	22.8
5	4.89	2.9	4.6	0.09	2.2	370.4	19.1	212.7	240.8	70.3	7.2	33.5	19.9
6	4.95	2.5	3.8	0.11	2.4	342.7	15.8	140.6	180.3	62	9.1	25.6	25.3
7	4.91	1.8	3.2	0.12	2.2	322.2	13.9	168.7	230.3	30.4	6.4	28.7	25.4
Kulanada													
1	5.25	1.8	4.3	0.12	3.5	290.7	48.6	308.8	400.4	96.6	2.5	33.8	25.3
2	5.38	1.5	4	0.12	1	284.3	36.7	492.9	350.3	120.2	5.2	32.7	21.8
3	5.25	1.8	4.5	0.19	1.5	313.6	49.9	467.1	410.4	110.2	0.8	31.2	24.1
4	5.4	2.2	4.7	0.2	2.2	303.2	44.3	280	360.3	120.1	2.2	19.1	25.2
5	5.38	1.4	3.7	0.21	1.3	313.4	45.8	315.6	350.5	98.3	8.1	30.8	23.8
6	5.25	1.4	4	0.12	2.2	284.3	37.4	332.1	400.9	115.1	3.1	31.1	23.7
7	5.31	1.3	3.8	0.19	1.5	298.3	45.9	312.2	360.3	120.1	2.7	32.4	24.8
8	5.24	1.5	3.7	0.12	1.4	313	47.1	340.7	330.4	78.5	5.1	32.6	25.5
kaviyur													
1	4.95	2.9	4.6	0.11	2.1	264.3	20.5	112.2	220.2	54.5	12.4	18.1	26.1
2	4.6	2.8	5.5	0.09	3.4	252.1	15.7	99.6	300.3	84.8	15.5	25.2	25.2

*Acid phosphatase activity(µg p-nitrophenol released g^{-1} soil hr^{-1} , *Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})

Appendix III (Continued)

Sl. No.	pH	Ex.Acidity (cmolg^{-1})	ECEC (meq/100g)	EC (dsm^{-1})	OC %	N2 (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	S (mgKg^{-1})	Acid Phosphatase*	Dehydrogenase*
Kaviyur													
3	4.88	2.5	3.9	0.08	2.3	313.6	14.1	78.7	210.7	66.6	8.9	27.8	24.2
4	4.66	2.7	4.3	0.09	3.1	311.7	21.2	134.5	150.5	75.7	17.3	29.1	26.1
5	4.89	2.7	4	0.06	2.2	320.1	35.7	89.4	180.4	66.9	22.5	18.8	20.9
6	4.88	2.7	4.6	0.09	2.2	320	15.9	120.7	220.5	70.4	11.9	36.5	25.1
7	4.6	2.8	4.6	0.08	2.4	265	24.9	99	210.7	66.6	9.8	36.7	24.1
Panthalam													
1	5.2	1.3	3.8	0.2	1.1	351.2	13.9	165.5	400.9	90.8	87.5	30.2	26.2
2	5.25	1.5	4.2	0.12	1.5	307.4	19.3	212.8	390.3	156.7	25.4	33.8	23.5
3	5.15	1.8	4.7	0.19	1.2	313.6	14.1	201.6	420.5	162.1	33.7	37.8	27.1
4	5.2	1.3	4.2	0.2	1.5	289.1	21.2	179.9	440.5	144.3	32.4	32.7	22.8
5	5.25	1.2	3.9	0.21	1.6	291.5	35.7	212.8	380.6	174.4	50.7	34.4	27.1
6	5.15	1.5	4.3	0.12	1.6	320.5	33.6	220	430.4	130.6	22.9	19.1	25.3
7	5.22	1.3	4	0.18	1.5	298.5	22.9	180.9	420.8	130.1	31.5	30.4	25.1
8	5.12	1.8	4.7	0.21	1.4	306.3	19.7	178.6	440.5	144.3	18.9	35.5	27.7
Thumbamon													
1	5.51	1.3	3.4	0.06	1.3	320.1	15.2	132.3	320.2	90.5	25	18.4	25.3
2	5.58	1.8	5	0.05	1.7	275.6	31.2	212.1	510.8	142.2	34.2	34.4	26.1
3	5.6	2.2	5.4	0.05	1.1	413.9	19.1	145.4	500.5	150.9	21.2	15.5	24.5

*Acid phosphatase activity(µg p-nitrophenol released g^{-1} soil hr^{-1}), *Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})

Appendix III (Continued)

Sl. No.	pH	Ex.Acidity ($cmolg^{-1}$)	ECEC (meq/100g)	EC (dsm^{-1})	OC %	N2 (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	S (mgKg^{-1})	Acid Phosphatase*	Dehydrogenase*
Thumbamon													
4	5.59	1.3	4.7	0.07	0.9	260.7	16.6	168.6	520.5	175.7	54.5	23.2	19.8
5	5.6	1.3	4.4	0.05	1.1	270.4	45.1	156.5	480.8	160.6	26.7	29.7	27.1
6	5.58	1.8	5	0.05	1.3	279.2	31.9	148	490.4	150.5	22.6	30.8	25.3
7	5.51	1.8	3.9	0.06	0.9	265.7	19.5	167.4	320.2	90.5	31.9	29.8	25.1
Mezhuveli													
1	5.2	1.4	3.6	0.2	1.4	326.1	65.5	341.1	330.1	90.9	0.5	18.2	25.1
2	5.25	0.8	3.6	0.12	1.5	301.5	51.8	459.5	440.4	96.5	17.8	34.2	26.2
3	5.15	1.1	3.1	0.11	0.8	200.7	48.7	320.5	320.1	54.5	9.7	18.6	25.1
4	5.15	1.4	3.6	0.11	1.1	258.2	43.2	290.9	350.3	96.7	25.4	36.5	25.3
5	5.1	1.4	3.7	0.12	1.4	234.2	43.1	255.2	380.8	90.2	8.6	15.5	24.8
6	5.11	0.8	2.8	0.12	1.1	205.6	42.3	330.3	320.2	51.6	15.5	57.8	25.1
7	5.12	1.1	4.3	0.13	1.4	222.9	51.3	320.9	480.8	160.6	11.1	30.8	24.7
8	5.2	1.4	3.5	0.12	1.3	311.8	65.4	298.4	320.2	90.5	9.5	36.5	26.2

*Acid phosphatase activity(µg p-nitrophenol released g^{-1} soil hr^{-1})
*Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})

Appendix III (Continued)

Sl. No.	pH	Ex.Acidity (cmolg^{-1})	ECEC (meq/100g)	EC (dsm^{-1})	OC %	N2 (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	S (mgKg^{-1})	Acid Phosphatase*	Dehydrogenase*
Kozhanchery													
1	5.31	1.1	3	0.12	0.4	260.2	55.5	347.3	240.2	132.1	33.2	16.3	18.9
2	5.31	1.5	4.1	0.13	0.5	258.4	45.5	374.7	410.1	90.8	86	30.5	26.1
3	5.4	1.5	3.7	0.12	0.6	209.1	25.4	270.2	320.5	110.7	55.4	18.4	26.2
4	5.32	0.7	2.9	0.21	1.2	311.2	35.2	330.3	310.4	120.2	82.4	25.4	25.1
5	5.39	1.3	3.6	0.15	0.7	274.3	25.7	250.2	350.5	98.6	37.4	25.3	26.3
6	5.31	1.1	3.3	0.12	0.5	250.5	25.7	321	331.4	96.2	33.2	24.2	25.2
7	5.32	1.5	3.7	0.12	0.7	274.9	38.4	330.1	320.5	110.7	31.1	28.8	24.8
Thottapuzhassery													
1	5.31	1.8	4	0.12	1.6	250.1	21.8	236.6	300.2	144.4	27.1	28.9	25.1
2	5.33	1.3	3.3	0.11	1.4	301.6	8.1	264.2	310.6	90.3	84.3	25.2	24.2
3	5.4	1.5	4.3	0.15	1.1	275.9	9.5	190.9	400.4	160.5	50.7	18.4	17.1
4	5.31	1.3	3.9	0.12	1.5	313.4	12.3	280.8	350.6	174.2	56.4	25.6	25.3
5	5.32	2.1	4.6	0.13	1.3	276.2	15.4	225.2	310.1	210.2	33.4	25.1	24.2
6	5.31	1.5	3.7	0.12	1.3	267.9	12.9	251.1	280.7	160.6	31.5	18.1	17.1
7	5.33	1.3	3.3	0.15	1.5	289.9	25.8	280.5	310.6	90.3	28.1	16	25.8
8	5.35	1.8	4.1	0.16	1.1	260.1	8.9	234.9	350.5	98.6	30.8	28.9	25.1

*Acid phosphatase activity (µg p-nitrophenol released g^{-1} soil hr^{-1})
*Dehydrogenase activity (µg TPF hydrolised g^{-1} soil 24 hr^{-1})

Appendix III

Results of micronutrients and heavy metals analysis

Sl. No.	B(mgKg^{-1})	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Cr (mg kg^{-1})
Aranmula									
1	0.2	120.9	28	3.64	4.81	0.032	ND	ND	ND
2	0.01	48.6	25.4	3.1	2.93	0.041	ND	ND	ND
3	0.41	84.3	29	2.09	2.13	0.036	ND	ND	ND
4	0.21	49.6	23.3	2.45	4.41	0.044	ND	ND	ND
5	0.24	106.8	20.7	3.03	4.18	0.035	ND	ND	ND
6	0.31	88.4	28.1	2.21	4.51	0.037	ND	ND	ND
7	0.24	47.5	28.5	2.31	4.33	0.041	ND	ND	ND
Mallappalli									
1	0.01	84.4	45.9	0.31	4.61	0.106	ND	ND	ND
2	0.05	88.9	135.5	0.93	5.07	0.108	ND	ND	ND
3	0.08	48.1	42.8	0.33	3.52	0.112	ND	ND	ND
4	0.06	44.3	35.1	0.37	4.91	0.113	ND	ND	ND
5	0.05	330	34.3	0.4	2.69	0.111	ND	ND	ND
6	0.08	32.6	51.1	0.52	4.31	0.107	ND	ND	ND
7	0.06	47.5	39.5	0.31	5.12	0.106	ND	ND	ND
8	0.05	98.1	38.9	0.51	4.12	0.109	ND	ND	ND

Appendix III (Continued)

Sl. No.	B(mgKg^{-1})	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Cr (mg kg^{-1})
Kalloopara									
1	0.1	73.9	24.7	0.97	4.61	0.154	ND	ND	ND
2	0.09	79.9	32.7	1.28	5.14	0.168	ND	ND	ND
3	0.06	77.5	10.3	0.98	5.01	0.178	ND	ND	ND
4	0.05	73.4	22.3	1.12	4.33	0.158	ND	ND	ND
5	0.08	78.9	25.7	0.93	4.66	0.164	ND	ND	ND
6	0.09	76.4	30.1	1.31	5.23	0.162	ND	ND	ND
7	0.07	77.3	20.5	0.99	4.85	0.164	ND	ND	ND
Kulanada									
1	0.06	31.6	85	0.94	8.55	0.135	ND	ND	ND
2	0.11	29.5	124.5	1.96	3.63	0.130	ND	ND	ND
3	0.31	34.4	74	1.03	5.33	0.141	ND	ND	ND
4	0.12	33.1	73.3	1.22	5.51	0.140	ND	ND	ND
5	0.09	30.4	84.4	1.01	5.23	0.134	ND	ND	ND
6	0.12	28.9	77.2	0.99	6.1	0.130	ND	ND	ND
7	0.09	31.5	81.9	1.13	5.39	0.133	ND	ND	ND
8	0.11	31.4	72.1	1.11	5.71	0.137	ND	ND	ND
Kaviyur									
1	0.12	140.2	35.5	1.21	6.1	0.033	ND	ND	ND
2	0.18	151.7	44.2	1.11	5.51	0.025	ND	ND	ND
3	0.09	92.5	98.5	0.59	5.24	0.026	ND	ND	ND

Appendix III (Continued)

Sl. No.	B(mgKg^{-1})	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Cr (mg kg^{-1})
Kaviyur									
4	0.21	146.2	37.7	1.34	4.99	0.012	ND	ND	ND
5	0.19	150.3	42.7	1.15	4.7	0.026	ND	ND	ND
6	0.12	145.3	46.3	1.29	5.32	0.024	ND	ND	ND
7	0.21	152.3	39.9	0.91	5.12	0.022	ND	ND	ND
Panthalam									
1	0.07	118.5	124.5	1.5	4.63	0.325	ND	ND	ND
2	0.25	118.8	91	1.24	4.2	0.313	ND	ND	ND
3	0.19	136.4	82.2	1.13	3.92	0.322	ND	ND	ND
4	0.09	125.5	84.8	1.33	4.32	0.312	ND	ND	ND
5	0.08	130.4	94.4	1.25	4.54	0.328	ND	ND	ND
6	0.21	120.1	100.5	1.44	4.22	0.354	ND	ND	ND
7	0.07	121.2	93.9	1.11	4.53	0.316	ND	ND	ND
8	0.19	119.1	88.4	1.5	4.1	0.327	ND	ND	ND
Thumbamon									
1	0.01	135.6	137.5	1.52	5.08	0.118	ND	ND	ND
2	0.45	102.2	115.8	1.31	4.41	0.108	ND	ND	ND
3	0.09	100.2	111	1.21	4.34	0.111	ND	ND	ND
4	0.21	94.1	106.5	1.37	4.29	0.110	ND	ND	ND
5	0.14	100.1	125.4	1.29	4.12	0.109	ND	ND	ND

Appendix III (Continued)

Sl. No.	B(mgKg^{-1})	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Cr (mg kg^{-1})
Thumbamon									
6	0.21	95.3	113.4	1.25	4.35	0.107	ND	ND	ND
7	0.14	18.8	120.1	1.44	4.51	0.107	ND	ND	ND
Mezhuveli									
1	0.05	64.3	50.6	0.87	1.11	0.165	ND	ND	ND
2	0.1	84.2	15.5	0.86	3.34	0.155	ND	ND	ND
3	0.41	25.7	19.9	0.49	1.63	0.150	ND	ND	ND
4	0.08	72.2	16.3	0.85	1.55	0.184	ND	ND	ND
5	0.12	65.5	15.4	0.66	1.83	0.178	ND	ND	ND
6	0.31	69.9	18.8	0.79	1.34	0.145	ND	ND	ND
7	0.09	80.4	22.3	0.84	1.19	0.170	ND	ND	ND
8	0.21	82.1	20.8	0.77	1.66	0.173	ND	ND	ND
Kozhanchery									
1	0.26	128.6	92.3	1.71	5.23	0.403	ND	ND	ND
2	0.02	115.1	111.8	2.1	5.47	0.411	ND	ND	ND
3	0.18	154	59.9	0.87	2.6	0.407	ND	ND	ND
4	0.09	116.3	95.6	1.54	5.31	0.410	ND	ND	ND
5	0.05	125.4	98.4	1.83	5.42	0.408	ND	ND	ND
6	0.18	120.3	107.2	1.77	5.29	0.411	ND	ND	ND
7	0.09	116.1	101.1	1.91	3.69	0.412	ND	ND	ND

Appendix III (Continued)

Sl. No.	B(mgKg^{-1})	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Cr (mg kg^{-1})
Thottapuzhassery									
1	0.09	249.6	263.3	2.91	11.66	0.015	ND	ND	ND
2	0.06	238.3	277	3.31	12.34	0.023	ND	ND	ND
3	0.03	253	289.3	3.54	13.26	0.021	ND	ND	ND
4	0.02	235.1	260.4	3.04	11.91	0.016	ND	ND	ND
5	0.05	245.1	271.9	3.22	12.12	0.043	ND	ND	ND
6	0.06	246.2	285.3	3.45	13.33	0.018	ND	ND	ND
7	0.03	250.3	269.5	3.33	11.94	0.022	ND	ND	ND
8	0.08	245.5	274.4	3.12	12.54	0.018	ND	ND	ND

Appendix III

SQI and LQI

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Aranmula	1	384	96.0	39.3	3.93
	2	333	83.3	71.9	7.19
	3	318	79.5	42.6	4.26
	4	338	84.5	60.7	6.08
	5	323	80.8	35.3	3.53
	6	338	84.5	59.8	5.99
	7	323	80.8	39.0	3.90
Mallapally	1	314	78.5	27.4	2.74
	2	318	79.5	33.4	3.34
	3	343	85.7	27.2	2.72
	4	333	83.2	24.1	2.41
	5	353	88.2	28.7	2.87
	6	338	84.5	30.3	3.03
	7	343	85.7	24.9	2.49
	8	338	84.5	29.0	2.90
Kalloopara	1	293	73.2	58.9	5.89
	2	263	65.7	49.5	4.95
	3	328	82.0	47.5	4.75
	4	258	64.5	55.1	5.51
	5	278	69.5	58.0	5.80
	6	323	80.7	48.2	4.82
	7	248	62.0	55.4	5.54
Kulanada	1	328	82.0	70.3	7.03
	2	333	83.2	18.3	1.83
	3	308	77.0	27.9	2.79
	4	268	67.0	56.4	5.64
	5	313	78.2	29.4	2.94
	6	313	78.2	44.2	4.42
	7	303	75.7	34.2	3.42
	8	318	79.5	25.8	2.58
Kaviyur	1	288	72.0	28.9	2.89
	2	273	68.2	55.5	5.55
	3	263	65.7	38.6	3.86
	4	303	75.7	52.5	5.25
	5	268	67.0	28.7	2.87
	6	268	67.0	37.2	3.72
	7	283	70.7	43.9	4.39

Appendix III (continued)

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Panthalam	1	308	77.0	20.1	2.01
	2	333	83.2	25.6	2.56
	3	323	80.7	22.1	2.21
	4	303	75.7	25.6	2.56
	5	358	89.5	31.9	3.19
	6	323	80.7	29.2	2.92
	7	308	77.0	29.0	2.90
	8	288	72.0	23.9	2.39
Thumbamon	1	288	72.0	22.0	2.20
	2	323	80.7	31.1	3.11
	3	343	85.7	21.6	2.16
	4	278	69.5	15.3	1.53
	5	303	75.7	18.4	1.84
	6	323	80.7	23.9	2.39
	7	318	79.5	17.6	1.76
Mezhuveli	1	343	85.7	28.3	2.83
	2	333	83.2	25.6	2.56
	3	293	73.2	17.0	1.70
	4	373	93.2	22.2	2.22
	5	338	84.5	28.7	2.87
	6	333	83.2	18.8	1.88
	7	348	87.0	28.1	2.81
	8	333	83.2	27.6	2.76
Kozhanchery	1	283	70.7	8.04	0.80
	2	323	80.7	10.2	1.02
	3	288	72.0	12.7	1.27
	4	373	93.2	24.8	2.48
	5	293	73.2	13.9	1.39
	6	323	80.7	10.0	1.00
	7	303	75.7	14.8	1.48
Thottapuzhassery	1	303	75.7	27.1	2.71
	2	338	84.5	25.4	2.54
	3	323	80.7	20.9	2.09
	4	318	79.5	25.6	2.56
	5	343	85.7	25.5	2.55
	6	318	79.5	22.2	2.22
	7	373	93.2	29.7	2.97
	8	338	84.5	21.2	2.12

Appendix IV

Soil parameters and fertility class of pre flood soils of AEU 9 of Pathanamthitta district*

Parameters	Fertility class	Percent of samples	
		Pre flood (KSPB, 2013)	Post flood
pH	Extremely acidic	15	_
	Very strongly acidic	34	29.3
	Strongly acidic	24	61.3
	Moderately acidic	16	9.3
	Slightly acidic	11	-
OC (%)	Low	10	4
	Medium	42	57.3
	High	48	38.7
Available P (kg ha^{-1})	Low	18.0	5.3
	Medium	17.0	37.3
	High	65.0	58.7
Available K (kg ha^{-1})	Low	8	6.7
	Medium	39	50.7
	High	53	44
Available Ca (mg kg^{-1})	Deficient	30	36.0
	Sufficient	70	65.3
Available Mg (mg kg^{-1})	Deficient	74	68
	Sufficient	26	33.3
Available S (mg kg^{-1})	Deficient	24	9.3
	Adequate	76	92

Appendix IV (Continued.)

Parameters	Fertility class	Percent of samples	
		Pre flood (KSPB, 2013)	Post flood
Available B (mg kg^{-1})	Deficient	59	100.0
	Sufficient	41	--
Cu (mg kg^{-1})	Deficient	13	
	Sufficient	87	100
Zn (mg kg^{-1})	Deficient	10	33.3
	Sufficient	90	66.7

*Kerala State Planning Board (2013)